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

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

General Instructions

Read the following instructions very carefully and strictly follow them:

1. First 15 minutes are allotted for the candidates to read the question paper.
2. All questions are compulsory.
3. This question paper consists of five Sections: Section A, Section B, Section C, Section D and Section E.
4. Section A is of multiple choice type and each question carries 1 mark.
5. Section B is of very short answer type and each question carries 1 mark.
6. Section C is of short answer type-I and each question carries 2 marks.
7. Section D is of short answer type-II and each question carries 3 marks.
8. Section E is of long answer type. Each question carries 5 marks. All four questions of this section have been given internal choice. You have to do only one question from the choice given in the questions.
9. The symbols used in question paper have usual meanings.

Section - A

(1)
a. A charge q is placed at the centre of the open end of a cylindrical vessel. The flux of the electric-field through the surface of the vessel is

(A) zero
(B) $\frac{q}{\epsilon_0}$
(C) $\frac{q}{2\epsilon_0}$
(D) $\frac{2q}{\epsilon_0}$

Correct Answer: (C) $\frac{q}{2\epsilon_0}$

Solution:

Step 1: Understanding the Concept:
This problem is based on Gauss's Law of electrostatics. Gauss's Law states that the total electric flux (Φ_E) through any closed surface (known as a Gaussian surface) is equal to $\frac{1}{\epsilon_0}$ times

the net electric charge (q_{enc}) enclosed by the surface.
The surface of the cylindrical vessel given in the problem is an open surface, not a closed one. Therefore, we cannot directly apply Gauss's law to it.

Step 2: Key Formula or Approach:
The key formula is Gauss's Law:

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0}$$

To use this law, we must construct a hypothetical closed surface (a Gaussian surface) for which the flux can be calculated, and then use symmetry to find the flux through the required open surface.

Step 3: Detailed Explanation:
Let's consider the open cylindrical vessel. The charge q is placed at the center of its open end. To create a closed surface, imagine an identical cylindrical vessel placed symmetrically on top of the first one, closing the open end.
This combination forms a closed cylinder, and the charge q is now located at the center of this closed cylinder.
According to Gauss's Law, the total electric flux through this entire closed cylindrical surface is:

$$\Phi_{total} = \frac{q}{\epsilon_0}$$

The closed surface consists of the original vessel and the identical imaginary vessel. Due to the symmetry of the charge's position, the electric field lines will pass equally through both halves of the closed cylinder.
Therefore, the flux through the original open cylindrical vessel will be exactly half of the total flux.

$$\Phi_{vessel} = \frac{\Phi_{total}}{2} = \frac{1}{2}\left(\frac{q}{\epsilon_0}\right) = \frac{q}{2\epsilon_0}$$

Step 4: Final Answer:
The flux of the electric-field through the surface of the vessel is $\frac{q}{2\epsilon_0}$.

Quick Tip

Whenever you encounter problems with open surfaces and need to find the electric flux, try to create a symmetrical closed surface by adding an imaginary part. Apply Gauss's Law to the closed surface and then use symmetry to determine the flux through the original open part.

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b. An electron projected towards East is deflected towards North by a magnetic field. The direction of magnetic field may be

(A) towards West
(B) towards South
(C) perpendicular to the plane upwards
(D) perpendicular to the plane downwards

Correct Answer: (D) perpendicular to the plane downwards

Solution:

Step 1: Understanding the Concept:
The force experienced by a charge moving in a magnetic field is given by the Lorentz force. The direction of this force can be determined using Fleming's Left-Hand Rule or the vector cross product. It's crucial to remember that the electron has a negative charge, which reverses the direction of the force compared to a positive charge.

Step 2: Key Formula or Approach:
The magnetic force $\vec{F}$ on a charge q moving with velocity $\vec{v}$ in a magnetic field $\vec{B}$ is given by:

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

For an electron, $q = -e$. So, $\vec{F} = -e(\vec{v} \times \vec{B})$.
This means the direction of the force on an electron is opposite to the direction given by the right-hand rule for $\vec{v} \times \vec{B}$. Alternatively, we can use Fleming's Left-Hand Rule, but remember to point the current direction (middle finger) opposite to the electron's velocity.

Step 3: Detailed Explanation:
Let's define the directions using a standard coordinate system:
- East is along the positive x-axis $(+\hat{\imath})$.
- North is along the positive y-axis $(+\hat{\jmath})$.
- Upwards is along the positive z-axis $(+\hat{k})$.
- Downwards is along the negative z-axis $(-\hat{k})$.

Given information:
- Direction of electron's velocity, $\vec{v}$, is towards East $(+\hat{\imath})$.
- Direction of magnetic force, $\vec{F}$, is towards North $(+\hat{\jmath})$.

Using the formula for the force on an electron:

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

The direction of $\vec{F}$ is North $(+\hat{\jmath})$. This implies that the direction of $(\vec{v} \times \vec{B})$ must be opposite, i.e., towards South $(-\hat{\jmath})$.
So we have:

$$(\text{direction of } \vec{v}) \times (\text{direction of } \vec{B}) = \text{South}$$

$$(+\hat{\imath}) \times (\text{direction of } \vec{B}) = -\hat{\jmath}$$

From the properties of vector cross products, we know that $\hat{\imath} \times (-\hat{k}) = -\hat{\jmath}$.
Therefore, the direction of the magnetic field $\vec{B}$ must be along $-\hat{k}$, which is perpendicular to

the plane (East-North plane) and directed downwards.

Step 4: Final Answer:
The direction of the magnetic field is perpendicular to the plane downwards.

> **Quick Tip**
>
> For questions involving forces on charged particles, always check the sign of the charge. For electrons (negative charge), the direction of the magnetic force is opposite to what the standard right-hand rule would predict for a positive charge. Using Fleming's Left-Hand Rule, point the current finger opposite to the electron's velocity.

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c. A free electron is placed in the path of a plane electromagnetic waves. The electron will start moving

(A) along the direction of electric field.
(B) along the direction of magnetic field.
(C) along the direction of propagation of wave.
(D) in a plane containing the magnetic field and direction of propagation.

Correct Answer: (A) along the direction of electric field.

Solution:

Step 1: Understanding the Concept:
An electromagnetic (EM) wave consists of oscillating electric ($\vec{E}$) and magnetic ($\vec{B}$) fields. These fields are perpendicular to each aother and to the direction of wave propagation. A charge placed in the path of an EM wave will experience forces from both these fields, as described by the Lorentz force equation.

Step 2: Key Formula or Approach:
The total force (Lorentz force) on a charge q in the presence of electric field $\vec{E}$ and magnetic field $\vec{B}$ is:

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

Here, $q = -e$ for an electron. The electron is initially free, so we can assume its initial velocity $\vec{v}$ is zero.

Step 3: Detailed Explanation:
When the free electron is initially placed in the path of the EM wave, its velocity $\vec{v}$ is zero. Let's analyze the Lorentz force at this initial moment ($t = 0$):

$$\vec{F} = (-e)\vec{E} + (-e)(\vec{0} \times \vec{B})$$

$$\vec{F} = -e\vec{E}$$

The magnetic force component is initially zero because the electron is at rest. The only force acting on the electron at the moment it is placed in the wave is the electric force, $\vec{F}_E = -e\vec{E}$.

This force will cause the electron to accelerate. The direction of this initial acceleration (and hence the initial motion) is opposite to the direction of the electric field $\vec{E}$ (due to the negative charge). However, since the electric field of an EM wave is oscillating, the force will also be oscillating. The motion of the electron will be along the line of the electric field vector.

Comparing the magnitudes of the forces: The force due to the electric field is $F_E = eE$. Once the electron starts moving, it will also experience a magnetic force $F_B = evB$. For an EM wave, the magnitudes of the fields are related by $E = cB$, where c is the speed of light.
Thus, $F_B = ev(E/c) = (v/c)F_E$. Since the velocity of the electron v will be much smaller than the speed of light c ($v \ll c$), the magnetic force F_B is significantly weaker than the electric force F_E. The dominant force that governs the motion of the electron is the electric force.

Step 4: Final Answer:
The electron will primarily be driven by the electric field and will start moving along the direction of the electric field.

> **Quick Tip**
>
> In problems involving the interaction of EM waves with charges, remember that the force exerted by the electric field component is almost always dominant over the force from the magnetic field component, unless the particle is moving at relativistic speeds.

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d. A double convex lens has radius of curvature R of each surface and refractive index of its material is $\mu = 1.5$. We have

(A) f = R/2
(B) f = R
(C) f = -R
(D) f = 2R

Correct Answer: (B) f = R

Solution:

Step 1: Understanding the Concept:
This problem requires the use of the Lens Maker's Formula, which relates the focal length of a lens to its refractive index and the radii of curvature of its two surfaces. It is essential to use the correct sign convention for the radii of curvature.

Step 2: Key Formula or Approach:
The Lens Maker's Formula is given by:

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

where: - f is the focal length of the lens.
- μ is the refractive index of the lens material with respect to the surrounding medium.
- R_1 is the radius of curvature of the first surface (where light enters).
- R_2 is the radius of curvature of the second surface.

Step 3: Detailed Explanation:
Let's apply the sign convention for a double convex lens. We assume light travels from left to right.
1. For the first surface, the center of curvature is on the right side. Thus, its radius of curvature is positive: $R_1 = +R$.
2. For the second surface, the center of curvature is on the left side. Thus, its radius of curvature is negative: $R_2 = -R$.

The given values are: - Refractive index, $\mu = 1.5$.
- Radius of curvature for both surfaces has magnitude R.

Now, substitute these values into the Lens Maker's Formula:

$$\frac{1}{f} = (1.5 - 1)\left(\frac{1}{+R} - \frac{1}{-R}\right)$$
$$\frac{1}{f} = (0.5)\left(\frac{1}{R} + \frac{1}{R}\right)$$
$$\frac{1}{f} = (0.5)\left(\frac{2}{R}\right)$$
$$\frac{1}{f} = \frac{1}{2} \times \frac{2}{R}$$
$$\frac{1}{f} = \frac{1}{R}$$

Taking the reciprocal of both sides, we get:

$$f = R$$

Step 4: Final Answer:
The focal length of the double convex lens is equal to its radius of curvature, $f = R$.

Quick Tip

Always be careful with the sign convention in optics problems. For radii of curvature, a common convention is to measure distances from the optical center. If the center of curvature is on the side where light emerges (right side for light incident from left), the radius is positive. If it's on the side where light is incident (left side), the radius is negative.

e. The peak voltage in a 220 volt A.C. source is

(A) 220 V
(B) about 160 V
(C) about 310 V
(D) 440 V

Correct Answer: (C) about 310 V

Solution:

Step 1: Understanding the Concept:
In AC (Alternating Current) circuits, the standard voltage rating (like the 220 V for household supply) refers to the RMS (Root Mean Square) value, not the peak or maximum voltage. The RMS value is a kind of average voltage that gives the same heating effect as a DC voltage of the same value. The peak voltage is the maximum value the voltage reaches during its sinusoidal cycle.

Step 2: Key Formula or Approach:
The relationship between the peak voltage (V_p or V_0) and the RMS voltage (V_{rms}) for a sinusoidal AC source is given by:

$$V_p = V_{rms} \times \sqrt{2}$$

or

$$V_{rms} = \frac{V_p}{\sqrt{2}}$$

Step 3: Detailed Explanation:
We are given the RMS voltage of the AC source:

$$V_{rms} = 220 \text{ V}$$

We need to find the peak voltage, V_p.
Using the formula:

$$V_p = V_{rms} \times \sqrt{2}$$

Substitute the given value:

$$V_p = 220 \times \sqrt{2}$$

We know that the value of $\sqrt{2}$ is approximately 1.414.

$$V_p \approx 220 \times 1.414$$

$$V_p \approx 311.08 \text{ V}$$

This value is approximately 310 V.

Step 4: Final Answer:
The peak voltage in a 220 volt A.C. source is about 310 V.

Quick Tip

Unless specified otherwise, any AC voltage or current value given in a problem is the RMS value. To find the peak value, multiply the RMS value by $\sqrt{2}$ (≈ 1.414). To find the RMS value from the peak, divide by $\sqrt{2}$.

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f. When an impurity is doped in a pure semiconductor, the conductivity of the semiconductor

(A) increases
(B) decreases
(C) remains the same
(D) becomes zero

Correct Answer: (A) increases

Solution:

Step 1: Understanding the Concept:
This question relates to the fundamentals of semiconductor physics. The conductivity of a material depends on the number of free charge carriers available to conduct electricity. A pure semiconductor (intrinsic semiconductor) has a relatively low number of charge carriers (electrons and holes, created by thermal excitation). Doping is the process of intentionally adding impurities to a pure semiconductor to significantly increase the number of charge carriers.

Step 2: Detailed Explanation:
The conductivity (σ) of a semiconductor is given by the formula:

$$\sigma = e(n_e\mu_e + n_h\mu_h)$$

where: - e is the elementary charge.
- n_e is the concentration of free electrons.
- n_h is the concentration of holes.
- μ_e and μ_h are the mobilities of electrons and holes, respectively.

In a pure (intrinsic) semiconductor at room temperature, the concentration of electrons is equal to the concentration of holes ($n_e = n_h = n_i$), and this intrinsic carrier concentration n_i is very small.

Doping involves adding impurity atoms:
1. **N-type Doping:** If a pentavalent impurity (e.g., Phosphorus, Arsenic) is added to a tetravalent semiconductor (e.g., Silicon), each impurity atom donates one free electron. This drastically increases the electron concentration ($n_e \gg n_i$). Electrons become the majority charge carriers, and conductivity increases significantly.
2. **P-type Doping:** If a trivalent impurity (e.g., Boron, Aluminum) is added, each impurity

atom creates a 'hole' (an absence of an electron). This drastically increases the hole concentration ($n_h \gg n_i$). Holes become the majority charge carriers, and conductivity increases significantly.

In both cases, doping substantially increases the concentration of majority charge carriers (n_e or n_h), which directly leads to a large increase in the overall conductivity (σ) of the semiconductor.

Step 3: Final Answer:
When an impurity is doped in a pure semiconductor, the number of charge carriers increases, and therefore, the conductivity of the semiconductor increases.

> **Quick Tip**
>
> Remember that the entire purpose of doping a semiconductor is to control and increase its conductivity. This process is fundamental to creating all modern semiconductor devices like diodes, transistors, and integrated circuits. Doping turns a poor conductor (intrinsic semiconductor) into a useful one (extrinsic semiconductor).

Section - B

(2)
a. Write the unit of specific resistance.

Correct Answer: The unit of specific resistance is the ohm-meter ($\Omega \cdot m$).

Solution:

Step 1: Understanding the Concept:
Specific resistance, also known as resistivity, is an intrinsic property of a material that quantifies how strongly it resists the flow of electric current. It is denoted by the Greek letter ρ (rho).

Step 2: Key Formula or Approach:
The resistance R of a uniform conductor is related to its resistivity (ρ), length (L), and cross-sectional area (A) by the formula:

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

We can rearrange this formula to solve for resistivity ρ:

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

Step 3: Detailed Explanation:
To find the unit of resistivity, we can substitute the SI units for the quantities on the right side of the rearranged formula:

- The unit of resistance (R) is the ohm (Ω).
- The unit of area (A) is the square meter (m^2).
- The unit of length (L) is the meter (m).

Substituting these units into the equation for ρ:

$$\text{Unit of } \rho = \frac{\text{Unit of } R \times \text{Unit of } A}{\text{Unit of } L} = \frac{\Omega \cdot m^2}{m}$$

Simplifying the expression, we get:

$$\text{Unit of } \rho = \Omega \cdot m$$

Step 4: Final Answer:
The SI unit of specific resistance (resistivity) is the ohm-meter ($\Omega \cdot m$).

Quick Tip

Remember the distinction: Resistance (R) is a property of a specific object and depends on its shape and size, measured in ohms (Ω). Resistivity (ρ) is a property of the material itself, measured in ohm-meters ($\Omega \cdot m$).

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b. A current of 10 A is flowing in a long wire along the positive Z-axis. Find the intensity of magnetic field at a point (10 cm, 0, 0).

Correct Answer: The intensity of the magnetic field is 2×10^{-5} T.

Solution:

Step 1: Understanding the Concept:
A long, straight wire carrying a current produces a magnetic field in the form of concentric circles around the wire. The magnitude of this field can be calculated using Ampere's Law or the Biot-Savart Law.

Step 2: Key Formula or Approach:
For an infinitely long, straight wire carrying a current I, the magnitude of the magnetic field B at a perpendicular distance r from the wire is given by:

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

where μ_0 is the permeability of free space, with a value of $4\pi \times 10^{-7}\,\text{T} \cdot \text{m/A}$.

Step 3: Detailed Explanation:
First, identify the given values and convert them to SI units:

- Current, $I = 10$ A.
- The wire is along the Z-axis.
- The point is P(10 cm, 0, 0).
- The perpendicular distance r of the point P from the Z-axis is its x-coordinate, which is 10 cm.
- Convert the distance to meters: $r = 10$ cm $= 0.1$ m.

Now, substitute these values into the formula for the magnetic field:

$$B = \frac{(4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}) \times (10\,\mathrm{A})}{2\pi \times (0.1\,\mathrm{m})}$$

Cancel out 2π from the numerator and denominator:

$$B = \frac{2 \times 10^{-7} \times 10}{0.1}$$

$$B = \frac{2 \times 10^{-6}}{10^{-1}}$$

$$B = 2 \times 10^{-6-(-1)} = 2 \times 10^{-5}\,\mathrm{T}$$

Step 4: Final Answer:
The intensity of the magnetic field at the point (10 cm, 0, 0) is 2×10^{-5} Tesla.
(Note: To find the direction, use the right-hand thumb rule. If the thumb points along the current (+Z direction), the curled fingers at the point (+X axis) will point in the +Y direction. So, $\vec{B} = 2 \times 10^{-5}\hat{j}$ T).

Quick Tip

Always ensure all units are in the SI system (meters, Amperes, etc.) before performing calculations. For finding the direction of the magnetic field from a straight wire, the Right-Hand Thumb Rule is the quickest method.

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c. Write Lenz's law.

Correct Answer: Lenz's law states that the direction of the induced electromotive force (EMF) and hence the induced current in a closed circuit is always such that it opposes the change in magnetic flux that produced it.

Solution:

Step 1: Understanding the Concept:
Lenz's law is a fundamental principle in electromagnetic induction, which provides the direction of the induced current. It is a consequence of the law of conservation of energy.

Step 2: Detailed Explanation:
The law can be broken down into key ideas:

- **Cause:** A change in magnetic flux ($\Delta\Phi_B$) through a conducting loop.
- **Effect:** An induced current is generated in the loop.
- **Opposition:** This induced current creates its own magnetic field. The direction of this induced magnetic field is such that it opposes the original *change* in flux.

For example:

- If the magnetic flux through a loop is *increasing*, the induced current will create a magnetic field in the opposite direction to counteract the increase.
- If the magnetic flux through a loop is *decreasing*, the induced current will create a magnetic field in the same direction to try and maintain the flux.

Mathematically, Lenz's law is represented by the negative sign in Faraday's law of induction:

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

where $\mathcal{E}$ is the induced EMF. The negative sign signifies the opposition.

Step 3: Final Answer:
Lenz's law states that the direction of the induced current is such that it will oppose the change in magnetic flux that is causing it.

Quick Tip

Think of Lenz's law as "electromagnetic inertia." The system (the conducting loop) resists any change to the magnetic flux passing through it, just as a massive object resists changes to its state of motion.

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d. What is total internal reflection?

Correct Answer: Total internal reflection (TIR) is the phenomenon where a light ray traveling from a denser to a rarer medium is completely reflected back into the denser medium if its angle of incidence is greater than the critical angle.

Solution:

Step 1: Understanding the Concept:
Total Internal Reflection (TIR) is a special case of reflection that occurs under specific conditions at the boundary between two transparent media. It's the principle behind optical fibers.

Step 2: Detailed Explanation:
For TIR to occur, two necessary conditions must be met:

1. **Medium of Travel:** The light ray must be traveling from a medium with a higher refractive index (optically denser) to a medium with a lower refractive index (optically rarer). For example, from water to air, or from glass to water.

2. **Angle of Incidence:** The angle of incidence (i) in the denser medium must be greater than a specific angle called the **critical angle** (i_c). The critical angle is the specific angle of incidence for which the angle of refraction is 90 degrees.

When these two conditions are satisfied, no light is refracted into the rarer medium; instead, the entire ray is reflected back into the denser medium, following the laws of reflection (angle of incidence = angle of reflection).

Step 3: Final Answer:
Total internal reflection is an optical phenomenon in which a light ray traveling from an optically denser medium to an optically rarer medium is completely reflected back into the denser medium. This happens when the angle of incidence at the interface is greater than the critical angle for the pair of media.

Quick Tip

Remember the two key conditions for TIR: 1. Denser to Rarer medium, and 2. Angle of incidence > Critical angle ($i > i_c$). Applications like optical fibers, mirages, and the sparkling of diamonds are all based on this principle.

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e. Define work-function.

Correct Answer: The work function of a metal is the minimum amount of energy required to just remove an electron from the surface of that metal.

Solution:

Step 1: Understanding the Concept:
The work function is a key concept in the study of the photoelectric effect. It represents the binding energy of the outermost (valence) electrons to the metal. To liberate an electron, this energy barrier must be overcome.

Step 2: Detailed Explanation:

- **Symbol and Units:** The work function is typically denoted by ϕ_0 (phi-naught) or W. It is a form of energy and is commonly measured in electron-volts (eV), although the SI unit is the joule (J).

- **Material Property:** It is an intrinsic property of a specific material. Different metals have different work functions. For example, alkali metals like cesium have very low work functions, making them good materials for photoelectric devices.

- **Photoelectric Effect Context:** In the photoelectric effect, if a photon with energy $E = hf$ strikes the metal, an electron is emitted only if the photon's energy is greater than or equal to the work function ($hf \geq \phi_0$). The minimum frequency required is called the threshold frequency (f_0), where $\phi_0 = hf_0$.

Step 3: Final Answer:
The work-function (ϕ_0) is defined as the minimum energy that must be supplied to an electron to remove it from the surface of a given metal to a point just outside the metal with zero kinetic energy.

> **Quick Tip**
>
> Think of the work function as an "exit fee" for an electron leaving a metal. A photon's energy is the "payment." If the payment is less than the fee ($E < \phi_0$), the electron cannot leave. If it's exactly the fee ($E = \phi_0$), the electron leaves with no leftover energy (zero kinetic energy).

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f. Write equation of energy of photon in terms of Planck's constant (h) and wavelength (λ).

Correct Answer: $E = \frac{hc}{\lambda}$

Solution:

Step 1: Understanding the Concept:
In quantum mechanics, light is described as being composed of discrete packets of energy called

photons. The energy of a single photon is related to the frequency and wavelength of the corresponding electromagnetic wave.

Step 2: Key Formula or Approach:
The derivation involves two fundamental equations:

1. The Planck-Einstein relation, which gives the energy of a photon (E) in terms of its frequency (f):
$$E = hf$$
where h is Planck's constant.

2. The wave equation, which relates the speed of light (c), its frequency (f), and its wavelength (λ):
$$c = f\lambda$$

Step 3: Detailed Explanation:
Our goal is to express the energy E in terms of h and λ. The first equation has h but uses f, not λ. We need to replace f using the second equation.
From the wave equation, we can express frequency as:
$$f = \frac{c}{\lambda}$$
Now, substitute this expression for f into the Planck-Einstein relation:
$$E = h\left(\frac{c}{\lambda}\right)$$
$$E = \frac{hc}{\lambda}$$
This is the required equation.

Step 4: Final Answer:
The equation for the energy of a photon (E) in terms of Planck's constant (h), the speed of light (c), and wavelength (λ) is:
$$E = \frac{hc}{\lambda}$$

> **Quick Tip**
>
> This equation shows an inverse relationship between energy and wavelength: shorter wavelengths (like blue or UV light) correspond to higher-energy photons, while longer wavelengths (like red or infrared light) correspond to lower-energy photons. This is a cornerstone of modern physics.

Section - C

(3)
a. Write Kirchhoff's laws related to electric circuit by drawing suitable circuit diagram.

Correct Answer: Kirchhoff's laws consist of the Junction Rule (or Current Law) and the Loop Rule (or Voltage Law), which are fundamental for analyzing electric circuits.

Solution:

Step 1: Understanding the Concept:
Kirchhoff's laws are two rules that deal with the conservation of charge and energy within electrical circuits. They provide a systematic way to analyze complex circuits that cannot be simplified into simple series or parallel combinations.

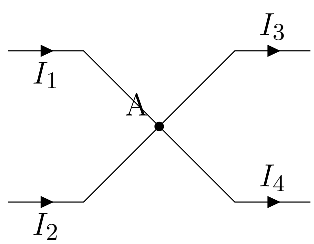
Step 2: Detailed Explanation:
1. Kirchhoff's First Law (Junction Rule or Kirchhoff's Current Law - KCL)

- **Statement:** The algebraic sum of all electric currents meeting at any junction (or node) in a circuit is zero. In other words, the total current entering a junction must equal the total current leaving that junction.

- **Principle:** This law is based on the **law of conservation of charge**. Charge cannot accumulate at a junction.

- **Equation:** $\sum I = 0$

- **Circuit Diagram:**
  Consider a junction 'A' where currents I_1 and I_2 are entering, and currents I_3 and I_4 are leaving.



According to KCL, if we consider incoming currents as positive and outgoing currents as negative:
$I_1 + I_2 - I_3 - I_4 = 0$
or,
$I_{in} = I_{out} \implies I_1 + I_2 = I_3 + I_4$

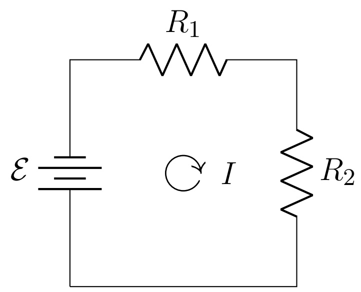
2. Kirchhoff's Second Law (Loop Rule or Kirchhoff's Voltage Law - KVL)

- **Statement:** The algebraic sum of the changes in electric potential (voltage) encountered in a complete traversal of any closed loop in a circuit is zero.

- **Principle:** This law is based on the **law of conservation of energy**. The net energy gained by a charge after moving around a closed loop must be zero.

- **Equation:** $\sum \Delta V = 0$

- **Circuit Diagram:**
  Consider a simple closed loop containing a voltage source (EMF $\mathcal{E}$) and two resistors R_1 and R_2, with a current I flowing through them.



  To apply KVL, we choose a direction (e.g., clockwise) and sum the potential changes:
  - Traversing the battery from negative to positive terminal: Potential gain of $+\mathcal{E}$.
  - Traversing resistor R_1 in the direction of current: Potential drop of $-IR_1$.
  - Traversing resistor R_2 in the direction of current: Potential drop of $-IR_2$.
  The sum of these potential changes is zero:
  $\mathcal{E} - IR_1 - IR_2 = 0$

Step 3: Final Answer:
Kirchhoff's two laws are the Junction Rule, which states that the sum of currents at a junction is zero ($\sum I = 0$), and the Loop Rule, which states that the sum of potential differences around any closed loop is zero ($\sum \Delta V = 0$).

Quick Tip

When applying KVL, establish a consistent sign convention. A common convention is:

- EMF is positive if traversed from the negative to the positive terminal.
- Potential drop across a resistor ($-IR$) is negative if traversed in the same direction as the current.

b. Draw ($i-\delta$) curve for a prism, and show angle of minimum deviation in the curve.

Correct Answer: The curve is a non-symmetrical U-shaped graph showing the variation of the angle of deviation (δ) with the angle of incidence (i). The lowest point on the curve represents the angle of minimum deviation (δ_m).

Solution:

Step 1: Understanding the Concept:
When a ray of light passes through a prism, it deviates from its original path. The angle between the incident ray and the emergent ray is called the angle of deviation (δ). This angle depends on the angle of incidence (i). The ($i - \delta$) curve is a graphical representation of this relationship.

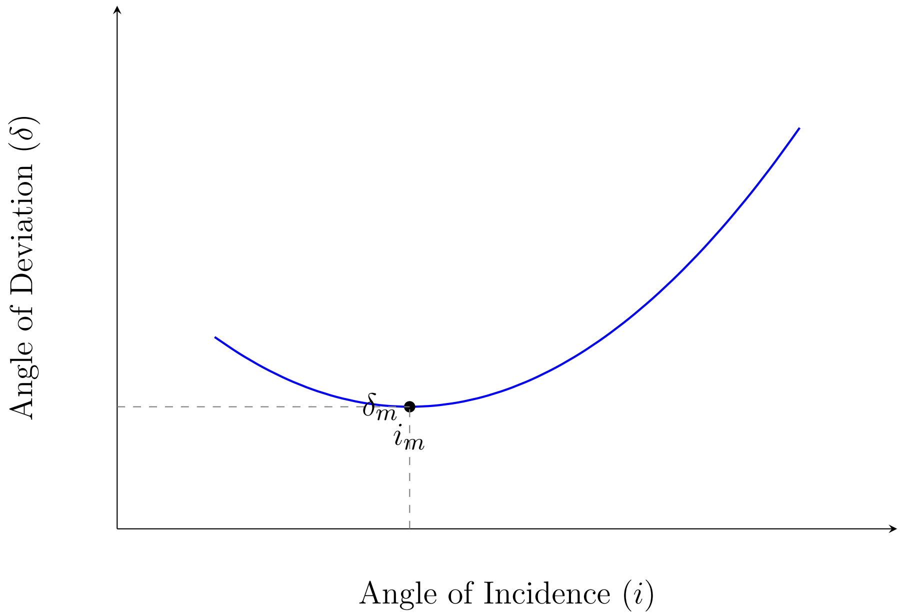
Step 2: Detailed Explanation and Diagram:
The graph of the angle of deviation (δ) as a function of the angle of incidence (i) has the following characteristics:

- **Axes:** The angle of incidence (i) is plotted on the X-axis, and the angle of deviation (δ) is plotted on the Y-axis.

- **Shape of the Curve:** As the angle of incidence i is increased from a small value, the angle of deviation δ first decreases, reaches a minimum value, and then starts to increase again. This results in a U-shaped curve that is not symmetric.

- **Angle of Minimum Deviation (δ_m):** The lowest point on the curve corresponds to the minimum possible value of the angle of deviation, denoted by δ_m. At this specific point, the angle of incidence is equal to the angle of emergence ($i = e$). For every other value of δ, there are two corresponding values of the angle of incidence.

Graphical Representation:



Step 3: Final Answer:
The $(i - \delta)$ curve for a prism shows that the angle of deviation initially decreases with an increase in the angle of incidence, reaches a minimum value (δ_m), and then increases. The point where the deviation is minimum is called the angle of minimum deviation.

Quick Tip

The condition for minimum deviation is crucial for many prism-related problems. At $\delta = \delta_m$, we have $i = e$ and $r_1 = r_2$, where r_1 and r_2 are the angles of refraction inside the prism. This symmetry simplifies the derivation of the prism formula.

---

c. Explain Nuclear fusion.

Correct Answer: Nuclear fusion is a nuclear reaction in which two or more light atomic nuclei combine to form a heavier nucleus, releasing a vast amount of energy in the process.

Solution:

Step 1: Understanding the Concept:
Nuclear fusion is the process that powers stars, including our Sun. It involves the merging of light nuclei, which results in a release of energy due to a phenomenon called mass defect.

Step 2: Detailed Explanation:

- **Process:** In a fusion reaction, two light nuclei, such as isotopes of hydrogen (like deuterium and tritium), are forced together with enough energy to overcome their mutual electrostatic repulsion (the Coulomb barrier). Once they are close enough, the attractive strong nuclear force takes over and fuses them into a single, heavier nucleus (like helium).

- **Energy Release:** The key to energy release is that the mass of the resulting heavier nucleus is slightly less than the sum of the masses of the original light nuclei. This difference in mass (Δm), known as the mass defect, is converted into a tremendous amount of energy (E) according to Albert Einstein's mass-energy equivalence principle, $E = \Delta mc^2$, where c is the speed of light.

- **Conditions Required:** Such reactions require extreme conditions of temperature (on the order of millions of degrees Celsius) and pressure. These conditions, found in the cores of stars, create a state of matter called plasma where nuclei are stripped of their electrons and have enough kinetic energy to overcome their repulsion and fuse.

- **Example (D-T Fusion):** A common example studied for terrestrial fusion reactors is the fusion of deuterium (${}^2_1$H or D) and tritium (${}^3_1$H or T):

$$ {}^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + {}^1_0\text{n} + 17.6\,\text{MeV (Energy)} $$

  Here, a deuterium nucleus and a tritium nucleus fuse to form a helium nucleus and a neutron, releasing 17.6 million electron-volts of energy.

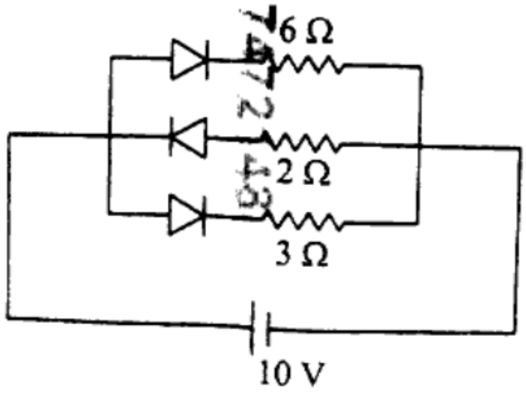
Step 3: Final Answer:
Nuclear fusion is a process where light atomic nuclei merge to form a heavier nucleus. This process releases a significant amount of energy because the final product has less mass than the initial reactants, with the lost mass being converted directly into energy. The process requires extremely high temperatures and pressures.

Quick Tip

Contrast nuclear fusion with nuclear fission. Fusion combines light nuclei (e.g., H + H → He), while fission splits a heavy nucleus (e.g., Uranium → Barium + Krypton). Both release enormous energy, but fusion generally releases more energy per nucleon and produces less long-lived radioactive waste.

---

d. Find current through the battery in the circuit shown in fig :



Correct Answer: 10 A

Solution:

Step 1: Understanding the Concept:
This problem requires analyzing a circuit containing diodes and resistors in parallel. The key is to first determine the biasing of each diode (forward or reverse) to see which branches will conduct current. Then, the circuit can be simplified to calculate the total current using Ohm's law.

Step 2: Detailed Explanation:
1. Analyze the Diode Biasing:
The circuit has a 10 V battery. The positive terminal of the battery is connected to the p-side (anode, the triangle part) of all three diodes. The negative terminal is connected (through the resistors) to the n-side (cathode, the line part) of all three diodes.
Since the p-side of each diode is at a higher potential than its n-side, all three diodes are **forward-biased**.

2. Simplify the Circuit:
Assuming the diodes are ideal, a forward-biased diode acts as a closed switch, meaning it behaves like a wire with zero resistance. Therefore, we can replace all three diodes with connecting wires.
After this simplification, the circuit consists of three resistors connected in parallel across the 10 V battery:

- $R_1 = 6\,\Omega$
- $R_2 = 2\,\Omega$
- $R_3 = 3\,\Omega$

3. Calculate the Equivalent Resistance (R_{eq}):
For resistors in parallel, the reciprocal of the equivalent resistance is the sum of the reciprocals of the individual resistances:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{6} + \frac{1}{2} + \frac{1}{3}$$

To add these fractions, we find a common denominator, which is 6:

$$\frac{1}{R_{eq}} = \frac{1}{6} + \frac{3}{6} + \frac{2}{6} = \frac{1+3+2}{6} = \frac{6}{6} = 1\,\Omega^{-1}$$

Therefore, the equivalent resistance is:

$$R_{eq} = 1\,\Omega$$

4. Calculate the Total Current:
The current through the battery is the total current flowing through the circuit. Using Ohm's Law, $V = I_{total} \cdot R_{eq}$:

$$I_{total} = \frac{V}{R_{eq}}$$

$$I_{total} = \frac{10\,\text{V}}{1\,\Omega} = 10\,\text{A}$$

Step 3: Final Answer:
The current through the battery is 10 A.

Quick Tip

When you see diodes in a DC circuit, the very first step is to check their biasing. A forward-biased ideal diode is a short circuit (wire), and a reverse-biased ideal diode is an open circuit (a break in the wire). This simplification is the key to solving such problems.

Section - D

(4)
a. Write Gauss's law. Derive the formula for electric field due to a linear charge distribution.

Correct Answer: Gauss's law states that the total electric flux through any closed surface is $\frac{1}{\epsilon_0}$ times the net charge enclosed by it. The electric field due to an infinite linear charge with density λ is $E = \frac{\lambda}{2\pi\epsilon_0 r}$.

Solution:

Step 1: Statement of Gauss's Law:
Gauss's law in electrostatics states that the total electric flux (Φ_E) through any closed hypothetical surface (called a Gaussian surface) is equal to $\frac{1}{\epsilon_0}$ times the net electric charge (q_{enc})

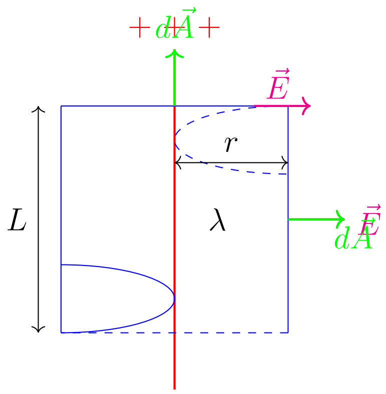
enclosed within that surface.
Mathematically, it is expressed as:

$$\Phi_E = \oint_S \vec{E} \cdot d\vec{A} = \frac{q_{enc}}{\epsilon_0}$$

where $\vec{E}$ is the electric field, $d\vec{A}$ is the differential area vector on the closed surface S, and ϵ_0 is the permittivity of free space.

Step 2: Derivation for a Linear Charge Distribution:
Consider an infinitely long, thin, straight wire with a uniform positive linear charge density λ (charge per unit length). We want to find the electric field E at a point P at a perpendicular distance r from the wire.

1. **Symmetry and Gaussian Surface:** By symmetry, the electric field $\vec{E}$ must be directed radially outward from the wire, and its magnitude must be the same at all points equidistant from the wire. We choose a cylindrical Gaussian surface of radius r and length L, coaxial with the wire, such that point P lies on its curved surface.



2. **Calculate Electric Flux (Φ_E):** The flux integral is taken over the entire closed surface, which consists of two flat circular caps (top and bottom) and the curved cylindrical surface.

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = \int_{\text{top}} \vec{E} \cdot d\vec{A} + \int_{\text{bottom}} \vec{E} \cdot d\vec{A} + \int_{\text{curved}} \vec{E} \cdot d\vec{A}$$

   - For the top and bottom caps, the area vector $d\vec{A}$ is perpendicular to the electric field $\vec{E}$ (i.e., angle is 90°). So, $\vec{E} \cdot d\vec{A} = E\,dA\cos(90°) = 0$. The flux through the caps is zero.
   - For the curved surface, the electric field $\vec{E}$ is parallel to the area vector $d\vec{A}$ at every point (angle is 0°). So, $\vec{E} \cdot d\vec{A} = E\,dA\cos(0°) = E\,dA$.

   The total flux is therefore only through the curved surface:

$$\Phi_E = \int_{\text{curved}} E\,dA$$

   Since E is constant in magnitude on this surface, we can take it out of the integral:

$$\Phi_E = E\int_{\text{curved}} dA = E \times (\text{Area of curved surface}) = E(2\pi rL)$$

3. **Calculate Enclosed Charge (q_{enc}):** The charge enclosed by the Gaussian surface of length L is the linear charge density multiplied by the length:

$$q_{enc} = \lambda L$$

4. **Apply Gauss's Law:** Now we equate the flux and the enclosed charge according to Gauss's law:

$$\Phi_E = \frac{q_{enc}}{\epsilon_0} \implies E(2\pi r L) = \frac{\lambda L}{\epsilon_0}$$

5. **Solve for E:** Canceling L from both sides, we get the expression for the electric field:

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

Quick Tip

The key to using Gauss's law is choosing the right Gaussian surface. The surface should be chosen such that the electric field is either parallel or perpendicular to the surface vector $d\vec{A}$, and the magnitude of E is constant on the parts of the surface where the flux is non-zero.

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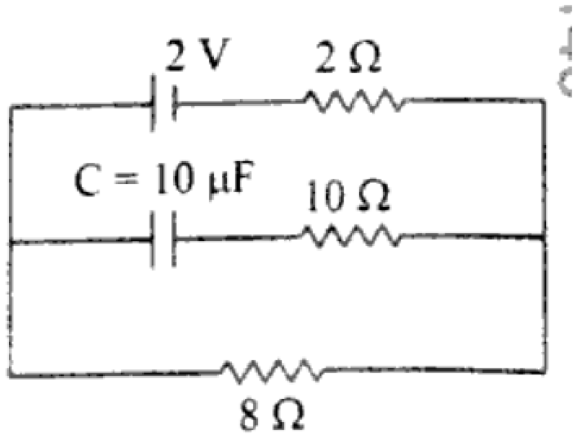
b. Find the currents in the resistors $2\,\Omega$ and $10\,\Omega$ in the network shown in figure, also find charge on the capacitor :



Correct Answer: Current in $2\,\Omega$ resistor is 0.2 A. Current in $10\,\Omega$ resistor is 0 A. Charge on the capacitor is $16\,\mu$C.

Solution:

Step 1: Understanding the Concept (Steady State in DC Circuit):
This is a DC circuit containing a capacitor. When a DC voltage is applied, the capacitor charges up. After a long time, it becomes fully charged and its acts as an open circuit, meaning no current can flow through the branch containing the capacitor. This is called the steady state.

Step 2: Circuit Analysis at Steady State:

1. **Current in the 10 Ω resistor:** At steady state, the capacitor $C = 10\,\mu$F is fully charged and blocks the flow of DC current. Therefore, the current in the middle branch, which contains the $10\,\Omega$ resistor, becomes zero.

$$I_{10\Omega} = 0 \text{ A}$$

2. **Current in the 2 Ω resistor:** Since no current flows through the middle branch, the circuit simplifies to a single series loop consisting of the 2 V battery, the $2\,\Omega$ resistor, and the $8\,\Omega$ resistor.
   The total resistance in this loop is:

$$R_{total} = 2\,\Omega + 8\,\Omega = 10\,\Omega$$

   Using Ohm's law, the current flowing through this loop is:

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

   This is the current flowing through both the $2\,\Omega$ and $8\,\Omega$ resistors.

3. **Charge on the Capacitor:** To find the charge Q on the capacitor, we first need to find the potential difference (voltage) V_C across it. The capacitor and the 10 Ω resistor are connected in parallel with the $8\,\Omega$ resistor (based on the common interpretation of this circuit's drawing). Therefore, the voltage across the capacitor branch is the same as the voltage across the $8\,\Omega$ resistor.

$$V_C = V_{8\Omega}$$

   The voltage across the $8\,\Omega$ resistor can be calculated using Ohm's law, with the current we found in the previous step:

$$V_{8\Omega} = I_{8\Omega} \times R_{8\Omega} = (0.2 \text{ A}) \times (8\,\Omega) = 1.6 \text{ V}$$

   So, the voltage across the capacitor is $V_C = 1.6$ V. Note that because the current through the 10 Ω resistor is zero, there is no voltage drop across it, so the full 1.6 V appears across the capacitor plates.
   The charge Q on the capacitor is given by $Q = CV_C$:

$$Q = (10\,\mu\text{F}) \times (1.6 \text{ V}) = 16\,\mu\text{C}$$

Step 3: Final Answer:

- Current in the $2\,\Omega$ resistor = **0.2 A**.
- Current in the $10\,\Omega$ resistor = **0 A**.
- Charge on the capacitor = **16 μC**.

Quick Tip

In any DC circuit problem with capacitors, always analyze the circuit at $t = 0$ (capacitor is a short circuit) and $t \to \infty$ (capacitor is an open circuit). The question usually implies the steady-state condition unless it asks about the transient phase.

---

c. Deduce the expression of intensity of magnetic field produced inside long current carrying solenoid with the help of Ampere's law.

Correct Answer: The magnetic field inside a long solenoid is uniform and is given by the expression $B = \mu_0 n I$, where n is the number of turns per unit length and I is the current.

Solution:

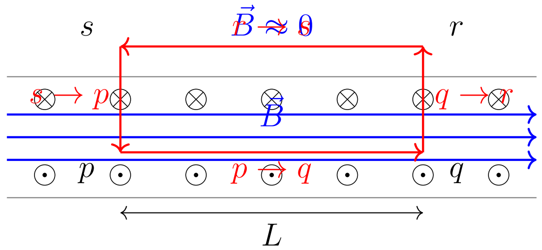
Step 1: Statement of Ampere's Circuital Law:
Ampere's law states that the line integral of the magnetic field $\vec{B}$ around any closed loop (called an Amperian loop) is equal to μ_0 times the total current I_{enc} passing through the area enclosed by the loop.

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

Step 2: Derivation for a Long Solenoid:
Consider a long solenoid with n turns per unit length, carrying a current I.

1. **Symmetry and Magnetic Field:** For an ideal long solenoid, the magnetic field inside is strong, uniform, and directed along the axis of the solenoid. The magnetic field outside is negligibly weak (approximately zero).

2. **Amperian Loop:** To apply Ampere's law, we choose a rectangular Amperian loop 'pqrs' of length L, as shown in the cross-sectional diagram. The side 'pq' is inside the solenoid, parallel to the axis, while the side 'rs' is outside.



3. **Evaluate the Line Integral:** We evaluate $\oint \vec{B} \cdot d\vec{l}$ for the loop 'pqrs'.

$$\oint_{pqrs} \vec{B} \cdot d\vec{l} = \int_p^q \vec{B} \cdot d\vec{l} + \int_q^r \vec{B} \cdot d\vec{l} + \int_r^s \vec{B} \cdot d\vec{l} + \int_s^p \vec{B} \cdot d\vec{l}$$

- **Along pq (inside):** $\vec{B}$ is parallel to $d\vec{l}$. So, $\int_p^q \vec{B} \cdot d\vec{l} = \int BL\cos(0°)dl = B\int_0^L dl = BL$.
- **Along qr and sp (perpendicular):** $\vec{B}$ is perpendicular to $d\vec{l}$. So, $\int \vec{B} \cdot d\vec{l} = \int Bdl\cos(90°) = 0$.
- **Along rs (outside):** The magnetic field outside is zero ($B = 0$). So, $\int_r^s \vec{B} \cdot d\vec{l} = 0$.

The total value of the line integral is: $\oint \vec{B} \cdot d\vec{l} = BL + 0 + 0 + 0 = BL$.

4. **Calculate Enclosed Current (I_{enc}):** The number of turns within the loop of length L is $N = nL$. Since each turn carries current I, the total current enclosed by the loop is:

$$I_{enc} = N \times I = nLI$$

5. **Apply Ampere's Law:**

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} \implies BL = \mu_0(nLI)$$

6. **Solve for B:** Canceling L from both sides gives the magnetic field inside the solenoid:

$$B = \mu_0 nI$$

Quick Tip

Remember that n in the formula $B = \mu_0 nI$ is the number of turns per unit length ($n = N/L$), not the total number of turns. This is a common point of confusion. The formula shows that the field inside a long solenoid is independent of its radius and the position within the solenoid.

---

d. A metallic rod of 1.0 m length is rotating about a perpendicular axis passing through its one end with an angular frequency of 400 rad/s. The other end of the rod is in contact with a ring of metal. Magnetic field of 0.5 T is along its axis. Calculate the induced emf between the ring and the axis.

Correct Answer: The induced emf is 100 V.

Solution:

Step 1: Understanding the Concept (Motional EMF):
When a conducting rod rotates in a uniform magnetic field, an electromotive force (EMF) is induced across its ends. This is a type of motional EMF. Each point on the rod moves with a different linear speed, so we must integrate the small EMFs generated across infinitesimal segments of the rod to find the total EMF.

Step 2: Key Formula and Derivation:
Consider a small element of the rod of length dr at a distance r from the axis of rotation.

The linear velocity of this element is given by $v = \omega r$, where ω is the angular frequency. The small EMF induced across this element dr is:

$$d\mathcal{E} = Bvdr = B(\omega r)dr$$

To find the total EMF induced between the axis ($r = 0$) and the outer end (the ring at $r = L$), we integrate this expression from 0 to L:

$$\mathcal{E} = \int_0^L d\mathcal{E} = \int_0^L B\omega r\, dr$$

Since B and ω are constant:

$$\mathcal{E} = B\omega \int_0^L r\, dr = B\omega \left[\frac{r^2}{2}\right]_0^L = B\omega \left(\frac{L^2}{2} - 0\right)$$

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

Step 3: Calculation:
We are given the following values:

- Length of the rod, $L = 1.0$ m.
- Angular frequency, $\omega = 400$ rad/s.
- Magnetic field strength, $B = 0.5$ T.

Substitute these values into the derived formula:

$$\mathcal{E} = \frac{1}{2}(0.5\text{ T})(400\text{ rad/s})(1.0\text{ m})^2$$

$$\mathcal{E} = \frac{1}{2} \times 0.5 \times 400 \times 1$$

$$\mathcal{E} = 0.25 \times 400$$

$$\mathcal{E} = 100\text{ V}$$

Step 4: Final Answer:
The induced emf between the ring and the axis is **100 V**.

Quick Tip

A common mistake is to use the linear velocity of the end of the rod ($v = \omega L$) and the formula for a linearly moving rod ($\mathcal{E} = BvL$). This gives $\mathcal{E} = B(\omega L)L = B\omega L^2$, which is incorrect by a factor of 2. Always remember the factor of $\frac{1}{2}$ for a rotating rod, which comes from the integration.

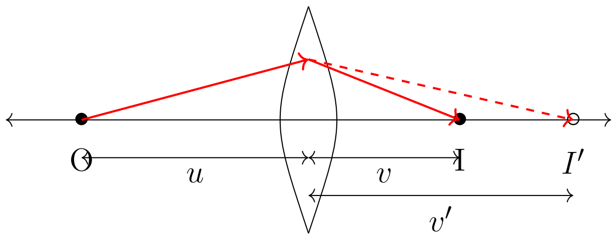
---

e. Derive Lens Maker's formula for a thin lens.

Correct Answer: The Lens Maker's formula is $\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.

Solution:

Step 1: Understanding the Concept and Setup:
The Lens Maker's formula relates the focal length (f) of a thin lens to the refractive index (μ) of its material and the radii of curvature (R_1 and R_2) of its two surfaces. It is derived by applying the formula for refraction at a single spherical surface twice.
Consider a thin convex lens of refractive index μ_2 placed in a medium of refractive index μ_1. A point object O is placed on the principal axis.



Step 2: Refraction at the First Surface (Radius R_1):
Light travels from the medium (μ_1) to the lens (μ_2). For the first surface, the object is at O (distance u). An intermediate image I' is formed at a distance v'. The formula for refraction at a single spherical surface is:

$$\frac{\mu_2}{v} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R}$$

Applying this to our case:

$$\frac{\mu_2}{v'} - \frac{\mu_1}{u} = \frac{\mu_2 - \mu_1}{R_1} \quad \cdots (1)$$

Step 3: Refraction at the Second Surface (Radius R_2):
The image I' formed by the first surface acts as a virtual object for the second surface. Light now travels from the lens (μ_2) back to the medium (μ_1). The final image is formed at I (distance v).
For this surface, the object distance is v'. Applying the single surface formula (with μ_1 and μ_2 interchanged):

$$\frac{\mu_1}{v} - \frac{\mu_2}{v'} = \frac{\mu_1 - \mu_2}{R_2}$$

$$\frac{\mu_1}{v} - \frac{\mu_2}{v'} = -\frac{\mu_2 - \mu_1}{R_2} \quad \cdots (2)$$

Step 4: Combining the Equations:
Adding equation (1) and equation (2):

$$\left(\frac{\mu_2}{v'} - \frac{\mu_1}{u}\right) + \left(\frac{\mu_1}{v} - \frac{\mu_2}{v'}\right) = \left(\frac{\mu_2 - \mu_1}{R_1}\right) - \left(\frac{\mu_2 - \mu_1}{R_2}\right)$$

The term $\frac{\mu_2}{v'}$ cancels out:

$$\frac{\mu_1}{v} - \frac{\mu_1}{u} = (\mu_2 - \mu_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Dividing the entire equation by μ_1:

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Step 5: Introducing Focal Length (f):
By definition, when the object is at infinity ($u = \infty$), the image is formed at the focal point ($v = f$). Substituting this into the above equation:

$$\frac{1}{f} - \frac{1}{\infty} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Since $\frac{1}{\infty} = 0$, we get:

$$\frac{1}{f} = \left(\frac{\mu_2}{\mu_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

If the surrounding medium is air or vacuum ($\mu_1 = 1$) and the lens material has refractive index $\mu_2 = \mu$, the formula simplifies to its most common form:

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

This is the Lens Maker's formula.

Quick Tip

The derivation hinges on the "thin lens approximation," where the thickness of the lens is considered negligible. This allows us to measure all distances from a single point (the optical center) and to use the image distance from the first surface directly as the object distance for the second surface. Remember to use the Cartesian sign convention consistently for u, v, R_1, and R_2 when solving problems.

---

(5)
a. What is radial magnetic field ? Explain principle of moving coil galvanometer with the help of suitable diagram. How can its sensitivity be increased ?

Correct Answer: A radial magnetic field is one where the field lines are directed along the radii of a circle, always perpendicular to the area vector of the coil. A moving coil galvanometer works on the principle that a current-carrying coil placed in a magnetic field experiences a torque. Its sensitivity can be increased by increasing the number of turns, the magnetic field strength, or the area of the coil, or by decreasing the torsional constant of the suspension spring.

Solution:

1. Radial Magnetic Field:
A radial magnetic field is a magnetic field in which the field lines are always directed along the radii from the center of a circle. In the context of a moving coil galvanometer, it is produced by

using cylindrically concave pole pieces of a magnet and placing a soft iron core at the center. This ensures that the plane of the coil is always parallel to the magnetic field lines, and thus the angle between the magnetic field vector ($\vec{B}$) and the area vector of the coil ($\vec{A}$) is always 90°, maximizing the torque.

2. Principle and Working of Moving Coil Galvanometer:

- **Principle:** The working of a moving coil galvanometer is based on the principle that a current-carrying loop placed in a uniform magnetic field experiences a torque.

- **Working:** When a current I flows through the rectangular coil of N turns and area A, placed in a magnetic field B, it experiences a deflecting torque (τ_d).

$$\tau_d = NIAB \sin\theta$$

  In a radial magnetic field, $\theta = 90°$, so $\sin\theta = 1$. The deflecting torque is maximum and constant for any position of the coil:

$$\tau_d = NIAB$$

  This torque causes the coil to rotate. As the coil rotates, the suspension wire gets twisted, producing a restoring torque (τ_r) that is proportional to the angle of deflection (ϕ).

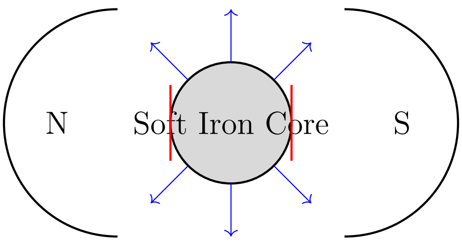
$$\tau_r = k\phi$$

  where k is the torsional constant of the spring. In equilibrium, the deflecting torque equals the restoring torque:

$$NIAB = k\phi \implies I = \left(\frac{k}{NAB}\right)\phi$$

  Since (k/NAB) is a constant, the current is directly proportional to the deflection ($I \propto \phi$). This allows for a linear scale for current measurement.

Diagram:



3. Increasing Sensitivity:
The current sensitivity of a galvanometer is defined as the deflection produced per unit current, $S_i = \frac{\phi}{I}$. From the equilibrium equation, we have:

$$S_i = \frac{\phi}{I} = \frac{NAB}{k}$$

To increase the sensitivity, we can:

- Increase the number of turns in the coil (N).
- Increase the magnetic field strength (B).
- Increase the area of the coil (A).
- Decrease the torsional constant (k) of the suspension fiber by using a material like phosphor-bronze.

Quick Tip

The purpose of the radial field is to make the torque ($\tau = NIAB\sin\theta$) maximum ($\theta = 90°$) and independent of the coil's orientation. This results in a linear relationship between current and deflection ($I \propto \phi$), which is essential for a calibrated measuring instrument.

---

b. The peak value of an alternating current is 14.14 Amp., and its frequency is 50 Hz. Draw current-time graph for two cycles. Find r.m.s. value of current. What time will the current take to reach the peak value starting from zero ?

Correct Answer: The r.m.s. value of the current is 10 A. The time taken to reach the peak value is 0.005 s.

Solution:

Step 1: Understanding the Concept and Given Data:
This problem deals with a sinusoidal alternating current (AC). We are given the peak value (I_0) and the frequency (f) and need to find its RMS value, the time to reach the first peak, and visualize its waveform.

- Peak current, $I_0 = 14.14$ A.
- Frequency, $f = 50$ Hz.

Step 2: Key Formulas and Calculations:
1. R.M.S. Value of Current (I_{rms}):
The relationship between the peak value and the RMS value of a sinusoidal current is:

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

We are given $I_0 = 14.14$ A. Note that $14.14 \approx 10 \times 1.414 = 10\sqrt{2}$.

$$I_{rms} = \frac{10\sqrt{2}}{\sqrt{2}} = 10\,\text{A}$$

2. Time to Reach the Peak Value:
The time period of one cycle is $T = \frac{1}{f}$.

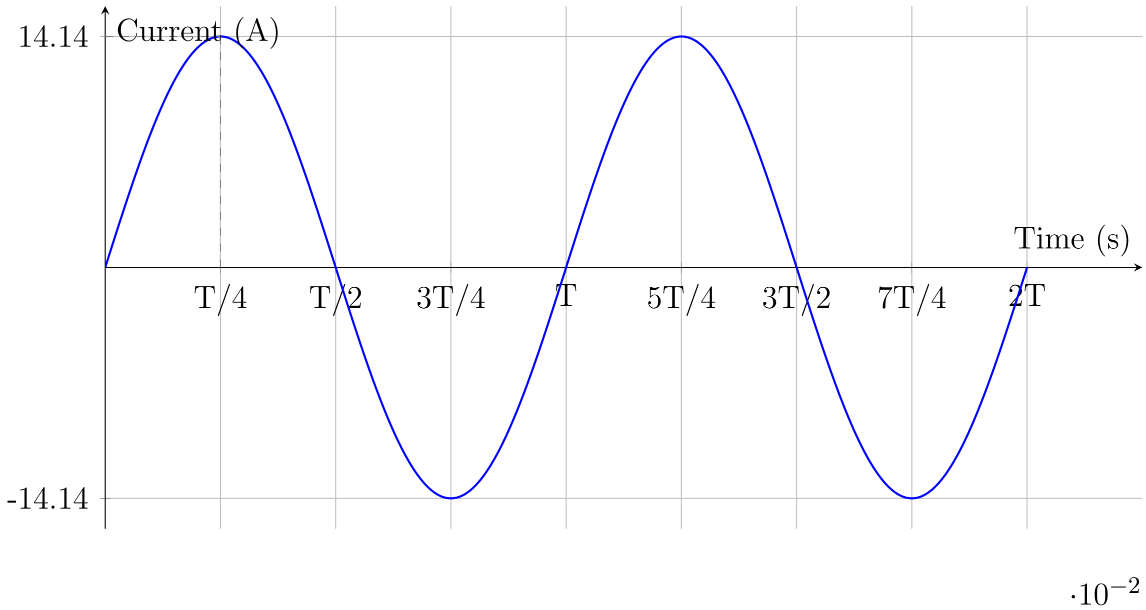
$$T = \frac{1}{50\,\text{Hz}} = 0.02\,\text{s}$$

A sinusoidal current starts from zero, reaches its first positive peak at one-quarter of the time period ($t = T/4$).

$$t_{peak} = \frac{T}{4} = \frac{0.02\,\text{s}}{4} = 0.005\,\text{s}$$

Step 3: Current-Time Graph for Two Cycles:

We need to draw the graph for a time duration of $2T = 2 \times 0.02 = 0.04$ s. The graph is a sine wave with an amplitude of 14.14 A.



Step 4: Final Answer:

- The r.m.s. value of the current is **10 A**.
- The time taken for the current to reach the peak value starting from zero is **0.005 s**.

Quick Tip

In AC problems, values like 14.14, 1.414, or 0.707 are often hints to use $\sqrt{2}$. Specifically, $14.14 \approx 10\sqrt{2}$ and $0.707 \approx 1/\sqrt{2}$. Recognizing these quickly can save a lot of calculation time.

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b. (OR) The amplitude of electric field vector of a plane electromagnetic wave is $E_0 = 150$ N/C and frequency $\nu = 50$ MHz. Find out
(i) Amplitude of magnetic field (B_0)
(ii) Angular frequency (ω)
(iii) Wavelength (λ)

Correct Answer: (i) $B_0 = 5 \times 10^{-7}$ T
(ii) $\omega = \pi \times 10^8$ rad/s or 3.14×10^8 rad/s
(iii) $\lambda = 6$ m

Solution:

Step 1: Understanding the Concept:
In a plane electromagnetic (EM) wave propagating in a vacuum, the electric field (E) and magnetic field (B) are mutually perpendicular and also perpendicular to the direction of wave propagation. Their amplitudes (E_0 and B_0) are related by the speed of light (c). The frequency (ν), angular frequency (ω), and wavelength (λ) are related through the wave speed equation.

Step 2: Key Formulas:
The formulas needed to solve this problem are:

1. Relation between electric and magnetic field amplitudes: $c = \frac{E_0}{B_0}$
2. Relation between angular frequency and linear frequency: $\omega = 2\pi\nu$
3. Relation between wave speed, frequency, and wavelength: $c = \nu\lambda$

We will use the constant value for the speed of light in vacuum, $c = 3 \times 10^8$ m/s.

Step 3: Detailed Calculations:
First, convert the given frequency to SI units:

$$\nu = 50\,\text{MHz} = 50 \times 10^6\,\text{Hz}$$

Given $E_0 = 150$ N/C.
(i) Amplitude of magnetic field (B_0):
From the formula $c = E_0/B_0$, we can rearrange to find B_0:

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

Substitute the given values:

$$B_0 = \frac{150\,\text{N/C}}{3 \times 10^8\,\text{m/s}} = 50 \times 10^{-8}\,\text{T}$$

$$B_0 = 5 \times 10^{-7}\,\text{T}$$

(ii) Angular frequency (ω):
Using the formula $\omega = 2\pi\nu$:

$$\omega = 2\pi \times (50 \times 10^6\,\text{Hz}) = 100\pi \times 10^6\,\text{rad/s}$$

$$\omega = \pi \times 10^8\,\text{rad/s}$$

Substituting $\pi \approx 3.14$:

$$\omega \approx 3.14 \times 10^8\,\text{rad/s}$$

(iii) Wavelength (λ):
From the formula $c = \nu\lambda$, we can rearrange to find λ:

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

Substitute the values:

$$\lambda = \frac{3 \times 10^8\,\text{m/s}}{50 \times 10^6\,\text{Hz}} = \frac{300 \times 10^6\,\text{m/s}}{50 \times 10^6\,\text{Hz}}$$

$$\lambda = \frac{300}{50}\,\text{m} = 6\,\text{m}$$

Step 4: Final Answer:

- (i) Amplitude of magnetic field, $B_0 = 5 \times 10^{-7}$ T.
- (ii) Angular frequency, $\omega = \pi \times 10^8$ rad/s.
- (iii) Wavelength, $\lambda = 6$ m.

Quick Tip

A very useful and easy way to remember the relationship between E and B in an EM wave is $E = cB$. Always ensure that all quantities are in their base SI units (Hz for frequency, m/s for speed, etc.) before starting calculations to avoid errors.

---

c. What is meant by 'displacement current' and write modified equation of Ampere's law.

Correct Answer: Displacement current is the current that comes into existence, in addition to the conduction current, whenever the electric field and hence the electric flux changes with time. The modified Ampere's law (Ampere-Maxwell law) is $\oint \vec{B} \cdot d\vec{l} = \mu_0(I_C + I_D) = \mu_0 \left(I_C + \epsilon_0 \frac{d\Phi_E}{dt}\right)$.

Solution:

Step 1: Understanding the Concept:
James Clerk Maxwell discovered an inconsistency in Ampere's Circuital Law, particularly when applied to situations with time-varying electric fields, such as the charging or discharging of a capacitor. To resolve this, he introduced the concept of displacement current.

Step 2: Explanation of Displacement Current:
Displacement current (I_D) is not a current in the traditional sense of flowing charges (which is conduction current, I_C). Instead, it is a theoretical current that is associated with a changing electric field.
Consider the gap between the plates of a capacitor being charged. While charges flow in the connecting wires (I_C), no charge actually crosses the gap. However, as charge accumulates on the plates, the electric field (E) between the plates changes with time. This changing electric field produces a magnetic field in the gap, just as a real current would.
Maxwell defined this displacement current as being proportional to the rate of change of electric flux (Φ_E) through a surface.
The displacement current is given by the formula:

$$I_D = \epsilon_0 \frac{d\Phi_E}{dt}$$

where $\Phi_E = \int \vec{E} \cdot d\vec{A}$ is the electric flux and ϵ_0 is the permittivity of free space. The existence of displacement current implies that a changing electric field is a source of a magnetic field.

Step 3: Modified Ampere's Law (Ampere-Maxwell Law):
The original Ampere's law was $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_C$. Maxwell modified this by adding the displacement current term to the total current.
The modified law, known as the Ampere-Maxwell Law, states that the line integral of the magnetic field around a closed loop is proportional to the sum of the conduction current (I_C) and the displacement current (I_D) passing through the surface enclosed by the loop.
The equation is:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 (I_C + I_D)$$

Substituting the expression for I_D, we get:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \left(I_C + \epsilon_0 \frac{d\Phi_E}{dt} \right)$$

Quick Tip

Remember the symmetry introduced by Maxwell: Faraday's law of induction states that a changing magnetic field produces an electric field. The concept of displacement current completes this symmetry by stating that a changing electric field produces a magnetic field. These two ideas are the foundation of electromagnetic waves.

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d. What is plane-polarised light ? How the ordinary light, partially polarised light and totally polarised light are distinguished with the help of a polaroid ?

Correct Answer: Plane-polarised light is light in which the electric field vibrations are confined to a single plane. They can be distinguished by rotating a polaroid: unpolarised light shows no change in intensity, partially polarised light shows a variation between a maximum and a non-zero minimum, and completely polarised light shows intensity varying from maximum to zero.

Solution:

1. Plane-Polarised Light:
An ordinary light wave (unpolarised light) consists of electric field vectors oscillating in all possible directions perpendicular to the direction of wave propagation. Plane-polarised light is a light wave in which the electric field oscillations are restricted to a single plane containing the direction of propagation. This plane is called the plane of polarisation.

2. Distinguishing between types of light using a Polaroid:
A polaroid (also called an analyser) is a device that only allows light with a specific polarisation orientation to pass through it. By passing the incident light through a polaroid and rotating

the polaroid by 360°, we can observe the intensity of the transmitted light and distinguish between the three types:

- **Case 1: Ordinary (Unpolarised) Light:**
  - **Process:** When unpolarised light is passed through a polaroid, the transmitted intensity is always half of the incident intensity ($I = I_0/2$).
  - **Observation:** As the polaroid is rotated, the intensity of the transmitted light remains **constant**. There is no variation in brightness.

- **Case 2: Totally (Plane) Polarised Light:**
  - **Process:** When plane-polarised light is passed through a polaroid, the transmitted intensity follows Malus's Law: $I = I_{max} \cos^2 \theta$, where θ is the angle between the polarisation plane of the light and the pass-axis of the polaroid.
  - **Observation:** As the polaroid is rotated, the intensity of the transmitted light **varies from a maximum value to zero**. The light will be completely extinguished (intensity becomes zero) at two positions in a full 360° rotation (when $\theta = 90°$ and $\theta = 270°$).

- **Case 3: Partially Polarised Light:**
  - **Process:** Partially polarised light is a mixture of unpolarised and plane-polarised light.
  - **Observation:** As the polaroid is rotated, the intensity of the transmitted light **varies between a maximum value and a non-zero minimum value**. Unlike totally polarised light, the intensity never becomes zero.

Quick Tip

The key to distinguishing the types of light is to look for the minimum intensity when rotating the analyser.

- No change in intensity $\implies$ Unpolarised.
- Intensity becomes zero $\implies$ Completely Polarised.
- Intensity has a non-zero minimum $\implies$ Partially Polarised.

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e. Find the maximum kinetic energy of the photo-electrons ejected, when light of wavelength 3300 Å is incident on a Cesium surface. Work function of Cesium = 1.9 eV.

Correct Answer: The maximum kinetic energy is 1.86 eV.

Solution:

Step 1: Understanding the Concept (Photoelectric Effect):
This problem uses Einstein's photoelectric equation, which describes the energy balance when a photon strikes a metal surface and ejects an electron (a photoelectron). The energy of the incident photon is used partly to overcome the work function of the metal and the rest is converted into the kinetic energy of the ejected electron.

Step 2: Key Formula or Approach:
Einstein's photoelectric equation is:

$$K.E._{max} = E_{photon} - \phi_0$$

where:

- $K.E._{max}$ is the maximum kinetic energy of the ejected photoelectron.
- E_{photon} is the energy of the incident photon.
- ϕ_0 is the work function of the metal.

The energy of a photon can be calculated from its wavelength λ. A very useful shortcut for calculations where wavelength is in Angstroms (Å) and energy is needed in electron-volts (eV) is:

$$E_{photon}(\text{in eV}) = \frac{hc}{e\lambda} \approx \frac{12400}{\lambda(\text{in Å})}$$

Step 3: Detailed Calculation:

1. **Given Data:**
   - Wavelength of incident light, $\lambda = 3300$ Å.
   - Work function of Cesium, $\phi_0 = 1.9$ eV.
2. **Calculate Photon Energy (E_{photon}):** Using the shortcut formula:
$$E_{photon} = \frac{12400}{\lambda(\text{in Å})}\,\text{eV} = \frac{12400}{3300}\,\text{eV}$$
$$E_{photon} = \frac{124}{33}\,\text{eV} \approx 3.757\,\text{eV}$$
   Let's use $E_{photon} \approx 3.76$ eV for our calculation.
3. **Calculate Maximum Kinetic Energy ($K.E._{max}$):** Now, substitute the values into the photoelectric equation:
$$K.E._{max} = E_{photon} - \phi_0$$
$$K.E._{max} = 3.76\,\text{eV} - 1.9\,\text{eV}$$
$$K.E._{max} = 1.86\,\text{eV}$$

Step 4: Final Answer:
The maximum kinetic energy of the ejected photo-electrons is **1.86 eV**.

Quick Tip

Memorizing the constant combination $hc \approx 1240\,\text{eV}\cdot\text{nm}$ or $12400\,\text{eV}\cdot\text{Å}$ is extremely helpful for modern physics problems. It allows you to directly convert wavelength in nanometers or Angstroms to photon energy in electron-volts without dealing with Planck's constant, the speed of light, and the charge of an electron individually.

Section - E

(6)
a. Deduce the equation of potential energy of a charged condenser and show that the energy density in the electric field between the plates of charged condenser is $\frac{1}{2}\epsilon_0 E^2$.

Correct Answer: The potential energy stored is $U = \frac{1}{2}CV^2$. The energy density is $u_E = \frac{1}{2}\epsilon_0 E^2$.

Solution:

Part 1: Deduction of Potential Energy of a Capacitor

Step 1: Understanding the Concept:
The potential energy stored in a capacitor is equal to the total work done in charging the capacitor. This work is done by an external agent (like a battery) to transfer charge from one plate to another against the electrostatic forces.

Step 2: Derivation:
Let's consider a capacitor of capacitance C. At an intermediate stage during charging, let q be the charge on the plates and V be the potential difference between them. By definition, $V = q/C$.
The work done (dW) to transfer an additional infinitesimal charge dq from the negative plate to the positive plate is given by:

$$dW = V\,dq$$

Substituting $V = q/C$:

$$dW = \frac{q}{C}\,dq$$

To find the total work done (W) in charging the capacitor from an initial charge of 0 to a final charge of Q, we integrate dW:

$$W = \int dW = \int_0^Q \frac{q}{C}\,dq$$

Since C is a constant:

$$W = \frac{1}{C}\int_0^Q q\,dq = \frac{1}{C}\left[\frac{q^2}{2}\right]_0^Q = \frac{1}{C}\left(\frac{Q^2}{2} - 0\right) = \frac{Q^2}{2C}$$

This work done is stored as electrostatic potential energy (U) in the capacitor.

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

Using the relation $Q = CV$, we can express the energy in other forms:

- $U = \frac{(CV)^2}{2C} = \frac{1}{2}CV^2$
- $U = \frac{Q^2}{2(Q/V)} = \frac{1}{2}QV$

Thus, the potential energy is $U = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$.

Part 2: Derivation of Energy Density

Step 1: Understanding the Concept:
Energy density (u_E) is the electrostatic potential energy stored per unit volume in the electric field.

Step 2: Derivation:
Consider a parallel plate capacitor with plate area A and separation distance d. The volume of the space between the plates is $Volume = A \times d$.
The capacitance of this capacitor is given by:

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

The electric field E between the plates is uniform and is related to the potential difference V by:

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

Now, let's use the potential energy formula $U = \frac{1}{2}CV^2$ and substitute the expressions for C and V:

$$U = \frac{1}{2}\left(\frac{\epsilon_0 A}{d}\right)(Ed)^2 = \frac{1}{2}\frac{\epsilon_0 A}{d}E^2 d^2$$

$$U = \frac{1}{2}\epsilon_0 E^2 (A \cdot d)$$

Energy density (u_E) is the energy per unit volume:

$$u_E = \frac{\text{Energy (U)}}{\text{Volume}} = \frac{U}{A \cdot d}$$

$$u_E = \frac{\frac{1}{2}\epsilon_0 E^2 (A \cdot d)}{A \cdot d}$$

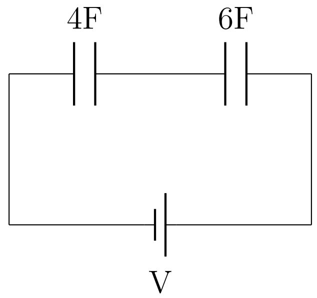
$$u_E = \frac{1}{2}\epsilon_0 E^2$$

This shows that the energy density in the electric field between the plates of a charged capacitor is $\frac{1}{2}\epsilon_0 E^2$.

Quick Tip

The three forms of capacitor energy ($U = \frac{1}{2}CV^2$, $U = \frac{Q^2}{2C}$, $U = \frac{1}{2}QV$) are all equivalent. Choose the most convenient one based on the quantities given in a problem. The energy density formula is general and applies to any electric field, not just the one in a capacitor.

(OR) Show that $\frac{\textbf{Farad}}{\textbf{meter}} = \frac{\textbf{coulomb}^2}{\textbf{newton}\times\textbf{meter}^2}$. Name its physical quantity. If potential difference across ends of capacitor of capacitance 6 μF is 2 volts, find out the potential difference across ends of the battery :



Correct Answer: The physical quantity is electric permittivity (ϵ). The potential difference across the battery is 5 V.

Solution:

Part 1: Unit Derivation

Step 1: Understanding the Concept:
We need to show the equivalence of two sets of units by breaking them down into their fundamental definitions.

Step 2: Derivation:
Let's start with the Left Hand Side (LHS): $\frac{\text{Farad}}{\text{meter}}$.
By definition, capacitance $C = Q/V$, so the unit Farad (F) is equivalent to Coulomb per Volt (C/V).

$$\text{LHS} = \frac{\text{C/V}}{\text{m}} = \frac{\text{C}}{\text{V} \cdot \text{m}}$$

The unit for potential difference, Volt (V), is defined as energy per unit charge, which is Joule per Coulomb (J/C).

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

The unit for energy, Joule (J), is defined as work done, which is force times distance, or Newton-meter $(N \cdot m)$.

$$J = N \cdot m$$

Substituting these back into our expression for the LHS:

$$V = \frac{N \cdot m}{C}$$

Now, substitute this expression for Volt into the LHS:

$$\text{LHS} = \frac{\text{C}}{\left(\frac{N \cdot m}{C}\right) \cdot \text{m}} = \frac{\text{C}^2}{N \cdot m^2}$$

In terms of base units, this is $\frac{\text{coulomb}^2}{\text{newton}\times\text{meter}^2}$, which is exactly the Right Hand Side (RHS). Thus, the relation is proven.

Part 2: Name the Physical Quantity

The unit $\frac{\text{Farad}}{\text{meter}}$ is the SI unit for **electric permittivity (ϵ)**. The permittivity of free space, ϵ_0, has a value of approximately 8.854×10^{-12} F/m.

Part 3: Circuit Problem

Step 1: Understanding the Circuit:

The circuit shows two capacitors, $C_1 = 4\,\mu\text{F}$ and $C_2 = 6\,\mu\text{F}$, connected in series to a battery of voltage V.

Step 2: Key Principles for Series Capacitors:

1. The charge stored on each capacitor is the same: $Q_1 = Q_2 = Q_{total}$.
2. The total voltage of the battery is the sum of the voltages across each capacitor: $V = V_1 + V_2$.

Step 3: Calculation:

We are given the potential difference across the $6\,\mu\text{F}$ capacitor:

$$V_2 = 2\,\text{V}$$

First, we find the charge stored on this capacitor using $Q = CV$:

$$Q_2 = C_2 V_2 = (6\,\mu\text{F})(2\,\text{V}) = 12\,\mu\text{C}$$

Since the capacitors are in series, the charge on the $4\,\mu\text{F}$ capacitor is the same:

$$Q_1 = Q_2 = 12\,\mu\text{C}$$

Now, we can find the voltage across the $4\,\mu\text{F}$ capacitor:

$$V_1 = \frac{Q_1}{C_1} = \frac{12\,\mu\text{C}}{4\,\mu\text{F}} = 3\,\text{V}$$

The total potential difference across the battery is the sum of the individual voltages:

$$V = V_1 + V_2 = 3\,\text{V} + 2\,\text{V} = 5\,\text{V}$$

Step 4: Final Answer:
The potential difference across the ends of the battery is **5 V**.

Quick Tip

For capacitors in series, the charge is the same on all of them. This is the key piece of information. Calculate the charge on the one capacitor where you have enough information (C and V), and then use that charge value for all other capacitors in the series branch.

---

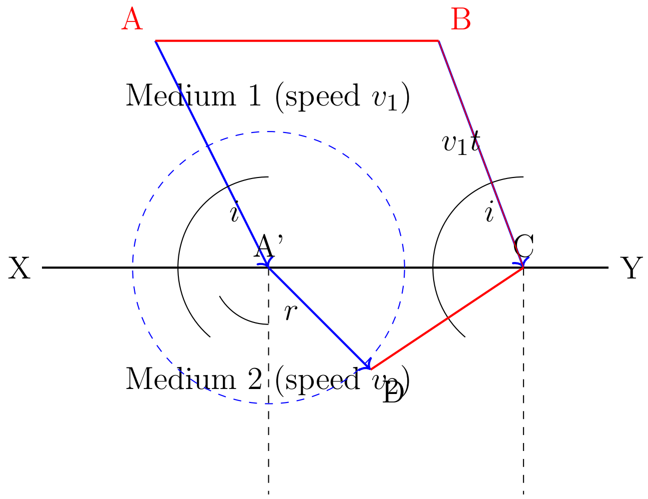
7. Define Wavefront. Explain, refraction of waves with the help of Huygen's secondary wavelet principle.

Correct Answer: A wavefront is the locus of all points vibrating in the same phase. Huygen's principle explains refraction by considering that each point on an incident wavefront acts as a source of secondary wavelets, which travel at different speeds in different media, causing the overall wavefront to bend and change direction, thus proving Snell's law.

Solution:

1. Definition of Wavefront:
A wavefront is defined as the continuous locus of all the particles of a medium which are vibrating in the same phase at any given instant. The direction of propagation of the wave is always perpendicular to the wavefront.

2. Refraction of Waves using Huygen's Principle:
Let us consider a plane wavefront AB incident on a refracting surface XY, separating two media, medium 1 (rarer) and medium 2 (denser). Let the speed of light in the two media be v_1 and v_2 respectively, with $v_1 > v_2$. The angle of incidence is i.



- According to Huygen's principle, every point on the incident wavefront AB is a source of secondary wavelets.

- When the wavefront strikes the surface at point A, A becomes a source of secondary wavelets in the second medium. Meanwhile, point B is still in the first medium.
- Let t be the time taken for the disturbance from point B to reach point C on the surface. Therefore, the distance $BC = v_1 t$.
- In the same time t, the secondary wavelets from point A will travel a distance $AD = v_2 t$ in the second medium.
- To find the new refracted wavefront, we draw a sphere (a circle in 2D) of radius $AD = v_2 t$ with A as the center.
- The tangent drawn from point C to this sphere gives the new refracted wavefront, CD.
- Now, in the right-angled triangle ABC:
$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}$$
- And in the right-angled triangle ADC:
$$\sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}$$
- Dividing the two equations, we get:
$$\frac{\sin i}{\sin r} = \frac{v_1 t/AC}{v_2 t/AC} = \frac{v_1}{v_2}$$
- The ratio of the speeds of light is equal to the refractive index of the second medium with respect to the first, n_{21}.
$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = n_{21}$$

This is Snell's law of refraction, thus proving the law using Huygen's principle.

Quick Tip

The key to proving laws of reflection or refraction using Huygen's principle is to correctly identify the distances traveled by the wavelets from two different points on the incident wavefront in the same interval of time. The new wavefront is the common tangent to all these secondary wavelets.

---

7. (OR) Focal lengths of objective and eye lenses of a telescope are 40 cm and 4 cm respectively. For an object placed in front of objective lens by 200 cm, what will be the distance between two lenses for normal vision ? Also find its magnification.

Correct Answer: The distance between the two lenses is 54 cm, and the magnification is -12.5.

Solution:

Step 1: Understanding the Concept and Given Data:
We are dealing with an astronomical telescope where the object is at a finite distance, not at infinity. For "normal vision" or "normal adjustment", the final image must be formed at infinity. This means the intermediate image formed by the objective lens must be located at the principal focus of the eyepiece.

- Focal length of objective, $f_o = +40$ cm.
- Focal length of eyepiece, $f_e = +4$ cm.
- Object distance for objective, $u_o = -200$ cm.

Step 2: Find the position of the intermediate image (v_o):
We use the lens formula for the objective lens:

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$$
$$\frac{1}{40} = \frac{1}{v_o} - \frac{1}{-200}$$
$$\frac{1}{40} = \frac{1}{v_o} + \frac{1}{200}$$
$$\frac{1}{v_o} = \frac{1}{40} - \frac{1}{200} = \frac{5-1}{200} = \frac{4}{200} = \frac{1}{50}$$
$$v_o = +50 \text{ cm}$$

The objective lens forms a real, inverted image 50 cm away from it.
Step 3: Find the distance between the lenses (L):
For the final image to be at infinity (normal vision), the intermediate image formed by the objective must be at the first focal point of the eyepiece. Thus, the distance of the intermediate image from the eyepiece is $u_e = f_e = 4$ cm. The total distance between the objective and eyepiece lenses is the sum of their separation:

$$L = |v_o| + |u_e| = v_o + f_e$$

$$L = 50 \text{ cm} + 4 \text{ cm} = 54 \text{ cm}$$

Step 4: Find the magnification (M):
The angular magnification of a telescope is given by $M = \frac{\beta}{\alpha}$, where β is the angle subtended by the final image at the eye and α is the angle subtended by the object at the objective.

$$\alpha \approx \frac{h_o}{|u_o|} \quad \text{and} \quad \beta \approx \frac{h_i}{f_e}$$

where h_o is the object height and h_i is the height of the intermediate image.

$$M = \frac{\beta}{\alpha} = \frac{h_i/f_e}{h_o/|u_o|} = \frac{h_i}{h_o} \times \frac{|u_o|}{f_e}$$

The linear magnification of the objective is $m_o = \frac{h_i}{h_o} = \frac{v_o}{u_o}$. The overall image is inverted.

$$M = \frac{v_o}{u_o} \times \frac{|u_o|}{f_e} = \frac{v_o}{f_e} \times \frac{|u_o|}{u_o} = -\frac{v_o}{f_e}$$

Substituting the values:

$$M = -\frac{50}{4} = -12.5$$

> **Quick Tip**
>
> For a telescope with an object at a finite distance, the formula for the length in normal adjustment becomes $L = v_o + f_e$ and the magnification becomes $M = -v_o/f_e$. Notice that if the object is at infinity ($u_o \to \infty$), then $v_o \to f_o$, and these formulas reduce to the standard ones: $L = f_o + f_e$ and $M = -f_o/f_e$.

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8. Write down Bohr's postulates for hydrogen atom. Prove that orbital radius (r) of hydrogen atom is directly proportional to square of the principal quantum number (n).

Correct Answer: Bohr's postulates are: electrons exist in stable, non-radiating orbits; their angular momentum is quantized ($L = nh/2\pi$); and energy is radiated only during orbital transitions. The proof shows that the radius of the n-th orbit is $r_n = (\frac{h^2\epsilon_0}{\pi m e^2})n^2$, which means $r \propto n^2$.

Solution:

1. Bohr's Postulates for the Hydrogen Atom:

1. **Postulate of Stationary Orbits:** An electron in an atom can revolve in certain stable, circular orbits called stationary orbits without emitting any radiation. Each orbit has a definite energy associated with it.
2. **Postulate of Quantization of Angular Momentum:** The angular momentum (L) of an electron in a stationary orbit is an integral multiple of $h/2\pi$, where h is Planck's constant.
$$L = m_e v r = n\frac{h}{2\pi}$$
where $n = 1, 2, 3, \ldots$ is the principal quantum number.
3. **Postulate of Energy Transition:** An electron can make a transition from a higher energy stationary orbit to a lower energy one. When it does so, a photon is emitted whose energy is equal to the energy difference between the initial (E_i) and final (E_f) orbits.
$$E_{photon} = h\nu = E_i - E_f$$

2. Proof that $r \propto n^2$:
Consider an electron of mass m_e and charge $-e$ revolving around a nucleus of charge $+e$ (for hydrogen, Z=1) in a circular orbit of radius r with a velocity v.

- **Force Balance:** The electrostatic force of attraction between the nucleus and the electron provides the necessary centripetal force for the circular motion.

$$F_{centripetal} = F_{electrostatic}$$

$$\frac{m_e v^2}{r} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2} \quad \cdots (1)$$

- **Bohr's Quantization Condition:** From the second postulate:

$$m_e v r = \frac{nh}{2\pi}$$

From this, we can express the velocity v as:

$$v = \frac{nh}{2\pi m_e r} \quad \cdots (2)$$

- **Substitution:** Substitute the expression for v from equation (2) into equation (1):

$$\frac{m_e}{r}\left(\frac{nh}{2\pi m_e r}\right)^2 = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r^2}$$

$$\frac{m_e}{r}\frac{n^2h^2}{4\pi^2 m_e^2 r^2} = \frac{e^2}{4\pi\epsilon_0 r^2}$$

- **Simplification and Solving for r:**

$$\frac{n^2h^2}{4\pi^2 m_e r^3} = \frac{e^2}{4\pi\epsilon_0 r^2}$$

Cancel 4π and r^2 from both denominators:

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

Rearranging the terms to solve for the radius r:

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

- **Conclusion:** In this expression, h, ϵ_0, π, m_e, and e are all fundamental constants. Therefore, we can write the radius as:

$$r = (\text{constant}) \times n^2$$

This proves that the radius of the orbital is directly proportional to the square of the principal quantum number ($r \propto n^2$).

Quick Tip

The derivation for Bohr's radius and energy levels relies on two fundamental equations: the force balance equation ($F_{centripetal} = F_{electric}$) and the angular momentum quantization condition ($mvr = nh/2\pi$). By combining these two, you can derive expressions for r, v, and E in terms of n.

8. (OR) What do you mean by Nuclear fission ? In the fission of U^{235} nucleus, 200 MeV energy is produced. Power of 4 MW is obtained by a reactor. How many nuclei are fissioned per sec in the reactor ?

Correct Answer: Nuclear fission is the splitting of a heavy nucleus into lighter nuclei, releasing energy. The number of nuclei fissioned per second in the reactor is 1.25×10^{17}.

Solution:

1. Nuclear Fission:
Nuclear fission is a nuclear reaction in which the nucleus of a heavy, unstable atom (such as Uranium-235 or Plutonium-239) absorbs a neutron and splits into two or more smaller, lighter nuclei (fission fragments). This process also releases a few neutrons and a very large amount of energy. The released neutrons can then go on to cause further fissions, leading to a self-sustaining chain reaction if controlled, as in a nuclear reactor.

2. Calculation of Fissions per Second:

Step 1: List the Given Data and Convert to SI Units:

- Energy released per fission, $E = 200$ MeV.
- Power of the reactor, $P = 4$ MW.

We need to convert these to Joules and Watts (Joules/second) respectively.

- $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \implies 1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$

$$E = 200 \times 10^6 \text{ eV} = 200 \times 1.6 \times 10^{-13} \text{ J} = 3.2 \times 10^{-11} \text{ J}$$

- $1 \text{ MW} = 10^6 \text{ W}$

$$P = 4 \times 10^6 \text{ W} = 4 \times 10^6 \text{ J/s}$$

Step 2: Relate Power, Energy, and Number of Fissions:
Power is the rate at which energy is produced. If N is the number of fissions occurring per second, then the total energy produced per second (Power) is the product of N and the energy per fission (E).

$$P = N \times E$$

We need to find N, the number of fissions per second.

$$N = \frac{P}{E}$$

Step 3: Calculate the Value of N:
Substitute the values in SI units into the equation:

$$N = \frac{4 \times 10^6 \text{ J/s}}{3.2 \times 10^{-11} \text{ J/fission}}$$

$$N = \frac{4}{3.2} \times 10^{6-(-11)} \text{ fissions/s}$$
$$N = \frac{40}{32} \times 10^{17} \text{ fissions/s} = \frac{5}{4} \times 10^{17} \text{ fissions/s}$$
$$N = 1.25 \times 10^{17} \text{ fissions/s}$$

Step 4: Final Answer:
The number of nuclei fissioned per second in the reactor is 1.25×10^{17}.

Quick Tip

In nuclear physics calculations, unit conversion is critical. Always convert energy from MeV to Joules and power from MW (or GW) to Watts before applying the formulas. Remember the relationship: Power = (Number of events per second) $\times$ (Energy per event).

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9. What are energy-bands in solids ? Differentiate conductors, insulators and semi-conductors on the basis of energy-bands and explain the effect of temperature on these.

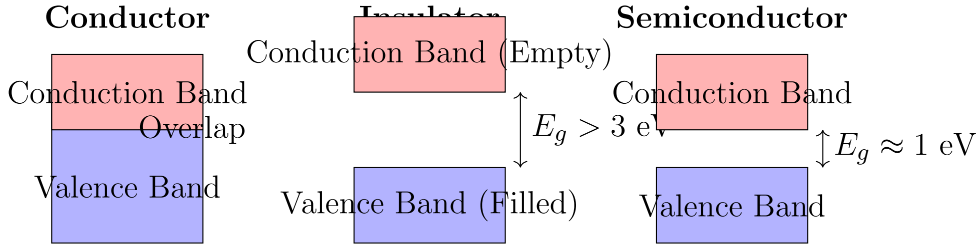
Correct Answer: Energy bands are closely spaced energy levels formed in solids. Conductors have overlapping valence and conduction bands. Insulators have a large energy gap (> 3 eV). Semiconductors have a small energy gap (< 3 eV). Temperature increases the resistance of conductors but decreases the resistance of semiconductors.

Solution:

1. Energy Bands in Solids:
In an isolated atom, electrons occupy discrete energy levels. When atoms are brought close together to form a crystalline solid, the electrons in the outer shells of an atom are influenced by the electrons and nuclei of neighboring atoms. This interaction causes the discrete energy levels of the isolated atoms to split and form a collection of a very large number of closely spaced energy levels, which are effectively continuous. These ranges of allowed energies are called **energy bands**. The two most important bands are:

- **Valence Band (VB):** The energy band containing the valence electrons. It is the highest occupied energy band at 0 K.
- **Conduction Band (CB):** The lowest unoccupied energy band. Electrons in this band are free to move and contribute to electrical conduction.
- **Forbidden Energy Gap (E_g):** The energy range between the top of the valence band and the bottom of the conduction band, which contains no allowed energy levels for electrons.

2. Differentiation based on Band Theory:



- **Conductors:** In conductors (metals), the valence band and the conduction band overlap. There is no forbidden energy gap between them. Due to this overlap, a large number of free electrons are readily available in the conduction band to conduct electricity, even at zero Kelvin.
- **Insulators:** In insulators, the valence band is completely filled, and the conduction band is completely empty. There is a very large forbidden energy gap ($E_g > 3$ eV) separating them. It is almost impossible for an electron to gain enough energy to jump from the valence band to the conduction band.
- **Semiconductors:** In semiconductors, the band structure is similar to that of insulators, but the forbidden energy gap is much smaller ($E_g < 3$ eV, e.g., ~ 1.1 eV for Silicon). At 0 K, they behave like insulators. However, at room temperature, some electrons can gain enough thermal energy to jump the gap into the conduction band, allowing for limited conductivity.

3. Effect of Temperature:

- **Conductors:** When the temperature of a conductor is increased, the thermal vibrations of the metal ions (lattice) increase. This leads to more frequent collisions between the free electrons and the ions, which increases the electrical resistance.
- **Insulators:** Due to the large band gap, an increase in temperature has very little effect on the conductivity of insulators, as very few electrons can be thermally excited to the conduction band.
- **Semiconductors:** When the temperature of a semiconductor is increased, more valence electrons gain sufficient thermal energy to jump across the small forbidden gap into the conduction band, creating electron-hole pairs. This increases the number of charge carriers, which significantly increases the conductivity (and decreases the resistance).

Quick Tip

The key distinguishing factor is the size of the forbidden energy gap (E_g). For conductors $E_g \approx 0$, for semiconductors E_g is small, and for insulators E_g is large. This gap size dictates how easily electrons can become charge carriers.

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9. (OR) Explain, the formation of 'Depletion-layer' at the junction p-n junction-diode. Explain potential-barrier and Avalanche breakdown.

Correct Answer: The depletion layer forms due to the diffusion of majority carriers across the p-n junction, leaving behind immobile ions. This creates a potential barrier that opposes further diffusion. Avalanche breakdown is a rapid current increase in strong reverse bias caused by charge carrier multiplication through impact ionization.

Solution:

1. Formation of Depletion Layer:
When a p-type semiconductor is joined with an n-type semiconductor to form a p-n junction, two processes begin: diffusion and drift.

- **Diffusion:** Due to the high concentration of holes on the p-side and electrons on the n-side, a concentration gradient exists across the junction. This causes holes to diffuse from the p-side to the n-side, and electrons to diffuse from the n-side to the p-side.
- **Recombination and Ion Formation:** When a hole diffuses to the n-side, it recombines with an electron. When an electron diffuses to the p-side, it recombines with a hole. This process is not instantaneous. The electron leaving the n-side leaves behind a positively charged (ionized) donor atom. Similarly, the hole leaving the p-side leaves behind a negatively charged (ionized) acceptor atom.
- **Depletion Region:** This creates a region near the junction which is depleted of mobile charge carriers (electrons and holes) but contains a layer of fixed positive ions on the n-side and fixed negative ions on the p-side. This region is known as the **depletion layer** or space-charge region.

2. Potential Barrier:
The accumulation of fixed positive and negative charges in the depletion layer sets up an electric field directed from the positive n-side to the negative p-side. This electric field creates a potential difference across the junction. This potential difference is called the **potential barrier** or barrier voltage (V_B). The potential barrier opposes the further diffusion of majority charge carriers. An equilibrium is reached when the electric force due to the potential barrier on the majority carriers becomes equal and opposite to the force due to the concentration gradient. For silicon, $V_B \approx 0.7$ V, and for germanium, $V_B \approx 0.3$ V at room temperature.

3. Avalanche Breakdown:
Avalanche breakdown is a phenomenon that occurs in a p-n junction diode under a high reverse bias voltage.

- **Reverse Bias:** In reverse bias, the applied voltage widens the depletion layer and increases the strength of the electric field across it. The current is very small and is due to minority carriers.
- **Carrier Acceleration:** These minority carriers are accelerated to very high velocities and gain significant kinetic energy as they are swept across the strong electric field in the depletion region.
- **Impact Ionization:** If the reverse voltage is high enough (the breakdown voltage), these energetic minority carriers can collide with the atoms of the semiconductor crystal lattice with enough force to knock valence electrons out of their covalent bonds. This process is called impact ionization, and it creates new electron-hole pairs.

- **Avalanche Effect:** The newly created charge carriers are also accelerated by the strong electric field and cause further impact ionizations, creating even more carriers. This process repeats, leading to a rapid, cumulative multiplication of charge carriers, much like an avalanche.
- **Breakdown:** This rapid multiplication results in a sharp increase in the reverse current, and the diode is said to be in the breakdown region. This process can be destructive to the diode if the current is not limited by an external circuit resistance.

Quick Tip

To remember the direction of the internal field in the depletion layer, think about the fixed ions left behind: positive ions are on the N-side and negative ions are on the P-side. The electric field always points from positive to negative, so it points from the N-side to the P-side.
