Physics (042)

CBSE Class 12 Board Examination 2027 – Practice Paper No. 2

Model Answer Paper

Time: 3 hours **Max. Marks: 70**

Model answers show one correct method; any other correct method gets full marks.

SECTION A Questions 1 to 16 carry 1 mark each. (Q.1–12 multiple choice; Q.13–16 assertion–reason) **[16]**

1. Two identical small metal spheres carry charges +8 μC and –2 μC. When placed a distance d apart, they attract each other with a force F. They are touched together and then placed again at the same distance d. The force between them now is

(A) 9F/16, attractive (B) 9F/16, repulsive

(C) 3F/8, repulsive (D) F, repulsive

Answer (1 mark)

(B) 9F/16, repulsive

On contact the total charge (+8 – 2) = +6 μC is shared equally: +3 μC each. $F \propto q_1 q_2$: $F'/F = (3 \times 3)/(8 \times 2) = 9/16$. Both charges are now positive, so the force is repulsive.

2. The electric potential along the x-axis in a region is $V = (5 - 3x^2)$ volt, where x is in metre. The electric field at x = 2 m is

(A) 12 V m^{-1} along +x (B) 12 V m^{-1} along –x

(C) 7 V m^{-1} along –x (D) 24 V m^{-1} along +x

Answer (1 mark)

(A) 12 V m^{-1} along +x

$E_x = -dV/dx = -(-6x) = 6x = 6 \times 2 = +12$ V m^{-1}, i.e. along +x (the field points in the direction of decreasing potential).

3. The free electrons in a metal wire acquire a drift speed of 1.5×10^{-4} m s^{-1} when the electric field inside the wire is 0.3 V m^{-1}. The mobility of the electrons is

(A) 5×10^{-4} m^2 V^{-1} s^{-1} (B) 2×10^{3} m^2 V^{-1} s^{-1}

(C) 4.5×10^{-5} m^2 V^{-1} s^{-1} (D) 5×10^{-5} m^2 V^{-1} s^{-1}

Answer (1 mark)

(A) 5×10^{-4} m^2 V^{-1} s^{-1}

Mobility $\mu = |v_d|/E = (1.5 \times 10^{-4})/0.3 = 5 \times 10^{-4}$ m^2 V^{-1} s^{-1}.

4. The current sensitivity of a moving coil galvanometer can be increased by

(A) increasing the number of turns N of the coil (B) using a suspension (spring) of larger torsional constant k

(C) using a weaker radial magnetic field B (D) reducing the area A of the coil

Answer (1 mark)

(A) increasing the number of turns N of the coil

Current sensitivity $\phi/I = NAB/k$. It increases with N, A and B and decreases with k; only option (A) increases it.

5. A piece of iron (a ferromagnetic material) is heated to a sufficiently high temperature. Which of the following then happens?

(A) It becomes diamagnetic.
(B) It becomes paramagnetic.
(C) Its domains grow larger and it becomes a stronger magnet.
(D) Its susceptibility becomes negative.

Answer (1 mark)
(B) It becomes paramagnetic.
The ferromagnetic property depends on temperature: at a high enough temperature the domain structure disintegrates and the ferromagnet becomes a paramagnet (χ small and positive).

6. A straight metal rod of length 25 cm moves with a speed of 8 m s^{-1} perpendicular to its own length and perpendicular to a uniform magnetic field of 0.5 T. The emf induced between the ends of the rod is

(A) 0.1 V
(B) 1.0 V
(C) 10 V
(D) 100 V

Answer (1 mark)
(B) 1.0 V
Motional emf $\varepsilon = Blv = 0.5 \times 0.25 \times 8 = 1.0$ V.

7. A parallel plate capacitor is being charged. At an instant when the conduction current in the connecting wires is 0.8 A, the displacement current in the gap between the plates is

(A) zero
(B) 0.8 A
(C) 0.8 ε_0 A
(D) (0.8/ε_0) A

Answer (1 mark)
(B) 0.8 A
The displacement current $i_d = \varepsilon_0 \, d\Phi_E/dt$ in the gap equals the conduction current in the wires, so the total current is continuous.

8. An object is placed 20 cm in front of a concave mirror of focal length 15 cm. The image is

(A) 60 cm in front of the mirror, real, inverted and three times the size of the object
(B) 60 cm behind the mirror, virtual, erect and three times the size
(C) 8.6 cm in front of the mirror, real, inverted and diminished
(D) 8.6 cm behind the mirror, virtual and erect

Answer (1 mark)
(A) 60 cm in front of the mirror, real, inverted and three times the size of the object
$f = -15$ cm, $u = -20$ cm: $1/v = 1/f - 1/u = -1/15 + 1/20 = -1/60 \Rightarrow v = -60$ cm (in front, real). $m = -v/u = -(-60)/(-20) = -3$ (inverted, magnified 3 times).

9. In a Young's double-slit experiment, the fringe width is β. The screen is moved from 1.0 m to 1.5 m from the slits and the slit separation is changed from 0.30 mm to 0.60 mm, the light remaining the same. The new fringe width is

(A) 0.75 β
(B) 1.33 β
(C) 3 β
(D) 0.25 β

Answer (1 mark)
(A) 0.75 β
$\beta = \lambda D/d$. $\beta'/\beta = (D'/D) \times (d/d') = (1.5/1.0) \times (0.30/0.60) = 0.75$.

10. The ratio of the momentum of a photon of violet light of wavelength 400 nm to that of a photon of red light of wavelength 700 nm is

(A) 4 : 7 (B) 7 : 4

(C) 16 : 49 (D) 1 : 1

Answer (1 mark)

(B) 7 : 4

Photon momentum $p = h/\lambda$, so $p_{violet}/p_{red} = \lambda_{red}/\lambda_{violet} = 700/400 = 7 : 4$.

11. The radius of a nucleus of mass number 64 is 4.8 fm. The radius of a nucleus of mass number 216 is

(A) 16.2 fm (B) 7.2 fm

(C) 3.2 fm (D) 10.8 fm

Answer (1 mark)

(B) 7.2 fm

$R = R_0A^{1/3}$: $R_2/R_1 = (216/64)^{1/3} = 6/4 = 1.5 \Rightarrow R_2 = 1.5 \times 4.8 = 7.2$ fm.

12. A silicon diode is connected in forward bias in series with a 200 Ω resistor across a 4.7 V battery. Taking the voltage drop across the conducting diode as a constant 0.7 V, the current in the circuit is

(A) 23.5 mA (B) 20 mA

(C) 3.5 mA (D) zero

Answer (1 mark)

(B) 20 mA

$I = (4.7 – 0.7)/200 = 4.0/200$ A = 0.02 A = 20 mA.

13. For Questions 13 to 16, 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 Assertion (A).

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

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

(D) Both Assertion (A) and Reason (R) are false.

Assertion (A): Heavy nuclei such as ^{235}U release energy when they undergo fission.

Reason (R): The nuclear force between two nucleons is nearly independent of their electric charge.

(A) Both A and R true; R explains A (B) Both A and R true; R does not explain A

(C) A true, R false (D) Both A and R false

Answer (1 mark)

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

Fission releases energy because the medium-mass fragments have a larger binding energy per nucleon than the heavy nucleus. The charge-independence of the nuclear force is a true property, but it does not explain the energy release.

14. **Assertion (A):** The total energy of the electron in a Bohr orbit of a hydrogen atom is negative.
Reason (R): The kinetic energy of the electron in the orbit is greater than the magnitude of its electrostatic potential energy.

(A) Both A and R true; R explains A (B) Both A and R true; R does not explain A
(C) A true, R false (D) Both A and R false

Answer (1 mark)
(C) A is true, but R is false.
$K = e^2/(8\pi\varepsilon_0 r)$ and $U = -e^2/(4\pi\varepsilon_0 r)$, so $K = |U|/2$ (less than $|U|$) and $E = K + U = -e^2/(8\pi\varepsilon_0 r)$ is negative: the electron is bound to the nucleus.

15. **Assertion (A):** A pure (intrinsic) semiconductor behaves like an insulator at T = 0 K.
Reason (R): At T = 0 K the valence band is completely filled and the conduction band is empty, and no electron has the thermal energy needed to cross the energy gap.

(A) Both A and R true; R explains A (B) Both A and R true; R does not explain A
(C) A true, R false (D) Both A and R false

Answer (1 mark)
(A) Both A and R are true and R is the correct explanation of A.
With no electrons in the conduction band and no holes in the valence band, there are no charge carriers at 0 K, so there is no conduction.

16. **Assertion (A):** The capacitance of a parallel plate capacitor increases when the separation between its plates is decreased.
Reason (R): The capacitance of a capacitor depends on the charge given to it.

(A) Both A and R true; R explains A (B) Both A and R true; R does not explain A
(C) A true, R false (D) Both A and R false

Answer (1 mark)
(C) A is true, but R is false.
$C = \varepsilon_0 A/d$ increases as d decreases. C depends only on the geometry and the medium; it does not depend on the charge Q (the ratio Q/V stays constant).

SECTION B Questions 17 to 21 carry 2 marks each. **[10]**

17. An electric dipole consists of charges +5 nC and –5 nC separated by 4 mm. It is placed in a uniform electric field of 2×10^5 N C^{-1} with its dipole moment along the field.
(i) Find the dipole moment and the potential energy of the dipole in this position.
(ii) How much work must an external agent do to turn the dipole slowly so that its dipole moment points opposite to the field? What torque acts on the dipole when its dipole moment makes an angle of 30° with the field?

Answer (2 marks)
(i) $p = q \times 2a = 5 \times 10^{-9} \times 4 \times 10^{-3} = 2 \times 10^{-11}$ C m (from –q to +q).
$U = -pE\cos\theta$; $\theta = 0° \Rightarrow U = -pE = -2 \times 10^{-11} \times 2 \times 10^5 = -4 \times 10^{-6}$ J.
(ii) $W = U_{final} - U_{initial} = (-pE\cos 180°) - (-pE\cos 0°) = 2pE = 8 \times 10^{-6}$ J.
Torque $\tau = pE\sin\theta = 2 \times 10^{-11} \times 2 \times 10^5 \times \sin 30° = 4 \times 10^{-6} \times 0.5 = 2 \times 10^{-6}$ N m (tending to align p with E).
Marking: $p = 2 \times 10^{-11}$ C m – ½ · $U = -4 \times 10^{-6}$ J – ½ · $W = 2pE = 8 \times 10^{-6}$ J – ½ · $\tau = pE\sin 30° = 2 \times 10^{-6}$ N m – ½
Examiner tip: Write $U = -pE\cos\theta$ and find the work as the change in potential energy; the sign of U at $\theta = 0°$ is negative. Torque uses sin θ, energy uses cos θ.

18. An aluminium wire of cross-sectional area 1.0 mm^2 carries a current of 3.6 A. The drift speed of the free electrons in it is 1.25×10^{-4} m s^{-1}.

(i) Find the number density of free electrons in the wire.

(ii) The number of aluminium atoms per cubic metre is 6.0×10^{28}. How many free electrons does each atom contribute, on average?

Answer (2 marks)

(i) $I = neAv_d \Rightarrow n = I/(eAv_d) = 3.6/(1.6 \times 10^{-19} \times 1.0 \times 10^{-6} \times 1.25 \times 10^{-4})$

$= 3.6/(2.0 \times 10^{-29}) = 1.8 \times 10^{29}\ m^{-3}$

(ii) Free electrons per atom = $(1.8 \times 10^{29})/(6.0 \times 10^{28}) = 3$ (aluminium is trivalent).

Marking: $I = neAv_d$ and substitution – ½ · n = $1.8 \times 10^{29}\ m^{-3}$ – ½ · Ratio taken – ½; 3 electrons per atom – ½

Examiner tip: Convert 1.0 $mm^2 = 1.0 \times 10^{-6}\ m^2$; most mistakes here are in the area conversion.

19. (A) The current in a coil changes uniformly from 6 A to 2 A in 0.05 s, and an average emf of 40 V is induced in it.

(i) Find the self-inductance of the coil.

(ii) By how much does the magnetic energy stored in the coil change?

OR

(B) Define mutual inductance and state its SI unit. When the current in coil P is increased steadily from 0 to 5 A in 0.02 s, an emf of 1.5 V is induced in a nearby coil S. Find the mutual inductance of the pair. What emf would be induced in P if the same change of current were made in S instead?

Answer (2 marks)

(A) (i) $|\varepsilon| = L|\Delta I/\Delta t| \Rightarrow L = 40/(4/0.05) = 40/80 = 0.5$ H.

(ii) $U = \tfrac{1}{2}LI^2$. Change = $\tfrac{1}{2} \times 0.5 \times (2^2 - 6^2) = 0.25 \times (-32) = -8$ J, i.e. the stored energy decreases by 8 J.

OR

(B) Mutual inductance M of a pair of coils is the flux linkage with one coil per unit current in the other ($N_2\Phi_2 = MI_1$); equivalently, the emf induced in one coil per unit rate of change of current in the other ($\varepsilon_2 = -M\, dI_1/dt$). SI unit: henry (H).

$M = \varepsilon/(\Delta I/\Delta t) = 1.5/(5/0.02) = 1.5/250 = 6 \times 10^{-3}$ H = 6 mH.

Since $M_{12} = M_{21} = M$, the same rate of change of current (250 A s^{-1}) in S induces the same emf, 1.5 V, in P.

Marking: (A) L = 0.5 H – 1; energy decreases by 8 J – 1 · (B) Definition with unit – ½; M = 6 mH – 1; 1.5 V ($M_{12} = M_{21}$) – ½

Examiner tip: Use the change in current (4 A), not the final current; energy change uses I^2 values (36 and 4).

20. (A) A hydrogen atom is in the state n = 3.
(i) What minimum energy must be supplied to ionise it from this state?
(ii) How many different wavelengths can it emit while returning to the ground state? Which transition gives the longest wavelength?

OR

(B) Using Bohr's postulates, obtain the expression for the radius of the n^{th} orbit of the electron in a hydrogen atom.

Answer (2 marks)

(A) (i) $E_n = -13.6/n^2$ eV $\Rightarrow E_3 = -13.6/9 = -1.51$ eV. Ionisation energy from n = 3 = 0 – (–1.51) = 1.51 eV.

(ii) Possible transitions: 3 → 2, 3 → 1 and 2 → 1, i.e. 3 different wavelengths.

The longest wavelength corresponds to the smallest energy difference: 3 → 2 ($\Delta E = 1.89$ eV, $\lambda \approx 658$ nm).

OR

(B) For an electron of mass m and speed v_n in a circular orbit of radius r_n about the proton:

Electrostatic attraction provides the centripetal force: $mv_n^2/r_n = e^2/(4\pi\varepsilon_0 r_n^2)$ ...(1)

Bohr's quantisation condition: $mv_n r_n = nh/2\pi \Rightarrow v_n = nh/(2\pi m r_n)$ ...(2)

Substituting (2) in (1): $m \times n^2h^2/(4\pi^2m^2r_n^2) \times (1/r_n) = e^2/(4\pi\varepsilon_0 r_n^2)$

$\Rightarrow r_n = n^2h^2\varepsilon_0/(\pi me^2)$ (so $r_n \propto n^2$; for n = 1, $r_1 \approx 0.53$ Å).

Marking: (A) 1.51 eV – 1; three wavelengths – ½; 3 → 2 longest – ½ · (B) Centripetal force equation – ½; quantisation condition – ½; elimination and final expression – 1

Examiner tip: Ionisation energy from level n is $+13.6/n^2$ eV, not 13.6 eV; the longest wavelength comes from the smallest energy gap.

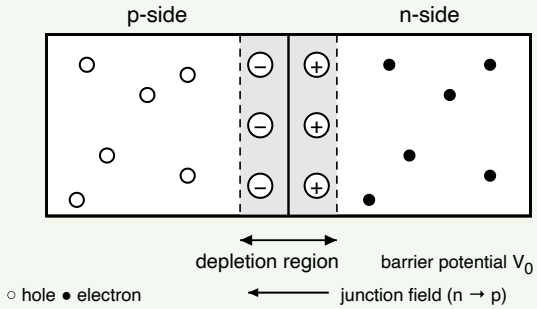
21. With the help of a labelled diagram, explain how the depletion region and the barrier potential are formed at a p-n junction.

Answer (2 marks)

At the junction the electron concentration is high on the n-side and the hole concentration is high on the p-side. Hence electrons diffuse from n to p and holes diffuse from p to n (diffusion current).

An electron leaving the n-side leaves behind an immobile ionised donor (+ ion); a hole leaving the p-side leaves behind an immobile ionised acceptor (– ion). So a thin layer of positive space charge forms on the n-side and of negative space charge on the p-side, near the junction. This layer, depleted of free charge carriers, is the depletion region.

The space charge sets up an electric field from the n-side to the p-side (and a potential difference) across the junction, which opposes further diffusion and drives minority carriers across (drift current). Diffusion continues until the drift current equals the diffusion current; the potential difference then established across the junction is the barrier potential (about 0.6–0.7 V for Si).



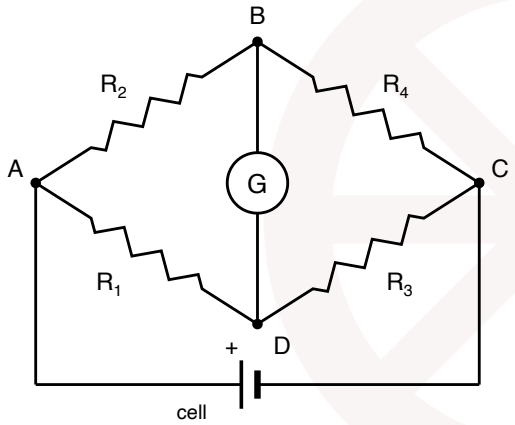
Marking: Diagram with immobile ions and depletion region labelled – ½ · Diffusion of majority carriers leaving behind ions – ½ · Junction field/drift opposing diffusion – ½ · Equilibrium ⇒ barrier potential – ½

Examiner tip: Mention that the ions left behind are immobile, and show the field direction from n to p.

SECTION C Questions 22 to 28 carry 3 marks each. **[21]**

22. (i) In the Wheatstone bridge shown, a cell of negligible internal resistance is connected between A and C, and a galvanometer G between B and D. Using Kirchhoff's rules, obtain the condition for the bridge to be balanced (no current through G).

(ii) In such a bridge $R_1 = 12\ \Omega$ (arm AD), $R_2 = 18\ \Omega$ (arm AB), $R_3 = 8\ \Omega$ (arm DC) and $R_4 = 15\ \Omega$ (arm BC). The bridge is not balanced. What resistance must be connected in parallel with R_4 to balance it?



For visually impaired candidates: In the Wheatstone bridge ABCD, the cell is connected across A and C and the galvanometer across B and D; R_1 is in arm AD, R_2 in arm AB, R_3 in arm DC and R_4 in arm BC.

Answer (3 marks)

(i) Let I_1 flow through R_1 (A → D), I_2 through R_2 (A → B), I_3 through R_3 (D → C), I_4 through R_4 (B → C). At balance $I_g = 0$.

Junction rule at D and B: $I_1 = I_3$ and $I_2 = I_4$.

Loop rule for loop ADBA: $-I_1R_1 + 0 + I_2R_2 = 0 \Rightarrow I_1/I_2 = R_2/R_1$.

Loop rule for loop CBDC (using $I_3 = I_1$, $I_4 = I_2$): $I_2R_4 + 0 - I_1R_3 = 0 \Rightarrow I_1/I_2 = R_4/R_3$.

Hence the balance condition: $R_2/R_1 = R_4/R_3$.

(ii) For balance the resistance in arm BC must be $R_4' = R_3R_2/R_1 = 8 \times 18/12 = 12\ \Omega$.

$R_4 = 15\ \Omega$ must be reduced to $12\ \Omega$ by a resistance X in parallel: $1/12 = 1/15 + 1/X \Rightarrow 1/X = 1/12 - 1/15 = 1/60 \Rightarrow X = 60\ \Omega$.

Marking: Junction rule ($I_1 = I_3$, $I_2 = I_4$) – ½ · Two loop equations – ½ + ½ · Balance condition – ½ · Required R_4' = 12 Ω – ½; X = 60 Ω in parallel – ½

Examiner tip: Write the loop equations with $I_g = 0$ clearly; in (ii) first find what the fourth arm should be, then the parallel resistance.

23. A coil draws a current of 2.0 A when connected to a 12 V dc supply. When the same coil is connected to a 12 V (rms), 50 Hz ac supply, it draws a current of 1.2 A (rms).
(i) Why does the coil draw a smaller current from the ac supply?
(ii) Find the resistance and the self-inductance of the coil.
(iii) Find the power factor and the average power consumed on the ac supply.

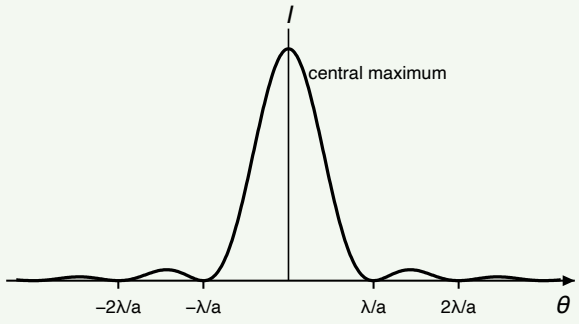
Answer (3 marks)
(i) With dc, only the resistance R opposes the current. With ac, the inductance also offers inductive reactance $X_L = \omega L$, so the impedance $Z = \sqrt{(R^2 + X_L^2)}$ is greater than R and the current is smaller.
(ii) $R = V/I$ (dc) $= 12/2.0 = 6\ \Omega$.
$Z = V_{rms}/I_{rms} = 12/1.2 = 10\ \Omega \Rightarrow X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(100 - 36)} = 8\ \Omega$.
$L = X_L/(2\pi\nu) = 8/(2\pi \times 50) = 0.08/\pi\ \text{H} \approx 0.0255\ \text{H} \approx 25.5\ \text{mH}$.
(iii) Power factor $\cos\phi = R/Z = 6/10 = 0.6$.
$P = V_{rms}I_{rms}\cos\phi = 12 \times 1.2 \times 0.6 = 8.64\ \text{W}$ (check: $I^2R = 1.44 \times 6 = 8.64\ \text{W}$).
Marking: (i) Reactance adds to the opposition – ½ · (ii) R = 6 Ω – ½; Z = 10 Ω, X_L = 8 Ω – ½; L = 0.08/π H ≈ 25.5 mH – ½ · (iii) cos ϕ = 0.6 – ½; P = 8.64 W – ½
Examiner tip: Get R from the dc data and Z from the ac data; do not divide the ac voltage by the dc current.

24. (i) Name the electromagnetic radiation that
(a) is produced when high-energy electrons strike a metal target,
(b) is emitted by hot bodies and is used in physical therapy,
(c) is used in radar systems for aircraft navigation.
Arrange these three radiations in increasing order of frequency.
(ii) A medium-wave radio station broadcasts at a frequency of 750 kHz. Find the wavelength of these waves.
(iii) At a certain place the amplitude of the electric field of these radio waves is 0.12 V m^{-1}. Find the amplitude of the magnetic field there.

Answer (3 marks)
(i) (a) X-rays (b) infrared waves (c) microwaves.
Increasing order of frequency: microwaves < infrared < X-rays.
(ii) $\lambda = c/\nu = (3 \times 10^8)/(750 \times 10^3) = 400\ \text{m}$.
(iii) $B_0 = E_0/c = 0.12/(3 \times 10^8) = 4 \times 10^{-10}\ \text{T}$.
Marking: (i) Three names – ½ each; correct order – ½ · (ii) λ = 400 m – ½ · (iii) $B_0 = 4 \times 10^{-10}$ T – ½
Examiner tip: Remember $E_0/B_0 = c$ for an electromagnetic wave in vacuum; convert kHz to Hz.

25. A student shines a laser pointer of wavelength λ normally on a narrow single slit of width a and observes the diffraction pattern on a distant wall.
(i) Sketch the variation of intensity with the angle θ in this pattern, marking the angular positions of the first two minima on either side of the centre.
(ii) The student now replaces the single slit by two such slits close together. Describe how the pattern on the wall changes, and state the role played by single-slit diffraction in the new pattern.
(iii) The dark bands of the pattern receive almost no light. Does this mean that light energy is destroyed there? Explain.

Answer (3 marks)
(i) Sketch (see figure): a broad, bright central maximum at θ = 0, with minima (zero intensity) at θ = ±λ/a, ±2λ/a, …; between the minima lie secondary maxima (near θ = ±3λ/2a, ±5λ/2a, …) whose intensity becomes weaker and weaker away from the centre.
(ii) The pattern now shows many narrow, equally spaced bright and dark interference fringes (Young's fringes). Their brightness is not uniform: the pattern is a superposition of the double-slit interference fringes and the single-slit diffraction pattern of each slit, so the fringes are bright within the central diffraction maximum and fade (following the single-slit envelope) away from it.
(iii) No. In interference and diffraction light energy is only redistributed: the energy missing from the dark bands appears in the bright bands, so there is no gain or loss of energy (energy is conserved).



Marking: (i) Sketch with broad central maximum and weaker secondary maxima – ½; minima at ±λ/a, ±2λ/a marked – ½ · (ii) Equally spaced interference fringes – ½; superposition with (envelope of) single-slit diffraction – ½ · (iii) No – energy is redistributed, conserved – 1
Examiner tip: Mark the minima at θ = nλ/a (not at the secondary maxima), and draw the central maximum twice as wide as the others and much brighter.

26. (A) When ultraviolet light of wavelength 310 nm falls on a metal surface, the stopping potential of the emitted photoelectrons is found to be 1.8 V.

(i) Find the energy of each incident photon in eV and the work function of the metal.

(ii) Find the maximum speed of the photoelectrons.

(iii) Find the threshold wavelength of the metal. Will red light of wavelength 650 nm eject photoelectrons from it?

OR

(B) (i) Draw graphs showing the variation of photoelectric current with the collector plate (anode) potential for two radiations of frequencies ν_1 and ν_2 ($\nu_2 > \nu_1$) of the same intensity. Why is the stopping potential different for the two radiations?

(ii) Draw the graph of stopping potential V_0 against frequency ν for two metals A and B whose threshold frequencies are $\nu_{0A} < \nu_{0B}$. What does the slope of each line represent? Are the two lines parallel?

Answer (3 marks)

(A) (i) Photon energy $E = hc/\lambda = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(310 \times 10^{-9})$ J $= 6.42 \times 10^{-19}$ J $= 6.42/1.6$ eV ≈ 4.0 eV.

$K_{max} = eV_0 = 1.8$ eV. Einstein's equation: $\phi_0 = E - K_{max} = 4.0 - 1.8 = 2.2$ eV.

(ii) $\tfrac{1}{2}mv_{max}^2 = 1.8 \times 1.6 \times 10^{-19}$ J $= 2.88 \times 10^{-19}$ J

$v_{max} = \sqrt{(2 \times 2.88 \times 10^{-19}/9.1 \times 10^{-31})} = \sqrt{(6.33 \times 10^{11})} \approx 8.0 \times 10^{5}$ m s^{-1}.

(iii) $\lambda_0 = hc/\phi_0 = (6.63 \times 10^{-34} \times 3 \times 10^{8})/(2.2 \times 1.6 \times 10^{-19}) \approx 5.65 \times 10^{-7}$ m $= 565$ nm.

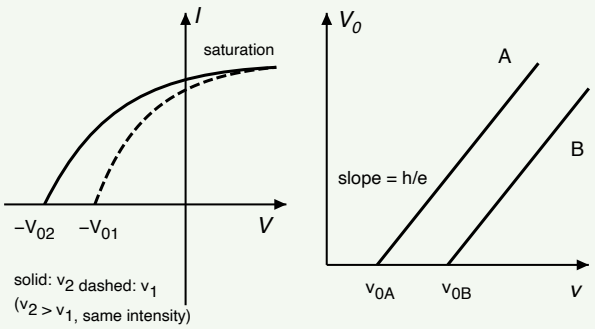
650 nm $> \lambda_0$ (photon energy ≈ 1.9 eV < 2.2 eV), so red light will **not** eject photoelectrons, however intense it is.

OR

(B) (i) Graph: both curves rise and reach the same saturation current; each falls to zero at a negative (retarding) potential, the curve for ν_2 at a more negative value ($-V_{02}$) than that for ν_1 ($-V_{01}$).

Reason: $eV_0 = K_{max} = h\nu - \phi_0$. The higher-frequency photons give the electrons a larger maximum kinetic energy, so a larger retarding potential is needed to stop them.

(ii) Graph: two straight lines cutting the ν-axis at ν_{0A} and ν_{0B}. From $V_0 = (h/e)\nu - \phi_0/e$, the slope of each line is h/e, a universal constant; so the lines are parallel (only the intercepts, which depend on the work functions, differ).



Marking: (A) Photon energy 4.0 eV – ½; $K_{max} = 1.8$ eV and $\phi_0 = 2.2$ eV – ½; $v_{max} \approx 8.0 \times 10^{5}$ m s^{-1} – 1; $\lambda_0 \approx 565$ nm (562–565 nm accepted) – ½; no emission for 650 nm – ½ · (B) (i) Graph – 1; reason – ½. (ii) Graph – 1; slope h/e and parallel – ½

Examiner tip: Use the photon energy in joules to find the speed; whether emission occurs depends on frequency (wavelength), not on intensity.

27. In a fusion reactor such as ITER (in which India is a partner), deuterium and tritium nuclei fuse:

$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + 17.6\ MeV$

Tritium is very scarce in nature, so fusion power plants are planned to produce ('breed') it in a 'blanket' containing lithium around the hot fuel, where the neutrons from fusion are absorbed by lithium-6:

$^{6}_{3}Li + {}^{1}_{0}n \rightarrow {}^{4}_{2}He + {}^{3}_{1}H$

(i) Calculate the energy released in one such lithium reaction.

(ii) Compare the energy released per nucleon taking part in the deuterium–tritium fusion reaction with that in the fission of ^{235}U (about 200 MeV per fission).

(iii) The deuterium–tritium fuel must be heated to an extremely high temperature for fusion to occur, but the lithium reaction needs no such heating. Explain why.

Given: $m(^{6}_{3}Li) = 6.015122$ u, $m(^{4}_{2}He) = 4.002603$ u, $m(^{3}_{1}H) = 3.016049$ u, $m_n = 1.008665$ u, 1 u = 931.5 MeV/c^2.

Answer (3 marks)

(i) Mass of reactants = 6.015122 + 1.008665 = 7.023787 u

Mass of products = 4.002603 + 3.016049 = 7.018652 u

Mass defect Δm = 7.023787 – 7.018652 = 0.005135 u

$Q = \Delta m \times 931.5$ MeV = 0.005135 × 931.5 ≈ 4.78 MeV released (Q > 0: exothermic).

(ii) Fusion: 17.6 MeV shared among 5 nucleons (2 + 3) ⇒ ≈ 3.5 MeV per nucleon.

Fission: 200 MeV among 236 nucleons (^{235}U + n) ⇒ ≈ 0.85 MeV per nucleon.

So the deuterium–tritium fusion releases about four times as much energy per nucleon as fission.

(iii) Deuterium and tritium nuclei are both positively charged and repel each other (Coulomb barrier). To come close enough (a few fm) for the short-range attractive nuclear force to act, they must have very large kinetic energy, which is obtained by heating the fuel to about 10^8 K (thermonuclear fusion).

The neutron is uncharged, so there is no Coulomb repulsion between it and the lithium nucleus; even a slow neutron can reach the nucleus and react, so no heating is needed.

Marking: (i) Mass defect 0.005135 u – ½; Q ≈ 4.78 MeV – ½ · (ii) 3.5 MeV vs 0.85 MeV per nucleon with comparison – 1 · (iii) Coulomb repulsion between D and T to be overcome – ½; neutron uncharged, so no Coulomb barrier – ½

Examiner tip: Use the same kind of masses (atomic masses) on both sides and subtract carefully to six decimal places; a slip of 0.001 u changes Q by almost 1 MeV.

28. (i) A crystal of pure germanium is doped with antimony (a pentavalent element). What type of extrinsic semiconductor is obtained? Draw its energy band diagram and mark the energy level introduced by the dopant.

(ii) In the doped crystal the concentration of antimony atoms is 4.8×10^{22} m^{-3}. The intrinsic carrier concentration of germanium at room temperature is 2.4×10^{19} m^{-3}. Find the electron and hole concentrations, assuming every antimony atom is ionised.

(iii) Why is the hole concentration in the doped crystal much smaller than the intrinsic carrier concentration of germanium?

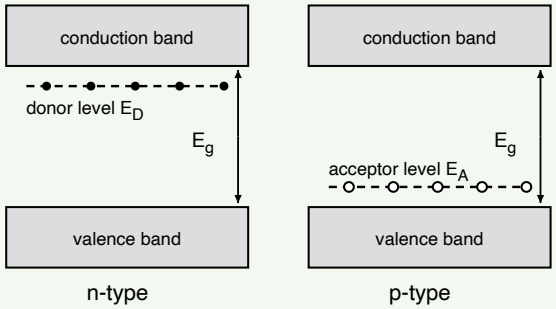
Answer (3 marks)

(i) n-type semiconductor (antimony is a donor). Energy band diagram: the donor energy level E_D lies slightly below the bottom of the conduction band; electrons from it are easily excited into the conduction band at room temperature. (For comparison, a p-type material has an acceptor level E_A just above the top of the valence band.)

(ii) $n_e \approx N_D = 4.8 \times 10^{22}\ m^{-3}$ ($N_D \gg n_i$).

$n_e n_h = n_i^2 \Rightarrow n_h = (2.4 \times 10^{19})^2/(4.8 \times 10^{22}) = (5.76 \times 10^{38})/(4.8 \times 10^{22}) = 1.2 \times 10^{16}\ m^{-3}$.

(iii) The donors supply a very large number of free electrons (majority carriers). The thermally generated holes therefore have a much greater chance of meeting electrons and recombining, so the hole (minority carrier) concentration falls far below n_i (consistent with $n_e n_h = n_i^2$).



Marking: (i) n-type – ½; band diagram with donor level just below conduction band – ½ · (ii) $n_e = 4.8 \times 10^{22}\ m^{-3}$ – ½; $n_e n_h = n_i^2$ – ½; $n_h = 1.2 \times 10^{16}\ m^{-3}$ – ½ · (iii) Increased recombination with the abundant electrons – ½

Examiner tip: Majority carriers ≈ dopant concentration; use $n_e n_h = n_i^2$ for the minority carriers, which are fewer than in the pure crystal.

SECTION D Questions 29 and 30 are case study based questions carrying 4 marks each. **[8]**

29. Read the following passage and answer the questions that follow.

The Koyna Hydroelectric Project in Satara district is one of the largest hydroelectric power stations in Maharashtra. Water from the Koyna dam flows down through tunnels and turns turbines, each coupled to an ac generator. In a generator, a coil and a magnetic field rotate relative to each other, so the magnetic flux linked with the coil changes continuously and an emf $e = NBA\omega \sin \omega t$ is induced, where ωt is the angle between the normal to the coil and the magnetic field. Suppose one generator gives an alternating voltage of rms value 11 kV at 50 Hz. The transformers have cores made of thin laminated sheets of soft iron. Before the power is sent over long transmission lines to cities such as Pune and Mumbai, transformers step this voltage up to 220 kV.

(i) The emf induced in the generator coil is maximum at the instant when

(A) the plane of the coil is perpendicular to the magnetic field

(B) the plane of the coil is parallel to the magnetic field

(C) the magnetic flux linked with the coil is maximum

(D) the coil is momentarily at rest

(ii) The core of a transformer is laminated mainly to

(A) reduce the flux leakage between the coils

(B) reduce the energy lost due to eddy currents in the core

(C) reduce the resistance of the windings

(D) increase the magnetic flux produced by the primary

(iii) For an ideal transformer that steps 11 kV up to 220 kV, the ratio of the number of turns N_s/N_p and the ratio of the currents I_s/I_p are respectively

(A) 20 and 1/20

(B) 20 and 20

(C) 1/20 and 20

(D) 1/20 and 1/20

(iv) The same electrical power is sent through the same transmission line, once at 11 kV and once at 220 kV. Find the ratio of the power lost as heat in the line at 220 kV to that at 11 kV.

Answer (4 marks)

(i) (B) The plane of the coil is parallel to the magnetic field ($\omega t = 90°$, $\sin \omega t = 1$). The flux is then zero but changing fastest.

(ii) (B) The alternating flux induces eddy currents in the iron core, which heat it; thin insulated laminations cut down these currents and the energy loss.

(iii) (A) 20 and 1/20. $N_s/N_p = V_s/V_p = 220/11 = 20$; for an ideal transformer $V_pI_p = V_sI_s \Rightarrow I_s/I_p = 1/20$.

(iv) For the same power P, the line current $I = P/V$. Heat loss $= I^2R \propto 1/V^2$.

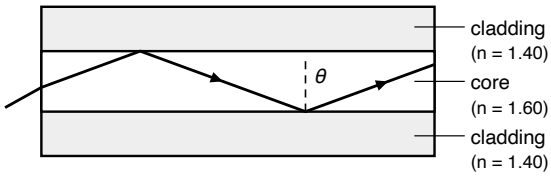
Loss at 220 kV : loss at 11 kV $= (11/220)^2 = 1 : 400$.

Marking: (i) – 1 · (ii) – 1 · (iii) – 1 · (iv) $I = P/V$ and loss $\propto 1/V^2$ – ½; 1 : 400 – ½

Examiner tip: The emf is maximum when the flux is zero, not when it is maximum – the emf depends on the rate of change of flux.

30. Read the following passage and answer the questions that follow.

Under the BharatNet project, optical fibre cables are being laid to bring high-speed internet to gram panchayats across India, including villages in Maharashtra. An optical fibre has a thin glass core surrounded by a cladding of slightly lower refractive index. Light entering one end strikes the core–cladding boundary at an angle larger than the critical angle, is totally internally reflected again and again, and so travels along the fibre with very little loss, even when the fibre is gently bent. In the fibre shown in the figure, the core has refractive index 1.60 and the cladding 1.40.



θ > C at every reflection (not to scale)

(i) For total internal reflection to take place at the core–cladding boundary, light must travel

(A) from the cladding to the core, with angle of incidence greater than the critical angle

(B) from the core to the cladding, with angle of incidence greater than the critical angle

(C) from the core to the cladding, with angle of incidence less than the critical angle

(D) from the cladding to the core, with angle of incidence less than the critical angle

(ii) The critical angle C at the core–cladding boundary is given by

(A) $\sin C = 7/8$

(B) $\sin C = 8/7$

(C) $\sin C = 5/8$

(D) $\sin C = 1/1.60$

(iii) The speed of light in the core is

(A) 1.875×10^8 m s^{-1}

(B) 2.14×10^8 m s^{-1}

(C) 4.8×10^8 m s^{-1}

(D) 3.0×10^8 m s^{-1}

(iv) A ray travelling in the core strikes the core–cladding boundary at an angle of incidence of 55°. Will it be totally internally reflected? Justify. ($\sin 55° = 0.82$)

For visually impaired candidates: the figure shows a ray zig-zagging along the core of a fibre, reflected at the core–cladding boundary; the core (n = 1.60) is surrounded by the cladding (n = 1.40).

Answer (4 marks)

(i) (B) TIR occurs only when light goes from the optically denser medium (core) to the rarer medium (cladding) and the angle of incidence exceeds the critical angle.

(ii) (A) $\sin C = n_{cladding}/n_{core} = 1.40/1.60 = 7/8 = 0.875$.

(iii) (A) $v = c/n = (3 \times 10^8)/1.60 = 1.875 \times 10^8$ m s^{-1}.

(iv) No. $\sin 55° = 0.82 < \sin C = 0.875$, so 55° is less than the critical angle (C ≈ 61°). The ray is partly refracted into the cladding (only partial reflection), so it is not totally internally reflected.

Marking: (i) – 1 · (ii) – 1 · (iii) – 1 · (iv) Comparison of sin 55° (0.82) with sin C (0.875) – ½; conclusion (not TIR) – ½

Examiner tip: For an interface between two media, $\sin C = n_{rarer}/n_{denser}$, not 1/n.

SECTION E Questions 31 to 33 carry 5 marks each. **[15]**

31. (A) (i) State Gauss's law in electrostatics. Using it, derive an expression for the electric field due to a uniformly charged infinite plane sheet of surface charge density σ.

(ii) Two large, thin, parallel plane sheets A and B are placed in air, with A to the left of B. Sheet A carries a uniform surface charge density of +17.7 nC m^{-2} and sheet B carries –8.85 nC m^{-2}. Find the magnitude and direction of the electric field (a) to the left of A, (b) between the sheets and (c) to the right of B. ($\varepsilon_0 = 8.85 \times 10^{-12}$ C^2 N^{-1} m^{-2})

OR

(B) (i) Derive an expression for the electric potential at a distance r from a point charge q. Draw graphs showing how the potential V and the field E vary with r for a positive point charge.

(ii) Point charges +2 μC and –3 μC are held fixed at points P and Q, 30 cm apart, in air.

(a) Find the electrostatic potential energy of this system of two charges.

(b) How much work must an external agent do to bring a third charge of +4 μC from infinity to the point R such that PQR is an equilateral triangle of side 30 cm?

(c) What is the total potential energy of the three-charge system? How much work is needed to separate all three charges to infinity?

(Take $1/4\pi\varepsilon_0 = 9 \times 10^9$ N m^2 C^{-2}.)

Answer (5 marks)

(A) (i) Gauss's law: the total electric flux through any closed surface equals $1/\varepsilon_0$ times the total charge enclosed by it: $\oint \mathbf{E}\cdot d\mathbf{S} = q_{enclosed}/\varepsilon_0$.

Derivation: by symmetry, the field of an infinite sheet is perpendicular to it, pointing away on both sides (σ > 0), with the same magnitude at equal distances. Take a Gaussian cylinder of cross-sectional area A whose axis is normal to the sheet and which extends equally on both sides.

Flux through the curved surface = 0 (E is parallel to it). Flux through each flat end = EA, so total flux = 2EA.

Charge enclosed = σA. Gauss's law: $2EA = \sigma A/\varepsilon_0 \Rightarrow E = \sigma/(2\varepsilon_0)$, directed normally away from the sheet (towards it if σ < 0); independent of distance.

(ii) Field due to A: $E_A = \sigma_A/2\varepsilon_0 = (17.7 \times 10^{-9})/(2 \times 8.85 \times 10^{-12}) = 1000$ N C^{-1}, pointing away from A.

Field due to B: $E_B = (8.85 \times 10^{-9})/(2 \times 8.85 \times 10^{-12}) = 500$ N C^{-1}, pointing towards B (negative sheet).

(a) Left of A: E_A to the left (1000), E_B to the right (500) ⇒ 500 N C^{-1} towards the left.

(b) Between: E_A to the right (1000), E_B to the right (500) ⇒ 1500 N C^{-1} towards the right (from A to B).

(c) Right of B: E_A to the right (1000), E_B to the left (500) ⇒ 500 N C^{-1} towards the right.

OR

(B) (i) The potential at P is the work done by an external force in bringing a unit positive test charge from infinity to P. At distance r′ the force on a unit positive charge is $q/(4\pi\varepsilon_0 r'^2)$ away from q, so the external force is equal and opposite.

$V = -\int_{\infty}^{r} q/(4\pi\varepsilon_0 r'^2)\, dr' = [q/(4\pi\varepsilon_0 r')]_{\infty}^{r} = q/(4\pi\varepsilon_0 r)$.

Graphs: $V \propto 1/r$ and $E \propto 1/r^2$; both fall as r increases, E falling more steeply.

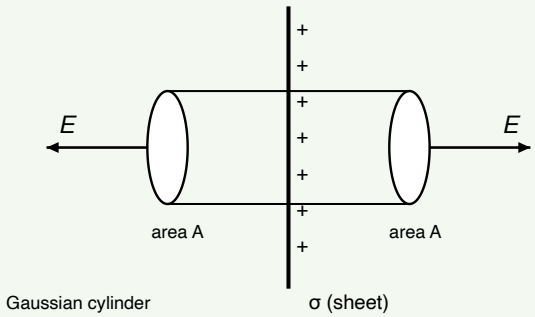
(ii) (a) $U_{PQ} = kq_Pq_Q/r = 9 \times 10^9 \times (2 \times 10^{-6})(-3 \times 10^{-6})/0.30 = -0.18$ J.

(b) Potential at R due to P and Q: $V_R = k(q_P + q_Q)/0.30 = 9 \times 10^9 \times (-1 \times 10^{-6})/0.30 = -3 \times 10^4$ V.

Work by external agent $W = q_R V_R = 4 \times 10^{-6} \times (-3 \times 10^4) = -0.12$ J (the field does 0.12 J of work; the agent has to hold the charge back).

(c) $U_{total} = -0.18 + (-0.12) = -0.30$ J.

Work needed to separate all charges to infinity = $0 - U_{total} = +0.30$ J.



Marking: (A) Statement of Gauss's law – 1; Gaussian cylinder and flux 2EA – 1; $E = \sigma/2\varepsilon_0$ – 1; fields 500 N C^{-1} (left), 1500 N C^{-1} (A to B), 500 N C^{-1} (right) with directions – 2 · (B) Derivation of $V = q/4\pi\varepsilon_0 r$ – 1½; graphs – ½; $U_{PQ} = -0.18$ J – 1; $W = -0.12$ J – 1; $U_{total} = -0.30$ J and +0.30 J to separate – 1

Examiner tip: For the two sheets, find each sheet's field separately (away from +, towards –) and add them with directions in each region; keep the signs of the charges in $U = kq_1q_2/r$.

32. (A) (i) Using the Biot–Savart law, derive an expression for the magnetic field at a point on the axis of a circular loop of radius R carrying a current I, at a distance x from its centre. Hence write the field at the centre of the loop.

(ii) A circular coil of 20 turns and radius 4.0 cm carries a current of 1.5 A. Find the magnetic field (a) at its centre and (b) at a point on its axis 3.0 cm from the centre.

OR

(B) (i) State Ampere's circuital law. Using it, obtain the magnetic field at a distance r from an infinitely long straight wire carrying a steady current I.

(ii) A beam of protons moving with speed 4×10^5 m s^{-1} passes undeflected through a region in which a uniform magnetic field of 0.05 T and a uniform electric field are perpendicular to each other and to the beam.

(a) Find the magnitude of the electric field.

(b) If the electric field is switched off, find the radius of the circular path of the protons.

(c) Does the kinetic energy of the protons change while they move in the magnetic field alone? Give a reason.

Answer (5 marks)

(A) (i) Consider a conducting element dl at the top of the loop; its distance from the axial point P is r, with $r^2 = x^2 + R^2$. dl is perpendicular to r, so by the Biot–Savart law

$dB = (\mu_0/4\pi)\, I\, dl/r^2 = (\mu_0/4\pi)\, I\, dl/(x^2 + R^2)$, directed perpendicular to the plane of dl and r.

dB has a component dB_x along the axis and a component $dB_\perp$ perpendicular to it. The perpendicular components due to diametrically opposite elements cancel; the axial components add.

$dB_x = dB \cos\theta$, where $\cos\theta = R/(x^2 + R^2)^{1/2}$.

$B = \oint dB_x = (\mu_0 IR/4\pi(x^2 + R^2)^{3/2}) \oint dl = (\mu_0 IR/4\pi(x^2 + R^2)^{3/2}) \times 2\pi R$

$\Rightarrow \mathbf{B} = \mu_0 IR^2/[2(x^2 + R^2)^{3/2}]$ along the axis (for N turns multiply by N).

At the centre (x = 0): $B_0 = \mu_0 I/2R$.

(ii) (a) $B_0 = \mu_0 NI/2R = (4\pi \times 10^{-7} \times 20 \times 1.5)/(2 \times 0.04) = 1.5\pi \times 10^{-4}$ T $\approx 4.71 \times 10^{-4}$ T.

(b) $x^2 + R^2 = (3^2 + 4^2)$ cm^2 = 25 cm^2 $\Rightarrow (x^2 + R^2)^{3/2} = 125$ cm^3.

$B = B_0 \times R^3/(x^2 + R^2)^{3/2} = 4.71 \times 10^{-4} \times 64/125 = 4.71 \times 10^{-4} \times 0.512 \approx 2.41 \times 10^{-4}$ T, along the axis.

OR

(B) (i) Ampere's circuital law: the line integral of **B** around any closed loop equals μ_0 times the total current threading the surface bounded by the loop: $\oint \mathbf{B}\cdot d\mathbf{l} = \mu_0 I$.

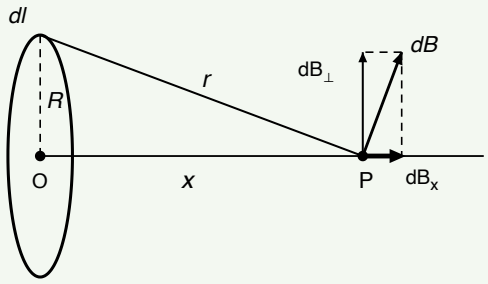
For a long straight wire take a circular Amperian loop of radius r centred on the wire, in a plane perpendicular to it. By symmetry B has the same magnitude everywhere on the loop and is tangential to it.

$\oint \mathbf{B}\cdot d\mathbf{l} = B \times 2\pi r = \mu_0 I \Rightarrow B = \mu_0 I/(2\pi r)$; the field lines are concentric circles (direction by the right-hand rule).

(ii) (a) No deflection $\Rightarrow$ the net (Lorentz) force $F = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ is zero: the electric force qE balances the magnetic force qvB ($v \perp B$). So $qE = qvB \Rightarrow E = vB = 4 \times 10^5 \times 0.05 = 2 \times 10^4$ V m^{-1} (N C^{-1}).

(b) $r = mv/(qB) = (1.7 \times 10^{-27} \times 4 \times 10^5)/(1.6 \times 10^{-19} \times 0.05) = (6.8 \times 10^{-22})/(8 \times 10^{-21}) = 0.085$ m = 8.5 cm.

(c) No. The magnetic force $q(\mathbf{v} \times \mathbf{B})$ is always perpendicular to the velocity, so it does no work; the speed and kinetic energy remain constant (only the direction changes).



I flows in the loop of radius R; P on the axis at distance x

Marking: (A) Diagram and dB from Biot–Savart law – 1; cancellation of perpendicular components and $dB_x = dB \cos\theta$ – 1; final expression and B at centre – 1; (ii)(a) 4.71×10^{-4} T – 1; (b) 2.41×10^{-4} T – 1 · (B) Statement – 1; derivation $B = \mu_0 I/2\pi r$ – 1; E = 2×10^4 V m^{-1} – 1; r = 8.5 cm – 1; KE unchanged with reason – 1

Examiner tip: State clearly why the perpendicular components cancel; in (ii)(b) use $R^3/(x^2 + R^2)^{3/2} = 64/125$ to avoid long arithmetic.

33. (A) (i) With the help of a ray diagram, derive the mirror equation $1/v + 1/u = 1/f$ for a concave mirror forming a real image of an object placed beyond its centre of curvature.
(ii) A dentist holds a small concave mirror of focal length 2.0 cm at a distance of 1.5 cm from a tooth. Find the position, nature and magnification of the image.

OR

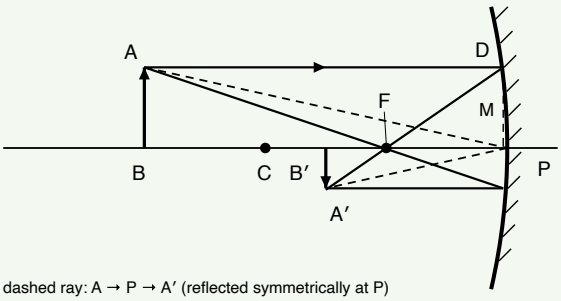
(B) (i) Two thin lenses of focal lengths f_1 and f_2 are placed in contact. Derive an expression for the focal length F of the combination and write the power of the combination in terms of the powers of the two lenses.
(ii) An object is placed 30 cm in front of a thin convex lens of focal length 20 cm.
(a) Find the position and magnification of the image.
(b) A second thin convex lens of focal length 60 cm is now placed in contact with the first lens. Find the focal length and power of the combination.
(c) Find the position and magnification of the image now formed by the combination.

Answer (5 marks)

(A) (i) Ray diagram: object AB beyond C; a ray from A parallel to the principal axis strikes the mirror at D and passes through F after reflection; a ray from A through F returns parallel; the reflected rays meet at A′, giving a real inverted image A′B′ between F and C. M is the foot of the perpendicular from D on the axis.
For small apertures M is very close to the pole P, so MF ≈ PF and DM ≈ AB.
△A′B′F ~ △DMF (vertically opposite angles at F, right angles at B′ and M): B′A′/MD = B′F/FM ⇒ B′A′/BA = B′F/FP ...(1) (since MD = BA, FM ≈ FP)
△A′B′P ~ △ABP (angle of incidence = angle of reflection at P): B′A′/BA = B′P/BP ...(2)
From (1) and (2): B′F/FP = B′P/BP ⇒ (B′P – FP)/FP = B′P/BP
Cartesian sign convention: B′P = –v, FP = –f, BP = –u:
(–v + f)/(–f) = (–v)/(–u) ⇒ (v – f)/f = v/u ⇒ v/f – 1 = v/u
Dividing by v: 1/f – 1/v = 1/u ⇒ 1/v + 1/u = 1/f.
(ii) f = –2.0 cm, u = –1.5 cm. 1/v = 1/f – 1/u = –1/2.0 + 1/1.5 = (–3 + 4)/6 = 1/6 ⇒ v = +6.0 cm.
The image is 6.0 cm behind the mirror: virtual and erect.
m = –v/u = –6.0/(–1.5) = +4: the image is magnified four times (this is why dentists use a concave mirror).

OR

(B) (i) Let an object O be at distance u from the first lens L_1. L_1 alone forms an image I_1 at v_1:
$1/v_1 – 1/u = 1/f_1$ ...(1)
I_1 acts as the object for the second lens L_2 (in contact, so the object distance is v_1), which forms the final image at v: $1/v – 1/v_1 = 1/f_2$ ...(2)
Adding (1) and (2): $1/v – 1/u = 1/f_1 + 1/f_2$.
If the combination is treated as a single lens of focal length F, $1/v – 1/u = 1/F$, so $1/F = 1/f_1 + 1/f_2$; in terms of power, $P = P_1 + P_2$.
(ii) (a) u = –30 cm, f = +20 cm: 1/v = 1/f + 1/u = 1/20 – 1/30 = 1/60 ⇒ v = +60 cm (real image on the other side).
m = v/u = 60/(–30) = –2 (inverted, twice the size).
(b) 1/F = 1/20 + 1/60 = (3 + 1)/60 = 1/15 ⇒ F = +15 cm (converging). P = 1/F = 100/15 D ≈ +6.7 D (= 5 D + 1.67 D).
(c) u = –30 cm, F = +15 cm: 1/v = 1/F + 1/u = 1/15 – 1/30 = 1/30 ⇒ v = +30 cm (real, on the other side). m = v/u = 30/(–30) = –1: real, inverted and of the same size (the object is at 2F of the combination).



dashed ray: A → P → A′ (reflected symmetrically at P)

Marking: (A) Ray diagram – 1; two pairs of similar triangles – 1; sign convention and final equation – 1; v = +6 cm (virtual, erect) – 1; m = +4 – 1 · (B) Derivation of $1/F = 1/f_1 + 1/f_2$ – 1½; $P = P_1 + P_2$ – ½; v = 60 cm, m = –2 – 1; F = 15 cm, P ≈ 6.7 D – 1; v = 30 cm, m = –1 – 1

Examiner tip: Apply the Cartesian sign convention at the end of the derivation, not halfway; for a concave mirror f is negative.

All the best for your exam!