

Question Paper

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 3 Hours

Maximum Marks: 70

General Instructions

- (i) This question paper contains **33 questions**. All questions are **compulsory**.
- (ii) The question paper is divided into Sections A, B, C, D, E.
- (iii) Section A - Questions 1 to 16 carry 1 mark each.
- (iv) Section B - Questions 17 to 21 carry 2 marks each.
- (v) Section C - Questions 22 to 28 carry 3 marks each.
- (vi) Section D - Questions 29 to 30 carry 4 marks each.
- (vii) Section E - Questions 31 to 33 carry 5 marks each.
- (viii) There is no overall choice. Where an internal choice is provided, attempt only one of the alternatives.

You may use the following values of physical constants wherever necessary:

$$\begin{aligned}c &= 3 \times 10^8 \text{ m/s} \\h &= 6.63 \times 10^{-34} \text{ Js} \\e &= 1.6 \times 10^{-19} \text{ C} \\\mu_0 &= 4\pi \times 10^{-7} \text{ T m A}^{-1} \\\epsilon_0 &= 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2} \\\frac{1}{4\pi\epsilon_0} &= 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}\end{aligned}$$

$$\begin{aligned}\text{Mass of electron } (m_e) &= 9.1 \times 10^{-31} \text{ kg} \\\text{Mass of neutron} &= 1.675 \times 10^{-27} \text{ kg} \\\text{Mass of proton} &= 1.673 \times 10^{-27} \text{ kg} \\\text{Avogadro's number} &= 6.023 \times 10^{23} \text{ per gm mole} \\\text{Boltzmann constant} &= 1.38 \times 10^{-23} \text{ JK}^{-1}\end{aligned}$$

Section A

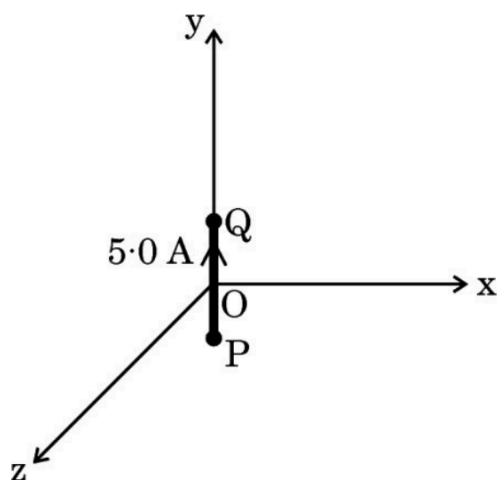
1. The plates P_1 and P_2 of a $2\ \mu\text{F}$ capacitor are at potentials $25\ \text{V}$ and $-25\ \text{V}$ respectively. The charge on plate P_1 will be:

- (A) $0.02\ \text{mC}$ (B) $0.1\ \text{mC}$
(C) $0.1\ \mu\text{C}$ (D) $1\ \mu\text{C}$

2. 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 $-5\ \text{V}$ and $+5\ \text{V}$ respectively. Assuming that kinetic energies of the proton at points P_1 and P_2 are zero, the work done on the proton is:

- (A) $-1.6 \times 10^{-18}\ \text{J}$ (B) $1.6 \times 10^{-18}\ \text{J}$
(C) Zero (D) $0.8 \times 10^{-18}\ \text{J}$

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



- (A) $(0.12\ \text{nT})\hat{j}$ (B) $-(0.10\ \text{nT})\hat{j}$
(C) $-(0.24\ \text{nT})\hat{k}$ (D) $(0.24\ \text{nT})\hat{k}$

4. Which of the following is a diamagnetic substance?

- (A) Gadolinium (B) Sodium
(C) Copper chloride (D) Sodium chloride

5. A current carrying circular loop of magnetic moment $\vec{M}$ is suspended in a vertical plane in an external magnetic field $\vec{B}$ such that its plane is normal to $\vec{B}$. The work done in rotating this loop by 45° about an axis perpendicular to $\vec{B}$ is closest to:

- (A) $-0.3 MB$ (B) $0.3 MB$
(C) $-1.7 MB$ (D) $1.7 MB$

6. The average value of the alternating voltage $v = (157\ \text{V}) \sin \omega t$ over its first half-cycle is:

- (A) $157\ \text{V}$ (B) $\frac{157}{\sqrt{2}}\ \text{V}$
(C) $78.5\ \text{V}$ (D) $100\ \text{V}$

7. 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:

- (A) both l and A are increased (B) l is decreased and A is increased
(C) l is increased and A is decreased (D) both l and A are decreased

8. A plane electromagnetic wave is travelling in air in $+x$ direction. At a particular moment, its electric field $\vec{E}$ is along $+y$ direction. At that moment, the magnetic field $\vec{B}$ is along:

- (A) $+z$ direction and in phase with $\vec{E}$ (B) $-z$ direction and in phase with $\vec{E}$
 (C) $+z$ direction and out of phase with $\vec{E}$ (D) $-z$ direction and out of phase with $\vec{E}$

9. 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:

- (A) $\frac{1}{2}$ (B) 2
 (C) $\frac{1}{4}$ (D) 4

10. The wavelength of matter wave associated with an electron of kinetic energy K is λ . If the kinetic energy of the electron is doubled, the associated wavelength becomes:

- (A) $\frac{\lambda}{\sqrt{2}}$ (B) $\frac{\lambda}{2}$
 (C) $\sqrt{2}\lambda$ (D) 2λ

11. 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:

- (A) increases by 87.5% (B) decreases by 87.5%
 (C) increases by 43.75% (D) decreases by 43.75%

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

- (A) 0.01 eV (B) 0.05 eV
 (C) 0.72 eV (D) 1.1 eV

Question numbers 13 to 16 are Assertion (A) and Reason (R) type questions. Two statements are given - one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C) and (D) as given below.

(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.

13. 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.

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

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

15. Assertion (A): A proton and an electron enter a uniform magnetic field $\vec{B}$ with the same momentum $\vec{p}$ such that $\vec{p}$ is perpendicular to $\vec{B}$. They describe circular paths of the same radius.

Reason (R): In a magnetic field, orbital radius r is equal to $\frac{p}{qB}$.

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

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

Section B

17(a). What is meant by 'relaxation time' of free electrons in a conductor? Show that the resistance of a conductor can be expressed by

$R = \frac{ml}{ne^2\tau A}$, where symbols have their usual meanings.

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

18. 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.

19. What is a sustained or stable interference pattern? What are the conditions for obtaining such an interference pattern?

20. Light of wavelength 600 nm is incident on potassium (work function 2.3 eV). Will photoemission of electrons occur? What is the longest wavelength that will cause photoemission of electrons? (Take $hc = 1240 \text{ eV}\cdot\text{nm}$)

21. 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 $n_i = 1.5 \times 10^{16} \text{ m}^{-3}$. Is the doped crystal n -type or p -type?

Section C

22. A current of 1.6 A flows through a wire when a potential difference of 1.0 V is applied across it. The length and cross-sectional area of the wire are 1.0 m and $1.0 \times 10^{-7} \text{ m}^2$ respectively. Calculate:

(a) Electric field across the wire

(b) Current density

(c) Average relaxation time (τ)

(Number density of free electrons in the wire is $9.0 \times 10^{28} \text{ m}^{-3}$)

23. An electron (charge $-e$, mass m) is revolving around a nucleus, in a hydrogen atom, in a circle of radius r . Derive an expression, in vector form, for the magnetic dipole moment, $\vec{\mu}$, in terms of its orbital angular momentum $\vec{L}$. What is gyromagnetic ratio?

24. Prove that induced charge depends on the net change in the magnetic flux and not on the time interval of the flux change.

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

$$\vec{E} = (6.3 \text{ N/C})[\cos((1.5 \text{ rad/m})y + (4.5 \times 10^8 \text{ rad/s})t)]\hat{i}$$

(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.

26. State Bohr's second postulate for his theory of hydrogen atom. Prove that the radius of Bohr's orbit of a hydrogen atom is directly proportional to n^2 , where n is the principal quantum number.

27. (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: $m(D) = 2.014102 \text{ u}$; $m_p = 1.007825 \text{ u}$; $m_n = 1.008665 \text{ u}$.

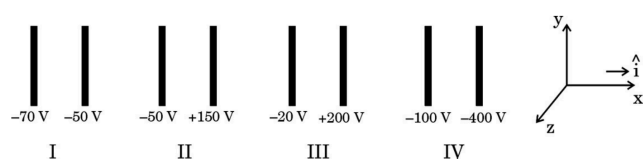
28(a). Draw the circuit diagrams for obtaining the $V - I$ characteristics of a $p-n$ junction diode. Explain briefly the salient features of the $V - I$ characteristics in (i) forward biasing, and (ii) reverse biasing.

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

Section D

Question numbers 29 and 30 are Case Study-based questions. Read the following paragraphs and answer the questions that follow.

29. 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.



Pair I: -70 V, -50 V Pair II: -50 V, +150 V Pair III: -20 V, +200 V Pair IV: -100 V, -400 V

For which pair of the plates is the electric field $\vec{E}$ along $\hat{i}$?

- (A) I (B) II
(C) III (D) IV

29(i). 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 $-\hat{i}$

29(ii). Let V_0 be the potential at the left plate of any set, taken to be at $x = 0$ m. Then the potential V at any point ($0 \leq x \leq 2$ cm) between the plates of that set can be expressed as:

- (A) $V = V_0 + \alpha x$ (B) $V = V_0 + \alpha x^2$
(C) $V = V_0 + \alpha x^{1/2}$ (D) $V = V_0 + \alpha x^{3/2}$

29(iii)(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) $E_2 > E_3 > E_4 > E_1$

OR

29(iii)(b). 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 $e/m = 1.76 \times 10^{11}$ 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

30(i). 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 $2\ \mu\text{m}$ each in an opaque material are separated by a distance of $6\ \mu\text{m}$. Monochromatic light of wavelength $450\ \text{nm}$ is incident normally on the slits. One finds a combined interference and diffraction pattern on the screen.

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 |

30(ii). 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 |

30(iii)(a). If instead of $450\ \text{nm}$ light, another light of wavelength $680\ \text{nm}$ is used, 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 |

30(iii)(b). 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) $\sin^{-1}(0.45)$ |

30(iv). The number of bright fringes formed due to interference on $1\ \text{m}$ of screen placed at $\frac{\pi}{3}\ \text{m}$ away from the slits is:

- | | |
|-------|--------|
| (A) 2 | (B) 3 |
| (C) 6 | (D) 10 |

Section E

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

(ii) A charge of $6 \mu\text{C}$ 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.

31(b). (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.

32(a). (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 $\left(0 - \frac{V}{2}\right)$.

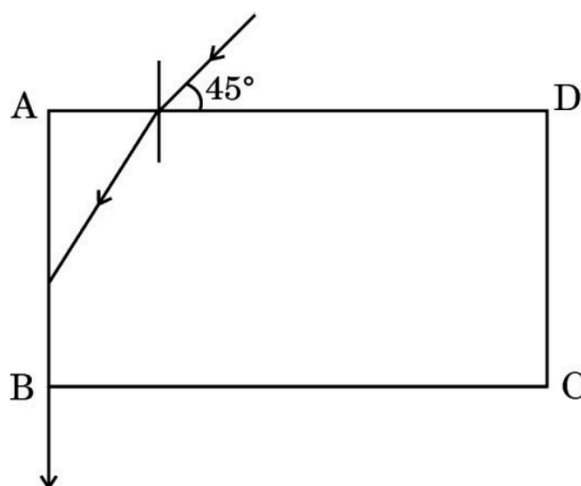
(ii) The magnetic flux through a coil of resistance 5Ω increases with time as: $\phi = (2.0t^3 + 5.0t^2 + 6.0t) \text{ mWb}$. Find the magnitude of induced current through the coil at $t = 2 \text{ s}$.

32(b). (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 $\pi^2 = 10$)

33(a). (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.



33(b). (i) The displacement of two light waves, each of amplitude ' a ' and frequency ω , emanating from two coherent sources of light, are given by $y_1 = a \cos \omega t$ and $y_2 = a \cos(\omega t + \phi)$. 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) $\frac{\lambda}{6}$ and (ii) $\frac{\lambda}{4}$.

- End of Question Paper -