UP Board Class 12 Physics 2024 (Code 346 FT) Question Paper with Solutions

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General Instructions

(i) This booklet contains 9 questions, each provided with a complete, step-by-step solution.

(ii) It has multiple-choice questions as well as questions that need a written answer.

(iii) Attempt each question on your own before reviewing the given solution.

1(a).

Electric charges are uniformly distributed in a small volume. The flux of electric field through a spherical surface of radius 2 cm surrounding the total charge is 10 V x m. The flux over a sphere of radius 4 cm will be:

(A) 10 V x m

(B) 20 V x m

(C) 40 V x m

(D) 80 V x m

Correct Answer: (A) 10 V x m

Solution:

The flux through a spherical surface depends only on the total charge enclosed, according to Gauss's law:

$$\Phi_E = \frac{q_{\text{enc}}}{\epsilon_0}.$$

Since the total charge q_{enc} remains constant, the flux through any spherical surface enclosing this charge will be the same. Therefore, the flux through the sphere with a radius of 4 cm is also 10 V x m.

Quick Tip: The electric flux through a spherical surface only depends on the enclosed charge, not on the radius of the sphere.

1(b).

A moving charge produces:

(A) electric field only

(B) magnetic field only

(C) both electric and magnetic fields

(D) none of the above

Correct Answer: (C) both electric and magnetic fields

Solution:

A moving charge creates both an electric field (due to its charge) and a magnetic field (due to its motion). This is the foundation of electromagnetism, as described by Maxwell's equations.

Quick Tip: A moving charge is the source of both electric and magnetic fields.

1(c).

An electromagnetic wave propagating through vacuum, described by $E = E_0 \sin(kx - \omega t)$, $B = B_0 \sin(kx - \omega t)$, then:

(A) $E_0 k = B_0 \omega$

(B) $E_0 \omega = B_0 k$

(C) $E_0 B_0 = \omega k$

(D) $E_0 B_0 = \sqrt{\omega k}$

Correct Answer: (B) $E_0 \omega = B_0 k$

Solution:

For an electromagnetic wave, the electric and magnetic field strengths E_0 and B_0 are related by the speed of light in vacuum c:

$$E_0 = cB_0.$$

The wave number k and angular frequency ω are related to the speed of light as:

$$c = \frac{\omega}{k}.$$

Combining the two equations, we get:

$$E_0 \omega = B_0 k.$$

Quick Tip: The electric and magnetic field amplitudes in an electromagnetic wave are related by the speed of light, $c = E_0/B_0$.

1(d).

A double convex lens is made of a material having refractive index 1.2. Both the surfaces of the lens are convex. If it is dipped into water of refractive index 1.33, it will behave like:

(A) a convergent lens

(B) a divergent lens

(C) a rectangular slab

(D) a prism

Correct Answer: (B) a divergent lens

Solution:

The focal length of a lens is determined by the refractive index difference between the material of the lens and the medium around it. When the lens is dipped in water, the refractive index of the medium increases, reducing the refractive index difference and causing the lens to behave more like a divergent lens.

Quick Tip: When the refractive index of the surrounding medium is greater than that of the lens material, the lens becomes divergent.

1(e).

The equation $E = pc$, (where E and p are energy and momentum respectively) is valid:

(A) for an electron as well as for a photon.

(B) for an electron but not for a photon.

(C) for a photon but not for an electron.

(D) neither for an electron nor for a photon.

Correct Answer: (C) for a photon but not for an electron.

Solution:

The equation $E = pc$ applies to massless particles like photons, where E is the energy, p is the momentum, and c is the speed of light. For particles with mass, such as electrons, the correct relationship is $E^2 = (pc)^2 + (mc^2)^2$.

Quick Tip: The equation $E = pc$ applies only to massless particles such as photons.

1(f).

Diffusion current in a p-n junction is greater than the drift current in magnitude:

(A) if the junction is forward biased

(B) if the junction is reverse biased

(C) if the junction is unbiased

(D) in none of them

Correct Answer: (B) if the junction is reverse biased

Solution:

In a p-n junction, the diffusion current is due to the movement of charge carriers from high concentration to low concentration, whereas the drift current arises due to the presence of an electric field. When the junction is reverse biased, the depletion region widens, increasing the diffusion current compared to the drift current.

Quick Tip: In reverse bias, the diffusion current is greater than the drift current due to the widening of the depletion region.

2(a).

Write the equation for the relationship between specific conductivity (σ) and drift velocity (v_d).

Correct Answer: —

Solution:

Specific conductivity (σ) is related to the drift velocity (v_d) by the equation:

$$\sigma = nqv_dA,$$

where:
- n is the number density of charge carriers,
- q is the charge of the carriers,
- A is the cross-sectional area of the conductor.

Quick Tip: The drift velocity of charge carriers is proportional to the

current and the specific conductivity of the material.

2(b).

State Ampere's Circuital Law.

Correct Answer: —

Solution:

Ampere's Circuital Law states that the magnetic field B around a closed loop is proportional to the current passing through the loop. The law is expressed mathematically as:

$$\oint_{\text{loop}} \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{\text{enc}},$$

where:
- $\oint_{\text{loop}} \mathbf{B} \cdot d\mathbf{l}$ is the circulation of the magnetic field around the loop,
- μ_0 is the permeability of free space,
- I_{enc} is the current enclosed by the loop.

Quick Tip: Ampere's Circuital Law relates the magnetic field around a closed loop to the current enclosed by that loop.

2(c).

Find the value of 1 kWh in Joules.

Correct Answer: —

Solution:

1 kWh (kilowatt-hour) is a unit of energy and can be converted to Joules as follows:

$$1\,\text{kWh} = 1\,\text{kW} \times 1\,\text{h} = 1000\,\text{W} \times 3600\,\text{s} = 3.6 \times 10^6\,\text{J}.$$

Quick Tip: 1 kWh is equivalent to 3.6×10^6 Joules.

2(d).

Deduce the dimensional equation of self-inductance.

Correct Answer: —

Solution:

Self-inductance (L) is defined by the relation:

$$\text{Emf} = -L\frac{dI}{dt},$$

where **Emf** is the induced electromotive force and I is the current. The dimensional formula of **Emf** is:

$$[\text{Emf}] = \left[\frac{\text{ML}^2}{\text{T}^3\text{A}}\right].$$

By substituting the dimensional formula of $\frac{dI}{dt}$ (which is T^{-1}A):

$$[L] = \frac{[\text{Emf}]}{\left[\frac{dI}{dt}\right]} = \frac{[\text{ML}^2]}{[\text{T}^3\text{A}] \times [\text{T}^{-1}\text{A}]} = [\text{ML}^2\text{T}^{-2}\text{A}^{-2}].$$

Quick Tip: The dimensional formula of self-inductance is $[ML^2T^{-2}A^{-2}]$.

2(e).

Ionisation energy of Hydrogen atom is 13.6 eV. In a state where $n = 2$, what will be ionisation energy of its electron?

Correct Answer: —

Solution:

The ionization energy for the n-th orbit of the hydrogen atom is given by:

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

For $n = 2$:

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

The ionization energy required for ionizing the electron from $n = 2$ to $n = \infty$ is the energy needed to remove it from the $n = 2$ level, which is 3.4 eV.

Quick Tip: The ionization energy decreases with increasing principal quantum number n.

2(f).

Define the 'wavefront' of a wave.

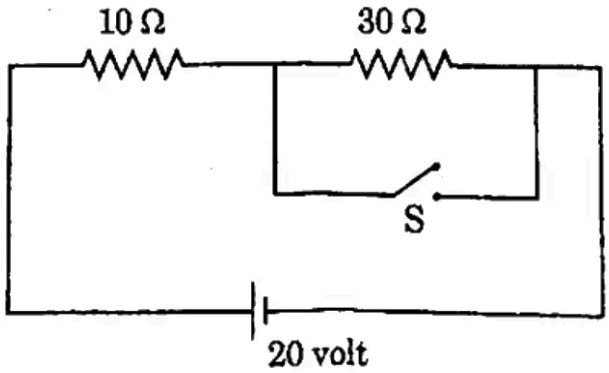
Correct Answer: —

Solution:

A wavefront is the surface over which the phase of the wave is constant. In other words, it is an imaginary surface connecting all points of a wave that are in the same phase, meaning the wave amplitude at every point on this surface is the same.

Quick Tip: Wavefronts represent the locus of points having the same phase in a wave, often used to study wave propagation.

3(a).



Find the current through the 10 Ω resistor when the switch S is open and closed in the given circuit.

Correct Answer: —

Solution:

Step 1: Understanding the Circuit:

The 10 Ω resistor and the 30 Ω resistor are in series with the 20 V battery.

The switch S is joined across the 30 Ω resistor, so it acts as a bypass wire for that resistor when it is closed.

Step 2: Key Formula or Approach:

The current in a circuit is the battery voltage divided by the total resistance (Ohm's law).

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

Resistors in series add up: $R_{\text{total}} = R_1 + R_2$.

Step 3: Switch S open:

With S open, no current can pass through the bypass wire. The current must pass through both resistors.

$$R_{\text{total}} = 10 + 30 = 40\ \Omega$$

$$I = \frac{20}{40} = 0.5\ \text{A}$$

The same current flows through the 10 Ω resistor because it is in series.

Step 4: Switch S closed:

With S closed, the switch wire joins the two ends of the 30 Ω resistor.

Current takes this zero-resistance path, so the 30 Ω resistor is short-circuited and carries no current.
Only the 10 Ω resistor is left in the circuit.

$$I = \frac{20}{10} = 2\ \text{A}$$

Final Answer:
When S is open, the current through the 10 Ω resistor is 0.5 A. When S is closed, it rises to 2 A.

$$\boxed{I_{\text{open}} = 0.5\ \text{A}, \quad I_{\text{closed}} = 2\ \text{A}}$$

Quick Tip: Open switch: series, $R = 40\ \Omega$, so $I = 20/40 = 0.5$ A. Closed switch: the 30 Ω resistor is shorted, so $I = 20/10 = 2$ A.

3(b).

Calculate the energy equivalence of unified atomic mass unit.

Correct Answer: —

Solution:

The energy equivalence of 1 unified atomic mass unit (1 amu) can be calculated using the relation:

$$E = mc^2,$$

where m is the mass of 1 amu, and c is the speed of light. The value of 1 amu is approximately:

$$m = 1.660539 \times 10^{-27}\ \text{kg}.$$

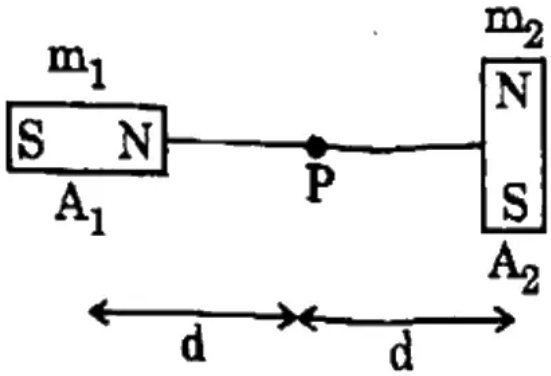
Substituting the values:

$$E = (1.660539 \times 10^{-27}\ \text{kg}) \times (3 \times 10^{8}\ \text{m/s})^2 = 1.492 \times 10^{-10}\ \text{J}.$$

So, 1 amu is equivalent to 1.492×10^{-10} J.

Quick Tip: The energy equivalent of an atomic mass unit can be found using $E = mc^2$, where m is the mass in kg and c is the speed of light.

3(c).



Two magnets of equal magnetic moment ($m_1 = m_2$) are placed as shown in the figure. If magnetic field intensity at P due to magnet A_1 is 2×10^{-3} Tesla, then find out total magnetic field intensity at P due to both the magnets.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

A short bar magnet produces a different field on its axis than on its equatorial line, even at the same distance. The point P is on the axis of magnet A_1, but on the equatorial line of magnet A_2.

The total field at P is the vector sum of the two fields.

Step 2: Key Formula or Approach:

For a short magnet of moment m, at distance d from its centre:

Axial point: $B_{\text{axial}} = \frac{\mu_0}{4\pi}\frac{2m}{d^3}$, directed along the moment (from S to N).

Equatorial point: $B_{\text{eq}} = \frac{\mu_0}{4\pi}\frac{m}{d^3}$, directed opposite to the moment.

Step 3: Field due to A1:

P lies on the axis of A_1 at distance d. So the field due to A_1 is the axial one.

$$B_1 = \frac{\mu_0}{4\pi}\frac{2m}{d^3} = 2 \times 10^{-3}\ \text{T}$$

Its direction is along the moment of A_1, which points from S to N, that is, to the right along the line joining the magnets.

Step 4: Field due to A2:

P lies on the equatorial line of A_2 at the same distance d, and $m_2 = m_1$.

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{d^3} = \frac{B_1}{2} = 1 \times 10^{-3}\ \text{T}$$

The moment of A_2 points upward (S to N), so the equatorial field points downward.

Step 5: Add the two fields:

B_1 is horizontal and B_2 is vertical, so they are at 90° to each other.

$$B = \sqrt{B_1^2 + B_2^2} = \sqrt{(2 \times 10^{-3})^2 + (1 \times 10^{-3})^2}$$

$$B = \sqrt{5} \times 10^{-3} \approx 2.24 \times 10^{-3}\ \text{T}$$

The direction makes an angle θ with the axis of A_1, where $\tan\theta = B_2/B_1 = 1/2$, so $\theta \approx 26.6°$ (tilted downward, towards the S pole of A_2).

Final Answer:

The total magnetic field at P is $\sqrt{5} \times 10^{-3}$ T, about 2.24×10^{-3} T.

$$\boxed{B = \sqrt{5} \times 10^{-3}\ \text{T} \approx 2.24 \times 10^{-3}\ \text{T}}$$

Quick Tip: P is on the axis of A_1 ($B_1 = 2 \times 10^{-3}$ T) and on the equatorial line of A_2 ($B_2 = B_1/2 = 10^{-3}$ T). The fields are perpendicular, so $B = \sqrt{B_1^2 + B_2^2} = \sqrt{5} \times 10^{-3}$ T.

3(d). In a Silicon p-n junction diode, for 20 V forward voltage the forward current produced is 10 mA. Calculate its forward resistance.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

When a p-n junction diode is forward biased, it conducts current. The

forward resistance is the ratio of the forward voltage to the forward current at that point.

Step 2: Key Formula or Approach:

Use Ohm's law for the diode at the given operating point.

$$R_f = \frac{V_f}{I_f}$$

Step 3: Substitute the values:

The forward voltage is $V_f = 20$ V.

The forward current is $I_f = 10\ \text{mA} = 10 \times 10^{-3}\ \text{A} = 10^{-2}\ \text{A}$.

$$R_f = \frac{20}{10^{-2}} = 2000\ \Omega$$

This is $2\ \text{k}\Omega$.

Final Answer:

The forward resistance of the diode is $2000\ \Omega$, that is $2\ \text{k}\Omega$.

$$\boxed{R_f = 2000\ \Omega = 2\ \text{k}\Omega}$$

Quick Tip: Forward resistance $R_f = V/I = 20/(10 \times 10^{-3}) = 2000\ \Omega$.

4(a).

Deduce the formula of torque on an electric dipole placed in a uniform electric field.

Correct Answer: —

Solution:

Consider an electric dipole consisting of two charges $+q$ and $-q$, separated by a distance d. The dipole moment $\mathbf{p}$ is given by:

$$\mathbf{p} = q \cdot \mathbf{d},$$

where $\mathbf{d}$ is the vector pointing from the negative to the positive charge. When the dipole is placed in a uniform electric field $\mathbf{E}$, it experiences a torque that tends to align the dipole with the electric field. The torque $\mathbf{T}$ is given by:

$$\mathbf{T} = \mathbf{p} \times \mathbf{E},$$

where the cross product ensures that the torque is perpendicular to both the dipole moment and the electric field. The magnitude of the torque is:

$$T = pE \sin \theta,$$

where θ is the angle between the dipole moment $\mathbf{p}$ and the electric field $\mathbf{E}$.

Quick Tip: The torque on an electric dipole in a uniform electric field is given by $T = pE \sin \theta$, where p is the dipole moment, E is the electric field, and θ is the angle between $\mathbf{p}$ and $\mathbf{E}$.

4(b).

The intensity of the magnetic field B due to a current-carrying circular coil of radius 12 cm at its center is 0.5×10^{-4} Tesla perpendicular to the plane of the coil upward. Calculate the magnitude and direction of current flowing in the coil.

Correct Answer: —

Solution:

The magnetic field at the center of a circular loop carrying current I is given by:

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

where $\mu_0 = 4\pi \times 10^{-7}\,\text{T m/A}$ is the permeability of free space, I is the current, and R is the radius of the coil. Rearranging for I:

$$I = \frac{2BR}{\mu_0}.$$

Substituting the given values ($B = 0.5 \times 10^{-4}\,\text{T}$, $R = 12\,\text{cm} = 0.12\,\text{m}$):

$$I = \frac{2 \times 0.5 \times 10^{-4} \times 0.12}{4\pi \times 10^{-7}} = 3.0\,\text{A}.$$

The direction of the current follows the right-hand rule: when the fingers of the right hand curl in the direction of the current in the coil, the thumb points in the direction of the magnetic field at the center, which is upward.

Quick Tip: The magnetic field at the center of a current-carrying circular coil is given by $B = \frac{\mu_0 I}{2R}$, where μ_0 is the permeability, I is the current, and R is the radius of the coil.

4(c).

What is total internal reflection and critical angle? What is the working principle of Optical Fibre.

Correct Answer: —

Solution:

\textit{Total Internal Reflection:} Total internal reflection occurs when a light ray traveling from a denser medium to a rarer medium hits the boundary at an angle greater than the critical angle and reflects completely back into the denser medium. \textit{Critical Angle:} The critical angle θ_c is the angle of incidence beyond which total internal reflection occurs. It is given by:

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

where n_1 and n_2 are the refractive indices of the denser and rarer media, respectively. \textit{Working Principle of Optical Fibre:} An optical fibre works based on the principle of total internal reflection. Light signals are transmitted through the fibre by multiple total internal reflections within the fibre, which is made of a core with a higher refractive index than the cladding surrounding it.

Quick Tip: Total internal reflection occurs when light moves from a denser to a rarer medium and strikes the boundary at an angle larger than the critical angle.

4(d).

In the given circuit, find the potential difference between A and B.

Correct Answer: —

Solution:

The circuit consists of three branches connected between points A and B, each having a $1\,\Omega$ resistor in series with voltage sources of $3\,\text{V}$, $2\,\text{V}$, and $1\,\text{V}$, respectively. The current in each branch can be calculated using Ohm's Law:

$$I = \frac{\text{Voltage}}{\text{Resistance}}.$$

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Since all resistances are equal, the potential difference between A and B is determined by the branch with the highest voltage source. Hence,

$$V_{AB} = 3\,\text{V}.$$

Quick Tip: For circuits with parallel branches, the potential difference between two points is primarily influenced by the voltage sources in the branches. Consider the highest voltage source when resistances are equal.

4(e). Define Mutual Inductance. Show that $\frac{\text{Henry}}{\text{Meter}} = \frac{\text{Newton}}{\text{Ampere}^2}$.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Take two coils placed close to each other. When the current in the first coil changes, its magnetic flux through the second coil changes too. By Faraday's law, an emf is induced in the second coil. This effect is called mutual induction.

Step 2: Definition of Mutual Inductance:

Let a current I_1 in coil 1 produce a flux ϕ_2 through coil 2. The flux is proportional to the current:

$$\phi_2 = MI_1$$

The constant M is the coefficient of mutual inductance. It is the flux linked with the second coil when unit current flows in the first coil. The induced emf in coil 2 is

$$\varepsilon_2 = -M\frac{dI_1}{dt}$$

So M is also the emf induced in one coil when the current in the other coil changes at the rate of one ampere per second. Its SI unit is the henry (H).

Step 3: Unit of M in terms of energy:

The energy stored in an inductor is $U = \frac{1}{2}LI^2$, and the same form holds for mutual inductance. So the henry has the unit of energy divided by current squared.

$$\text{Henry} = \frac{\text{Joule}}{\text{Ampere}^2}$$

Step 4: Divide by metre:

One joule is one newton-metre of work, so $\text{Joule} = \text{Newton} \times \text{Meter}$.

$$\text{Henry} = \frac{\text{Newton} \times \text{Meter}}{\text{Ampere}^2}$$

Now divide both sides by metre.

$$\frac{\text{Henry}}{\text{Meter}} = \frac{\text{Newton}}{\text{Ampere}^2}$$

This is the required result. It also shows that the unit of μ_0 can be written either as H/m or as N/A^2.

Final Answer:

Mutual inductance is $M = \phi_2/I_1$, the flux linked with one coil per unit current in the other coil. Its unit gives $\text{H/m} = \text{N/A}^2$.

$$\boxed{\frac{\text{Henry}}{\text{Meter}} = \frac{\text{Newton}}{\text{Ampere}^2}}$$

Quick Tip: $M = \phi_2/I_1$, the flux linked with one coil per unit current in the other. $\text{H} = \text{J/A}^2 = \text{N m/A}^2$, so $\text{H/m} = \text{N/A}^2$.

5(a).

What is the value of resistance of ideal ammeter and ideal voltmeter? Why are an ammeter and a voltmeter respectively connected in series and parallel in a circuit?

Correct Answer: —

Solution:

Ideal Ammeter: An ideal ammeter has zero resistance. It is connected in series with the circuit, as the current to be measured flows through the ammeter without affecting the circuit.

Ideal Voltmeter: An ideal voltmeter has infinite resistance. It is connected in parallel with the component across which the potential difference is to be measured. This ensures that no current is drawn by the voltmeter, and only the potential difference is measured.

Quick Tip: An ideal ammeter has zero resistance and is connected in series, while an ideal voltmeter has infinite resistance and is connected in parallel.

5(b).

A coil has a resistance of 10 Ω and inductance of 0.4 Henry. It is connected to an AC source of 6.5 V, 30 Hz. Find the average power consumed in the circuit.

Correct Answer: —

Solution:

Given:

- Resistance $R = 10\,\Omega$
- Inductance $L = 0.4\,\text{H}$
- AC Voltage $V = 6.5\,\text{V}$
- Frequency $f = 30\,\text{Hz}$ The inductive reactance X_L is given by:

$$X_L = 2\pi f L = 2\pi \times 30 \times 0.4 = 75.4\,\Omega.$$

The impedance Z of the coil is:

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{10^2 + 75.4^2} = \sqrt{100 + 5684.16} = 75.7\,\Omega.$$

The RMS value of the current I_{rms} is:

$$I_{\text{rms}} = \frac{V}{Z} = \frac{6.5}{75.7} = 0.086\,\text{A}.$$

The average power consumed is:

$$P_{\text{avg}} = I_{\text{rms}}^2 R = (0.086)^2 \times 10 = 0.074\,\text{W}.$$

Quick Tip: In an R-L circuit, the average power consumed is given by $P_{\text{avg}} = I_{\text{rms}}^2 R$, where I_{rms} is the RMS current.

5(c).

Explain Maxwell's displacement current and write its equation. What is the phase difference between it and the conduction current?

Correct Answer: —

Solution:

Maxwell's displacement current is a term added by Maxwell in the Ampere's law to account for the changing electric field in a capacitor or any region where the electric field is changing with time. The displacement current density J_D is given by:

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

where ϵ is the permittivity of the medium, and $\frac{\partial E}{\partial t}$ is the time rate of change of the electric field. The displacement current causes a magnetic field in the same way as conduction current, ensuring continuity of current even in regions without free charge carriers. The displacement current and conduction current are in phase, meaning they oscillate together.

Quick Tip: Maxwell's displacement current accounts for the changing electric field and ensures that the magnetic field is continuous even in regions without free charge carriers.

5(d).

What is interference of light? Mention the condition for (A) constructive and (B) destructive interference.

Correct Answer: —

Solution:

Interference of Light:

Interference is the phenomenon that occurs when two or more light waves superpose to form a resultant wave. Depending on the phase relationship between the waves, the interference can be constructive or destructive.

Condition for Constructive Interference:

When the path difference between the waves is an integer multiple of the wavelength $m\lambda$, the waves interfere constructively:

$$\Delta x = m\lambda, \quad m = 0, 1, 2, \ldots$$

Condition for Destructive Interference:

When the path difference is an odd multiple of half the wavelength $(m + 1/2)\lambda$, the waves interfere destructively:

$$\Delta x = (m + 1/2)\lambda, \quad m = 0, 1, 2, \ldots$$

Quick Tip: Interference occurs when two light waves superpose. Constructive interference occurs when the path difference is $m\lambda$, and destructive interference occurs when the path difference is $(m + 1/2)\lambda$.

OR

What is polarization of light ? State the principle and two uses of a polaroid.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Light is a transverse electromagnetic wave. In ordinary (unpolarised) light, the electric field vibrates in all directions perpendicular to the

direction of travel. Polarisation deals with restricting these vibrations.

Step 2: Definition of polarisation:

The phenomenon of restricting the vibrations of light to a single direction in a plane perpendicular to the direction of propagation is called polarisation of light.

Light whose vibrations are confined to one direction is called plane polarised light. That polarisation is possible at all is proof that light waves are transverse.

Step 3: Principle of a polaroid:

A polaroid is a thin sheet containing long chain molecules that are aligned in one direction. It works on the principle of selective absorption (dichroism).

The sheet absorbs light whose electric vector is parallel to the molecular chains and lets through the light whose vibrations are perpendicular to them. So the light coming out vibrates along only one direction, called the pass axis.

If plane polarised light of intensity I_0 falls on a second polaroid whose axis is at angle θ, the transmitted intensity follows Malus' law:

$$I = I_0 \cos^2 \theta$$

Step 4: Uses of a polaroid:

1. Sun glasses and car windshields use polaroids to cut the glare of light reflected from roads and water.

2. Polaroid filters in cameras remove reflections and improve contrast in photographs.

Other uses: 3-D movie glasses, LCD displays, and controlling the

brightness of light in aircraft windows.

Final Answer:
Polarisation limits light vibrations to one direction. A polaroid works by selective absorption, and it is used in sunglasses and camera filters.

Polaroid: selective absorption; uses: sun glasses, camera filters

Quick Tip: Polarisation: restricting light vibrations to one direction. Polaroid principle: selective absorption (dichroism). Uses: sunglasses, camera filters.

5(e).

Find the maximum magnitude of velocity and linear momentum of a photoelectron emitted when light of wavelength 4000 Ã... falls on a metal having work function 2.5 eV.

Correct Answer: —

Solution:

Given:
- Wavelength $\lambda = 4000\,\text{Ã...} = 4 \times 10^{-7}\,\text{m}$
- Work function $\phi = 2.5\,\text{eV} = 2.5 \times 1.6 \times 10^{-19}\,\text{J}$
- Planck's constant $h = 6.626 \times 10^{-34}\,\text{J} \cdot \text{s}$
- Speed of light $c = 3 \times 10^{8}\,\text{m/s}$ The energy of the incoming photon is:

$$E_{\text{photon}} = \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{4 \times 10^{-7}} = 4.97 \times 10^{-19}\,\text{J}.$$

The kinetic energy of the emitted photoelectron is:

$$E_k = E_{\text{photon}} - \phi = 4.97 \times 10^{-19} - 2.5 \times 1.6 \times 10^{-19} = 2.57 \times 10^{-19}\ \text{J}.$$

The maximum velocity of the photoelectron is given by:

$$v = \sqrt{\frac{2E_k}{m_e}} = \sqrt{\frac{2 \times 2.57 \times 10^{-19}}{9.11 \times 10^{-31}}} = 7.52 \times 10^5\ \text{m/s}.$$

The linear momentum p of the photoelectron is:

$$p = m_e v = 9.11 \times 10^{-31} \times 7.52 \times 10^5 = 6.85 \times 10^{-25}\ \text{kg} \cdot \text{m/s}.$$

Quick Tip: The kinetic energy of a photoelectron is the energy of the photon minus the work function. The maximum velocity and linear momentum of the photoelectron can be determined using this energy.

6.

State and explain Gauss's law in electrostatics. Using it, find the electric field due to a uniformly charged thin spherical shell (charge = q and radius = R) at

(A) external point of shell

(B) internal point of shell

(C) on the surface of shell.

Correct Answer: —

Solution:

Gauss Law: Gauss law states that the electric flux Φ_E through any closed surface is proportional to the charge Q_{enclosed} enclosed by the surface. Mathematically:

$$\Phi_E = \oint_S \mathbf{E} \cdot d\mathbf{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0},$$

where $\mathbf{E}$ is the electric field, $d\mathbf{A}$ is the differential area vector, and ϵ_0 is the permittivity of free space.

Now, applying Gauss's law to a uniformly charged thin spherical shell, we can find the electric field at various points:

(A) At an external point (at a distance $r > R$ from the center of the shell): Since the charge distribution is spherically symmetric, we can use a spherical Gaussian surface of radius r (where $r > R$). The total charge Q is enclosed within this Gaussian surface, and the electric field at a distance r is given by:

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

so the electric field is:

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

(B) At an internal point (at a distance $r < R$ from the center of the shell): For a point inside the uniformly charged spherical shell, the electric flux through the Gaussian surface is zero because no charge is enclosed within the Gaussian surface. Thus, the electric field inside the shell is:

$$E = 0.$$

(C) At a point on the surface of the shell (at $r = R$): At the surface, the electric field will have the same magnitude as at any

external point on a spherical shell with radius $r = R$. Thus, the electric field is:

$$E = \frac{q}{4\pi\epsilon_0 R^2}.$$

Quick Tip: Gauss's law simplifies the calculation of the electric field in situations with spherical symmetry, such as around a uniformly charged spherical shell.

OR

Calculate the following in the given circuit:

(A) The equivalent capacitance of the circuit.

(B) The charge on $3\,\mu$F and $2\,\mu$F capacitors.

\includegraphics[]{equivalent capac.PNG}

Correct Answer: —

Solution:

(A) Equivalent Capacitance of the Circuit: The given circuit has capacitors arranged in a combination of series and parallel connections. Let us simplify step by step: 1. The $6\,\mu$F and $12\,\mu$F capacitors are in series:

$$\frac{1}{C_1} = \frac{1}{6} + \frac{1}{12} \quad \Rightarrow \quad C_1 = \frac{12}{3} = 4\,\mu\text{F}.$$

2. The $6\,\mu$F and $3\,\mu$F capacitors are in series:

$$\frac{1}{C_2} = \frac{1}{6} + \frac{1}{3} \quad \Rightarrow \quad C_2 = 2\,\mu\text{F}.$$

3. The $C_1 = 4\,\mu$F, $2\,\mu$F, and $C_2 = 2\,\mu$F are in parallel:

$$C_{eq} = C_1 + C_2 + 2 \quad \Rightarrow \quad C_{eq} = 4 + 2 + 2 = 8\,\mu\text{F}.$$

Thus, the equivalent capacitance of the circuit is:

$$\boxed{8\,\mu\text{F}}.$$

(B) Charge on $3\,\mu$F and $2\,\mu$F capacitors: The total charge in the circuit is given by:

$$Q_{\text{total}} = C_{eq} \cdot V = 8\,\mu\text{F} \cdot 10\,\text{V} = 80\,\mu\text{C}.$$

For the $3\,\mu$F capacitor, the voltage across $C_2 = 2\,\mu$F is the same as the voltage across the series combination of $6\,\mu$F and $3\,\mu$F. Using charge conservation:

$$Q = C \cdot V = 3\,\mu\text{F} \cdot 10\,\text{V} = 30\,\mu\text{C}.$$

Similarly, for the $2\,\mu$F capacitor:

$$Q = C \cdot V = 2\,\mu\text{F} \cdot 10\,\text{V} = 20\,\mu\text{C}.$$

Thus, the charges are:

$$\boxed{30\,\mu\text{C on the } 3\,\mu\text{F capacitor, and } 20\,\mu\text{C on the } 2\,\mu\text{F capacitor.}}$$

Quick Tip: For capacitors in series, the equivalent capacitance is given by:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$$

For capacitors in parallel, the equivalent capacitance is given by:

$$C_{eq} = C_1 + C_2 + \cdots$$

7. Explain image formation in a reflecting telescope with the help of a ray diagram. Compare its qualities with a refracting telescope.

Correct Answer: —

Solution:

In a reflecting telescope, the image is formed using a concave mirror. When parallel rays of light from a distant object fall on the mirror, they converge at the focal point to form the image. The ray diagram of the image formation is as follows: \includegraphics[]{reflrcting tele.PNG} **Comparison with a refracting telescope:** \begin{itemize} \item **Optical Medium:** A reflecting telescope uses a mirror, while a refracting telescope uses lenses. \item **Aberrations:** Reflecting telescopes do not suffer from chromatic aberration, whereas refracting telescopes do. \item **Size:** Reflecting telescopes are generally more compact than refracting ones for the same focal length and aperture size. \item **Cost:** Mirrors are easier and cheaper to produce than large lenses, making reflecting telescopes more cost-effective. \end{itemize}

Quick Tip: Reflecting telescopes do not suffer from chromatic aberrations, making them ideal for astronomical observations, especially for large telescopes.

OR

Explain the differences between diffraction and interference of waves. Observe qualitatively the diffraction pattern of a single slit.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:

Both interference and diffraction come from the wave nature of light, and both are explained by the superposition of waves. The difference lies in where the superposing waves come from.

Step 2: Key Formula or Approach:

1. Interference by two slits: bright fringe at path difference $\Delta = n\lambda$, dark fringe at $\Delta = (n + \frac{1}{2})\lambda$.
2. Single slit of width a: dark fringes at $a \sin\theta = n\lambda$ with $n = \pm 1, \pm 2, \ldots$

Step 3: Differences between interference and diffraction:

Source of the waves: interference needs two separate coherent sources (or two slits). Diffraction comes from different points of the same wavefront passing through one slit or around one edge.

Fringe width: in interference all fringes have the same width $\beta = \lambda D/d$. In diffraction the central maximum is twice as wide as the other maxima.

Intensity: in interference the bright fringes are all about equally bright. In diffraction the intensity falls quickly on both sides of the central maximum.

Dark fringes: in interference with equal amplitudes the dark fringes are completely dark. In diffraction the minima are dark but the secondary maxima are very weak.

Number of fringes: interference gives many clear fringes. Diffraction gives a bright centre and only a few faint maxima.

Step 4: Diffraction pattern of a single slit:

Let monochromatic light of wavelength λ fall on a narrow slit of width a, and let the pattern form on a screen at distance D. Every point of

the slit acts as a secondary source, and these sources interfere on the screen.
At the centre of the screen all secondary waves arrive in phase, so we get a broad and very bright central maximum.
At angle θ the path difference between the two edges of the slit is $a \sin\theta$. When this equals $n\lambda$, the slit can be split into pairs of points whose waves cancel, so the screen is dark.

$$a \sin\theta = n\lambda \quad (n = \pm 1, \pm 2, \ldots)$$

Between two successive minima we get a secondary maximum, where $a \sin\theta \approx (n + \frac{1}{2})\lambda$.

Step 5: Shape and width of the pattern:
The first minima lie at $\sin\theta = \pm\lambda/a$. So the angular width of the central maximum is $2\lambda/a$, and its linear width on the screen is $2\lambda D/a$. Each secondary maximum has a width of only $\lambda D/a$, which is half the central width.
The intensity of the first secondary maximum is about 4.5 percent of the central one, and the next is about 1.6 percent. So the pattern is a very bright centre with faint, narrow bands on both sides, symmetric about the centre.
If the slit is made narrower, a decreases and the pattern spreads out. If the slit is wider, the pattern shrinks.

Final Answer:
Interference is the superposition of waves from two coherent sources and gives equally wide, equally bright fringes. Diffraction is the superposition of secondary waves from one wavefront and gives a

wide bright centre with weaker side maxima, with minima at $a \sin\theta = n\lambda$.

$$\boxed{a \sin\theta = n\lambda \text{ (minima), central width } = \frac{2\lambda D}{a}}$$

Quick Tip: Compare interference (two coherent sources, equal fringes) with diffraction (one slit, wide central maximum). Single slit minima: $a \sin\theta = n\lambda$.

8. Explain postulates of Bohr's model for Hydrogen atom. Show the number of lines in the (A) emission and (B) absorption spectra of Hydrogen atom corresponding to transition between energy states $n = 1$ and $n = 4$.

Correct Answer: —

Solution:

Bohr's Postulates for Hydrogen Atom:

(A) The electron in the atom revolves in specific orbits without radiating energy.
(B) The electron can only occupy discrete energy levels or orbits. The energy of the electron in the n-th orbit is given by:

$$E_n = -\frac{ke^2}{2r_n}$$

where k is Coulomb's constant, e is the electron charge, and r_n is the radius of the n-th orbit.

(C) The transition of the electron between orbits results in the emission or absorption of energy corresponding to the difference in energy levels.

Emission and Absorption Spectra:

For transition between $n = 1$ and $n = 4$, the emission and absorption spectra can be derived using the following formulas:

1. Emission:

When the electron transitions from a higher to a lower energy state, the frequency of the emitted radiation is:

$$f = \frac{E_{\text{higher}} - E_{\text{lower}}}{h}$$

2. Absorption:

The electron absorbs energy when it moves to a higher energy state.

(A) Emission Spectrum Lines:

The number of lines in the emission spectrum is given by the number of possible transitions from $n=4$ to $n=1$, including intermediate states. The transitions are as follows:

$$4 \to 3, \quad 4 \to 2, \quad 4 \to 1, \quad 3 \to 2, \quad 3 \to 1, \quad 2 \to 1.$$

There are a total of 6 emission lines.

(B) Absorption Spectrum Lines:

Similarly, for absorption, the number of lines will be the same, as absorption also happens when the electron moves from a lower to a higher energy state. The number of lines is 6.

Quick Tip: The number of spectral lines increases with the number of possible energy level transitions.

OR

What is meant by binding energy of a nucleus ? Draw variation of binding energy per nucleon against the mass number. Discuss fission and fusion with the help of this variation.

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
A nucleus is lighter than the sum of the masses of its separate protons and neutrons. This missing mass is called the mass defect. By Einstein's relation $E = mc^2$, the mass defect shows up as energy that was released when the nucleus formed.

Step 2: Binding energy:
For a nucleus ${}^{A}_{Z}X$ with atomic mass number A and atomic number Z, the mass defect is $\Delta m = Zm_p + (A - Z)m_n - M$. The binding energy is

$$E_b = \Delta m\, c^2 = [Zm_p + (A - Z)m_n - M]\, c^2$$

It is the minimum energy needed to separate the nucleus into free protons and neutrons. The binding energy per nucleon is E_b/A, and it measures how firmly a nucleon is held.

Step 3: The binding energy curve:

Plot E_b/A in MeV on the vertical axis against mass number A on the horizontal axis. The curve behaves as follows.

For very light nuclei the value is small, for example about 1.1 MeV for deuterium ${}_1^2H$ and about 7.1 MeV for ${}_2^4He$.

It then rises steeply, and for A between about 30 and 170 it stays nearly flat at about 8 MeV, with a peak near $A = 56$ (iron) at about 8.7 MeV.

For heavier nuclei it falls slowly, reaching about 7.6 MeV for uranium ($A = 238$).

So the graph looks like a hill with a steep left side, a broad flat top near iron, and a gentle slope on the right.

Step 4: Nuclear fission:

A heavy nucleus with A around 235 has E_b/A of about 7.6 MeV. If it splits into two middle-mass nuclei (A around 120), each has E_b/A of about 8.5 MeV.

The products are more tightly bound, so the extra binding energy is released. For one nucleus the gain is about $235 \times (8.5 - 7.6) \approx 200$ MeV.

Example: ${}_{92}^{235}U + {}_0^1n \rightarrow {}_{56}^{141}Ba + {}_{36}^{92}Kr + 3\,{}_0^1n + 200$ MeV.

Step 5: Nuclear fusion:

Light nuclei such as hydrogen isotopes sit on the steep left side of the curve, where E_b/A is small. When two of them join to make a heavier nucleus, the product lies higher on the curve.

So the product is more tightly bound and energy is released. Example:

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

Fusion needs very high temperature (about 10^7 K or more) so that the nuclei can overcome their electric repulsion. This is what powers the Sun.

Final Answer:
Binding energy is the energy needed to break a nucleus into its nucleons. The curve of E_b/A against A peaks near iron, so both fission of heavy nuclei and fusion of light nuclei move the product up the curve and release energy.

$$\boxed{E_b = [Zm_p + (A - Z)m_n - M]c^2}$$

Quick Tip: Binding energy is $[Zm_p + (A - Z)m_n - M]c^2$. The curve peaks near iron, so fission of heavy and fusion of light nuclei both release energy.

9. Calculate the conductivity of an n-type semiconductor from the following data: Density of conduction electrons = $8 \times 10^{13}\ \text{cm}^{-3}$ Density of holes = $5 \times 10^{12}\ \text{cm}^{-3}$ Mobility of electrons = $2.3 \times 10^4\ \text{cm}^2/\text{V-s}$ Mobility of holes = $100\ \text{cm}^2/\text{V-s}$

Correct Answer: —

Solution:

\textit{Conductivity of N-Type Semiconductor:} The electrical conductivity (σ) of a semiconductor is given by:

$$\sigma = q \cdot (n_e\mu_e + n_h\mu_h),$$

where:
- q is the charge of an electron,
- n_e is the density of conduction electrons,
- n_h is the density of holes,
- μ_e is the mobility of electrons,
- μ_h is the mobility of holes. Using the given values, the conductivity can be calculated as:

$$\sigma = (1.6 \times 10^{-19}) \cdot \left((8 \times 10^{13}) \cdot (2.3 \times 10^{4}) + (5 \times 10^{12}) \cdot (100)\right).$$

Quick Tip: The conductivity of a semiconductor depends on the density and mobility of both electrons and holes.

OR

Explain the depletion layer and potential barrier in the formation of p-n junction. How are both changing in the condition of forward biasing and reverse biasing ?

Correct Answer: —

Solution:

Step 1: Understanding the Concept:
A p-n junction is made by joining a p-type semiconductor, which has many holes, to an n-type semiconductor, which has many free electrons. The two sides have very different carrier concentrations at the moment they touch, and this drives everything that follows.

Step 2: Formation of the depletion layer:
Electrons are plentiful on the n side and few on the p side, so electrons diffuse across the junction from n to p. In the same way

holes diffuse from p to n.
An electron that crosses over combines with a hole near the junction. Both free carriers disappear.
Each electron that leaves an n-side donor atom leaves behind a fixed positive ion. Each hole that leaves a p-side acceptor atom leaves behind a fixed negative ion.
So a thin region on both sides of the junction has no free carriers and only fixed ions. This region is the depletion layer. Its width is of the order of 10^{-6} m.

Step 3: Formation of the potential barrier:
The fixed positive ions on the n side and fixed negative ions on the p side set up an electric field pointing from n to p across the depletion layer. This field opposes further diffusion of electrons and holes.
The potential difference across the layer is called the barrier potential V_0. It is about 0.7 V for silicon and about 0.3 V for germanium.
Diffusion goes on until the field becomes strong enough to stop it, and then the junction is in equilibrium.

Step 4: Forward biasing:
Connect the p side to the positive terminal and the n side to the negative terminal of a battery of voltage V. The applied field points opposite to the junction field.
The majority carriers are pushed toward the junction, and they enter the depletion layer. So the depletion layer becomes narrower.
The effective barrier falls from V_0 to $(V_0 - V)$. Once V is greater than about 0.7 V for silicon, a large current flows, and it rises rapidly with voltage.

Step 5: Reverse biasing:
Connect the p side to the negative terminal and the n side to the

positive terminal. Now the applied field points the same way as the junction field.
Holes and electrons are pulled away from the junction, so more fixed ions are uncovered and the depletion layer becomes wider.
The barrier rises to $(V_0 + V)$. Majority carriers cannot cross, and only a tiny current of minority carriers (the reverse saturation current, in microamperes) flows.

Final Answer:
Depletion layer: a region near the junction with no free carriers and only fixed ions. Potential barrier: the voltage across it, about 0.7 V for Si. In forward bias the layer narrows and the barrier falls to $V_0 - V$. In reverse bias the layer widens and the barrier rises to $V_0 + V$.

$$\boxed{\text{Forward: width} \downarrow,\ V_0 - V; \quad \text{Reverse: width} \uparrow,\ V_0 + V}$$

Quick Tip: Diffusion leaves fixed ions at the junction, forming the depletion layer and barrier. Forward bias narrows it and lowers the barrier; reverse bias widens it and raises the barrier.