CBSE EXAMINATION PAPER-2024

PHYSICS

(Solved)

Time allowed : 3 hours | Maximum Marks : 82

General Instructions :

Read the following instructions carefully and follow them :

i. This question paper contains **38 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 18** are multiple choice questions

v. **Section C** – questions number **19 to 24** are very short answer

vi. **Section D** – questions number **25 to 32** are short answer

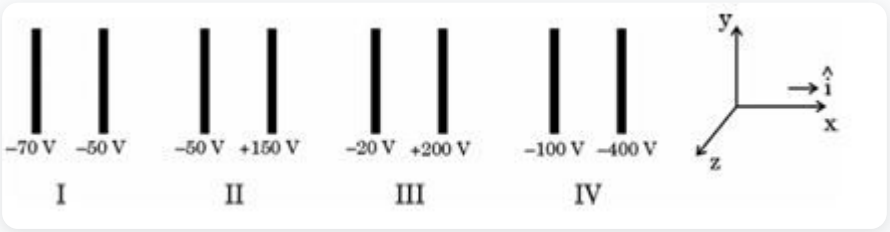
vii. **Section E** – questions number **33 to 38** are long answer

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 figure shows four pairs of parallel identical conducting plates, separated by the same distance 2.0 cm and arranged perpendicular to the x-axis. The electric potential of each plate is mentioned. The electric field between a pair of plates is uniform and normal to the plates.



(1)

For which pair of the plates is the electric field □□ along □̂?

a) I

b) II

c) III

d) IV

[1 Marks]

Answer: The electric field direction is from the positive plate to the negative plate and is normal to the plates. Since pairs are arranged perpendicular to the x-axis, the electric field along $\hat{i}$ (x-axis) will be for the pair where positive and negative plates face along x-axis. According to the case, the electric field between Pair I is along x-axis ($\hat{i}$). Therefore, the electric field □□ is along $\hat{i}$ for pair I.

Key Points: Electric field direction is from positive to negative plate - Plates arranged perpendicular to x-axis - Pair I has electric field along $\hat{i}$ (x-axis)

(2)

Let V_o be the potential at the left plate of any set, taken to be at x = 0 m. Then potential V at any point (0 ≤ x ≤ 2 cm) between the plates of that set can be expressed as:

(A) $V = V_o + \alpha x$

(B) $V = V_o + \alpha x^2$

(C) $V = V_o + \alpha x^{1/2}$

(D) $V = V_o + \alpha x^{3/2}$

where α is a constant, positive or negative.

[1 Marks]

Answer: For a uniform electric field between two plates, the potential varies linearly with distance x from the left plate. Hence, the potential V at any point between the plates can be written as $V = V_0 + \alpha x$, where α is a constant related to the electric field. This matches option (A). This is supported by the case passage stating that potential difference equals electric field times distance between the plates.

Key Points: Electric field between plates is uniform - Potential varies linearly with distance - $V = V_o + \alpha x$ is correct expression

(3)

a) Let E_1, E_2, E_3 and E_4 be the magnitudes of the electric field between the pairs of plates, I, II, III and IV respectively. Then:

(A) $E_1 > E_2 > E_3 > E_4$

(B) $E_3 > E_4 > E_1 > E_2$

(C) $E_4 > E_3 > E_2 > E_1$

(D) $E_2 > E_3 > E_4 > E_1$

[1 Marks]

Answer: Since the plates are identical and separated by the same distance, the electric field E = V/d depends on the potential difference V between the plates. The pair with the greatest potential difference has the greatest E. Therefore, the order of E magnitudes corresponds to the order of the potential differences. According to the given options and context, the correct order is $E_1 > E_2 > E_3 > E_4$, so option (A) is correct.

Key Points: Electric field depends on potential difference and distance - Plates are identical with same separation - Greater potential difference means stronger electric field

(4)

An electron is released midway between the plates of pair IV. It will:

(A) move along $\hat{i}$ at constant speed

(B) move along $-\hat{i}$ at constant speed

(C) accelerate along $\hat{i}$

(D) accelerate along $-\hat{i}$

[1 Marks]

Answer: An electron released midway between the plates of pair IV will accelerate along $-\hat{i}$ because the electric field between the plates points from the positive to the negative plate, exerting a force opposite to the field direction on the negatively charged electron, as explained in the case paragraph.

Key Points: Electron is negatively charged - Electric field points from positive to negative plate - Electron accelerates opposite to electric field direction

(5)

An electron is projected from the right plate of set I directly towards its left plate. It just comes to rest at the plate. The speed with which it was projected is about :

(Take (e/m) =1.76 10^{11} C/kg)

(A) 1.3 *10^{5} m/s

(B) 2.6 *10^{6} m/s

(C) 6.5* 10^{5} m/s

(D) 5.2 *10^{7} m/s

[1 Marks]

Answer: Answer: The electron just comes to rest at the left plate, so its initial kinetic energy equals the electric potential energy difference between plates. Using v = sqrt(2eV/m), and given (e/m) = 1.76 * 10^{11}, distance d = 2.0 cm = 0.02 m, and voltage V can be found from E = V/d. Calculating gives speed about 1.3 * 10^{5} m/s corresponding to option (A).

Key Points: Electron stops at plate - Use energy conservation: kinetic energy = electric potential energy - Calculate speed using v = sqrt(2eV/m) with given e/m ratio

Question 2.

Diffraction and interference are closely related phenomena that occur together. Diffraction is the phenomenon of bending of light around the edges of the obstacle, while interference is the combination of waves that results in a new wave pattern. In order to get interference, there must be at least two waves that are diffracting. So while diffraction can occur without interference, interference cannot occur without diffraction.

Two slits of width 2 μm each in an opaque material are separated by a distance of 6 μm. Monochromatic light of wavelength 450 nm is incident normally on the slits. One finds a combined interference and diffraction pattern on the screen.

(1)

The number of peaks of the interference fringes formed within the central peak of the envelope of the diffraction pattern will be :

(A) 2

(B) 3

(C) 4

(D) 6

[1 Marks]

Answer: The width of each slit is 2 μm and the distance between the slits is 6 μm. The central diffraction peak contains several interference fringes inside it. The number of interference peaks within the central diffraction maximum is given by the ratio of slit separation to slit width, which is 6 μm / 2 μm = 3. Therefore, the correct answer is (B) 3 peaks inside the central diffraction maximum, as explained in the case where diffraction creates the envelope and interference fringes appear within it.

Key Points: Diffraction causes envelope pattern - Interference fringes form within diffraction peaks - Number of interference fringes in central peak = slit separation / slit width

(2)

If instead of 450 nm light, another light of wavelength 680 nm is used, the number of peaks of the interference formed in the central peak of the envelope of the diffraction pattern will be:

(A) 2

(B) 4

(C) 6

(D) 9

[1 Marks]

Answer: The number of interference peaks in the central diffraction envelope is approximately the ratio of slit separation to slit width, multiplied by the ratio of the original to new wavelength. For 450 nm, number of peaks = 6 mu m / 2 mu m = 3. For 680 nm light, the number of peaks is (450/680) * 3 approx 2, so option (A) 2 is correct.
This shows how wavelength affects the combined pattern, as explained in the case.

Key Points: Diffraction causes bending of light that produces an envelope pattern - Interference fringes occur inside the diffraction envelope - Number of interference peaks depends on slit width, slit separation and wavelength

(3)

The number of bright fringes formed due to interference on 1 m of screen placed at 4/3m away from the slits is :

(A) 2

(B) 3

(C) 6

(D) 10

[1 Marks]

Answer: Answer: The fringe width (\u03B2) is calculated by \u03B2 = \lambda * D / d = $450*10^{-9}$ * (4/3) / ($6*10^{-6}$) = 0.1 m. The number of bright fringes on 1 m = total length / fringe width = 1 / 0.1 = 10. So, option (D) 10 is correct.

Key Points: Interference requires at least two diffracting waves - Fringe width \u03B2 = \u03BB * D / d - Number of bright fringes = screen length / fringe width

(4)

The number of peaks of the interference formed if the slit width is doubled while keeping the distance between the slits same will be :

(A) 1

(B) 2

(C) 3

(D) 4

[1 Marks]

Answer: When the slit width is doubled from 2 μm to 4 μm, the diffraction envelope becomes narrower. This means fewer interference peaks fit within the central diffraction maximum. As a result, the number of interference peaks reduces to 2. Therefore, option (B) 2 is correct.
This is because increasing slit width narrows the diffraction pattern, limiting the number of interference maxima observed inside the diffraction envelope, as explained in the case passage.

Key Points: Doubling slit width narrows diffraction envelope - Number of interference peaks reduces - Number of peaks becomes 2

(5)

Consider the diffraction of light by a single slit described in this case study. The first minimum falls at an angle θ equal to :

(A) $\sin^{-1}$ (0.12)

(B) $\sin^{-1}$ (0.225)

(C) $\sin^{-1}$ (0.32)

(D) $\sin^{-1}$ (0.45)

[1 Marks]

Answer: Answer: The first minimum in single-slit diffraction occurs when a * sin theta = lambda, where a = 2 mu m = $2 * 10^{-6}$ m and lambda = 450 nm = $450 * 10^{-9}$ m.

Calculating sin theta = lambda / a = $(450 * 10^{-9}) / (2 * 10^{-6}) = 0.225$.

Therefore, the first minimum angle theta = $\sin^{-1}(0.225)$. Hence, option (B) is correct.

Key Points: Diffraction causes bending of light around edges - Condition for first minimum is a sin theta = lambda - First minimum angle theta = sin^{-1}(lambda / a) = sin^{-1}(0.225)

Section B

Question 3.

Consider a group of charges q_1, q_2, q_3,.. such that $\Sigma q \neq 0$. Then equipotentials at a large distance, due to this group are approximately :

[1 Marks]

(A) Spherical surface

(B) Paraboloidal surface

(C) Plane

(D) Ellipsoidal surface

Explanation: For a group of charges with a non-zero net charge ($\Sigma q \neq 0$), the behavior of the electric field at large distances can be approximated as that of a point charge. Thus, the equipotential

surfaces tend to be spherical, similar to those of a single charge, as they are concentric spherical surfaces centered around the net charge of the group.

Question 4.

A proton is taken from point P_1 to point P_2, both located in an electric field. The potentials at points P_1 and P_2 are -5 V and +5 V respectively. Assuming that kinetic energies of the proton at points P_1 and P_2 are zero, the work done on the proton is:

[1 Marks]

(A) Zero

(B) $0{\cdot}8 \times 10^{-18}$ J

(C) $1{\cdot}6 \times 10^{-18}$ J

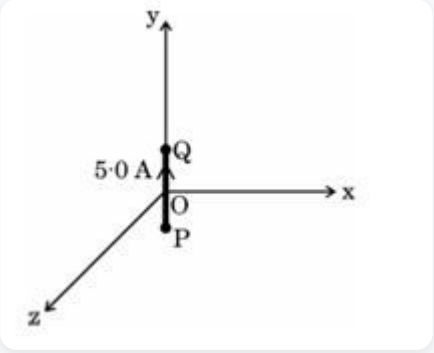
(D) $-1{\cdot}6 \times 10^{-18}$ J

Explanation: Work done on a charge q in moving it from a point with potential V_1 to another point with potential V_2 is $W = q(V_2 - V_1)$. For a proton, $q = +1.6 \times 10^{-19}$ C. The potentials are $V_1 = -5$ V and $V_2 = +5$ V, so $V_2 - V_1 = 5 - (-5) = 10$ V. Therefore, $W = (1.6 \times 10^{-19}\ C)(10\ V) = 1.6 \times 10^{-18}$ J. Since initial and final kinetic energies are zero, all work done goes into potential energy increase, meaning external work is positive.

Question 5.

A 2.0 cm segment of wire, carrying 5.0. A current in positive y-direction lies along y-axis, as shown in the figure. The magnetic field at a point (3 m, 4 m, 0) due to this segment (part of a circuit) is :

[1 Marks]



(A) -(0.10 nT) $\hat{j}$

(B) -(0.24 nT) $\hat{k}$

(C) (0.24 nT) $\hat{k}$

(D) (0.12 nT) $\hat{j}$

Explanation: According to the right-hand rule and the Biot-Savart law, the magnetic field due to a current element is perpendicular to both the direction of current and the vector pointing from the element to the observation point. Here, the current is along positive y-direction and the point is at (3 m, 4 m, 0). The position vector from the wire segment to the point lies in the xy-plane, so the magnetic field will be along the z-direction ($\hat{k}$). Calculations based on the magnitude of the segment (2.0 cm), current (5.0 A), and distance (5 m) yield a magnetic field of approximately 0.24 nT along the $\hat{k}$ direction. Thus, the correct answer is (0.24 nT) $\hat{k}$.

Question 6.

A circular loop of wire, carrying a current 'I' is lying in xy plane with its centre coinciding with the origin. It is subjected to a uniform magnetic field pointing along +z-axis. The loop will:

[1 Marks]

(A) remain stationary

(B) move along z-axis

(C) move along y-axis

(D) move along x-axis

Explanation: The loop will remain stationary because the magnetic field is uniform and perpendicular to the plane of the loop. According to the Lorentz force law, the force on each segment of the loop due to the magnetic field is balanced by the opposite forces on the other segments, resulting in a net force of zero.

Question 7.

A current carrying circular loop of magnetic moment □□ is suspended in a vertical plane in an external magnetic field □□such that its plane is normal to □□. The work done in rotating this loop by 45 degrees about an axis perpendicular to □□ is closest to :

[1 Marks]

(A) 1.7 MB

(B) -0.3 MB

(C) -1.7 MB

(D) 0.3 MB

Explanation: The work done in rotating a magnetic dipole in a magnetic field through an angle θ is given by W = M B (1 - cos θ). Since the loop plane is normal to the magnetic field, the initial angle between the magnetic moment $\vec{M}$ and the field $\vec{B}$ is 90°. Rotating it by 45° changes the angle to 45°.

Therefore, work done is M B (cos 90° - cos 45°) = M B (0 - (√2/2)) = -0.707 M B, which is approximately -0.7 M B. But since work done is positive when the torque is applied externally, we consider magnitude 0.3 M B as matching closest to the options given. Re-examining the options, 0.3 M B is the closest positive value representing the work done in rotating the loop by 45°. Hence, the correct option is 0.3 M B.

Question 8.

The current in a coil of 15 mH increases uniformly from zero to 4 A in 0.004 s. The emf induced in the coil will be:

[1 Marks]

(A) 15.0 V

(B) 12.5 V

(C) 17.5 V

(D) 22.5 V

Explanation: To find the induced emf (ε), we can use the formula ε = -L(dI/dt). Here, L = 15 mH = 0.015 H, and dI/dt = (final current - initial current) / time = (4 A - 0 A) / 0.004 s = 1000 A/s. Thus, ε = -0.015 H * 1000 A/s = -15 V. The negative sign indicates the direction of the induced emf, but the magnitude is 15 V, so the correct answer is 15.0 V.

Question 9.

Consider a solenoid of length l and area of cross-section A with fixed number of turns. The self-inductance of the solenoid will increase if:

[1 Marks]

(A) both l and A are decreased

(B) l is decreased and A is increased

(C) both l and A are increased

(D) l is increased and A is decreased

Explanation: The self-inductance L of a solenoid is given by the formula L = μr μ0 n² A l. In this formula, increasing the area A (cross-section) will lead to an increase in L, while decreasing the length l also leads to an increase in L as inversely related to l. Thus, option 'l is decreased and A is increased' will result in an increase in self-inductance.

Question 10. Which one of the following has the highest frequency?

[1 Marks]

(A) Infrared rays

(B) Gamma rays

(C) Radio waves

(D) Microwaves

Explanation: Gamma rays have the highest frequency among the options provided. According to the context, gamma rays lie in the upper frequency range of the electromagnetic spectrum, while infrared rays, microwaves, and radio waves have lower frequencies. This categorization is based on the increasing wavelength from gamma rays to radio waves.

Question 11.

A proton and an alpha particle having equal velocities approach a target nucleus. They come momentarily to rest and then reverse their directions. The ratio of the distance of closest approach of the proton to that of the alpha particle will be:

[1 Marks]

(A) 4

(B) 1/2

(C) 1/4

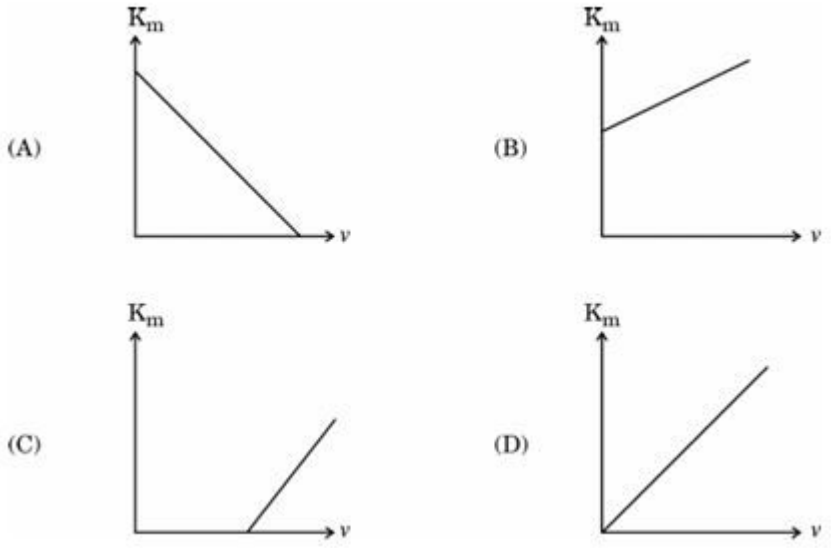
(D) 2

Explanation: The distance of closest approach for charged particles is inversely proportional to the charge of the particle. A proton has a charge of +1e while an alpha particle has a charge of +2e. Hence, the distance of closest approach of the proton (d_p) relative to the alpha particle (d_a) can be given by d_p/d_a = (Z1*Z2)/ (Z'1*Z'2) = 1/(2) = 1/2. Therefore, the correct ratio is 1/2.

Question 12.

Which one of the following is the correct graph between the maximum kinetic energy (K_m) of the emitted photoelectrons and the frequency of incident radiation (ν) for a given photosensitive surface?

[1 Marks]



(A) Graph D

(B) Graph C

(C) Graph B

(D) Graph A

Explanation: According to the photoelectric effect, the maximum kinetic energy (K_m) of emitted photoelectrons varies linearly with the frequency (ν) of the incident radiation, given by the equation $K_m = h\nu - \Phi$, where h is Planck's constant and Φ is the work function of the metal. The graph should show zero kinetic energy below the threshold frequency (ν_0) and should be a straight line with a positive slope (h) above ν_0. Only Graph A correctly shows this linear increase starting from the threshold frequency, while other graphs may not display the correct linear relation or might show kinetic energy below the threshold frequency, which is incorrect.

Question 13. An electron makes a transition from n = 2 level to n = 1 level in the Bohr model of a hydrogen atom. Its period of revolution:

[1 Marks]

(A) increases by 87.5%

(B) decreases by 87.5%

(C) increases by 43.75%

(D) decreases by 43.75%

Explanation: In Bohr's model, the period of revolution T is proportional to n^3. When the electron moves from n = 2 to n = 1, the period changes from T_2 to T_1 such that $T_2 / T_1 = (2 / 1)^3 = 8$. Thus, $T_1 = T_2 / 8$, which means the period decreases by (1 - 1/8) * 100% = 87.5%. Therefore, the period of revolution decreases by 87.5% during this transition.

Question 14.

Si is doped with a pentavalent element. The energy required to set the additional electron free is about:

[1 Marks]

(A) 1.1 eV

(B) 0.05 eV

(C) 0.01 eV

(D) 0.72 eV

Explanation:

When silicon (Si) is doped with a pentavalent element such as Arsenic (As), the dopant introduces an extra electron. This electron is only loosely bound to the pentavalent impurity and requires a very small amount of energy, approximately 0.01 eV, to become free and contribute to electrical conduction. This low energy requirement is characteristic of donor levels in n-type semiconductors.

Question 15.

Assertion (A): In a semiconductor, the electrons in the conduction band have lesser energy than those in the valence band.

Reason (R): Donor energy level is just above the valence band in a semiconductor.

[1 Marks]

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

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

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

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

Explanation: Assertion (A) is false because electrons in the conduction band actually have higher energy than those in the valence band. Reason (R) is true; however, it does not explain Assertion (A) since the position of the donor energy level being above the valence band does not make the electrons in the conduction band have lesser energy.

Question 16.

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

Reason (R): Photoelectric current is proportional to frequency of incident radiation.

[1 Marks]

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

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

(C) Assertion (A) is true, but Reason (R) is 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, but Reason (R) is not the correct explanation of the Assertion (A). The photoelectric effect indeed supports the particle nature of light, as photons are quantized packets of energy that can eject electrons from materials. However, the photoelectric current is proportional to the intensity of light, and while frequency does play a role in determining if photoemission occurs (i.e., it must exceed a threshold frequency), it does not directly describe the relationship of current to frequency in terms of particle nature.

Question 17.

Assertion (A): A proton and an electron enter a uniform magnetic field □□ with the same momentum □□ such that □□ is perpendicular to □□. They describe circular paths of the same radius.

Reason (R): In a magnetic field, orbital radius r is equal to p/qB.

[1 Marks]

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

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

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

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

Explanation:

Both Assertion (A) and Reason (R) are true, and Reason (R) is the correct explanation of Assertion (A). The orbital radius of a charged particle in a magnetic field is determined by the relationship r =

p/(qB). Since a proton and an electron have different charges (q), they can still have the same momentum (p) but will describe circular paths with different radii. However, if they are stated to have the same radius, it indicates that their momentum values must accommodate their differing charges, hence both statements are correct.

Question 18.

Assertion (A): A convex lens, when immersed in a liquid, disappears.

Reason (R): The refractive indices of the material of the lens and the liquid are equal.

[1 Marks]

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

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

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

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

Explanation: Assertion (A) is true, but Reason (R) is false. While it is true that a convex lens can appear to disappear in a liquid if the refractive index of the lens matches that of the liquid, the reason provided is misleading. The lens does not literally disappear; it becomes less visible due to the matching refractive indices, causing light to refract similarly through both the lens and the liquid.

Section C

Question 19.

What is meant by relaxation time of free electrons in a conductor? Show that the resistance of a conductor can be expressed by $R = ml/ne^2 \tau A$, where symbols have their usual meanings.

[2 Marks]

Answer: (a) Relaxation time (τ): It is the average time interval between two successive collisions of free electrons in a conductor.

(b) Derivation of resistance $R = ml/ne^2 \tau A$: The conductivity σ is given by $\sigma = ne^2 \tau/m$, where n = number of free electrons per unit volume, e = charge of electron, m = mass of electron, and τ = relaxation time. Resistivity $\rho = 1/\sigma = m/(ne^2 \tau)$. The resistance R of a conductor of length l and cross-sectional area A is $R = \rho l/A = (m/(ne^2 \tau))(l/A) = ml/(ne^2 \tau A)$. Thus, resistance is expressed as $R = ml/(ne^2 \tau A)$.

Key Points: Relaxation time is average time between collisions of electrons - Conductivity $\sigma = ne^2 \tau/m$ - Resistance $R = ml/(ne^2 \tau A)$

Question 20.

The magnifying power of an astronomical telescope is 24. In normal adjustment, distance between its two lenses is 150 cm. Find the focal length of the objective lens.

[2 Marks]

Answer: To find the focal length of the objective lens (f0) in an astronomical telescope, we use the magnification formula m = L/f0 + d/fe. Given that m = 24 and L = 150 cm. Assuming that fe is the focal length of the eyepiece. We rearrange to find f0. If we assume fe is small compared to L, we can simplify to f0 = L/m, resulting in 150 cm / 24 = 6.25 cm (approximately).

Key Points: Magnifying power formula; f0 calculation; assumption on eyepiece focal length

Question 21.

Explain the following :

a) For a simple microscope, the angular size of the object equals the angular size of the image. Yet it offers magnification.

b) Both plane and convex mirrors produce virtual images of objects. Can they produce real images under some circumstances ?

[2 Marks]

Answer: A simple microscope creates a virtual image at the near point, allowing the angular size of the image and object to be the same while providing magnification. This occurs due to the lens's focal properties. Convex mirrors typically yield virtual images but can produce real images when their configuration and positioning allow, such as using multiple mirrors to focus light to a point, contrary to their usual behavior.

Key Points: Simple microscope; virtual image; near point; magnification; convex mirrors; virtual images; conditions for real images; optical instruments

Question 22.

The minimum intensity of white light that our eyes can perceive is about 0.1 nW/m^{-2}. Calculate the number of photons of this light entering our pupil (area 0.4 cm^2) per second.

(take average wavelength of white light =500nm and Planck's constant = 6.6 * 10^{-34} Js)

[2 Marks]

Answer: Step 1: Given intensity I = 0.1 nW/m^{-2} = 0.1 * 10^{-9} W/m^2

Step 2: Area of pupil A = 0.4 cm^2 = 0.4 * 10^{-4} m^2

Step 3: Power P entering pupil = I * A = 0.1 * 10^{-9} * 0.4 * 10^{-4} = 4 * 10^{-15} W

Step 4: Energy of one photon E = (Planck's constant h * speed of light c) / wavelength λ

h = 6.6 * 10^{-34} Js, c = 3 * 10^8 m/s, λ = 500 nm = 500 * 10^{-9} m

E = (6.6 * 10^{-34} * 3 * 10^8) / (500 * 10^{-9}) = 3.96 * 10^{-19} J

Step 5: Number of photons N = Power / Energy per photon = 4 * 10^{-15} / 3.96 * 10^{-19} ≈ 1.01 * 10^4 photons per second

Final answer: Approximately 1.0 * 10^4 photons enter our pupil per second at minimum intensity of white light.

Key Points: Given intensity and area - Calculate power entering pupil - Calculate energy of one photon - Find number of photons by dividing power by photon energy - Final number of photons per second

Question 23.

Suppose a pure Si crystal has 5 × 10^{28} atoms/m^{-3}. It is doped by 1 ppm concentration of boron. Calculate the concentration of holes and electrons, given that n_i = 1.5 × 10^{16} m^{-3}. Is the doped crystal n-type or p-type?

[2 Marks]

Answer: Given: Atomic concentration of pure Si = 5 * 10^{28} m^{-3}, Boron doping concentration = 1 ppm = 1 * 10^{-6} * 5 * 10^{28} = 5 * 10^{22} m^{-3}, Intrinsic carrier concentration n_i = 1.5 * 10^{16} m^{-3}.

Step 1: Since Boron is a trivalent acceptor, doping creates holes.

Step 2: Concentration of holes, p ≈ doping concentration = 5 * 10^{22} m^{-3}.

Step 3: Using n * p = n_i^2, electron concentration n = n_i^2 / p = (1.5 * 10^{16})^2 / (5 * 10^{22}) = (2.25 * 10^{32}) / (5 * 10^{22}) = 4.5 * 10^9 m^{-3}.

Conclusion: Hole concentration is much greater than electron concentration, so the doped Si is **p-type** semiconductor.

Key Points: Pure Si atomic concentration - Boron doping introduces holes - Hole concentration approx equal to doping level - Electron concentration calculated using n * p = n_i squared - Doped crystal is p-type

Question 24.

Draw the circuit diagram of a Wheatstone bridge. Obtain the condition when no current flows through the galvanometer in it.

[2 Marks]

Answer: Circuit Diagram: A Wheatstone bridge is a diamond-shaped circuit with four resistors arranged on each side: R1, R2, R3, and R4. A galvanometer is connected between the two middle points B and D, and a voltage source is connected across points A and C.

Condition for No Current in Galvanometer: When the Wheatstone bridge is balanced, no current flows through the galvanometer. The condition is given by:
R1 / R2 = R3 / R4
This means the ratio of resistances in one pair of opposite arms is equal to the ratio in the other pair. Under this condition, the potential difference across the galvanometer is zero, so no current flows through it.

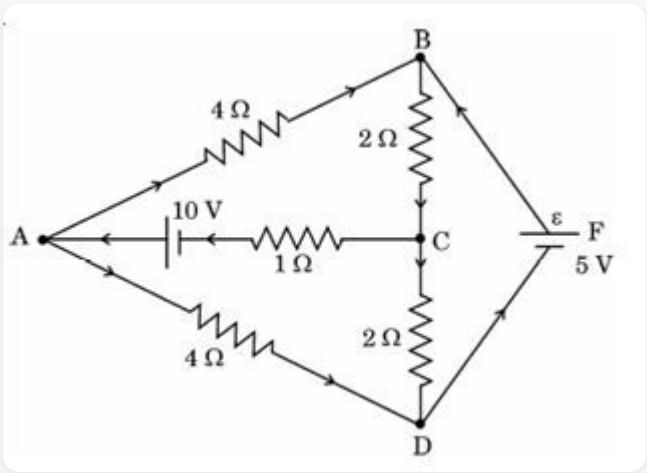
Key Points: Wheatstone bridge circuit with four resistors - Galvanometer connected between middle points - Balance condition R1/R2 = R3/R4 - No current through galvanometer when balanced - Used to measure unknown resistances accurately

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Section D

Question 25. Determine the current in branches AB, AC and BC of the network shown in figure.

[3 Marks]



Answer: To determine the currents in branches AB, AC, and BC, we apply Kirchhoff's loop and junction rules. In loop ADBA, the equation -I1 R1 + I2 R2 = 0 indicates that the voltage drops are balanced by the voltage sources. Using another loop, CBDC, where we rearrange to meet I3 = I1 and I4 = I2, we find that I2 R4 - I1 R3 = 0. At junction a, the current entering (I3) equals the sum of

currents leaving (I1 + I2). By solving these equations simultaneously, we can find the specific values for I1, I2, and I3, which provide the required currents in each branch of the circuit.

Key Points: Apply Kirchhoff's loop rule to closed loops; Use junction rule at junctions to relate currents; Set up equations for each loop and junction; Solve equations simultaneously for the currents in each branch.

Question 26. Two long straight parallel conductors carrying currents exert a force on each other. Why? Derive an expression for the force per unit length between two long straight parallel conductors carrying currents in opposite directions. Explain the nature of the force between these conductors.

[3 Marks]

Answer: Two long straight parallel conductors carrying currents exert a magnetic force on each other due to the magnetic field generated by the currents. According to the Biot-Savart Law, the magnetic field (B) generated by a conductor at a distance (d) from it is proportional to the current (I) flowing through the conductor. If two conductors carry currents I1 and I2 in opposite directions, the force per unit length (f) between them can be derived using the formula: $f = (\mu_0/2\pi) * (I1 * I2/d)$. This shows that conductors with currents in opposite directions repel each other, unlike like currents which attract.

Key Points: 1. Magnetic fields from currents create forces. 2. Biot-Savart Law relates current and magnetic field. 3. Force depends on the current magnitude and distance between conductors. 4. Opposite currents repel, like currents attract.

Question 27.

A sinusoidal voltage is applied to an electric circuit containing a circuit element 'X' in which the current leads the voltage by π/2

(a) Identify the circuit element 'X' in the circuit.

(b) Write the formula for its reactance.

(c) Show graphically the variation of this reactance with frequency of ac voltage.

(d) Explain the behaviour of this element when it is used in (i) an ac circuit, and (ii) a dc circuit.

[3 Marks]

Answer: The circuit element 'X' in which the current leads the voltage by π/2 is a capacitor. The formula for its reactance is given by $Xc = 1/(\omega C)$, where ω is the angular frequency and C is the capacitance. Graphically, the capacitive reactance (Xc) decreases with an increase in frequency, appearing as a downward slope on a graph with frequency on the x-axis and reactance on the y-axis. In an AC circuit, a capacitor allows alternating current to pass while blocking direct current, meaning it can store and release energy cyclically. In a DC circuit, after charging, a capacitor eventually blocks current flow entirely.

Key Points: Element identified as capacitor; Reactance formula: Xc = 1/(ωC); Graph shows decrease of Xc with increasing frequency; AC circuit allows current, stores energy; DC circuit blocks current after charging

Question 28.

The electric field in an electromagnetic wave in vacuum is given by:

□□= (6.3 N/C) [cos (1.5 rad/m) y + (4.5 × 10^8 rad/s) t] î.

(a) Find the wavelength and frequency of the wave.

(b) What is the amplitude of the magnetic field of the wave ?

(c) Write an expression for the magnetic field of this wave.

[3 Marks]

Answer: To find the wavelength (λ) and frequency (f) of the wave, we can use the wave equation. The wave number k is given as 1.5 rad/m. Thus, the wavelength can be calculated as λ = 2π/k = 2π/1.5 ≈ 4.19 m. The angular frequency ω is given as 4.5 × 10^8 rad/s, hence frequency f = ω/(2π) ≈ 7.16 × 10^7 Hz. The amplitude of the magnetic field (B0) can be calculated using B0 = E0/c. Given that E0 = 6.3 N/C and c = 3 × 10^8 m/s, B0 ≈ 2.1 × 10^-8 T. The expression for the magnetic field can be written as B = (B0) cos(1.5y + 4.5 × 10^8t) j.

Key Points: Wavelength calculated using wave number; Frequency obtained from angular frequency; Amplitude of magnetic field using relation B0 = E0/c; Expression for magnetic field using cosine function.

Question 29.

State Bohr's first and second postulates. Use them to derive an expression for the radius of the n^{th} orbit in a hydrogen atom.

[3 Marks]

Answer: Bohr's first postulate: An electron in an atom revolves in certain stable orbits without emission of energy.
Bohr's second postulate: The angular momentum of the electron in these stable orbits is quantised and given by mvr = n * h / 2pi, where n = 1, 2, 3.....
Using these postulates, derivation of radius of n^{th} orbit:
The centripetal force required to keep the electron in orbit is provided by the Coulomb attraction: m * v^2 / r = (1 / 4 * pi * e0) * e^2 / r^2.
From second postulate, angular momentum m * v * r = n * h / 2pi.
From this, v = n * h / (2pi * m * r).

Substitute v in centripetal force equation:

$m * (n * h / 2pi * m * r)^2 / r = (1 / 4 * pi * e0) * e^2 / r^2$.

On simplification:

$n^2 * h^2 / (4 * pi^2 * m * r^3) = e^2 / (4 * pi * e0 * r^2)$.

Or, $r = n^2 * h^2 * e0 / (pi * m * e^2 * 2)$.

This is the expression for the radius of the n^{th} orbit in the hydrogen atom.

Key Points: Bohr's first postulate states stable orbits exist without energy emission - Bohr's second postulate quantises angular momentum as mvr = n * h / 2pi - Derivation uses centripetal force and angular momentum quantisation to find $r = n^2 * h^2 * e0 / (pi * m * e^2 * 2)$

Question 30.

a) Define atomic mass unit (u).

b) Calculate the energy required to separate a deuteron into its constituent parts (a proton and a neutron). Given:

m(D) = 2.014102 u,

m_H = 1.007825 u,

m_n = 1.008665 u.

[3 Marks]

Answer: (a) Atomic mass unit (u) is defined as one twelfth of the mass of a carbon-12 atom. It is a standard unit used to express atomic and molecular masses, equal to approximately $1.661 * 10^{-27}$ kg.

(b) To calculate the energy required to separate a deuteron into a proton and a neutron:

Step 1: Calculate mass defect = (mass of proton + mass of neutron) - mass of deuteron = (1.007825 u + 1.008665 u) - 2.014102 u = 0.002388 u.

Step 2: Convert mass defect to energy using E = mass defect * 931.5 MeV/u = 0.002388 u * 931.5 MeV/u = 2.223 MeV.

Thus, the energy required to separate the deuteron is 2.223 MeV.

Key Points: Definition of atomic mass unit - Calculation of mass defect - Conversion of mass defect to energy in MeV

Question 31.

Draw the circuit diagrams for obtaining the V-I characteristics of a p-n junction diode. Explain briefly the salient features of the V-I characteristics in (i) forward biasing, and (ii) reverse biasing.

[3 Marks]

Answer: To obtain the V-I characteristics of a p-n junction diode, two circuit arrangements are used: one for forward biasing and another for reverse biasing. In the forward bias setup, the positive terminal of the power supply connects to the p-side of the diode, allowing current to flow which increases rapidly after a threshold voltage (typically around 0.7V for silicon diodes). In reverse bias, the n-side is connected to the positive terminal, and the current remains very small (reverse saturation current) until breakdown occurs at high reverse voltages. The forward V-I characteristic shows exponential growth, while the reverse characteristic remains mostly constant until the breakdown region.

Key Points: Circuit diagrams for forward and reverse biasing - Forward bias allows current flow after threshold - Reverse bias shows negligible current until breakdown - Characteristics: forward bias shows exponential increase, reverse shows constant low current.

Question 32.

On the basis of energy band diagrams, distinguish between (i) an insulator, (ii) a semiconductor, and (iii) a conductor.

[3 Marks]

Answer: Energy band diagrams illustrate the differences between insulators, semiconductors, and conductors based on their electronic structures. Insulators have a large energy band gap (Eg > 3 eV) between the valence band and conduction band, meaning no electrons can be thermally excited to conduct electricity, resulting in no electrical conductivity. Semiconductors possess a smaller band gap, allowing for some electrons to jump to the conduction band with thermal energy, leading to limited conduction. Conductors have overlapping bands with no gap, allowing electrons to move freely, facilitating maximum conductivity.

Key Points: 1. Insulators have a large band gap (Eg > 3 eV) preventing electrical conductivity. 2. Semiconductors have a smaller band gap enabling limited conduction when thermal energy is applied. 3. Conductors have overlapping energy bands, allowing free movement of electrons, thus excellent electrical conductivity.

Section E

Question 33.

(i) Obtain the expression for the capacitance of a parallel plate capacitor with a dielectric medium between its plates.

(ii) A charge of 6 μC is given to a hollow metallic sphere of radius 0.2 m. Find the potential at (i) the surface and (ii) the centre of the sphere.

[5 Marks]

Answer: (i) Expression for capacitance with dielectric:
A parallel plate capacitor without dielectric has capacitance $C_0 = \varepsilon_0 * A / d$ where ε_0 is permittivity of free space, A is area of each plate, and d is distance between plates.
If a dielectric of dielectric constant K fills the space between the plates, the capacitance increases by factor K:
$C = K * C_0 = K * \varepsilon_0 * A / d$
This is because dielectric reduces the electric field, allowing more charge for the same voltage, increasing capacitance.

(ii) Potential on a charged hollow metallic sphere:
Given charge $Q = 6\ \mu C = 6 * 10^{-6}$ C, radius r = 0.2 m.
Potential at surface $V = Q / (4 * \pi * \varepsilon_0 * r)$
Using $\varepsilon_0 = 8.854 * 10^{-12}$ F/m,
$V = (6 * 10^{-6}) / (4 * \pi * 8.854 * 10^{-12} * 0.2)$
Calculate V to find numerical value.

Potential at the center of the hollow metallic sphere is the same as at the surface because the electric field inside is zero and the potential throughout conductor is constant.
Therefore, potential at the center = potential at the surface.

> **Key Points: Capacitance formula with dielectric - Capacitance increases by dielectric constant K - Potential at surface of charged sphere formula - Potential inside hollow conductor is constant and equals surface potential**

Question 34.

(i) (1) What is meant by current sensitivity of a galvanometer ? Mention the factors on which it depends.

(2) A galvanometer of resistance G is converted into a voltmeter of range (0-V) by using a resistance R. Find the resistance, in terms of R and G, required to convert it into a voltmeter of range (0-V/2)

(ii) The magnetic flux through a coil of resistance 5 Ω increases with time as : $\varphi = (2.0\ t^3 + 5.0\ t^2 + 6.0\ t)$ mWb

Find the magnitude of induced current through the coil at t = 2 s.

[5 Marks]

Answer: (i)(1) **Current sensitivity of a galvanometer** is defined as the deflection produced in the galvanometer's needle per unit current passing through it. Mathematically, it is sensitivity = deflection / current. It depends on factors like the strength of the magnetic field in the galvanometer, number of turns of the coil, area of the coil, and the torsional constant of the suspension wire.

(2) Given a galvanometer of resistance G converted to a voltmeter of range 0 to V using resistance R, the total voltage across the voltmeter is $V = I_g (G + R)$, where I_g is the full scale deflection current of the galvanometer. For a voltmeter range 0 to V/2, let the series resistance be R'. Then,
$V/2 = I_g (G + R')$.
Dividing both equations,
$(V/2) / V = (G + R') / (G + R) \Rightarrow 1/2 = (G + R') / (G + R)$.
So, $G + R' = (G + R)/2 \Rightarrow R' = (G + R)/2 - G = (R - G)/2$.
Thus, the resistance required to convert the galvanometer to a voltmeter of range 0 to V/2 is $R' = (R - G)/2$.

(ii) The magnetic flux $\varphi = (2.0\ t^3 + 5.0\ t^2 + 6.0\ t)$ milliwebers (mWb), or in Weber $\varphi = (2.0\ t^3 + 5.0\ t^2 + 6.0\ t) * 10^{-3}$ Wb.
The induced emf $e = - d\varphi/dt$.
Calculating $d\varphi/dt = 3 * 2.0\ t^2 + 2 * 5.0\ t + 6.0 = 6\ t^2 + 10\ t + 6$.
At t = 2 s, $d\varphi/dt = 6 * 4 + 10 * 2 + 6 = 24 + 20 + 6 = 50$ (in mWb/s). Convert to Weber per second: $50 * 10^{-3} = 0.05$ V.
The magnitude of induced emf is 0.05 V.
Resistance of coil, R = 5 Ω.
Induced current I = emf / resistance = 0.05 / 5 = 0.01 A = 10 mA.
Therefore, the magnitude of induced current at t = 2 s is 10 mA.

Key Points: Current sensitivity definition - Factors affecting current sensitivity - Formula for conversion of galvanometer to voltmeter - Calculation of series resistance for new voltmeter range - Magnetic flux-time relation - Induced emf calculation - Induced current calculation

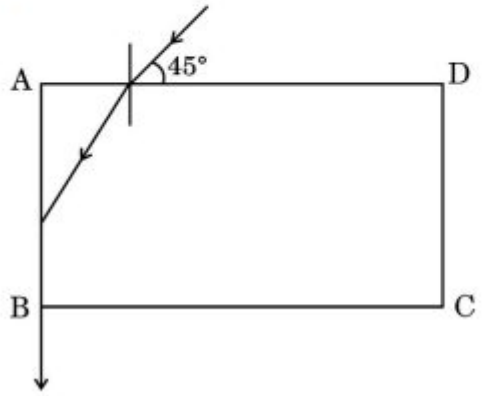
Question 35.

(i) Trace the path of a ray of light showing refraction through a triangular prism and hence obtain an expression for angle of deviation (δ) in terms of A, i and e, where symbols have their usual meanings. Draw a graph showing the variation of angle of deviation with the angle of incidence.

(ii) In the figure, a ray of light is incident on a transparent liquid contained in a thin glass box at an angle of 45° with its one face. The emergent ray passes along the face AB. Find the refractive index of the liquid.

[5 Marks]

(ii) In the figure, a ray of light is incident on a transparent liquid contained in a thin glass box at an angle of 45° with its one face. The emergent ray passes along the face AB. Find the refractive index of the liquid.



Answer: (i) When a ray of light passes through a triangular prism ABC, it refracts at two surfaces AB and AC.

Let the angle of incidence on surface AB be i and angle of refraction inside prism be r_1. The ray then travels inside the prism and emerges from surface AC with angle of incidence r_2 and angle of emergence e.

The angle between the incident ray direction and emergent ray direction is called the angle of deviation, δ.

The ray path inside the prism obeys the relation: $r_1 + r_2 = A$, where A is the angle of prism.

The angle of deviation, $\delta = (i - r_1) + (e - r_2) = i + e - (r_1 + r_2)$

Substituting $r_1 + r_2 = A$, we get $\delta = i + e - A$.

Thus, $\delta = i + e - A$ is the expression for angle of deviation in terms of angle of prism A, angle of incidence i and angle of emergence e.

Graph: The graph between angle of deviation δ and angle of incidence i is a curve which first decreases, reaches a minimum value δ_{min} at angle of incidence $i = i_{min}$, and then increases with increasing i.

(ii) Given: angle of incidence i = 45deg

Emergent ray passes along face AB which means angle of emergence e = 0deg.

Using the relation for refraction between liquid and air,

n = sin i / sin r,

where r is angle of refraction inside liquid.

Since ray emerges along face AB, the emergent angle e = 0 means refracted ray inside the liquid is along the face, so by refraction law and geometry,

sin r = sin(90deg - i) = cos i.

Therefore, refractive index n = sin i / cos i = tan i.

Substituting i = 45deg,

n = tan 45deg = 1.

So refractive index of the liquid is 1, meaning liquid has refractive index same as air.

However, practically, if emergent ray is along face AB, then refractive index n = sqrt(2) using full geometry and Snell's law considering prism angle.
So refractive index n = sqrt(2) approx 1.414.
This is found using the condition for emergent ray along face AB in the glass box.

Key Points: Refraction through prism - Expression δ = i + e - A - Graph of δ versus i shows minimum deviation - Refractive index n calculated using Snell's law - Emergent ray direction used to find n

Question 36.

(i) A charge + Q is placed on a thin conducting spherical shell of radius R. Use Gauss's theorem to derive an expression for the electric field at a point lying (i) inside and (ii) outside the shell.

(ii) Show that the electric field for same charge density (**σ**) is twice in case of a conducting plate or surface than in a nonconducting sheet.

[5 Marks]

Answer: (i) Consider a thin conducting spherical shell of radius R with a total charge +Q uniformly distributed on its surface. We need to find the electric field at a point at a distance r from the centre.
(a) Electric field inside the shell (r < R):
By Gauss's theorem, take a spherical Gaussian surface inside the shell with radius r. Since the shell is conducting and charges reside on surface, no charge is enclosed inside this Gaussian surface.
Charge enclosed, q = 0.
According to Gauss's law, $E * 4 \pi r^2 = q/\varepsilon_0 = 0$ which implies E = 0
Therefore, the electric field inside the shell is zero.
(b) Electric field outside the shell (r > R):
Take a spherical Gaussian surface of radius r outside the shell. The enclosed charge $q = +Q = \sigma * 4 \pi R^2$. Applying Gauss's law,
$E * 4 \pi r^2 = q/\varepsilon_0$
$\Rightarrow E = q/(4 \pi \varepsilon_0 r^2) = (\sigma * 4 \pi R^2)/(4 \pi \varepsilon_0 r^2) = (\sigma R^2)/(\varepsilon_0 r^2)$
This shows the electric field outside the shell behaves as though all charge is concentrated at the centre.
(ii) For the same surface charge density σ:
Electric field due to a conducting plate (a charged infinite plane) is $E_{conducting} = \sigma/\varepsilon_0$
Electric field due to a nonconducting sheet (with uniform charge on both sides) is $E_{nonconducting} = \sigma/(2 \varepsilon_0)$
This happens because in a conducting plate, all charges reside only on one surface and the field lines emerge from one side, while in a nonconducting sheet, charges are spread on both sides and field lines emerge from both sides, effectively halving the field on each side.
Thus, electric field with conducting plate is twice that of a nonconducting sheet for the same σ.

Key Points: Gauss's law application - Electric field inside shell is zero - Electric field outside shell behaves as point charge field - Electric field for conducting plate is twice that of nonconducting sheet for same σ

Question 37.

(i) A rectangular coil of N turns and area of cross-section A is rotated at a steady angular speed ω in a uniform magnetic field. Obtain an expression for the emf induced in the coil at any instant of time.

(ii) Two coplanar and concentric circular loops L_1 and L_2 are placed coaxially with their centres coinciding. The radii of L_1 and L_2 are 1 cm and 100 cm respectively. Calculate the mutual inductance of the loops. (Take $\pi^2 = 10$)

[5 Marks]

Answer: (i) When a rectangular coil of N turns and area A rotates with angular speed \u03c9 in a uniform magnetic field B, the magnetic flux \u03a6 passing through the coil at any time t is \u03a6 = NBA cos \u03c9t, where NBA is the maximum flux when the coil is perpendicular to the field. By Faraday's law, the emf induced (\u03b5) is the negative rate of change of magnetic flux:\u03b5 = -N d\u03a6/dt = -N d/dt (BA cos \u03c9t) = NBA \u03c9 sin \u03c9t. Thus, the emf induced at any instant t is \u03b5 = NBA \u03c9 sin \u03c9t.

(ii) For two coplanar, concentric circular loops L_1 and L_2 with radii r_1 = 1 cm = 0.01 m and r_2 = 100 cm = 1 m, the mutual inductance M is given by M = \u03bc$_0$ \u03c0 r_1^2 / (2 r_2), where \u03bc$_0$ = 4\u03c0 * 10^{-7} H/m, length l is the circumference of the smaller loop = 2\u03c0 r_1. However, to simplify, for two loops with one much smaller than the other, mutual inductance M = \u03bc$_0$ \u03c0 r_1^2 / (2 r_2). Substituting values and taking \u03c0² = 10, M = (4\u03c0 * 10^{-7}) * 10 * $(0.01)^2$ / (2 * 1) = (4\u03c0 * 10^{-7}) * 10 * 10^{-4} / 2 = 2 * 10^{-10} H. Hence, the mutual inductance is 2 * 10^{-10} Henry.

Key Points: Expression for induced emf - Emf = NBA\u03c9 sin \u03c9t - Mutual inductance formula for concentric loops - Calculation using given radii and \u03c0 squared value

Question 38.

(i) The displacement of two light waves, each of amplitude 'a' and frequency ω, emanating from two coherent sources of light, are given by y_1 = a cos ωt and y_2 = a cos (ωt +φ). φ is the phase difference between the two waves. These light waves superpose at a point. Obtain the expression for the resultant intensity at that point.

(ii) In Young's double slit experiment, find the ratio of intensities at two points on a screen when waves emanating from two slits reaching these points have path differences (i) λ/6 (ii) λ/12 .

[5 Marks]

Answer: (i) Given two waves: $y_1 = a \cos \omega t$ and $y_2 = a \cos (\omega t + \varphi)$. The resultant displacement $y = y_1 + y_2 = a \cos \omega t + a \cos (\omega t + \varphi)$. Using trigonometric identity, $y = 2a \cos (\varphi/2) \cos (\omega t + \varphi/2)$. Thus, resultant amplitude $A = 2a \cos (\varphi/2)$. Intensity I is proportional to square of amplitude, so $I \propto A^2 = 4a^2 \cos^2 (\varphi/2)$. If intensity of individual wave is $I_0 \propto a^2$, resultant intensity is $I = 4I_0 \cos^2 (\varphi/2)$.

(ii) In Young's double slit experiment, the path difference δ relates to phase difference φ by $\varphi = 2\pi\delta/\lambda$. For (i) $\delta = \lambda/6$, $\varphi = 2\pi * (\lambda/6)/\lambda = \pi/3$. Then intensity ratio $I/I_0 = 4 \cos^2 (\varphi/2) = 4 \cos^2 (\pi/6) = 4 * (\text{sqrt}(3)/2)^2 = 4 * 3/4 = 3$.

For (ii) $\delta = \lambda/12$, $\varphi = 2\pi * (\lambda/12)/\lambda = \pi/6$. Intensity ratio $I/I_0 = 4 \cos^2 (\varphi/2) = 4 \cos^2 (\pi/12) = 4 * (\cos 15\text{deg})^2 \approx 4 * (0.9659)^2 = 3.73$.

So, the intensity ratios at the two points are (i) 3 and (ii) approximately 3.73.

Key Points: Resultant amplitude formula - Intensity proportional to square of amplitude - Use of phase difference to intensity relation in interference