

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

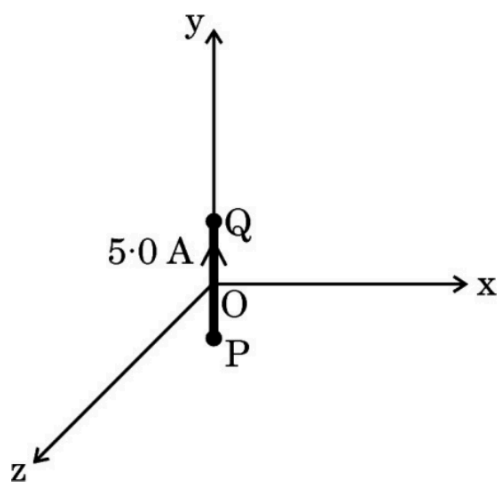
1. An isolated conductor, with a cavity, has a net charge $+Q$. A point charge $+q$ is inside the cavity. The charges on the cavity wall and the outer surface are respectively:

- (A) 0 and Q (B) $-q$ and $Q - q$
 (C) $-q$ and $Q + q$ (D) 0 and $Q - q$

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 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:

- (A) -1.6×10^{-18} J (B) 1.6×10^{-18} J
 (C) Zero (D) 0.8×10^{-18} J

3. 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 $(3 \text{ m}, 4 \text{ m}, 0)$ 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. Two thin long parallel wires separated by a distance ' a ' carry current I in opposite directions. The wires will:

- (A) Repel each other with a force $\frac{\mu_0 I^2}{2\pi a^2}$ per unit length. (B) Attract each other with a force $\frac{\mu_0 I^2}{2\pi a^2}$ per unit length.
 (C) Attract each other with a force $\frac{\mu_0 I^2}{2\pi a}$ per unit length. (D) Repel each other with a force $\frac{\mu_0 I^2}{2\pi a}$ per unit length.

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 mutual inductance of two coils C_1 and C_2 is 20 mH. In coil C_1 , the current changes from 4 A to zero in 0.2 s. If the resistance of coil C_2 is 4Ω , then the charge that flows through it per second will be:

- (A) 4.0 C (B) 1.5 C
 (C) 0.05 C (D) 0.1 C

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

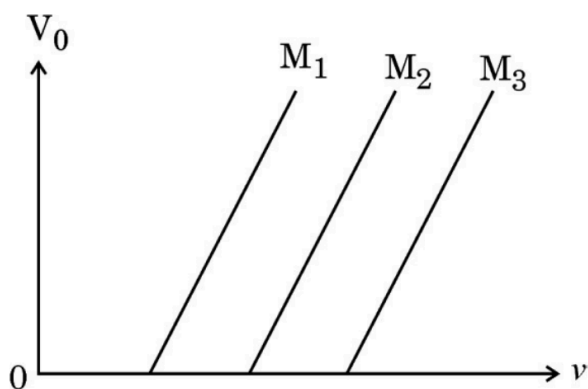
8. Electromagnetic waves with frequency 1.0×10^{18} Hz are known as:

- (A) Infrared rays (B) Ultraviolet rays
(C) X-rays (D) Gamma rays

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 figure shows the variation of stopping potential V_0 with frequency ν of incident radiation, for three materials M_1 , M_2 and M_3 with work functions ϕ_1 , ϕ_2 and ϕ_3 respectively. Then:



- (A) $\phi_1 > \phi_2 > \phi_3$ (B) $\phi_2 > \phi_3 > \phi_1$
(C) $\phi_3 > \phi_2 > \phi_1$ (D) $\phi_2 > \phi_1 > \phi_3$

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. Write two points of difference between interference and diffraction of light.

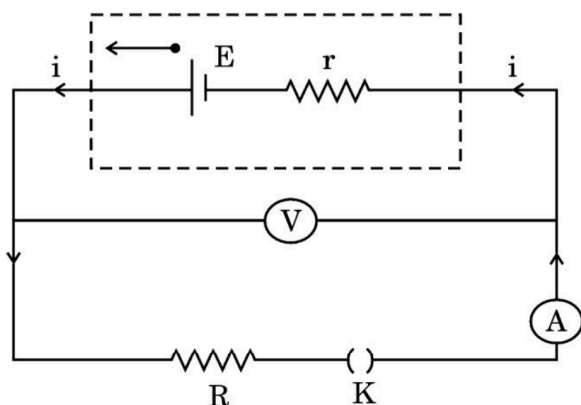
20. Light of wavelength 500 nm is incident on caesium metal (work function 2.14 eV) and photoemission of electrons occurs. Calculate the (i) kinetic energy (in eV) of the fastest electrons and (ii) stopping potential for this situation. (Take $hc = 1240 \text{ eV}\cdot\text{nm}$)

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 battery of unknown emf E and internal resistance r is connected in a circuit as shown in the figure. When the key (K) is open, the voltmeter reads 10.0 V and ammeter reads 0 A. In the closed circuit, the voltmeter reads 6.0 V and ammeter reads 2.0 A. Calculate:

- (a) emf of the battery,
- (b) internal resistance of the battery (r), and
- (c) external resistance (R).



23. A rectangular loop of area $\vec{A}$, carrying current I , is placed in a uniform magnetic field $\vec{B}$. With the help of a suitable diagram, derive an expression, in vector form, for the torque acting on the loop.

24. Distinguish between reactance and impedance of an ac circuit. Show that an ideal inductor in an ac circuit does not dissipate any power.

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. Explain the origin of the spectral lines of hydrogen atom using Bohr's theory. Draw the energy level diagram of hydrogen atom showing its various spectral series.

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

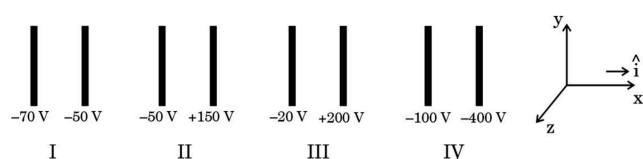
28(a). Draw the circuit diagrams for obtaining the $V - I$ characteristics of a $p-n$ junction diode. Explain briefly the salient features of the $V - I$ characteristics in (i) forward biasing, and (ii) reverse biasing.

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

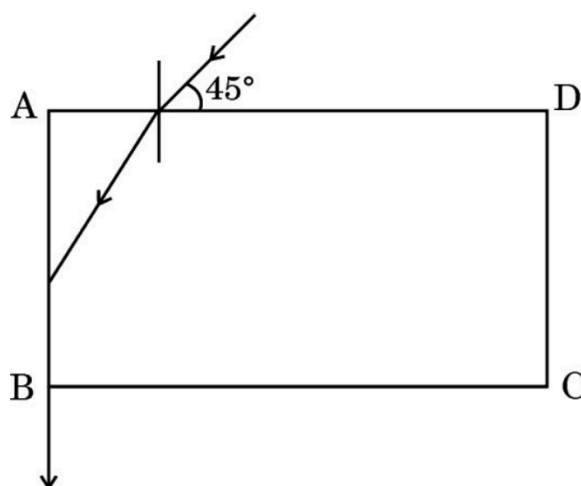
(ii) The magnetic flux through a coil of resistance 5Ω increases with time as: $\phi = (2.0t^3 + 5.0t^2 + 6.0t) \text{ mWb}$. Find the magnitude of induced current through the coil at $t = 2 \text{ s}$.

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 -