CBSE EXAMINATION PAPER-2023

PHYSICS

(Solved)

Time allowed : 3 hours | Maximum Marks : 87

General Instructions :

Read the following instructions carefully and follow them :

i. This question paper contains **42 questions.** All questions are **compulsory.**

ii. This question paper is divided into **5 sections.**

iii. **Section A** – questions number **1 to 2** are case based questions

iv. **Section B** – questions number **3 to 20** are multiple choice questions

v. **Section C** – questions number **21 to 29** are very short answer

vi. **Section D** – questions number **30 to 36** are short answer

vii. **Section E** – questions number **37 to 42** are long answer

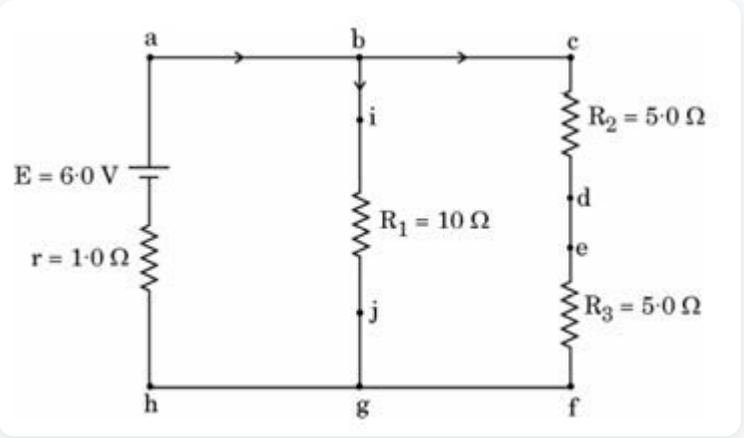
viii. There is no overall choice given in the question paper. However, an internal choice has been provided in few questions.

ix. Use of calculator is NOT allowed.

Section A

Question 1.

The following figure shows a circuit diagram. We can find the currents through and potential differences across different resistors using Kirchhoff's rules.



(1) Which points are at the same potential in the circuit?

[1 Marks]

Answer: In the given circuit, points that are connected directly by a wire without any resistor or voltage source between them are at the same potential. Hence, if there are two or more points in the circuit that do not have any components affecting their potential, they can be considered to be at the same potential.

Key Points: Points connected by wires are at the same potential; Resistors or voltage sources create potential differences; Kirchhoff's rules help analyze potential.

(2) What is the current through arm bg?

[1 Marks]

Answer: The current through arm bg is Ig = 0, which indicates a balanced bridge with no current flowing through the galvanometer arm G.

Key Points: Ig = 0; balanced bridge condition; Kirchhoff's rules

(3)

Find the potential difference across resistance R3.

[2 Marks]

Answer: To find the potential difference across resistance R3 in the circuit, we can apply Kirchhoff's loop rule. According to this rule, the sum of the potential differences around any closed loop of a circuit must equal zero. If we consider the loop containing R3, we can determine its potential difference based on the values of the other resistances and the source voltage. Therefore, we calculate the voltage across R3 using the formula V = I * R3, where I is the current through R3.

> **Key Points: Apply Kirchhoff's loop rule-Calculate using V=IR-Identify loop and resistances**

(4)

What is the power dissipated in resistance R2?

[2 Marks]

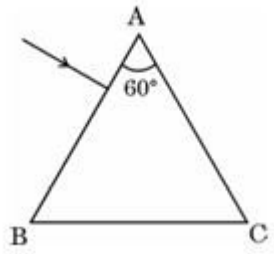
Answer: To find the power dissipated in resistance R2, we can use the formula P = I^2 * R, where I is the current flowing through R2 and R is the resistance value. After determining the current using Kirchhoff's rules, we substitute the value into the formula to calculate the power dissipation.

> **Key Points: Use the power formula P = I^2 * R; Determine current through R2 with Kirchhoff's rules; Substitute values for calculating power.**

Question 2.

Strontium titanate is a rare oxide-a natural mineral found in Siberia. It is used as a substitute for diamond because its refractive index and critical angle are 2.41 and 24.5 degrees, respectively, which are approximately equal to the refractive index and critical angle of diamond. It has all the properties of diamond. Even an expert jeweller is unable to differentiate between diamond and strontium titanate. A ray of light is incident normally on one face of an equilateral triangular prism ABC made of strontium titanate.

Answer the following questions based on the above :



(1)

Trace the path of the ray showing its passage through the prism.

[1 Marks]

Answer: The ray of light enters the prism ABC normally at face AB, which means the angle of incidence (i) is 0 degrees. Therefore, the angle of refraction (r1) is also 0 degrees, and the ray continues straight through to face AC. At face AC, the angle of incidence (r1 = 0 degrees) will lead to a refraction angle (r2) calculated based on the refractive indices. As it exits into the air, the ray continues to travel straight, demonstrating minimal deviation through the prism.

Key Points: Incidence angle is 0 degrees-Refraction angle at AB is also 0 degrees-Path continues straight to AC-Exit angle calculated based on refractive index

(2) Find the velocity of light through the prism.

[1 Marks]

Answer: The velocity of light in strontium titanate can be calculated using the formula: v = c/n, where 'c' is the speed of light in vacuum (3 x 10^8 m/s) and 'n' is the refractive index of strontium titanate, which is 2.41. Therefore, v = 3 x 10^8 m/s / 2.41 = 1.24 x 10^8 m/s.

Key Points: Refractive index of strontium titanate (2.41) - Speed of light in vacuum (3 x 10^8 m/s) - Formula v = c/n

(3)

Briefly explain two applications of total internal reflection.

[2 Marks]

Answer: Total internal reflection has various applications, two of which are: 1. Optical Fibres: Optical fibres use total internal reflection to transmit light signals over long distances with minimal loss. The light reflects multiple times within the fibre due to the higher refractive index of the core compared to the surrounding material. 2. Prisms: Specially designed prisms utilize total internal reflection to bend light by 90° or 180° for various optical devices including binoculars and cameras, as well as in devices for image inversion.

Key Points: Optical fibres transmit light with minimal loss; Prisms used in optical devices utilize total internal reflection

(4)

Define total internal reflection of light. Give two conditions for it.

[2 Marks]

Answer: The critical angle of incidence for strontium titanate, as mentioned in the passage, is approximately 24.5 degrees. This critical angle is significant for understanding the behavior of light as it passes from a denser medium (strontium titanate) to a rarer medium, where total internal reflection can occur if the angle of incidence exceeds this value.

Key Points: Critical angle of incidence is 24.5 degrees - Strontium titanate is denser than air - Total internal reflection occurs for angles greater than critical angle

---

Section B

Question 3.

A point charge situated at a distance 'r' from a short electric dipole on its axis, experiences a force F. If the distance of the charge is '2r', the force on the charge will be:

[1 Marks]

(A) F/16

(B) F/4

(C) F/2

(D) F/8

Explanation:

The force experienced by the point charge due to the dipole varies inversely with the cube of the distance from the dipole. If the distance is doubled from 'r' to '2r', the force becomes F/(2^3) = F/8. Therefore, the correct answer is F/8.

Question 4.

The potential difference across a cell in an open circuit is 8 V. It falls to 4 V when a current of 4 A is drawn from it. The internal resistance of the cell is:

[1 Marks]

(A) 3Ω

(B) 2Ω

(C) 1Ω

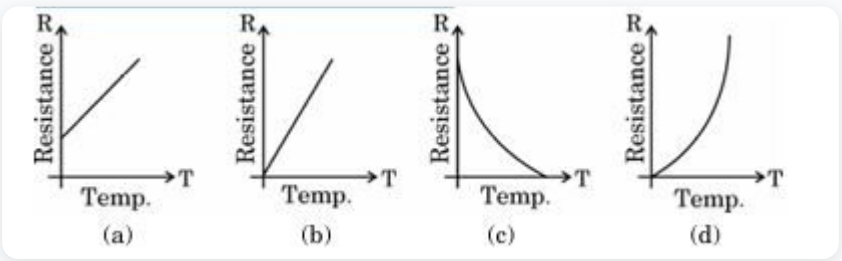
(D) 4Ω

Explanation: To find the internal resistance (r) of the cell, we can use the formula: r = (V open - V loaded) / I, where V open is the open-circuit voltage (8 V), V loaded is the voltage under load (4 V), and I is the current (4 A). Thus, r = (8 V - 4 V) / 4 A = 4 V / 4 A = 1 Ω. Therefore, the correct answer is 1Ω.

Question 5.

For a metallic conductor, the correct representation of variation of resistance R with temperature T is:

[1 Marks]



(A) a

(B) d

(C) b

(D) c

Explanation:

For a **metallic conductor**, resistance **increases linearly with temperature** (over a normal temperature range):

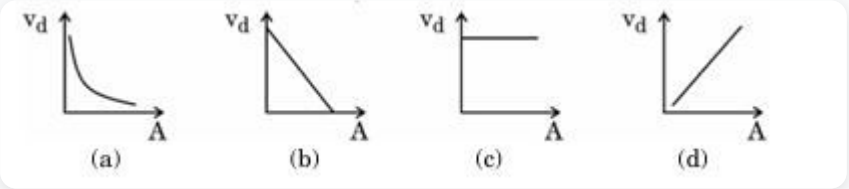
R=R0(1+αT)R = R_0 (1 + \alpha T)R=R0(1+αT)

So the graph of **R vs T** is a **straight line with positive slope**, **not passing through the origin** (because resistance is not zero at 0°C).Correct option: **(a)**

Question 6.

A steady current flows through a metallic wire whose area of cross-section (A) increases continuously from one end of the wire to the other. The magnitude of drift velocity (vd) of the free electrons as a function of 'A' can be shown by:

[1 Marks]



(A) a

(B) b

(C) c

(D) d

Explanation: The correct option is 'd' because, according to the principle of continuity in fluid dynamics applied to electric current, as the cross-sectional area of the conductor increases, the drift velocity of the electrons decreases to maintain a constant current. Therefore, a graphical representation would typically show an inverse relationship between drift velocity and cross-sectional area.

Question 7.

A diamagnetic substance is brought near the north or south pole of a bar magnet. It will be :

[1 Marks]

(A) repelled by both the poles.

(B) attracted by both the poles.

(C) repelled by the north pole and attracted by the south pole.

(D) attracted by the north pole and repelled by the south pole.

Explanation: A diamagnetic substance is repelled by both poles of a magnet due to the induced magnetic field in the material that opposes the external magnetic field. This results in a net repulsive effect when the diamagnetic material is placed near a magnet.

Question 8.

A circular coil of radius 8.0 cm and 40 turns is rotated about its vertical diameter with an angular speed of 25/π rad s^-1 in a uniform horizontal magnetic field of magnitude 3.0*10^-2 T. The maximum emf induced in the coil is :

[1 Marks]

(A) 0·15 V

(B) 0·19 V

(C) 0·22 V

(D) 0·12 V

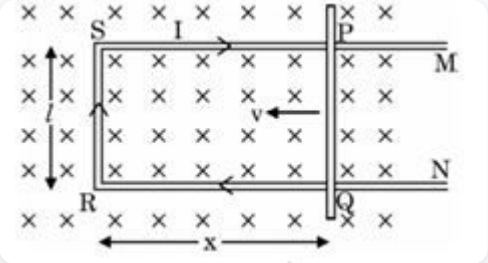
Explanation:

The maximum induced emf in a rotating coil is given by the formula: ε_max = N * B * A * ω, where N is the number of turns, B is the magnetic field strength, A is the area of the coil, and ω is the angular speed. For this coil, A = π * (0.08 m)² = 0.0201 m². Substituting N = 40, B = 3.0 * 10^-2 T, and ω = 25/π rad/s, we find ε_max = 40 * (3.0 * 10^-2) * (0.0201) * (25/π) ≈ 0.19 V. Therefore, the correct answer is 0.19 V.

Question 9.

Figure shows a rectangular conductor PSRQ in which movable arm PQ has a resistance 'r' and resistance of PSRQ is negligible. The magnitude of emf induced when PQ is moved with a velocity v does not depend on :

[1 Marks]



(A) magnetic field (B)

(B) resistance (r)

(C) velocity (v)

(D) length of PQ

Explanation: The correct answer is 'resistance (r)'. The induced emf in a conductor moving through a magnetic field is given by the formula E = B * l * v, where E is the induced emf, B is the magnetic field strength, l is the length of the conductor, and v is the velocity. As observed from this equation, resistance does not appear in the expression for induced emf. Thus, the induced emf depends on the length of PQ, velocity (v), and magnetic field (B) but not on the resistance (r).

Question 10.

In the process of charging of a capacitor, the current produced between the plates of the capacitor is :

[1 Marks]

(A) $1/\varepsilon_0 \, d\phi E/dt$

(B) $1/\mu_0 \, d\phi E/dt$

(C) $\varepsilon_0 \, d\phi E/dt$

(D) $\mu_0 \, d\phi E/dt$

Explanation:

The correct option is $\varepsilon_0 \, d\phi E/dt$. This is based on the relationship from Maxwell's equations, where the displacement current, which is related to the change in electric flux (ϕE), is proportional to the rate of change of electric field, and ε_0 is the permittivity of free space. Therefore, the formula correctly describes the charging current between the plates of a capacitor.

Question 11.

For a concave mirror of focal length 'f', the minimum distance between the object and its real image is:

[1 Marks]

(A) zero

(B) f

(C) 2f

(D) 4f

Explanation: The correct answer is 4f. In a concave mirror, the relationship between the object distance (u), the image distance (v), and the focal length (f) is given by the mirror formula: 1/f = 1/v + 1/u. The minimum distance occurs when the object is placed at the center of curvature (2f), where the real image will also form at the same distance (2f). Therefore, the minimum distance between the object and its real image is 4f (2f + 2f).

Question 12.

The radius of the nth orbit in Bohr model of hydrogen atom is proportional to :

[1 Marks]

(A) n^2

(B) 1/n^2

(C) 1/n

(D) n

Explanation:

According to the Bohr model, the radius of the nth orbit is given by the formula r_n = n^2 * a_0, where a_0 is the Bohr radius. Thus, the radius is directly proportional to n^2.

Question 13.

Hydrogen atom initially in the ground state, absorbs a photon which excites it to n = 5 level. The wavelength of the photon is :

[1 Marks]

(A) 975 nm

(B) 523 nm

(C) 740 nm

(D) 95 nm

Explanation: To find the wavelength of the photon, we use the formula for the energy levels in a hydrogen atom: E = -13.6 eV/n^2. The difference in energy between the n = 1 and n = 5 levels is approximately 13.6 eV(1 - 1/25) = 13.6 eV(24/25) = 13.056 eV. Using the relation E = hc/λ, we can calculate the wavelength λ. Using h = 4.14 x 10^-15 eV·s and c = 3 x 10^8 m/s gives λ ≈ 95 nm. Therefore, the correct option is 95 nm.

Question 14.

The mass density of a nucleus of mass number A is :

[1 Marks]

(A) proportional to A^1/3

(B) proportional to A^3

(C) proportional to A^2/3

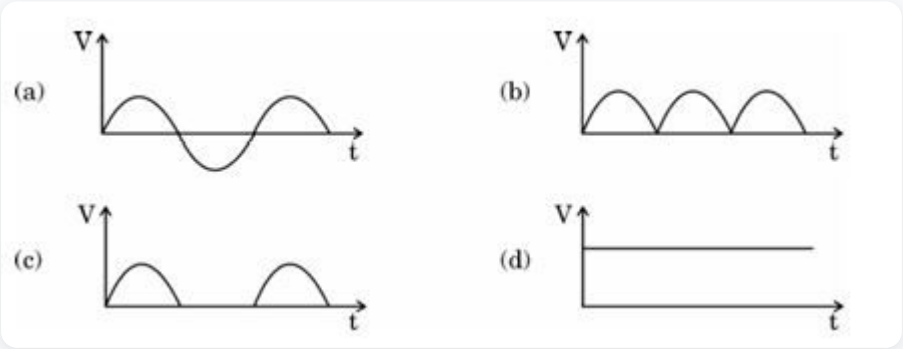
(D) independent of A

Explanation: The mass density of a nucleus is independent of its mass number A because the volume of the nucleus increases with the cube of the radius, while the mass increases linearly with A. Therefore, the correct answer is 'independent of A'.

Question 15.

An ac source of voltage is connected in series with a p-n junction diode and a load resistor. The correct option for output voltage across load resistance will be :

[1 Marks]



(A) b

(B) a

(C) d

(D) c

Explanation:

The correct answer is option 'c', since the output voltage across the load resistor in a circuit with a p-n junction diode will depend on the conduction of the diode, which allows current to pass only in one direction. In an AC circuit, only the positive half-cycles would contribute to the output voltage, leading to a reduced or rectified output across the load resistor.

Question 16.

When an intrinsic semiconductor is doped with a small amount of trivalent impurity, then :

[1 Marks]

(A) its resistance increases.

(B) it becomes a p-type semiconductor.

(C) dopant atoms become donor atoms.

(D) there will be more free electrons than holes in the semiconductor.

Explanation: The correct answer is 'it becomes a p-type semiconductor.' When a trivalent impurity is added to an intrinsic semiconductor, it creates 'holes' by accepting electrons, resulting in a higher concentration of holes than electrons. This defines a p-type semiconductor.

Question 17.

In the energy-band diagram of n-type Si, the gap between the bottom of the conduction band Ec and the donor energy level ED is of the order of :

[1 Marks]

(A) 10eV

(B) 1eV

(C) 0.1eV

(D) 0.01eV

Explanation: The correct option is 0.01eV. In n-type silicon, the donor energy level is typically close to the conduction band, and the energy gap between the bottom of the conduction band Ec and the donor level ED is usually around 0.01 eV, which indicates that the donors can easily contribute electrons to the conduction band.

Question 18.

Assertion (A) : When a bar of copper is placed in an external magnetic field, the field lines get concentrated inside the bar.

Reason (R) : Copper is a paramagnetic substance.

[1 Marks]

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

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

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

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

Explanation: Assertion (A) is false because copper is actually a diamagnetic material, which means it repels magnetic field lines rather than concentrating them inside. Reason (R) is also false as copper is not a paramagnetic substance.

Question 19.

Assertion (A) : The phase difference between any two points on a wavefront is zero.

Reason (R) : All points on a wavefront are at the same distance from the source and thus oscillate in the same phase.

[1 Marks]

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

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

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

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

Explanation:

Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A). This is because, on a wavefront, all points are at the same distance from the source, meaning they originate from the same phase of the wave and therefore have zero phase difference.

Question 20.

Assertion (A) : Photoelectric effect demonstrates the particle nature of light.

Reason (R) : Photoelectric current is proportional to intensity of incident radiation for frequencies more than the threshold frequency.

[1 Marks]

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

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

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

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

Explanation:

Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A). The photoelectric effect does indeed demonstrate the particle nature of light (Assertion A is true), but the proportionality of photoelectric current to intensity at frequencies above the threshold is not a specific explanation for why the photoelectric effect demonstrates particle nature; it relates more to the number of photons than to the fundamental nature of light itself.

Section C

Question 21.

An alpha particle is projected with velocity v = (3·0 *10^5 m/s) ^ i into a region in which magnetic field B = [(0·4 T) ^ i + (0·3 T) ^ j] exists. Calculate the acceleration of the particle in the region. ^ i , ^ j and ^ k are unit vectors along x, y and z axis respectively and charge to mass ratio for alpha particle is 4·8 *10^7 C/kg.

[2 Marks]

Answer: To find the acceleration of the alpha particle in the magnetic field, we use the formula: a = (q/m) * (v x B). Here, q/m = 4.8 * 10^7 C/kg, v = (3.0 * 10^5 m/s) ^ i, and B = (0.4 T) ^ i + (0.3 T) ^ j. The cross product v x B results in a vector with components in the k direction. Calculating gives us a = (4.8 * 10^7) * (9.0 * 10^5) ^ k m/s², yielding an acceleration of 4.32 * 10^13 m/s².

Key Points: Use the formula a = (q/m) * (v x B); Calculate the cross product v x B; Substitute values for q/m and v; Resultant acceleration in k direction.

Question 22.

Consider an induced magnetic field due to changing electric field and an induced electric field due to changing magnetic field. Which one is more easily observed ? Justify your answer.

[2 Marks]

Answer: The induced electric field due to a changing magnetic field is more easily observed than the induced magnetic field from a changing electric field. This is primarily because induced electric fields can be detected directly via circuits or sensors, as they create observable currents. In contrast, detecting induced magnetic fields requires sensitive magnetometers, making them harder to measure. Moreover, Faraday's Law of Induction highlights that the induced electric field responds instantly to changes in the magnetic field, further facilitating observation.

> **Key Points: Induced electric field easier to detect-Induced magnetic field requires sensitive equipment-Faraday's Law emphasizes response to changes in magnetic fields-direct observations possible with current and sensors**

Question 23.

(a) Using Huygen's principle, draw a ray diagram showing the propagation of a plane wave refracting at a plane surface separating two media. Also verify Snell's law of refraction.

[2 Marks]

Answer: Huygen's principle states that every point on a wavefront can be considered a source of secondary wavelets. When a plane wave strikes a boundary between two media, part of the wavefront is refracted and creates a new wavefront in the second medium. The angle of incidence, i, and the angle of refraction, r, are related by Snell's law: sin(i)/sin(r) = v1/v2, where v1 and v2 are the speeds of the wave in the respective media. This verifies that the angles of incidence and refraction are in a consistent ratio as described by Snell's law.

> **Key Points: Huygen's principle-wavefront-secondary wavelets-refraction-Snell's law**

Question 24.

Two coherent monochromatic light beams of intensities I and 4I superpose each other. Find the ratio of maximum and minimum intensities in the resulting beam.

[2 Marks]

Answer: When two coherent beams interfere, the maximum intensity is given by I_max = (I1 + I2)^2 = (I + 4I)^2 = 25I^2, leading to a maximum intensity of 5I. The minimum intensity is I_min = (I1 - I2)^2 = (I - 4I)^2 = 9I^2, leading to a minimum intensity of I. Therefore, the ratio of maximum to minimum intensity is 25:1.

Key Points: Interference of coherent light beams - Maximum intensity calculation - Minimum intensity calculation - Ratio of intensities

Question 25.

The ground state energy of hydrogen atom is -13.6 eV. What is the potential energy and kinetic energy of an electron in the third excited state ?

[2 Marks]

Answer: In the hydrogen atom, the energy of an electron in the nth state is given by the formula $E = -13.6\ eV/n^2$. For the third excited state (n=4), $E = -13.6\ eV / (4^2) = -0.85\ eV$. The kinetic energy (KE) is half the absolute value of the energy, so $KE = 0.85\ eV / 2 = 0.425\ eV$. The potential energy (PE) is twice the kinetic energy, thus $PE = 2 * KE = 0.85\ eV$. Therefore, $PE = 0.85\ eV$ and $KE = 0.425\ eV$.

Key Points: Energy formula: $E = -13.6\ eV/n^2$ - n=4 (3rd excited state) - Calculate KE as half of |E| - PE is twice KE

Question 26.

(a) Differentiate between intrinsic and extrinsic semiconductors.

[2 Marks]

Answer: Intrinsic semiconductors are pure materials, such as silicon or germanium, without any significant impurities. Their electrical conductivity is solely determined by the temperature and the energy band structure. Extrinsic semiconductors, on the other hand, are doped with impurities to enhance their conductivity. N-type semiconductors are doped with electron-rich materials, while P-type semiconductors are doped with materials that create holes. This doping process increases the number of charge carriers in the material.

Key Points: Intrinsic semiconductors are pure; Extrinsic semiconductors are doped; N-type has extra electrons; P-type has holes.

Question 27.

Briefly explain how the diffusion and drift currents contribute to the formation of potential barrier in a p-n junction diode.

[2 Marks]

Answer: In a p-n junction diode, diffusion current arises when electrons from the n-side diffuse to the p-side, and holes from the p-side diffuse to the n-side due to concentration differences. This movement leads to a charge imbalance near the junction. As charges accumulate, a built-in electric

field is established, opposing further diffusion. This electric field creates a drift current, which balances the diffusion current. Together, they form a potential barrier that stabilizes the junction.

Key Points: Diffusion current from n-side to p-side; Charge imbalance near junction; Formation of electric field; Drift current opposing diffusion; Establishment of potential barrier.

Question 28.

(b) Why is a reflecting telescope preferred over a refracting telescope? Justify your answer giving two reasons.

[2 Marks]

Answer: Reflecting telescopes are preferred over refracting telescopes for two main reasons. First, reflecting telescopes eliminate chromatic aberration, as mirrors focus all colors of light to the same point, ensuring clearer images. Second, mirrors are lighter and can be supported uniformly over their entire surface, making them easier to build and maintain than heavy glass lenses, which can only be supported at their edges.

Key Points: Elimination of chromatic aberration-Uniform support reducing mechanical issues

Question 29.

(b) Draw the circuit arrangement for studying the V -I characteristics of a p-n junction diode in forward bias and reverse bias. Show the plot of V- I characteristic of a silicon diode.

[2 Marks]

Answer: To study the V-I characteristics of a p-n junction diode, we connect it in two configurations: forward bias (p-side to positive terminal, n-side to negative terminal) and reverse bias (n-side to positive terminal, p-side to negative terminal). The forward bias allows current to flow when voltage exceeds a threshold, whereas reverse bias restricts it. The V-I characteristic plot shows the current sharply rising in forward bias after the threshold and remaining minimal in reverse bias.

Key Points: circuit arrangement in forward bias, circuit arrangement in reverse bias, current-voltage relationship, V-I characteristic curve

---

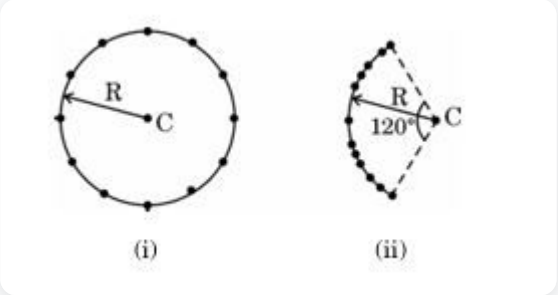
Section D

Question 30.

(a) Twelve negative charges of same magnitude are equally spaced and fixed on the circumference of a circle of radius R as shown in figure (i). Relative to potential being zero at infinity, find the electric potential and electric field at the centre C of the circle.

(b) If the charges are unequally spaced and fixed on an arc of 120 degrees of radius R as shown in Fig (ii), find electric potential at the centre of the arc.

[3 Marks]



Answer: To determine the electric potential at the center C due to twelve negative charges equally spaced on a circle, we use the formula V = k * Σ(q/r). Each charge contributes to the potential, and since they are equally spaced, their contributions sum symmetrically. The electric potential at C, given that the charges are negative, results in a negative value. The total electric potential V at point C is V = -12kq/R. For the electric field, it results from the vector sum of the fields due to each charge, yielding zero since they cancel. In the case of charges on a 120-degree arc, only some charges contribute, so we can find the potential by considering the specific positions and contributions of these charges, leading to a similar but modified potential formula.

Key Points: Electric potential due to point charges; symmetry leads to zero electric field; negative charge contributions; electric potential formula V = k * Σ(q/r); modification for charges on 120-degree arc

Question 31.

(a) How does the resistance differ from impedance? With the help of a suitable phasor diagram, obtain an expression for impedance of a series LCR circuit, connected to a source v = vm sin(ωt).

[3 Marks]

Answer: Resistance is a measure of the opposition to direct current (DC) flow and is frequency independent. Impedance, however, is the total opposition to alternating current (AC) flow, comprising both resistance and reactance, which varies with frequency. In a series LCR circuit connected to v = Vm sin(ωt), the impedance (Z) is given by $Z = \sqrt{(R^2 + (XL - XC)^2)}$, where XL is inductive reactance and XC is capacitive reactance. At resonance, XL equals XC, minimizing impedance to just R, leading to maximum current flow.

Key Points: Resistance vs Impedance, Definition of Impedance, Phasor Diagram, Expression for Impedance, Series LCR Circuit, Resonance Condition, Factors Affecting Resonant Frequency

Question 32.

A long solenoid of radius r consists of n turns per unit length. A current $I = I_0 \sin(\omega t)$ flows in the solenoid. A coil of N turns is wound tightly around it near its center. What is

(a) the induced emf in the coil?

(b) the mutual inductance between the solenoid and the coil ?

[3 Marks]

Answer: The induced emf (ε) in a coil due to a changing magnetic field can be calculated using Faraday's law of electromagnetic induction. Since the magnetic field (B) inside the solenoid is given by $B = \mu_0 nI$, substituting I leads to $B = \mu_0 n I_0 \sin(\omega t)$. The magnetic flux (Φ) through the coil is $\Phi = B \times A$, where A is the area of the coil. The emf induced in the coil is $\varepsilon = -d\Phi/dt$. Using these relationships, the mutual inductance (M) can be computed as $M = (N\Phi)/(I)$. Therefore, the induced emf is proportional to $-N\mu_0 nA\omega I_0 \cos(\omega t)$ and the mutual inductance is given by $M = \mu_0 nA(N/l)$ for the solenoid. Thus, the final expressions are $\varepsilon = -N\mu_0 nA\omega I_0 \cos(\omega t)$ for the emf and $M = \mu_0 nA(N/l)$ for mutual inductance.

Key Points: Faraday's law - Induced emf = $-d\Phi/dt$ - $B = \mu_0 nI$ - Magnetic flux = $B \times A$ - Mutual inductance = $(N\Phi)/(I)$ - Induced emf = $-N\mu_0 nA\omega I_0 \cos(\omega t)$ - Mutual inductance = $\mu_0 nA(N/l)$

Question 33.

How does Einstein's photoelectric equation explain the emission of electrons from a metal surface? Explain briefly.

Plot the variation of photocurrent with:

(a) collector plate potential for different intensity of incident radiation, and

(b) intensity of incident radiation.

[3 Marks]

Answer: Einstein's photoelectric equation states that the energy of incident photons is directly proportional to their frequency, given by E = hf, where 'E' is photon energy, 'h' is Planck's constant, and 'f' is frequency. When light of sufficiently high frequency strikes a metal surface, photons transfer their energy to electrons, which can then overcome the metal's work function, resulting in electron emission. The photocurrent depends on the number of emitted electrons, which varies with the

intensity of radiation. In plotting photocurrent against collector plate potential, we see that as the plate potential increases, the photocurrent also increases until it stabilizes, showing saturation. For varying intensity, the photocurrent rises with intensity, revealing that more intense light produces more emitted electrons.

Key Points: Einstein's photoelectric equation; photon energy and frequency; emission of electrons; dependence on light intensity; graph of photocurrent vs collector potential; graph of photocurrent vs intensity

Question 34.

(a) Draw the energy level diagram for a hydrogen atom. Mark the transitions corresponding to the series lying in the ultraviolet region, visible region, and infrared region.

[3 Marks]

Answer: The energy level diagram for a hydrogen atom consists of several discrete energy levels, denoted by quantum number n, ranging from n=1 (ground state) to n=∞ (ionization). The Lyman series (n=1 to n≥2) corresponds to ultraviolet transitions, for example the transition from n=2 to n=1 results in a photon of 91 nm. The Balmer series (n=2 to n≥3) corresponds to visible light, with the transition from n=3 to n=2 producing a photon of 656 nm. The Paschen series (n=3 to n≥4) falls in the infrared region, with the transition from n=4 to n=3 contributing to this category. Each transition releases energy proportional to the difference in energy levels.

Key Points: Energy levels labeled with principal quantum number n-Transitions for Lyman (UV), Balmer (visible), and Paschen (IR) series-Illustrate transitions with wavelengths

Question 35.

(b) Find the condition for resonance in a series LCR circuit connected to a source v = vm sin(ωt), where ω can be varied. Give the factors on which the resonant frequency of a series LCR circuit depends. Plot a graph showing the variation of electric current with frequency in a series LCR circuit.

[3 Marks]

Answer: In a series LCR circuit, resonance occurs when the inductive reactance (XL) equals the capacitive reactance (XC). This condition is mathematically represented as XL = XC or ωL = 1/(ωC). The resonant frequency, ω0, is given by the formula ω0 = 1/√(LC). The resonant frequency depends on the values of the inductance (L) and capacitance (C). At resonance, the current amplitude is maximum and is expressed as I = V/R. A graph of current versus frequency typically shows a peak at the resonant frequency.

Key Points: Condition for resonance: XL = XC; Resonant frequency formula: ω0 = 1/√(LC); Factors affecting resonant frequency: Inductance (L), Capacitance (C); Current amplitude at resonance: I = V/R; Graph shows peak current at resonant frequency.

Question 36.

(b) Draw a diagram to show the variation of binding energy per nucleon with mass number for different nuclei and mention its two features. Why do lighter nuclei usually undergo nuclear fusion?

[3 Marks]

Answer: The binding energy per nucleon generally varies with mass number (A) in a distinctive manner. When plotted, the graph shows that light nuclei (A < 30) and heavy nuclei (A > 170) have lower binding energy per nucleon, while intermediate nuclei possess higher binding energies. Two notable features are: 1) The peak of the curve corresponds to nuclei like iron (A ≈ 56), indicating stability. 2) Lighter nuclei often undergo fusion because they yield a heavier nucleus with greater binding energy, releasing energy in the process.

Key Points: Binding energy varies with mass number; Light and heavy nuclei have lower binding energy; Intermediate nuclei have higher binding energy; Peak of the curve indicates stability; Lighter nuclei fuse to form heavier ones, resulting in energy release.

Section E

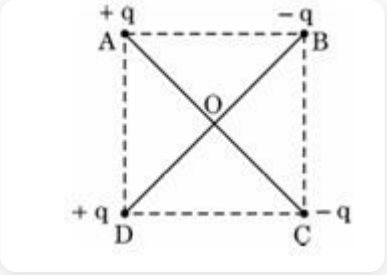
Question 37.

(a) (i) State Coulomb's law in electrostatics and write it in vector form, for two charges.

(ii) Gauss's law is based on the inverse-square dependence on distance contained in the Coulomb's law. Explain.

(iii) Two charges A (charge q) and B (charge 2q) are located at points (0, 0) and (a, a) respectively. Let ^ i and ^ j be the unit vectors along x-axis and y-axis respectively. Find the force exerted by A on B, in terms of ^ i and ^ j.

[5 Marks]



Answer: Coulomb's law states that the force F between two point charges q_1 and q_2 separated by a distance r in vacuum is directly proportional to the product of the magnitudes of the charges and inversely proportional to the square of the distance between them. This can be expressed in vector form as: $$\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r}$$ where k is Coulomb's constant and $\hat{r}$ is the unit vector pointing from one charge to the other. Gauss's law relates to Coulomb's law by highlighting that the electric field behaves inversely with the square of the distance due to the symmetric distribution of charge.

For the charges A and B, we have: $F_{AB} = k \frac{q \cdot 2q}{(a\sqrt{2})^2} = k \frac{2q^2}{2a^2} = \frac{kq^2}{a^2}$. The direction of the force from A to B, given the positions, can be expressed as $F_{AB} = \frac{kq^2}{a^2}(-\hat{i}-\hat{j})$. Thus, the final answer is: $$\vec{F}_{AB} = -\frac{kq^2}{a^2}(\hat{i} + \hat{j})$$.

Key Points: Coulomb's law definition-Coulomb's law in vector form-Gauss's law explanation-force calculation for charges A and B

Question 38.

(a) (i) State Biot-Savart's law for the magnetic field due to a current carrying element. Use this law to obtain an expression for the magnetic field at the centre of a circular loop of radius 'a' and carrying a current 'I'. Draw the magnetic field lines for a current loop indicating the direction of magnetic field.

(ii) An electron is revolving around the nucleus in a circular orbit with a speed of 10^7 ms^-1 . If the radius of the orbit is 10^-10 m, find the current constituted by the revolving electron in the orbit.

[5 Marks]

Answer: Biot-Savart's law states that the magnetic field dB at a point in space due to an infinitesimal current element Idl is given by $dB = (\mu_0/4\pi) * (I\, dl \times \hat{r}) / r^2$, where r is the distance from the element to the point, and $\hat{r}$ is the unit vector. For a circular loop of radius 'a' carrying current 'I', at the center, the magnetic field B can be derived by integrating the contributions from each element. The result is $B = \mu_0 I / (2a)$. Magnetic field lines around the current loop form concentric circles showing that the field is directed outwards from the loop's center. For the revolving electron, the current I due to the electron can be calculated as $I = e/T$, where T is the period of rotation. Given the speed (v) and radius (r), $T = 2\pi r/v$, thus $I = e * v / (2\pi r) = (1.6 \times 10^{-19}\ C) * (10^7\ m/s) / (2\pi * 10^{-10}\ m) \approx 1.59 \times 10^{-3}\ A$.

Key Points: Biot-Savart's law; Expression for magnetic field; Calculation for electron current; Circular loop current description; Magnetic field lines direction.

Question 39.

(a) (i) 1. Write two points of difference between an interference pattern and a diffraction pattern.

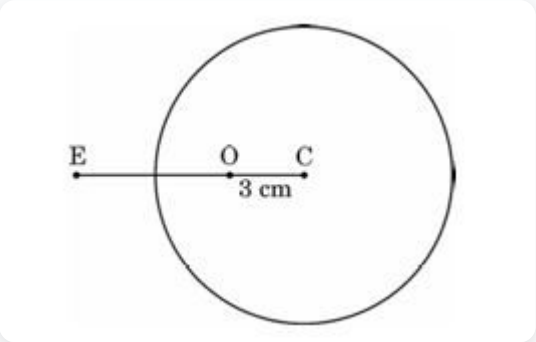
2. Name any two factors on which the fringe width in a Young's double-slit experiment depends.

(ii) In Young's double-slit experiment, the two slits are separated by a distance equal to 100 times the wavelength of light that passes through the slits. Calculate :

(1) the angular separation in radians between the central maximum and the adjacent maximum.

(2) the distance between these two maxima on a screen 50 cm from the slits.

[5 Marks]



Answer: Interference patterns and diffraction patterns are distinct phenomena in wave optics. First, interference patterns are created when two coherent light sources overlap, producing a series of bright and dark fringes due to constructive and destructive interference. In contrast, diffraction patterns arise from light passing through a single slit or aperture, causing the light to spread out and form a pattern with a central maximum and subsequent minima and maxima. The fringe width in Young's double-slit experiment depends on the wavelength of light used and the distance between the slits. \n\nFor the calculations: Let the wavelength be λ. Given, d = 100λ. The angular separation θ between the central maximum and the adjacent maximum is given by θ = λ / d = λ / (100λ) = 1/100 radians. \n\nThe distance 'y' between these maxima on a screen at distance 'L' can be determined using y = L * tan(θ) ≈ L * θ (for small angles). Therefore, y = 50 cm * (1/100) = 0.5 cm.

Key Points: Interference creates bright/dark fringes; Diffraction creates a single central max with spread; Fringe width depends on wavelength and slit separation; Angular separation formula θ = λ/d; Distance formula y = L * θ.

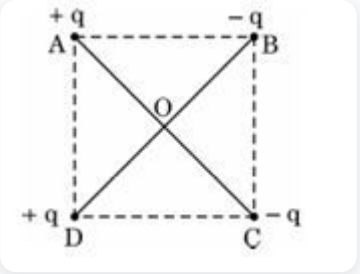
Question 40.

(b) (i) Derive an expression for the electric field at a point on the equatorial plane of an electric dipole consisting of charges q and -q separated by a distance 2a.

(ii) The distance of a far off point on the equatorial plane of an electric dipole is halved. How will the electric field be affected for the dipole ?

(iii) Two identical electric dipoles are placed along the diagonals of a square ABCD of side √2 m as shown in the figure. Obtain the magnitude and direction of the net electric field at the centre (O) of the square.

[5 Marks]



Answer: To derive the expression for the electric field (E) on the equatorial plane of an electric dipole, consider two charges, q and -q, separated by 2a. The electric field due to charge q at a point P, a distance r from the center, and the field due to -q act in opposite directions. By vector addition, the net electric field is given by $E = (1/4\pi\varepsilon_0) * (2pq)/(r^3)$, where p is the dipole moment ($p = q * 2a$). Furthermore, if the distance is halved, E increases by a factor of 8 ($1/(0.5)^3 = 8$), as the field strength is inversely proportional to the cube of the distance. For the configuration of two identical dipoles at the square's diagonals, symmetry indicates at point O, the fields due to each dipole will add up vectorially, determined by their orientations. The resultant electric field at O will be directed along the line connecting the midpoints of the opposite sides of the square.

Key Points: Electric dipole definition-Derivation of electric field on equatorial plane-Effect of halved distance on electric field-Symmetry in electric fields of dipoles-Resultant electric field direction at square center

Question 41.

(b) (i) Derive an expression for the force acting on a current carrying straight conductor kept in a magnetic field. State the rule which is used to find the direction of this force. Give the condition under which this force is (1) maximum, and (2) minimum.

(ii) Two long parallel straight wires A and B are 2.5 cm apart in air. They carry 5.0 A and 2.5 A currents respectively in opposite directions. Calculate the magnitude of the force exerted by wire A on a 10 cm length of wire B.

[5 Marks]

Answer: The force F acting on a straight conductor of length l carrying a current I in a magnetic field B can be expressed as $F = I\, l \times B$, where the angle θ between l and B determines the magnitude of the force. The right-hand rule helps in determining the direction of the force, stating that if the thumb points in the direction of current I and fingers in the direction of B, the palm points in the force direction. The force is maximum ($F = IlB$) when l is perpendicular to B ($\theta = 90°$) and minimum ($F = 0$) when l is parallel to B ($\theta = 0°$). For wires A and B, the magnetic field due to wire A at wire B can be calculated using the formula $B = \mu_0 I/(2\pi d)$. With $I_A = 5.0$ A, $I_B = 2.5$ A, and $d = 0.025$ m, the force on a length $l = 0.1$ m of wire B is $F = I_B * l * B$, which requires substituting B to find the force magnitude.

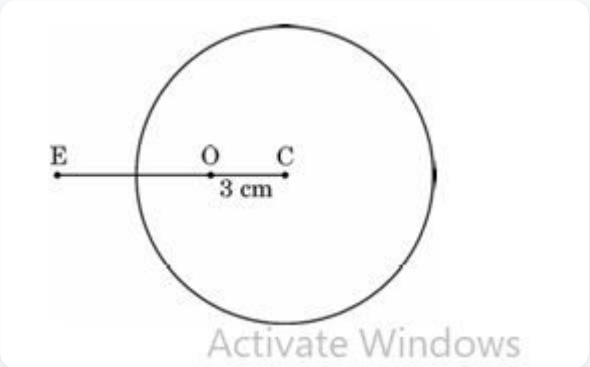
Key Points: 1. F = I l × B; 2. Right-hand rule determines force direction; 3. Force is maximum at θ = 90° (F = IlB); 4. Force is minimum at θ = 0° (F = 0); 5. Calculate B from wire A for wire B; 6. Substitute values for final force calculation

Question 42.

(b) (i) A spherical surface of radius of curvature R separates two media of refractive indices n1 and n2 . A point object is placed in front of the surface at distance u in medium of refractive index n1 and its image is formed by the surface at distance v, in the medium of refractive index n2. Derive a relation between u and v. \

(ii) A solid glass sphere of radius 6.0 cm has a small air bubble trapped at a distance 3.0 cm from its centre C as shown in the figure. The refractive index of the material of the sphere is 1 5. Find the apparent position of this bubble when seen through the surface of the sphere from an outside point E in air.

[5 Marks]



Answer: To find the relation between the object distance (u) and image distance (v) for a spherical surface separating two media with refractive indices n1 and n2, we can apply the refraction formula. The formula states that n2/v - n1/u = (n2-n1)/R. Here, u is the object distance in medium n1, v is the image distance in medium n2, and R is the radius of curvature of the spherical surface. This equation is crucial for understanding image formation through curved surfaces which are applicable in optical systems. For the second part, we determine the apparent position of the air bubble using the formula of refraction. Given that R is 6 cm and the bubble is at 3 cm from center and n = 1.5, we find the bubble's apparent distance by considering the refraction at the curved surface. Using n1 = 1 and applying the formula, we can calculate the actual distance of the bubble as perceived from outside, yielding an apparent position of approximately 2 cm.

Key Points: Derivation of refraction formula; n2/v - n1/u = (n2 - n1)/R; Explanation of parameters u, v, R; Applying the formula to find apparent position; Use of refractive index for bubble in glass sphere