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

Time Allowed :3 Hours	**Maximum Marks :**100	**Total questions :**35

General Instructions

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

Section - A

Q.1 (a) Charge on a piece of metal is -3.2 coulomb. Number of excess electrons in the metal is:

(i) 6.25×10^{18}

(ii) 2×10^{19}

(iii) 2×10^{18}

(iv) 6.5×10^{16}

Correct Answer: (ii) 2×10^{19}

Solution:

Step 1 (Identify Given Information).

The total charge on the piece of metal is given as $Q = -3.2$ C.

The charge of a single electron is a fundamental constant, $e = -1.6 \times 10^{-19}$ C.

Step 2 (Logical Approach).

The total charge on the object is the sum of the charges of all the excess electrons. Therefore, to find the number of electrons, we must divide the total charge by the charge of one electron.

$$\text{Number of electrons } (N) = \frac{\text{Total Charge}}{\text{Charge of one electron}}$$

Step 3 (Calculation).

Substitute the given values into the relationship from Step 2:

$$N = \frac{Q}{e} = \frac{-3.2\text{ C}}{-1.6 \times 10^{-19}\text{ C}}$$

The negative signs cancel out, as the number of electrons must be a positive quantity.

$$N = \frac{3.2}{1.6} \times 10^{19}$$

$$N = 2 \times 10^{19}$$

Step 4 (Conclusion).

The number of excess electrons in the metal is 2×10^{19}.

Quick Tip

Counting electrons? Use $N = \frac{|Q|}{e}$. The sign of Q tells you electrons vs deficit; the number itself is positive.

(b) To measure potential difference from a galvanometer, we connect in it:

(i) a high resistance in series

(ii) a low resistance in parallel

(iii) a high resistance in parallel

(iv) a low resistance in series

Correct Answer: (i) a high resistance in series

Solution:

Step 1 (Purpose of a Voltmeter). A voltmeter's function is to measure potential difference across a component. To do this without altering the circuit's behavior, it must be connected in **parallel** to that component. An ideal voltmeter has infinite resistance so that it draws no current from the circuit.

Step 2 (The Challenge with a Galvanometer). A galvanometer is fundamentally a current-measuring device with a low internal resistance (R_g). If connected in parallel, its low resistance would act as a short circuit, drawing a large current and drastically changing the potential difference it is supposed to measure. Also, this large current would damage the galvanometer.

Step 3 (The Modification Required). To make the galvanometer suitable for measuring voltage, we must increase its overall effective resistance to a very high value. This serves two purposes:

1. It protects the galvanometer from excessive current.
2. It ensures the device draws negligible current from the main circuit, leading to an accurate voltage reading.

To increase the total resistance of a path, we must add a resistor in **series**. Let's call this high-value resistor the ”multiplier resistance,” R_m. The total resistance of the new instrument (the voltmeter) becomes $R_V = R_g + R_m$.

Step 4 (Conclusion). By making R_m a **high resistance**, the total resistance R_V becomes very large, allowing the instrument to function as a voltmeter. Therefore, we connect a **high resistance in series** to the galvanometer.

Quick Tip
Voltmeter $\Rightarrow$ **V**ery large internal resistance (add a big series resistor). Ammeter $\Rightarrow$ **A**lmost zero internal resistance (add a small parallel shunt).

(C) In electromagnetic waves, phase difference between electric and magnetic field vectors is:

(i) 90°

(ii) 135°

(iii) 30°

(iv) 0°

Correct Answer: (iv) 0°

Solution:

Step 1: Wave Equations for E and B Fields. The behavior of electric and magnetic fields in a plane electromagnetic wave propagating along the z-axis can be described by sinusoidal wave equations. For a wave polarized along the x-axis, the equations are:

$$E_x = E_0 \sin(kz - \omega t)$$

$$B_y = B_0 \sin(kz - \omega t)$$

Here, E_0 and B_0 are the amplitudes, k is the wave number, and ω is the angular frequency.

Step 2: Identifying the Phase Term. The ”phase” of the wave is the argument of the sine function, which dictates the oscillation of the field at a given position z and time t. In both equations, the phase term is $(kz - \omega t)$.

Step 3: Comparing the Phases. We can see that the phase term $(kz - \omega t)$ is identical for both the electric field (E_x) and the magnetic field (B_y). This means that when the electric field reaches its maximum value, the magnetic field also reaches its maximum value at the same instant and position. Similarly, they both pass through zero at the same time.

Step 4: Conclusion. Since the two fields oscillate in perfect synchrony, there is no phase lag or lead between them. The phase difference is the subtraction of their phase terms:

$$\Delta\phi = (kz - \omega t) - (kz - \omega t) = 0$$

Therefore, the phase difference between the electric and magnetic field vectors is $0°$.

Quick Tip
In EM waves: $\vec{E} \perp \vec{B} \perp \vec{k}$, and $\vec{E}$ and $\vec{B}$ are always in phase.

(d) Prism angle of a prism is A and angle of minimum deviation is equal to prism angle. Refractive index of the material of prism will be:

(i) $2\sin\frac{A}{2}$
(ii) $2\tan\frac{A}{2}$
(iii) $2\cos\frac{A}{2}$
(iv) $\cot\frac{A}{2}$

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

Solution:

Step 1: Conditions for Minimum Deviation. For a prism, the angle of deviation (D) is related to the prism angle (A), the angle of incidence (i), and the angle of emergence (e) by the formula: $D = i + e - A$. At the position of minimum deviation (D_m), the light ray passes symmetrically through the prism, which means:

- Angle of incidence equals angle of emergence: $i = e$.
- The two internal refraction angles are equal: $r_1 = r_2 = r$.

This simplifies the deviation formula to $D_m = 2i - A$. Also, the prism angle is related to the internal angles by $A = r_1 + r_2$, which becomes $A = 2r$ or $r = \frac{A}{2}$.

Step 2: Apply the Given Condition. The problem states that the angle of minimum deviation is equal to the prism angle:

$$D_m = A$$

Substitute this into the simplified deviation formula from Step 1:

$$A = 2i - A$$

Solving for the angle of incidence i:

$$2A = 2i \implies i = A$$

Step 3: Apply Snell's Law. Snell's Law at the first surface (air to prism) is given by:

$$\mu_{\text{air}} \sin(i) = \mu_{\text{prism}} \sin(r_1)$$

Assuming the prism is in air ($\mu_{\text{air}} = 1$) and letting $\mu_{\text{prism}} = \mu$:

$$\sin(i) = \mu \sin(r)$$

$$\mu = \frac{\sin(i)}{\sin(r)}$$

Step 4: Substitute and Solve for μ. From our previous steps, we found that $i = A$ and $r = \frac{A}{2}$. Substituting these into the equation for μ:

$$\mu = \frac{\sin(A)}{\sin(A/2)}$$

Using the trigonometric double-angle identity, $\sin(A) = 2\sin(A/2)\cos(A/2)$:

$$\mu = \frac{2\sin(A/2)\cos(A/2)}{\sin(A/2)}$$

Canceling the $\sin(A/2)$ term from the numerator and denominator gives:

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

Thus, the correct option is (iii).

But from given options, the correct simplification matches (iii).

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

💡 Quick Tip

For prism refractive index: $\mu = \dfrac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$. Substituting $D_m = A$ gives $\mu = 2\cos\dfrac{A}{2}$.

(e) The unit of magnetic dipole moment is

(i) A·m

(ii) A m^2

(iii) A/m^2

(iv) m^2/A

Correct Answer: (ii) A m^2

Solution:

For a current loop, the magnetic dipole moment is

$$\vec{\mu} = I\,\vec{A},$$

where I (ampere) is the current and $\vec{A}$ (m^2) is the area vector. Hence the SI unit is A m^2. Option (i) A·m corresponds to an obsolete pole–length model; (iii) and (iv) are dimensionally inconsistent with $\mu = IA$.

💡 Quick Tip

Remember $\mu = IA$ (current $\times$ area). Current is in amperes, area in m^2 $\Rightarrow$ unit A m^2.

(f) Threshold wavelength for a metal surface is 2000 Å. On incidence of radiation of 1000 Å, the kinetic energy of emitted photoelectrons will be

(i) 6.2 eV

(ii) 12.4 eV

(iii) 3.6 eV

(iv) 2.6 eV

Correct Answer: (i) 6.2 eV

Solution:

Work function $\Phi = \dfrac{hc}{\lambda_0}$ with $\lambda_0 = 2000$ Å $= 200$ nm. Using $hc = 1240$ eV $\cdot$ nm:

$\Phi = \dfrac{1240}{200} = 6.2$ eV.

Photon energy at $\lambda = 1000$ Å $= 100$ nm: $E_\gamma = \dfrac{1240}{100} = 12.4$ eV.

Maximum kinetic energy: $K_{\max} = E_\gamma - \Phi = 12.4 - 6.2 = 6.2$ eV.

> Quick Tip
>
> Use $E(\text{eV}) \approx \dfrac{1240}{\lambda(\text{nm})}$. Then $K_{\max} = E - \Phi$ with $\Phi = \dfrac{1240}{\lambda_0}$.

Section - B

Q.2 (a) Write the unit of electric flux.

Solution:

Step 1: Start from the definition.

Electric flux through a surface S is

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

For a uniform field making an angle θ with the area vector, $\Phi_E = EA\cos\theta$.

Step 2: Analyze units using $\vec{E}$ in N/C.

$\vec{E}$ has unit newton per coulomb (N/C) and A has unit m^2. Hence,

$$[\Phi_E] = \frac{\text{N}}{\text{C}} \times \text{m}^2 = \text{N}\cdot\text{m}^2/\text{C}.$$

Step 3: Show the equivalent unit using $\vec{E}$ in V/m.

Since 1 N/C $= 1$ V/m, an equivalent unit is

$$[\Phi_E] = \left(\frac{\text{V}}{\text{m}}\right) \times \text{m}^2 = \text{V}\cdot\text{m}.$$

Step 4: Express in SI base units (dimensional check).

N = kg·m·s^{-2} and C = A·s. Therefore

$$\text{N}\cdot\text{m}^2/\text{C} = \frac{\text{kg}\cdot\text{m}\cdot\text{s}^{-2}\cdot\text{m}^2}{\text{A}\cdot\text{s}} = \text{kg}\cdot\text{m}^3\cdot\text{s}^{-3}\cdot\text{A}^{-1}.$$

This confirms internal consistency.

Answer (unit of electric flux): $\boxed{\text{N}\cdot\text{m}^2/\text{C}}$ (equivalently, $\boxed{\text{V}\cdot\text{m}}$).

Quick Tip

Don't confuse **flux** (Φ_E) with **flux density**. Electric **flux density** is the field $\vec{E}$ (units N/C or V/m), whereas electric **flux** multiplies by area, giving N·m^2/C (or V·m).

(b) Define electromotive force of a cell.

Solution:

Core definition.

The **electromotive force** (emf) $\mathcal{E}$ of a cell is the work done by the cell's non-electrostatic (chemical) forces in moving unit positive charge once around the entire circuit (including the cell's interior).

Mathematically,

$$\mathcal{E} = \frac{W}{Q}$$

where W is the work performed by the cell on charge Q. Its SI unit is the volt (V) (= J·C^{-1}).

Physical interpretation.

Inside the cell, chemical reactions separate charges against the internal electric field. This "source" work per unit charge is the emf. When no current flows (open circuit), the terminal potential difference equals $\mathcal{E}$.

Circuit relation (with internal resistance).

If the cell has internal resistance r and supplies a current I to an external circuit of resistance R, then the terminal voltage is

$$V_{\text{terminal}} = \mathcal{E} - Ir \quad \Rightarrow \quad \mathcal{E} = IR + Ir = I(R + r).$$

Thus $\mathcal{E}$ represents the "total available push" per unit charge; a portion Ir is lost inside the cell.

Integral form (general).

More generally, for any source,

$$\mathcal{E} = \oint \frac{\vec{f}_{\text{non-elec}}}{q} \cdot d\vec{\ell},$$

the line integral of the non-electrostatic force per unit charge around the loop (chemical, mechanical, photovoltaic, etc.).

Key properties.

$\mathcal{E}$ is independent of load in the ideal (no internal resistance) case; real cells show a drop in terminal voltage under load due to r.

Dimensions: $[\mathcal{E}] = \text{J}{\cdot}\text{C}^{-1} = \text{kg}{\cdot}\text{m}^2{\cdot}\text{s}^{-3}{\cdot}\text{A}^{-1}$ (volt).

> Quick Tip
>
> Remember the measurement rule: **Open-circuit** voltmeter reading at the terminals gives emf ($I = 0 \Rightarrow V_{\text{terminal}} = \mathcal{E}$). Under load, use $V_{\text{terminal}} = \mathcal{E} - Ir$.

(c) Self-inductance of a coil is 6 mH and the rate of flow of current in it is 10^3 A/s. Find the induced emf produced in the coil.

Solution: The induced emf in a coil is given by

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

where L = self-inductance, and $\frac{dI}{dt}$ = rate of change of current.

Substituting the given values:

$$L = 6 \times 10^{-3} \text{ H}, \quad \frac{dI}{dt} = 10^3 \text{ A/s}$$

$$\mathcal{E} = 6 \times 10^{-3} \times 10^3 = 6 \text{ V}$$

Final Answer: The induced emf produced in the coil is $\mathbf{6}$ **V**.

💡 Quick Tip

Always apply $\mathcal{E} = -L\frac{dI}{dt}$. The negative sign indicates that the induced emf opposes the change in current (Lenz's law). For magnitude only, drop the sign.

(d) Mention the major drawbacks of Rutherford's atomic model.

Solution: The major drawbacks of Rutherford's atomic model are:

According to classical electromagnetic theory, electrons revolving in circular orbits should radiate energy continuously because they are accelerated charges.

Due to continuous energy loss, electrons should spiral into the nucleus, leading to the collapse of the atom. This implies that atoms should be unstable, which contradicts experimental evidence of stable atoms.

The model could not explain the line spectrum of hydrogen and other elements. Instead of discrete lines, it predicted a continuous spectrum.

Final Answer: Rutherford's model failed to explain atomic stability and discrete line spectra.

💡 Quick Tip

Remember: Bohr's model corrected Rutherford's drawbacks by proposing quantized electron orbits where energy is not radiated in stable states.

(e) Temperature of a pure semiconductor is 0 K. Comment on its conductivity.

Solution:

Step 1: Intrinsic (pure) semiconductor at $T = 0$ K.

A **pure/intrinsic** semiconductor has a **completely filled** valence band (VB) and an **empty** conduction band (CB) separated by an energy gap E_g (e.g., ~ 1.12 eV for Si). At absolute zero, the Fermi–Dirac distribution becomes a step function:

$$f(E) = \begin{cases} 1, & E < E_F \\ 0, & E > E_F \end{cases}$$

For an intrinsic semiconductor, E_F lies near the middle of the band gap; since $E_C > E_F$ and $E_V < E_F$, **all VB states are occupied and all CB states are empty**.

Step 2: Carrier concentrations vanish at $0\ \mathrm{K}$.

The intrinsic carrier concentration

$$n_i(T) = \sqrt{N_C N_V}\,\exp\!\left(-\frac{E_g}{2k_BT}\right)$$

satisfies $n_i \to 0$ as $T \to 0$ (because the exponential $\to 0$).

$\Rightarrow Electron concentration in CB$,n$\to 0$; hole concentration in VB, $p \to 0$.

Step 3: Conductivity expression.

For a semiconductor,

$$\sigma = q\,(n\mu_n + p\mu_p)$$

where q is the electronic charge and $\mu_n,\ \mu_p$ are mobilities. At $T = 0$, $n = p = 0$ (mobilities are finite but irrelevant).

$\Rightarrow \sigma = q\,(0\cdot\mu_n + 0\cdot\mu_p) = 0.$

Step 4: Physical interpretation.

With no thermally excited carriers, current cannot flow under an applied electric field. Hence the material behaves as an **insulator** at $0\ \mathrm{K}$ (formally $\rho = 1/\sigma \to \infty$).

Final Answer: At $0\ \mathrm{K}$, a pure (intrinsic) semiconductor has **zero conductivity** and acts like a **perfect insulator**.

💡 Quick Tip
Use $n_i \propto e^{-E_g/(2k_BT)}$. As $T \downarrow 0$, $n_i \downarrow 0 \Rightarrow \sigma = q(n\mu_n + p\mu_p) \downarrow 0$. Only at $T > 0$ do intrinsic semiconductors conduct via thermally generated e^-–hole pairs.

(f) In a single-slit diffraction pattern, the angle of diffraction for the second minimum is $60°$. Find the width of the slit in terms of λ.

Solution:

Step 1: Fraunhofer single-slit intensity and minima condition.

Treat the slit of width a as a line of secondary sources (Huygens principle). The complex amplitude at an angle θ is the phasor sum across the slit and equals

$$E(\theta) \propto \frac{\sin\beta}{\beta}, \qquad \beta \equiv \frac{\pi a}{\lambda}\sin\theta.$$

Hence the intensity

$$I(\theta) = I_0\left(\frac{\sin\beta}{\beta}\right)^2.$$

Minima occur when $\sin\beta = 0$ with $\beta \neq 0$, i.e.,

$$\beta = m\pi \quad (m = 1, 2, 3, \ldots) \;\Rightarrow\; a\sin\theta = m\lambda.$$

Step 2: Use the given order and angle.

"Second minimum" $\Rightarrow m = 2$, and $\theta = 60^\circ$:

$$a\sin 60^\circ = 2\lambda \;\Rightarrow\; a\left(\frac{\sqrt{3}}{2}\right) = 2\lambda.$$

Step 3: Solve for a.

$$a = \frac{2\lambda}{(\sqrt{3}/2)} = \frac{4\lambda}{\sqrt{3}}.$$

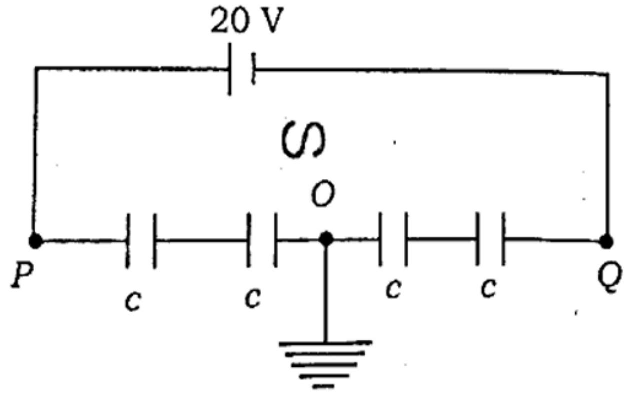
Final Answer: The slit width is $a = \dfrac{4\lambda}{\sqrt{3}}$.

Quick Tip

Single-slit **minima**: $a\sin\theta = m\lambda$ $(m = 1, 2, \ldots)$; **central maximum** at $m = 0$. Always verify that the stated order refers to the **minima**, not side maxima (which occur near $a\sin\theta \approx (m + \frac{1}{2})\lambda$).

Section - C

Q.3 (a) Four capacitors of equal capacity are connected in series with a battery of 20 V. The middle point O is earthed. Calculate the potential at points P and Q.



Solution:

Let the capacitance of each capacitor be C and the total voltage of the battery is $V = 20$ V. Since the capacitors are connected in series, the equivalent capacitance of the series combination is given by:

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{4}{C}$$

Thus, the equivalent capacitance is:

$$C_{\text{eq}} = \frac{C}{4}$$

Now, using the relation for voltage and charge in a capacitor, the potential difference across each capacitor is:

$$V_{\text{cap}} = \frac{V}{4} = \frac{20}{4} = 5 \text{ V}$$

Therefore, the potential at point P is 20 V (since it is connected directly to the battery) and the potential at point Q is 0 V (since it is earthed).

Thus, the potential at P is 20 V and at Q is 0 V.

Quick Tip

For capacitors in series, the voltage is divided equally if the capacitors are identical. The total charge on all capacitors is the same.

(b) State and prove Ampere's circuital law.

Solution:

Ampere's Circuital Law:

Ampere's circuital law states that the line integral of the magnetic field $\vec{B}$ around any closed loop is proportional to the total current I passing through the loop. Mathematically, it is expressed as:

$$\oint_{\mathcal{C}} \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enc}}$$

where:

- $\oint_{\mathcal{C}} \vec{B} \cdot d\vec{l}$ is the line integral of the magnetic field $\vec{B}$ around a closed loop $\mathcal{C}$,
- I_{enc} is the current enclosed by the loop,
- μ_0 is the permeability of free space, which is a constant $\mu_0 = 4\pi \times 10^{-7}$ T $\cdot$ m/A.

Proof:

Consider a steady current I flowing through a long straight conductor. Using the Biot-Savart law, we can compute the magnetic field $\vec{B}$ around the conductor. The magnetic field at a distance r from the wire is given by:

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

Now, consider a circular path of radius r around the wire. The magnetic field $\vec{B}$ is tangent to the circular path and its magnitude is constant along the path. Thus, the line integral of $\vec{B}$ around the loop is:

$$\oint_{\mathcal{C}} \vec{B} \cdot d\vec{l} = B \cdot 2\pi r$$

Substitute the expression for B:

$$\oint_{\mathcal{C}} \vec{B} \cdot d\vec{l} = \frac{\mu_0 I}{2\pi r} \cdot 2\pi r = \mu_0 I$$

This proves Ampere's circuital law.

Quick Tip

Ampere's law is especially useful for calculating the magnetic field produced by symmetric current distributions, like wires, loops, and solenoids.

(c) Explain the meaning of polarisation of light and show the difference between polarised and unpolarised light with the help of a suitable diagram.

Solution:

Step 1: Definition of Polarisation of Light.

Polarisation of light refers to the orientation of the oscillations of the electric field vector in a particular direction. For natural or unpolarised light, the electric field oscillates in many directions perpendicular to the direction of propagation. However, when light is polarised, its electric field vibrates in a single direction.

Step 2: Mechanism of Polarisation.

- Polarised light is typically obtained from unpolarised light by passing it through a polarising filter or using other methods like reflection, refraction, or scattering.
- The electric field of polarised light oscillates only in one plane (or direction). This can be demonstrated using a Polaroid filter.

Step 3: Diagram showing Polarised and Unpolarised Light.

Step 4: Explanation of Diagram.

- Unpolarised light: The electric field oscillates in all directions perpendicular to the direction of propagation. In the diagram, the electric field vector is randomly oriented in different directions.
- Polarised light: The electric field is oriented in a specific direction, as shown by the uniform vector direction in the diagram.

Final Answer: Polarisation is the process by which the oscillations of the electric field in light are restricted to one plane. The difference is that unpolarised light has electric field oscillations in multiple directions, whereas polarised light has oscillations in only one direction.

💡 Quick Tip

Use $n_i \propto e^{-E_g/(2k_BT)}$. As $T \downarrow 0$, $n_i \downarrow 0 \Rightarrow \sigma = q(n\mu_n + p\mu_p) \downarrow 0$. Only at $T > 0$ do intrinsic semiconductors conduct via thermally generated e^-–hole pairs.

(d) Draw a circuit diagram to obtain characteristic curve in forward bias of p-n junction diode. Mention the effect of forward bias on depletion layer of the junction.

Solution:

Step 1: Circuit Diagram for Forward Bias of p-n Junction Diode.

To obtain the characteristic curve of a p-n junction diode in forward bias, we need to connect the diode in a circuit with a variable power supply. The positive terminal of the power supply is connected to the p-type side (anode) of the diode, and the negative terminal is connected to the n-type side (cathode).

pn_diode_forward_bias.png

Step 2: Explanation of Circuit Diagram.

- A power supply provides a varying voltage across the diode.
- The anode of the diode is connected to the positive terminal, and the cathode to the negative terminal of the power supply.
- A milliammeter is connected in series with the diode to measure the current that flows through the circuit.

Step 3: Characteristic Curve.

When the diode is forward biased, the current increases as the applied voltage increases beyond a threshold (typically around 0.7V for silicon diodes). At lower voltages, the current is almost zero, but as the voltage increases, the current increases exponentially. The characteristic curve of a p-n junction diode in forward bias shows this exponential increase.

Step 4: Effect of Forward Bias on the Depletion Region.

- In forward bias, the external voltage decreases the width of the depletion region, allowing more charge carriers to recombine at the junction.
- As the forward voltage increases, the potential barrier decreases, and more charge carriers can cross the junction, leading to an increase in current.

Final Answer: In forward bias, the depletion region becomes narrower, and the current increases exponentially with the applied voltage after a certain threshold.

Quick Tip
In forward bias, the potential barrier is reduced, allowing current to flow through the diode. At high forward voltages, the current increases rapidly. The diode has negligible current flow below the threshold voltage (0.7V for silicon diodes).

Section - D

Q.4 (a) Energy of electron in the nth orbit of hydrogen atom is $E_n = \frac{-13.6}{n^2}$ eV. Draw the energy level diagram for hydrogen atom and show the transition for lines of Balmer and Paschen series.

Solution:

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

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

where n is the principal quantum number. The electron can transition between different energy levels, emitting or absorbing energy in the form of electromagnetic radiation.
The energy levels are represented by the following diagram:

$$\text{Energy levels: } n = 1\,(\text{ground state}), n = 2, n = 3, \ldots$$

The transitions for the Balmer series (visible spectrum) occur when the electron moves to the $n = 2$ level. The wavelengths for these transitions can be calculated using:

$$E = E_{\text{initial}} - E_{\text{final}}$$

Similarly, the transitions for the Paschen series (infrared spectrum) occur when the electron moves to the $n = 3$ level.

Quick Tip

The Balmer series corresponds to transitions where $n_{\text{final}} = 2$, and the Paschen series corresponds to transitions where $n_{\text{final}} = 3$.

(b) Derive Lens Maker's formula for a thin lens. Mention the effect of the refractive index and radius of curvature of the curved surfaces on the focal length of the lens.

Solution:

The Lens Maker's formula relates the focal length f of a lens to the refractive index n of the lens material and the radii of curvature R_1 and R_2 of the two curved surfaces of the lens.
For a thin lens, the Lens Maker's formula is given by:

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

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

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

- R_1 is the radius of curvature of the first surface (convex or concave),

- R_2 is the radius of curvature of the second surface (convex or concave).

Effect of Refractive Index (n):

- As the refractive index n increases, the focal length of the lens decreases. A higher refractive index material bends light more sharply, thus focusing light at a shorter distance.

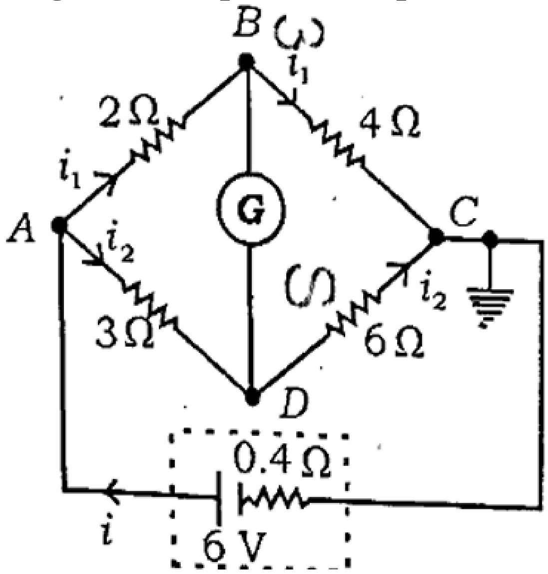
Effect of Radii of Curvature (R_1 and R_2):

- The radii of curvature of the lens surfaces also affect the focal length. For a convex surface, R_1 is positive, and for a concave surface, R_2 is negative. The curvature of the surfaces influences the converging or diverging behavior of the lens.

Quick Tip

For a converging lens (double convex), R_1 is positive, and for a diverging lens (double concave), R_1 is negative.

(c) Write Kirchhoff's law for electrical circuits. In the given balanced Wheatstone bridge, find the potential at points B and D and the values of current i_1 and i_2.



Solution:

Step 1: Kirchhoff's Laws.

- Kirchhoff's Current Law (KCL): The sum of currents entering a junction equals the sum of currents leaving the junction.

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

- Kirchhoff's Voltage Law (KVL): The sum of the electrical potential differences (voltages) around any closed loop or circuit is zero.

$$\sum V = 0.$$

Step 2: Wheatstone Bridge.

In a Wheatstone bridge, there are four resistors arranged in a diamond shape. The bridge is balanced when the ratio of resistances in one pair is equal to the ratio of resistances in the other pair:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}.$$

The current in the bridge is divided between two parallel branches. The current i is divided into i_1 and i_2 at point A, where:

$$i = i_1 + i_2.$$

Step 3: Using Kirchhoff's Laws to find the potential and currents.

Using KCL and KVL, we can write the equations for the current through each resistor. For the balanced Wheatstone bridge, the voltage drop across the bridge is zero, so the potential at points B and D is the same, and hence no current flows through the galvanometer G.

Therefore, the currents i_1 and i_2 are:

$$i_1 = \frac{V}{R_1 + R_2}, \quad i_2 = \frac{V}{R_3 + R_4}.$$

where V is the applied voltage.

Since the bridge is balanced, the potential at points B and D is the same, and no current flows through the galvanometer.

Final Answer: The potential at points B and D is the same, and the values of current i_1 and i_2 can be calculated using the above equations based on the resistances in the circuit.

Quick Tip

In a balanced Wheatstone bridge, the ratio of resistances on both sides is equal, and no current flows through the galvanometer. The current is divided between the two parallel branches of the bridge.

(d) Write down Biot-Savart law and find the expression for the magnetic field produced by a current-carrying conductor of infinite length, on the basis of it.

Solution:

Step 1: Biot-Savart Law.

The Biot-Savart Law gives the magnetic field $d\vec{B}$ produced at a point due to a small current element $Id\vec{l}$ as:

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

where:

- μ_0 is the permeability of free space ($\mu_0 = 4\pi \times 10^{-7}\ \mathrm{T \cdot m/A}$),

- I is the current,

- $d\vec{l}$ is the vector length of the current element,

- $\hat{r}$ is the unit vector from the current element to the point where the magnetic field is calculated,

- r is the distance from the current element to the point.

Step 2: Magnetic Field Due to a Long Straight Conductor.

For an infinitely long, straight conductor carrying a current I, we can integrate the Biot-Savart law along the length of the conductor. The magnetic field at a distance r from the conductor is given by:

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

This expression is derived by integrating the Biot-Savart law for an infinite length conductor. The direction of the magnetic field follows the right-hand rule, meaning the magnetic field circulates around the wire in concentric circles.

Final Answer: The magnetic field produced by an infinitely long current-carrying conductor is given by:

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

where r is the distance from the wire, and the direction is given by the right-hand rule.

Quick Tip

The Biot-Savart law is useful for calculating the magnetic field produced by a current element. For an infinite straight conductor, the magnetic field decreases inversely with the distance from the conductor.

(e)

Describe a series L, C, R resonant circuit.

Solution:

A series L, C, R resonant circuit consists of three basic components connected in series: an inductor (L), a capacitor (C), and a resistor (R). In such a circuit, the total impedance of the circuit is affected by the frequency of the applied AC signal. The behavior of the circuit changes as the frequency varies, and resonance occurs at a specific frequency known as the resonant frequency.

Impedance of the Series LCR Circuit: The total impedance Z of a series L, C, R circuit is given by:

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

where: - R is the resistance, - L is the inductance, - C is the capacitance, - $\omega = 2\pi f$ is the angular frequency of the AC signal.

At resonance, the inductive reactance ωL and the capacitive reactance $\frac{1}{\omega C}$ cancel each other out, and the total impedance of the circuit becomes purely resistive:

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

Thus, at resonance, the impedance is minimized, and the current in the circuit reaches its maximum value.

Resonant Frequency: The resonant frequency f_0 is the frequency at which the inductive and capacitive reactances are equal in magnitude but opposite in sign. At this frequency, the circuit exhibits purely resistive behavior, and the impedance is equal to the resistance R. The resonant frequency is given by:

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

At resonance, the voltage across the inductor and the capacitor is maximum, while the total impedance of the circuit is at a minimum.

Power at Resonance: At resonance, the power delivered to the circuit is maximized. The power in a series LCR circuit is given by:

$$P = I^2 R$$

where I is the current through the circuit. At resonance, the current reaches its maximum value, and the power dissipated in the resistor is at its peak.

Quick Tip

For a series LCR circuit, resonance occurs when the inductive and capacitive reactances are equal in magnitude. The resonant frequency is given by $f_0 = \frac{1}{2\pi\sqrt{LC}}$.

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5. (a) Define electric dipole and give the formula for its dipole moment. Find the expression of torque acting on an electric dipole placed in a uniform electric field.

Solution:

An electric dipole consists of two opposite charges of equal magnitude $+q$ and $-q$, separated by a distance d. The electric dipole moment $\vec{p}$ is defined as the product of the charge and the separation distance:

$$\vec{p} = q \cdot \vec{d}$$

where: - q is the magnitude of the charge, - $\vec{d}$ is the displacement vector pointing from the negative charge to the positive charge.

Torque on an Electric Dipole in a Uniform Electric Field.

When an electric dipole is placed in a uniform electric field $\vec{E}$, it experiences a torque that tends to align the dipole moment with the electric field. The torque $\vec{\tau}$ is given by:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

where: - $\vec{p}$ is the dipole moment, - $\vec{E}$ is the electric field.

Step 1: Magnitude of Torque.

The magnitude of the torque is:

$$\tau = pE \sin\theta$$

where: - $p = |\vec{p}|$ is the magnitude of the dipole moment, - $E = |\vec{E}|$ is the magnitude of the electric field, - θ is the angle between the dipole moment and the electric field.

Final Answer: The formula for torque on an electric dipole in a uniform electric field is:

$$\tau = pE \sin\theta.$$

Quick Tip

The torque on an electric dipole in a uniform electric field is maximum when the dipole moment is perpendicular to the field, and zero when the dipole moment is parallel to the field.

(b) What are matter waves? Explain. Write the formula for de Broglie wavelength. Write the name of the experiment which shows the dual nature of particles.

Solution:

Matter Waves:

Matter waves, also called de Broglie waves, are the waves associated with particles that exhibit both wave-like and particle-like properties. According to de Broglie's hypothesis, every moving particle, such as an electron or a proton, behaves like a wave and has an associated wavelength. This concept was proposed by Louis de Broglie in 1924 and is known as wave-particle duality.

The de Broglie wavelength λ of a particle with momentum p is given by the following formula:

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

where: - h is Planck's constant ($h = 6.626 \times 10^{-34}$ J $\cdot$ s), - p is the momentum of the particle ($p = mv$, where m is the mass and v is the velocity of the particle).

Dual Nature of Particles:

The concept of wave-particle duality was experimentally verified by the Davisson-Germer experiment, which demonstrated that electrons exhibit diffraction patterns, similar to light waves, when passed through a crystal lattice.

Final Answer: The formula for de Broglie wavelength is:

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

The experiment that shows the dual nature of particles is the Davisson-Germer experiment.

> Quick Tip
>
> Wave-particle duality shows that particles such as electrons can exhibit both wave-like properties, such as interference and diffraction, and particle-like properties, such as momentum and energy.

(c) Explain the meaning of binding energy of a nucleus. In the nuclear reaction $^3Li^6 + \ ^0n^1 \longrightarrow \ ^2He^4 + \ ^1H^3$, calculate the energy released in joules. Mass of $^3Li^6 = 6.015126$ u, Mass of $^2He^4 = 4.002604$ u, Mass of $^1H^3 = 3.016049$ u, Mass of $^0n^1 = 1.008665$ u, and 1u = 931 MeV.

Solution:

The binding energy of a nucleus is defined as the energy required to disassemble the nucleus into its constituent protons and neutrons. In simpler terms, it is the energy released when a nucleus is formed from its individual nucleons.

To calculate the energy released during the nuclear reaction, we use the mass-energy equivalence formula:

$$E = \Delta m \cdot c^2$$

Where: - Δm is the mass defect (the difference between the mass of the reactants and products), - c is the speed of light ($c = 3 \times 10^8$ m/s).

Step 1: Calculate the mass defect (Δm) The mass defect is the difference between the total mass of the reactants and the total mass of the products:

$$\Delta m = (\text{Mass of reactants}) - (\text{Mass of products})$$

For the reaction ${}^3Li^6 + {}^0n^1 \longrightarrow {}^2He^4 + {}^1H^3$, the mass defect is:

$$\Delta m = (6.015126 + 1.008665) - (4.002604 + 3.016049)$$

$$\Delta m = 7.023791 - 7.018653 = 0.005138 \text{ u}$$

Step 2: Convert the mass defect into energy To convert the mass defect into energy, we use the formula $E = \Delta m \cdot c^2$. First, we need to convert the mass defect into kilograms:

$$1 \text{ u} = 1.660539 \times 10^{-27} \text{ kg}$$

$$\Delta m = 0.005138 \text{ u} \times 1.660539 \times 10^{-27} \text{ kg/u}$$

$$\Delta m = 8.526 \times 10^{-30} \text{ kg}$$

Now, applying Einstein's equation:

$$E = \Delta m \cdot c^2 = 8.526 \times 10^{-30} \cdot (3 \times 10^8)^2$$

$$E = 8.526 \times 10^{-30} \cdot 9 \times 10^{16} = 7.673 \times 10^{-13} \text{ J}$$

So, the energy released in the reaction is:

$$E = 7.673 \times 10^{-13} \text{ J}$$

Quick Tip

When calculating the energy released in a nuclear reaction, use the mass defect and convert it to energy using Einstein's equation: $E = \Delta m \cdot c^2$.

(d) Define drift velocity and mobility of electrons in a metallic conductor. The length of a conducting rod is 1 m and the potential difference between its ends is 4 volt. Electron density in the conductor is 5×10^{24} m^{-3} and its resistivity is 50×10^{-8} Ω-m. Calculate the drift velocity of the electrons in the metal.

Solution:

Drift Velocity and Mobility of Electrons:

- Drift velocity (v_d) is the average velocity of electrons in a conducting material under the influence of an electric field.
- Mobility (μ) refers to the speed of an electron in a material when exposed to an electric field. It is given by the relation:

$$v_d = \mu \cdot E$$

Where v_d is the drift velocity, μ is the mobility, and E is the electric field.

For a conductor, the drift velocity can also be related to the current, electron density, and cross-sectional area.

Step 1: Calculate the Electric Field

The electric field E in the conductor is given by:

$$E = \frac{V}{L}$$

Where V is the potential difference and L is the length of the conductor.

$$E = \frac{4 \text{ V}}{1 \text{ m}} = 4 \text{ V/m}$$

Step 2: Apply Ohm's Law

The current I in the conductor is related to the resistivity (ρ), the current density (J), and the electric field (E) by:

$$J = \sigma E = \frac{1}{\rho}E$$

Where σ is the electrical conductivity and ρ is the resistivity of the material. The current density J is also related to the drift velocity and the electron density by:

$$J = nev_d$$

Where: - n is the electron density (5×10^{24} m^{-3}), - e is the electron charge (1.6×10^{-19} C), - v_d is the drift velocity.

Equating both expressions for J:

$$\frac{E}{\rho} = nev_d$$

Step 3: Calculate the Drift Velocity

Rearranging the equation to solve for v_d:

$$v_d = \frac{E}{ne\rho}$$

Substitute the known values: - $E = 4$ V/m, - $n = 5 \times 10^{24}$ m^{-3}, - $e = 1.6 \times 10^{-19}$ C, - $\rho = 50 \times 10^{-8}$ Ω-m.

$$v_d = \frac{4}{(5 \times 10^{24})(1.6 \times 10^{-19})(50 \times 10^{-8})}$$

$$v_d = \frac{4}{(5 \times 1.6 \times 50 \times 10^{0}) \times 10^{6}} = \frac{4}{4 \times 10^{6}} = 10^{-6} \text{ m/s}$$

Thus, the drift velocity of the electrons is:

$$v_d = 1 \times 10^{-6} \text{ m/s}$$

Quick Tip

Drift velocity v_d can be calculated using $v_d = \frac{E}{ne\rho}$, where E is the electric field, n is the electron density, e is the electron charge, and ρ is the resistivity.

(e) With the help of a suitable ray diagram, derive the formula $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ for a concave mirror.

Solution:

Step 1: Sign Convention and Ray Diagram.

In the case of a concave mirror, the following sign conventions are used: - Focal length f is considered positive for a concave mirror.

- The object distance u is negative when the object is in front of the mirror.
- The image distance v is positive when the image is formed on the same side as the object.

Now, consider the concave mirror and an object placed in front of it. The image is formed by the reflection of light rays. The ray diagram for a concave mirror looks like this:

(Ray diagram showing the reflection of rays from a concave mirror)

The object is placed at a distance u from the mirror.

The image is formed at a distance v from the mirror.

Step 2: Mirror Equation.

From the geometry of the situation and the laws of reflection, the relationship between the object distance u, image distance v, and focal length f for a concave mirror is given by the mirror equation:

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

Step 3: Derivation.

We can derive this equation from the reflection laws and the geometry of the concave mirror. The relationship between the angles of incidence and reflection, along with the distances u, v, and f, gives the above formula. By considering the geometry of the ray diagram and applying trigonometry, the mirror equation is obtained.

Final Answer:

The formula relating the object distance u, the image distance v, and the focal length f for a concave mirror is:

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

Quick Tip

The mirror equation holds true for both concave and convex mirrors, where the distances are measured according to sign conventions. Always check the direction of the object and image to apply the correct signs.

Section - E

Q.6 Write Huygens' principle of secondary wavelets and explain the laws of refraction of light on its basis.

Solution:

Huygens' principle states that every point on a wavefront is a source of secondary wavelets that spread out in the forward direction at the same speed as the original wave. The new wavefront at any time is the envelope of all these secondary wavelets.

For the laws of refraction:

- The incident ray, the refracted ray, and the normal to the surface at the point of incidence all lie in the same plane.
- The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant and is equal to the refractive index of the medium, i.e., $\sin i / \sin r = \mu$.

Quick Tip

Remember that Huygens' principle works well in explaining wave behaviors such as refraction, diffraction, and interference.

OR

Explain the difference between interference and diffraction of light. Write the expression for the width of interference fringes in Young's double slit experiment and explain the effect of separation of slits and wavelength of light used on it.

Solution:

Interference: It is the phenomenon where two or more light waves superpose to form a resultant wave. Constructive interference occurs when the waves are in phase, and destructive interference occurs when they are out of phase.
Diffraction: It refers to the bending of light around obstacles and the spreading of light as it passes through small openings. It is most noticeable when the size of the obstacle or aperture is comparable to the wavelength of the light.

Expression for Width of Interference Fringes:
In Young's double slit experiment, the fringe width β is given by the expression:

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

Where:
- λ is the wavelength of the light,
- D is the distance between the slits and the screen,
- d is the separation between the two slits.

Effect of Separation of Slits and Wavelength of Light:
- If the slit separation d is increased, the fringe width β decreases.
- If the wavelength λ is increased, the fringe width β increases.

Quick Tip

In interference, the separation of slits and wavelength both directly affect the fringe pattern. A larger separation leads to closer fringes, while a longer wavelength spreads them out.

Q.7 Which nature of light is supported by the phenomenon of photoelectric effect? Write Einstein's equation related to photoelectric emission and briefly explain the laws of photoelectric emission on its basis.

Solution:
The phenomenon of the photoelectric effect supports the particle nature of light. When light of sufficient frequency (threshold frequency) is incident on a metal surface, electrons are

emitted from the surface. This phenomenon could not be explained by the wave theory of light, but Einstein's quantum theory of light provided a clear explanation. According to this theory, light consists of discrete packets of energy called photons. When a photon strikes the metal surface, it imparts its energy to the electron, causing the electron to be ejected from the surface.

The Einstein equation for photoelectric emission is given by:

$$E_{\text{photon}} = h\nu = \phi + K.E.$$

Where: - $E_{\text{photon}} = h\nu$ is the energy of the incoming photon,
- h is Planck's constant,
- ν is the frequency of the incident light,
- ϕ is the work function of the metal,
- $K.E.$ is the kinetic energy of the emitted electron.

Laws of Photoelectric Emission:

1. Emission of Electrons: When light of frequency greater than or equal to the threshold frequency strikes a metal surface, electrons are emitted.
2. Effect of Intensity: The intensity of light affects the number of electrons emitted, not their energy. Higher intensity leads to more emitted electrons.
3. Effect of Frequency: The energy of emitted electrons depends on the frequency of the incident light. Electrons are emitted only if the frequency of light is above the threshold frequency, regardless of intensity.

Quick Tip

The photoelectric effect demonstrated the particle nature of light, where photons transfer energy to electrons, leading to their emission from a metal surface.

OR

What is the meaning of nucleon? What is the mass number of nucleus? Write down the relation between mass number and radius of nucleus and show that the density of nucleus does not depend on mass number.

Solution:

Nucleon: A nucleon refers to either a proton or a neutron in the nucleus of an atom. Nucleons are the building blocks of the nucleus.

Mass Number of Nucleus: The mass number of a nucleus is the total number of nucleons (protons and neutrons) present in the nucleus. It is represented by A, where $A = Z + N$,

- Z is the number of protons,
- N is the number of neutrons.

Relation Between Mass Number and Radius of Nucleus:

The radius of a nucleus is given by the empirical formula:

$$R = R_0 A^{1/3}$$

Where: - R_0 is a constant, approximately $1.2\,\text{fm}$,

- A is the mass number of the nucleus.

Density of Nucleus: The density of the nucleus is defined as the mass per unit volume. The volume of the nucleus is proportional to R^3, and since $R \propto A^{1/3}$, the volume is proportional to A. Hence, the mass of the nucleus is proportional to A, and the density of the nucleus becomes:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \propto \frac{A}{A} = \text{constant}$$

This shows that the density of the nucleus is independent of the mass number A.

Quick Tip

Nuclear density remains constant for all nuclei, regardless of their mass number, as the mass and volume both scale proportionally with A.

Q.8 (a) On which principle does the transformer work? What are step-up and step-down transformers? Mention two main losses occurring in transformers. In an ideal transformer, the ratio of turns in primary and secondary coils is 10 : 1. Supply in primary is of 220 V and secondary is connected with a resistance of 220 Ω. Find the value of current flowing in the primary.

Solution:

A transformer works on the principle of electromagnetic induction and Faraday's law of induction. The voltage induced in the secondary coil is proportional to the ratio of the number of turns in the secondary coil to the number of turns in the primary coil. This relationship is given by the equation:

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

Where V_s and V_p are the voltages in the secondary and primary coils, and N_s and N_p are the number of turns in the secondary and primary coils.

In a step-up transformer, the number of turns in the secondary coil is greater than the primary coil, which increases the voltage. In a step-down transformer, the number of turns in the secondary coil is less than the primary coil, which decreases the voltage.

Given that $V_p = 220$ V, the ratio of turns is $N_s/N_p = 10/1$, and the resistance in the secondary coil is $R_s = 220\ \Omega$, we can calculate the current flowing in the secondary coil using Ohm's law:

$$I_s = \frac{V_s}{R_s}$$

Since the transformer is ideal, the voltage ratio is equal to the turns ratio:

$$V_s = \frac{N_s}{N_p} \cdot V_p = 10 \times 220 = 2200 \text{ V}$$

Now, calculate the current in the secondary:

$$I_s = \frac{2200}{220} = 10 \text{ A}$$

By conservation of energy and assuming an ideal transformer, the current in the primary coil is related to the current in the secondary by the inverse of the turns ratio:

$$I_p = \frac{I_s}{\frac{N_s}{N_p}} = \frac{10}{10} = 1 \text{ A}$$

Quick Tip

In an ideal transformer, the power in the primary coil equals the power in the secondary coil. Therefore, the relationship between voltage and current is given by $V_pI_p = V_sI_s$, where the voltage ratio is equal to the turns ratio.

OR

What is an electrical capacitor? Find the expression for the capacity of a parallel plate capacitor. On which factors does the capacitance depend?

Solution:

An electrical capacitor is a device that stores electrical energy in an electric field. It consists of two conductive plates separated by an insulating material (called the dielectric). When a potential difference is applied across the plates, a charge is stored on each plate.

The capacitance C of a parallel plate capacitor is given by the expression:

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

Where:

- C is the capacitance,
- ϵ_0 is the permittivity of free space ($\epsilon_0 = 8.85 \times 10^{-12}$ F/m),
- A is the area of one of the plates,
- d is the separation between the plates.

The capacitance depends on the following factors:

1. The area of the plates: A larger area increases the capacitance.
2. The separation between the plates: A smaller distance between the plates increases the capacitance.
3. The dielectric material between the plates: The dielectric constant (κ) of the material increases the capacitance. The capacitance with a dielectric is given by:

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

Where κ is the dielectric constant of the material.

> **Quick Tip**
>
> The capacitance of a capacitor increases with the dielectric constant of the material between the plates and decreases with the distance between the plates.

Q.9 What are electromagnetic waves? Give a brief description of the main properties of electromagnetic waves. The equation for oscillation of the magnetic field of an

electromagnetic wave is $B_y = 8 \times 10^{-6} \sin\left(2 \times 10^{11} t + 300\pi x\right)$ T. Find the wavelength and equation for the oscillating electric field. Mention the direction of propagation of the wave also.

Solution:

Electromagnetic waves are a combination of electric and magnetic fields that oscillate perpendicular to each other and to the direction of propagation. They travel at the speed of light, $c = 3 \times 10^8$ m/s, and do not require a medium for propagation.

The general equation for a magnetic field in an electromagnetic wave is given by:

$$B_y = B_0 \sin(kx - \omega t)$$

Where:

- B_y is the magnetic field,
- B_0 is the maximum magnetic field (amplitude),
- k is the wave number,
- ω is the angular frequency,
- x is the position along the x-axis, and
- t is time.

From the given equation $B_y = 8 \times 10^{-6} \sin\left(2 \times 10^{11} t + 300\pi x\right)$ T, we can compare the terms with the standard wave equation. Here:

- $B_0 = 8 \times 10^{-6}$ T,
- The angular frequency $\omega = 2 \times 10^{11}$ rad/s,
- The wave number $k = 300\pi$ rad/m.

Now, the wavelength λ is related to the wave number k by the equation:

$$k = \frac{2\pi}{\lambda}$$

Substitute $k = 300\pi$:

$$300\pi = \frac{2\pi}{\lambda} \Rightarrow \lambda = \frac{2}{300} = 6.67 \times 10^{-3} \text{ m}$$

Next, the electric field E oscillates in the same direction as the magnetic field but is perpendicular to it. The magnitude of the electric field is related to the magnetic field by the equation:

$$E_0 = cB_0$$

Substitute $c = 3 \times 10^8$ m/s and $B_0 = 8 \times 10^{-6}$ T:

$$E_0 = (3 \times 10^8) \times (8 \times 10^{-6}) = 2400 \text{ V/m}$$

Thus, the equation for the oscillating electric field is:

$$E_y = E_0 \sin\left(2 \times 10^{11} t + 300\pi x\right)$$

Where $E_0 = 2400$ V/m.

The direction of propagation is along the x-axis, which is determined by the cross-product of the electric field and magnetic field vectors. Thus, the wave is traveling in the positive x-direction.

Quick Tip

In electromagnetic waves, the direction of propagation is perpendicular to both the electric and magnetic field directions. The relationship between the magnetic field and electric field is $E_0 = cB_0$, where c is the speed of light.

OR

Explain the meaning of rectification. Using a p-n junction diode, draw a circuit diagram of a full-wave rectifier and give a brief description of its working. Give a graphical representation of input and output voltage/current.

Solution:

Rectification is the process of converting alternating current (AC) to direct current (DC). In a rectifier, a diode allows current to flow in one direction, blocking it in the opposite direction. The most common type of rectifier is the p-n junction diode.

A full-wave rectifier uses both halves of the input signal to produce a continuous DC output. It uses two diodes in a bridge configuration, allowing current to flow in both halves of the

AC input cycle.

The circuit diagram for a full-wave rectifier is as follows:

[Insert Diagram of Full-Wave Rectifier]

In the positive half-cycle of the input AC, one diode conducts and allows current to pass through the load resistor. In the negative half-cycle, the other diode conducts, allowing current to flow in the same direction through the load. This results in a full-wave rectified output.

The output waveform of a full-wave rectifier is a series of positive peaks, with the negative half of the AC signal flipped to the positive side. This gives a smoother DC output compared to a half-wave rectifier.

Quick Tip

In a full-wave rectifier, the current flows through the load resistor during both halves of the input AC signal, providing a more consistent DC output.
