Roll No. ☐☐☐☐☐☐☐☐

Q.P. Code 55/1/1

PHYSICS (THEORY)

CBSE Class XII Board Examination 2023 — with answers

Time allowed: 3 hours **Maximum Marks: 70**

General Instructions:

1. The paper has 35 questions in five sections (A to E); all of them must be answered.
2. Section A: Q1–18, multiple choice (Q16–18 Assertion-Reason), 1 mark each.
3. Section B: Q19–25, very short answer, 2 marks each.
4. Section C: Q26–30, short answer, 3 marks each.
5. Section D: Q31–33, long answer, 5 marks each.
6. Section E: Q34–35, case-based, 4 marks each.
7. There is no overall choice, but internal choices (OR) are given in 2 questions of Section B, 2 of Section C, 3 of Section D and 2 of Section E. Calculators are not allowed.
8. Constants you may use: $c = 3 \times 10^{8}$ m/s, $h = 6.63 \times 10^{-34}$ J s, $e = 1.6 \times 10^{-19}$ C, $\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}, $\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2}, $1/(4\pi\varepsilon_0) = 9 \times 10^{9}$ N m^2 C^{-2}, $m_e = 9.1 \times 10^{-31}$ kg, $m_n = 1.675 \times 10^{-27}$ kg, $m_p = 1.673 \times 10^{-27}$ kg, Avogadro number = 6.023×10^{23} per gram mole, Boltzmann constant = 1.38×10^{-23} J K^{-1}.

SECTION A

Q1–18 carry 1 mark each (MCQ; Q16–18 are Assertion-Reason).

1. A point charge kept on the axis of a short electric dipole at distance r from it feels a force $\vec{F}$. If the charge is moved to distance 2r (still on the axis), the force on it becomes: **1**

(A) $\vec{F}/16$ **(B)** $\vec{F}/8$

(C) $\vec{F}/4$ **(D)** $\vec{F}/2$

ANSWER

(b) F/8

Field of a short dipole on its axis: $E = \frac{2kp}{r^3}$, so force on the charge F = qE $\propto 1/r^3$.

Doubling r: F' = F/$(2)^3$ = F/8.

Common mistake: using the $1/r^2$ law of a point charge – a dipole field falls as $1/r^3$.

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2. Which graph correctly shows how the resistance R of a metallic conductor varies with temperature T? **1**

(a) a straight rising line with a positive intercept on the R-axis

(b) a straight rising line passing through the origin

(c) a falling curve (R decreases as T increases)

(d) a rising curve that bends upward (R increases faster and faster with T, small at low T)

(A) Graph (a): straight rising line with an intercept on R-axis

(B) Graph (b): straight rising line through the origin

(C) Graph (c): R decreasing with T

(D) Graph (d): R rising non-linearly, curving upward

ANSWER

(d) R rises non-linearly with T

In a metal, raising temperature increases collisions of free electrons (relaxation time τ decreases), so $\rho = m/(ne^2\tau)$ increases – this rules out (c).

Over a wide temperature range the rise is not linear: the NCERT plot of resistivity of copper vs T is a curve bending upward, starting small at low temperatures.

The linear relation $\rho = \rho_0[1 + \alpha(T - T_0)]$ is only an approximation over a limited range.

CBSE key: (d).

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3. A cell shows 8 V across its terminals on open circuit. When 4 A is drawn from it, the terminal voltage drops to 4 V. Its internal resistance is: **1**

(A) 4 Ω **(B)** 3 Ω

(C) 2 Ω **(D) 1 Ω**

ANSWER

(d) r = 1 Ω

Open-circuit voltage = emf, E = 8 V.
Terminal voltage V = E − Ir ⇒ 4 = 8 − 4r.
r = 4/4 = 1 Ω.

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4. A steady current flows through a metal wire whose cross-sectional area A increases continuously from one end to the other. Which graph shows the drift speed v_d of the free electrons as a function of A? **1**

(a) a decreasing hyperbola-like curve
(b) a straight line decreasing to zero
(c) a horizontal line (constant)
(d) a straight line increasing with A

(A) (a) v_d falls as a hyperbola ($\propto$ 1/A)

(B) (b) $\boldsymbol{v_d}$ falls linearly

(C) (c) $\boldsymbol{v_d}$ constant

(D) (d) $\boldsymbol{v_d}$ rises linearly

ANSWER

(a) v_d ∝ 1/A (hyperbola)

Current is the same at every cross-section (steady current): I = neAv_d.
n and e are constant, so v_d = I/(neA) ∝ 1/A.
A plot of y ∝ 1/x is a rectangular hyperbola – graph (a).

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5. A diamagnetic sample is brought close to either the north pole or the south pole of a bar magnet. The sample will be: **1**

(A) repelled by both poles **(B)** attracted by both poles

(C) repelled by N and attracted by S **(D)** attracted by N and repelled by S

ANSWER

(a) repelled by both poles

A diamagnetic substance gets a weak induced magnetisation opposite to the applied field ($\chi < 0$).
So it always moves from a stronger to a weaker field region – away from the magnet – whichever pole is used.
Hence it is repelled by both poles.

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6. A circular coil of 40 turns and radius 8.0 cm spins about its vertical diameter at $\frac{25}{\pi}$ rad s^{-1} in a uniform horizontal magnetic field of 3.0×10^{-2} T. The peak emf induced in it is: **1**

(A) 0.12 V **(B)** 0.15 V

(C) 0.19 V **(D)** 0.22 V

ANSWER

(c) ≈ 0.19 V

Peak emf: $e_0 = NBA\omega$.

$A = \pi r^2 = \pi(0.08)^2 = 0.0064\pi$ m².

$e_0 = 40 \times 3.0\times10^{-2} \times 0.0064\pi \times (25/\pi) = 40 \times 0.03 \times 0.0064 \times 25 = 0.192$ V ≈ 0.19 V.

Note how π cancels – that is why ω was given as 25/π.

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7. A rectangular frame PSRQ lies in a uniform magnetic field directed into the page. Its sliding arm PQ (length l) has resistance r, while the rest of the frame has negligible resistance. PQ is moved with velocity $\vec{v}$. The size of the induced emf does NOT depend on: **1**

(A) magnetic field $\vec{B}$ **(B)** velocity $\vec{v}$

(C) resistance r **(D)** length of PQ

ANSWER

(c) resistance r

Motional emf: ε = Blv.

It depends on B, l and v only.

The resistance r decides the current I = ε/r, not the emf.

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8. While a capacitor is being charged, the current that exists in the gap between its plates is (symbols have usual meanings): **1**

(A) $\mu_0 \frac{d\phi_E}{dt}$

(B) $\frac{1}{\mu_0} \frac{d\phi_E}{dt}$

(C) $\varepsilon_0 \frac{d\phi_E}{dt}$

(D) $\frac{1}{\varepsilon_0} \frac{d\phi_E}{dt}$

ANSWER

(c) $I_d = \varepsilon_0 \, d\varphi_E/dt$

No charges cross the gap; the changing electric flux there gives Maxwell's displacement current.

$I_d = \varepsilon_0 \frac{d\phi_E}{dt}$.

Check: $\varphi_E = q/\varepsilon_0$ between plates, so $I_d = dq/dt$ = conduction current in the wires – continuity of current.

9. For a concave mirror of focal length f, what is the least possible distance between an object and its real image? **1**

(A) zero **(B)** f

(C) 2f **(D)** 4f

ANSWER
(a) zero

When the object is at the centre of curvature (u = −2f), the real image also forms at the centre of curvature (v = −2f).
Object and image coincide, so the distance between them is zero.
Common mistake: answering 4f – that is the minimum object–real-image distance for a convex LENS, not a mirror.

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10. In Bohr's model of the hydrogen atom, the radius of the nth orbit varies as: **1**

(A) $1/n^2$ **(B)** $1/n$

(C) n^2 **(D)** n

ANSWER
(c) $r \propto n^2$

$$r_n = \frac{n^2 h^2 \varepsilon_0}{\pi m e^2} = 0.53\, n^2 \text{ Å}.$$

So $r \propto n^2$.

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11. A hydrogen atom in its ground state absorbs a photon and is raised to the n = 5 level. The photon's wavelength is: **1**

(A) 975 nm **(B)** 740 nm

(C) 523 nm **(D) 95 nm**

ANSWER
(d) $\lambda \approx 95$ nm

$\Delta E = 13.6(1 - 1/25) = 13.6 \times 24/25 = 13.056$ eV.
$\lambda = hc/\Delta E = 1240$ eV·nm / 13.056 eV ≈ 95 nm.
(Or $1/\lambda = R(1 - 1/25) = 1.097 \times 10^7 \times 0.96 \Rightarrow \lambda \approx 9.5 \times 10^{-8}$ m.)

12. For a nucleus of mass number A, the nuclear mass density is: **1**

(A) proportional to $A^{1/3}$

(B) proportional to $A^{2/3}$

(C) proportional to A^3

(D) independent of A

ANSWER

(d) independent of A

$R = R_0 A^{1/3} \Rightarrow$ volume $= (4/3)\pi R_0^3 A$.

Mass $\approx A \cdot m$.

Density $= Am / [(4/3)\pi R_0^3 A] = 3m/(4\pi R_0^3)$ – no A left.

So all nuclei have about the same density ($\sim 2.3 \times 10^{17}$ kg m^{-3}).

13. An ac voltage source is joined in series with a p-n junction diode and a load resistor. Which output voltage waveform appears across the load? **1**

(a) the full sine wave (positive and negative halves)

(b) positive humps with no gaps (every half-cycle positive)

(c) positive humps separated by flat zero gaps (alternate half-cycles only)

(d) a steady constant voltage

(A) (a) full sine wave

(B) (b) continuous positive humps

(C) (c) positive humps with zero gaps between them

(D) (d) constant dc

ANSWER

(c) half-wave rectified output

A single diode conducts only when forward biased, i.e. during one half of each cycle.

In the other half it is reverse biased and the output is (nearly) zero.

So the load gets one hump every cycle with a gap in between – half-wave rectification, graph (c).

(b) would need a full-wave rectifier (two diodes / bridge).

14. An intrinsic semiconductor is doped with a small quantity of a trivalent impurity. Then: **1**

(A) its resistance increases

(B) it becomes a p-type semiconductor

(C) it has more free electrons than holes

(D) the dopant atoms act as donors

ANSWER

(b) it becomes p-type

A trivalent atom (B, Al, In) has only 3 valence electrons, so one bond is incomplete – a hole is created.

The dopant accepts electrons (acceptor), holes become majority carriers ⇒ p-type.

Carrier density rises, so resistance decreases, not increases.

15. In the energy-band diagram of n-type silicon, the separation between the bottom of the conduction band E_C and the donor level E_D is of the order of: **1**

(A) 10 eV

(B) 1 eV

(C) 0.1 eV

(D) 0.01 eV

ANSWER

(d) ~0.01 eV

The donor level lies just below the conduction band; for Si it is about 0.01–0.05 eV below E_C.
That is why donors are ionised easily at room temperature (kT ≈ 0.025 eV).
1 eV (≈1.1 eV) is the full band gap of Si – don't confuse the two.

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16. Assertion (A): A copper bar placed in an external magnetic field draws the field lines into itself (lines crowd inside the bar). **1**
Reason (R): Copper is a paramagnetic material.

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

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

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

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

ANSWER

(d) A false, R false

Copper is diamagnetic, not paramagnetic – so R is false.
A diamagnetic bar pushes field lines out (field inside is slightly reduced); lines do not concentrate inside – so A is false.
Both false ⇒ (d).

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17. Assertion (A): Any two points on a wavefront have zero phase difference. **1**
Reason (R): Every point of a wavefront is equally far from the source, so all of them oscillate in the same phase.

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

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

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

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

ANSWER

(a) both true, R explains A

A wavefront is defined as the locus of points vibrating in the same phase – so A is true.
For a wave from a point source the wavefront is a sphere: all its points are the same distance from the source, the wave reaches them at the same time and they are in phase – R is true and explains A.

18. Assertion (A): The photoelectric effect shows that light behaves as particles. **1**
Reason (R): Above the threshold frequency, the photoelectric current is proportional to the intensity of the incident radiation.

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

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

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

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

ANSWER

(b) both true, R not the explanation

A is true: threshold frequency, instantaneous emission and K_max depending only on frequency can be explained only by photons (hv).
R is true: more intensity = more photons = more electrons emitted.
But the current-intensity proportionality alone would also fit the wave picture; the particle nature is proved by the frequency dependence and threshold. So R does not explain A ⇒ (b).

SECTION B

Q19–25 carry 2 marks each.

19. An alpha particle enters, with velocity $\vec{v} = (3.0 \times 10^5\ \text{m/s})\,\hat{i}$, a region having magnetic field $\vec{B} = (0.4\ \text{T})\hat{i} + (0.3\ \text{T})\hat{j}$. The charge-to-mass ratio of the alpha particle is 4.8×10^7 C/kg. Find its acceleration in this region. **2**

ANSWER

$a = 4.32 \times 10^{12}\ \hat{k}\ \text{m s}^{-2}$

Lorentz force: $\vec{F} = q(\vec{v} \times \vec{B})$.

$\vec{v} \times \vec{B} = 3 \times 10^5\,\hat{i} \times (0.4\hat{i} + 0.3\hat{j}) = 3 \times 10^5 \times 0.3\,(\hat{i} \times \hat{j}) = 0.9 \times 10^5\,\hat{k}$ (since $\hat{i}\times\hat{i} = 0$).

$\vec{a} = \frac{q}{m}(\vec{v} \times \vec{B}) = 4.8 \times 10^7 \times 0.9 \times 10^5\,\hat{k} = 4.32 \times 10^{12}\,\hat{k}\ \text{m s}^{-2}$.

Always state the direction (+z) – the component of B along v gives no force.

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20. Compare (i) a magnetic field induced by a changing electric field and (ii) an electric field induced by a changing magnetic field. Which of the two is easier to observe? Give a reason. **2**

ANSWER

The electric field induced by a changing magnetic field (EMI) is observed far more easily.

Identification: the induced electric field due to a changing magnetic field (Faraday's induction) is easily observed.

Justification: it is produced and detected easily – rotating or moving a coil in a magnetic field, moving a magnet towards a coil, changing the area of a coil – and gives measurable emf/current in everyday devices (generators, transformers).

The magnetic field produced by a changing electric field (displacement current $I_d = \varepsilon_0\, d\phi_E/dt$) is extremely small in ordinary situations because ε_0 is tiny ($\sim 10^{-11}$), so it is hard to detect.

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21. Using Huygens' principle, draw a diagram showing a plane wavefront being refracted at a plane boundary between two media, and use it to prove Snell's law of refraction. **2**

ANSWER

$\sin i / \sin r = v_1/v_2 = n_2/n_1$ (Snell's law)

Diagram: plane wavefront AB strikes the surface at A at angle i; medium 1 speed v_1, medium 2 speed v_2 ($v_2 < v_1$ for a denser medium 2).

Let τ be the time for point B to reach C on the surface: $BC = v_1\tau$.

In the same time the wavelet from A spreads into medium 2 as a sphere of radius $AE = v_2\tau$.

The tangent CE from C to this sphere is the refracted wavefront; it makes angle r with the surface.

From triangles ABC and AEC: $\sin i = BC/AC = v_1\tau/AC$ and $\sin r = AE/AC = v_2\tau/AC$.

Dividing: $\sin i / \sin r = v_1/v_2 =$ constant. With $n = c/v$ this gives $n_1 \sin i = n_2 \sin r$ – Snell's law.

OR

Why is a reflecting telescope preferred to a refracting telescope? Give two reasons.

ANSWER

No chromatic aberration; large mirror is lighter/cheaper and easier to support (also spherical aberration removed with parabolic mirror).

Any two:

1. A mirror has no chromatic aberration (reflection does not depend on wavelength); a lens objective does.
2. Using a parabolic mirror removes spherical aberration.
3. A large-aperture mirror is much lighter, cheaper and easier to make than an equally large lens, and can be supported over its whole back surface; a big lens sags and is hard to support only at its rim.
4. Large aperture gives high light-gathering power and better resolving power.

22. Two coherent monochromatic light beams with intensities I and 4I overlap. Find the ratio of the maximum to the minimum intensity in the resultant pattern. **2**

ANSWER

$I_{max} : I_{min} = 9 : 1$

Intensity $\propto$ (amplitude)^2, so $a_1 \propto \sqrt{I}$ and $a_2 \propto \sqrt{(4I)} = 2\sqrt{I}$.

$I_{max} = (\sqrt{I_1} + \sqrt{I_2})^2 = (\sqrt{I} + 2\sqrt{I})^2 = 9I$.

$I_{min} = (\sqrt{I_2} - \sqrt{I_1})^2 = (2\sqrt{I} - \sqrt{I})^2 = I$.

Ratio = 9 : 1.

Common mistake: adding intensities (5I) instead of amplitudes.

23. The energy of the hydrogen atom in its ground state is −13.6 eV. Find the kinetic energy and the potential energy of the electron in the third excited state. **2**

ANSWER

Third excited state n = 4: E = −0.85 eV, K = +0.85 eV, U = −1.70 eV

Third excited state means n = 4 (ground n=1, first excited n=2, …).

$E_4 = -13.6/4^2 = -0.85$ eV.

For a Bohr orbit: K = −E and U = 2E.

K = +0.85 eV; U = 2(−0.85) = −1.70 eV.

Common mistake: taking third excited state as n = 3.

24. Distinguish between intrinsic and extrinsic semiconductors. **2**

ANSWER

Intrinsic: pure, $n_e = n_h$, low conductivity, depends only on T. Extrinsic: doped, $n_e \neq n_h$, higher conductivity controllable by doping.

Intrinsic semiconductor:

• pure Si/Ge, no impurity

• electron density = hole density ($n_e = n_h = n_i$)

• very low conductivity, which depends only on temperature

Extrinsic semiconductor:

• doped with pentavalent (n-type) or trivalent (p-type) impurity

• $n_e \neq n_h$ ($n_e \gg n_h$ in n-type, $n_h \gg n_e$ in p-type)

• much higher conductivity, controlled by the amount of doping

(Any two clear differences earn the marks.)

OR

Draw the circuit used to study the V–I characteristics of a p-n junction diode in forward bias and in reverse bias. Sketch the V–I characteristic of a silicon diode.

ANSWER

Forward: battery + to p via rheostat, milliammeter, voltmeter across diode; reverse: battery reversed, microammeter. Curve: tiny current till ≈0.7 V then steep rise; reverse: tiny μA current, sudden rise at breakdown.

Forward bias circuit: battery with potentiometer/rheostat, p-side connected to + terminal, n-side to −; a milliammeter in series and a voltmeter across the diode.

Reverse bias circuit: battery terminals reversed (p to −), a microammeter in series, voltmeter across the diode.

Graph: forward side – current nearly zero up to the threshold (knee) voltage ≈ 0.7 V for Si, then rises steeply (mA scale).

Reverse side – very small, almost constant current (μA) due to minority carriers, until the breakdown voltage, where the reverse current increases suddenly.

Label axes: V (volts) horizontal, I (mA forward / μA reverse) vertical.

25. Explain briefly how diffusion current and drift current together lead to the formation of the potential barrier in a p-n junction. **2**

ANSWER

Diffusion of majority carriers leaves immobile ions → depletion layer and field (barrier); the field drives a drift current opposite to diffusion; equilibrium when the two are equal fixes the barrier.

Because of the concentration difference, holes diffuse from p to n and electrons from n to p – the diffusion current.
Each electron leaving the n-side leaves a positive donor ion; each hole leaving the p-side leaves a negative acceptor ion. These fixed ions form the depletion layer.
The ions set up an electric field from n to p, i.e. a potential barrier.
This field pushes minority carriers across the junction (electrons p→n, holes n→p) – the drift current, opposite to diffusion current.
At first diffusion is large and drift small; as the layer grows, the field and drift increase until drift current = diffusion current. Then there is no net current and the barrier potential stays fixed.

SECTION C

Q26–30 carry 3 marks each.

26. (a) Twelve equal negative charges (each −q) are fixed at equal spacing around a circle of radius R. Taking potential at infinity as zero, find the electric potential and electric field at the centre C. **3**

(b) If the same twelve charges are instead fixed, unequally spaced, along a 120° arc of radius R centred at C, find the potential at C.

ANSWER

(a) $V = -12q/(4\pi\varepsilon_0 R)$, $E = 0$; (b) $V = -12q/(4\pi\varepsilon_0 R)$

(a) Every charge is at the same distance R from C. Potential is a scalar, so it simply adds:
$V = 12 \times (-q)/(4\pi\varepsilon_0 R) = -12q/(4\pi\varepsilon_0 R) = -3q/(\pi\varepsilon_0 R)$.
Field is a vector: charges are placed symmetrically, so the field of each charge is cancelled by the diametrically opposite one ⇒ $E = 0$.
(b) Each charge is still at distance R from C, and potential does not depend on direction or spacing:
$V = -12q/(4\pi\varepsilon_0 R)$ (unchanged).
Key idea: potential (scalar) depends only on distance; field (vector) depends on the arrangement.

27. How is impedance different from resistance? Using a suitable phasor diagram, derive the impedance of a series LCR circuit connected to a source $v = v_m \sin \omega t$. **3**

ANSWER

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

Difference: resistance is the opposition of a resistor alone, does not depend on frequency and V, I are in phase; impedance is the total effective opposition of an ac circuit (R together with reactances X_L, X_C), it depends on frequency and in general V and I differ in phase.

Phasor diagram: take current i = i_m sin(ωt + φ) as reference (common to all elements in series).

V_R = i_mR along the current phasor; V_L = i_mX_L leading it by 90°; V_C = i_mX_C lagging it by 90°.

V_L and V_C are opposite, so their resultant is (V_L − V_C), perpendicular to V_R.

By Pythagoras: $v_m^2 = V_R^2 + (V_L - V_C)^2 = i_m^2[R^2 + (X_L - X_C)^2]$.

So $i_m = \dfrac{v_m}{\sqrt{R^2 + (X_L - X_C)^2}}$ and $Z = \sqrt{R^2 + (X_L - X_C)^2}$, with tan φ = (X_C − X_L)/R.

OR

A series LCR circuit is driven by $v = v_m \sin \omega t$ with adjustable ω. Find the condition for resonance. On what factors does the resonant frequency depend? Sketch how the current varies with frequency.

ANSWER

Resonance when X_L = X_C ⇒ $\omega_0 = 1/\sqrt{LC}$; depends only on L and C; current peaks (= v_m/R) at ω_0.

Current amplitude i_m = v_m/Z with $Z = \sqrt{R^2 + (X_L - X_C)^2}$.

i_m is maximum when Z is minimum, i.e. when X_L = X_C.

ωL = 1/(ωC) ⇒ $\omega_0 = \dfrac{1}{\sqrt{LC}}$, $\nu_0 = \dfrac{1}{2\pi\sqrt{LC}}$. Then Z = R and i_max = v_m/R.

Resonant frequency depends only on inductance L and capacitance C (not on R).

Graph: i_m vs ω rises, reaches a sharp peak at ω_0, then falls; a smaller R gives a taller, sharper peak.

28. A long solenoid of radius r has n turns per unit length and carries current $I = I_0 \sin \omega t$. A coil of N turns is wound tightly around its middle. Find: **3**

(a) the emf induced in the coil;

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

ANSWER

(a) $e = -\mu_0 n N \pi r^2 I_0 \omega \cos \omega t$; (b) $M = \mu_0 n N \pi r^2$

Field inside the solenoid near its centre: $B = \mu_0 n I$.

Flux through the coil (same cross-section πr^2): $\Phi = NBA = \mu_0 n N \pi r^2 I$.

(a) $e = -d\Phi/dt = -\mu_0 n N \pi r^2 \, dI/dt = -\mu_0 n N \pi r^2 I_0 \omega \cos \omega t$.

(b) Compare with $e = -M \, dI/dt$ (or $\Phi = MI$): $M = \mu_0 n N \pi r^2$.

Note M depends only on geometry, not on the current.

29. How did Einstein's photoelectric equation explain the emission of electrons from a metal surface? Explain briefly. Also plot how the photocurrent varies with: (a) the collector plate potential, for different intensities of incident light; (b) the intensity of incident light. **3**

ANSWER

$K_{max} = h\nu - \varphi_0$; (a) curves with same stopping potential, saturation current higher for higher intensity; (b) straight line through origin.

Explanation: light is a stream of photons of energy $h\nu$. An electron absorbs one whole photon. If $h\nu$ exceeds the work function φ_0, the electron escapes; the extra energy appears as kinetic energy: $K_{max} = h\nu - \varphi_0$. If $h\nu < \varphi_0$, no emission at any intensity (threshold frequency $\nu_0 = \varphi_0/h$).

(a) Photocurrent vs collector potential: for each intensity the current rises and saturates for positive potentials; all curves fall to zero at the same negative stopping potential $-V_0$; higher intensity → higher saturation current.

(b) Photocurrent vs intensity (fixed $\nu > \nu_0$): a straight line through the origin (current $\propto$ intensity).

30. Draw the energy level diagram of the hydrogen atom and mark the transitions that give the spectral series in the ultraviolet, visible and infrared regions. **3**

ANSWER

Levels $E_n = -13.6/n^2$ eV; Lyman (→n=1) UV, Balmer (→n=2) visible, Paschen/Brackett/Pfund (→n=3,4,5) IR.

Draw horizontal levels: n=1 (−13.6 eV), n=2 (−3.4 eV), n=3 (−1.51 eV), n=4 (−0.85 eV), n=5 (−0.54 eV), … n=∞ (0 eV).

Mark downward arrows:

• Lyman series – transitions ending on n = 1 → ultraviolet.

• Balmer series – transitions ending on n = 2 → visible.

• Paschen (ending n = 3), Brackett (n = 4), Pfund (n = 5) → infrared.

The levels get closer together as n increases.

OR

Sketch the variation of binding energy per nucleon with mass number for different nuclei and state two of its features. Why do light nuclei usually undergo fusion?

ANSWER

Curve rises steeply, peaks ≈8.75 MeV at A≈56, falls to ≈7.6 MeV at A=238; light nuclei fuse because the product has higher BE/nucleon (more tightly bound), releasing energy.

Graph: BE/A (MeV) vs A – rises sharply for light nuclei (with peaks at He-4, C-12, O-16), flattens for 30 < A < 170, maximum ≈ 8.75 MeV near A = 56 (Fe), then slowly falls to ≈ 7.6 MeV at A = 238.

Features (any two):

1. BE/A is nearly constant for middle mass numbers (30 < A < 170) – shows saturation/short range of nuclear force.

2. Maximum ≈ 8.75 MeV at A ≈ 56.

3. BE/A is lower for both light (A < 30) and heavy (A > 170) nuclei.

Fusion: when two light nuclei join, the product nucleus has a higher binding energy per nucleon, so it is more tightly bound; the difference in binding energy is released. Hence light nuclei gain stability by fusion.

SECTION D

Q31–33 carry 5 marks each.

31. (i) State Coulomb's law of electrostatics and write it in vector form for two charges. **5**

(ii) Explain the statement: 'Gauss's law rests on the inverse-square dependence on distance present in Coulomb's law.'

(iii) Charge A (q) is at (0, 0) and charge B (2q) is at (a, a). With î and ĵ the unit vectors along x and y, find the force exerted by A on B in terms of î and ĵ.

ANSWER

(iii) $\vec{F} = \dfrac{q^2}{4\sqrt{2}\,\pi\varepsilon_0 a^2}(\hat{i}+\hat{j})$

(i) The force between two point charges is directly proportional to the product of the charges, inversely proportional to the square of the distance between them, and acts along the line joining them.

Vector form: $\vec{F}_{21} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$, force on q_2 due to q_1, $\hat{r}_{21}$ pointing from q_1 to q_2.

(ii) To get Gauss's law, flux through a sphere around a point charge is $E \times 4\pi r^2 = (q/4\pi\varepsilon_0 r^2) \times 4\pi r^2$. The $1/r^2$ of Coulomb's field cancels the r^2 of the area, so flux $= q/\varepsilon_0$ is independent of r and of the surface shape. If the force were not exactly inverse-square, the flux would depend on r and Gauss's law would fail.

(iii) $\vec{r}_{AB} = a\hat{i} + a\hat{j}$, $|r| = \sqrt{2}\,a$, unit vector $= (\hat{i}+\hat{j})/\sqrt{2}$.

$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{q(2q)}{(\sqrt{2}a)^2}\cdot\frac{\hat{i}+\hat{j}}{\sqrt{2}} = \frac{q^2}{4\sqrt{2}\,\pi\varepsilon_0 a^2}(\hat{i}+\hat{j}).$$

Magnitude $= q^2/(4\pi\varepsilon_0 a^2)$, directed away from A (repulsion, both positive).

OR

(i) Derive the expression for the electric field at a point on the equatorial plane of a dipole made of charges +q and −q separated by 2a.

(ii) If the distance of a far-off point on the equatorial plane is halved, how does the dipole's field there change?

(iii) Two identical dipoles lie along the diagonals of a square ABCD of side √2 m: +q at A and −q at C, +q at D and −q at B (A top-left, B top-right, C bottom-right, D bottom-left). Find the magnitude and direction of the net electric field at the centre O.

ANSWER

(i) $\vec{E} = -\dfrac{\vec{p}}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}$; (ii) becomes 8 times; (iii) $E = 2\sqrt{2}\,kq = 2\sqrt{2}q/(4\pi\varepsilon_0)$ N/C, parallel to DC (D→C)

(i) Point P at distance r from the centre on the perpendicular bisector. Each charge is at distance $\sqrt{(r^2+a^2)}$.

$|E_+| = |E_-| = kq/(r^2+a^2)$.

Components perpendicular to the dipole axis cancel; components along the axis add (both pointing from + to −):

$E = 2 \times kq/(r^2+a^2) \times a/\sqrt{(r^2+a^2)} = k(2qa)/(r^2+a^2)^{3/2}$.

With $p = 2qa$: $\vec{E} = -\dfrac{k\vec{p}}{(r^2+a^2)^{3/2}}$ (opposite to p). For $r \gg a$, $E = kp/r^3$.

(ii) $E \propto 1/r^3 \Rightarrow r \to r/2$ gives $E \to 8E$.

(iii) Half-diagonal $= (\sqrt{2} \times \sqrt{2})/2 = 1$ m, so each charge is 1 m from O.

Dipole A–C: field of +q at A points away from A (towards C); field of −q at C points towards C. Sum

= 2kq along OC.
Dipole D–B: similarly 2kq along OB.
OB and OC are perpendicular, so E_net = $\sqrt{[(2kq)^2 + (2kq)^2]} = 2\sqrt{2}$ kq.
Direction: bisector of OB and OC, i.e. parallel to DC (pointing from D towards C / towards side BC).
E_net = $2\sqrt{2}q/(4\pi\varepsilon_0)$ N/C.

32. (i) State the Biot–Savart law for the magnetic field of a current element. Using it, derive the magnetic field at the centre of a circular loop of radius R carrying current I. Sketch the field lines of a current loop showing the field direction. **5**
(ii) An electron moves round the nucleus in a circular orbit of radius 10^{-10} m at a speed of 10^7 m s^{-1}. Find the current due to this revolving electron.

ANSWER
(i) B = $\mu_0 I/(2R)$; (ii) I ≈ 2.55×10^{-3} A = 2.55 mA

(i) Biot–Savart law: $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{l} \times \vec{r}}{r^3}$, magnitude dB = $(\mu_0/4\pi)$ I dl sin θ / r^2.
At the centre of a loop every element dl is at distance R and perpendicular to the radius (θ = 90°), and all dB point the same way (along the axis).
B = $\oint (\mu_0/4\pi)$ I dl / R^2 = $(\mu_0 I/4\pi R^2) \times 2\pi R = \mu_0 I/(2R)$.
Field lines: closed loops encircling the wire, passing straight through the centre along the axis; direction given by right-hand rule (anticlockwise current as seen → field towards the viewer).
(ii) I = e/T = ev/(2πr).
I = $(1.6\times10^{-19} \times 10^7)/(2\pi \times 10^{-10}) = (1.6\times10^{-12})/(6.28\times10^{-10}) \approx 2.55\times10^{-3}$ A.

OR

(i) Derive the force on a straight current-carrying conductor placed in a magnetic field. Name the rule that gives the direction of this force, and state when the force is (1) maximum and (2) minimum.
(ii) Two long straight parallel wires A and B, 2.5 cm apart in air, carry 5.0 A and 2.5 A in opposite directions. Find the magnitude of the force that wire A exerts on a 10 cm length of B.

ANSWER
(i) $\vec{F} = I\vec{l} \times \vec{B}$; max (IlB) at θ = 90°, zero at θ = 0° or 180°; (ii) F = 1.0×10^{-5} N (repulsive)

(i) Rod of length l, area A, carrier density n, charge q, drift velocity v_d. Number of carriers = nAl.
Force on each: q(v_d × B). Total: $\vec{F} = nAl\,q(\vec{v}_d \times \vec{B})$.
Since I = nqAv_d, $\vec{F} = I\vec{l} \times \vec{B}$, magnitude F = IlB sin θ.
Direction: Fleming's left-hand rule – forefinger along B, middle finger along current, thumb gives force.
(1) Maximum F = IlB when θ = 90° (conductor ⊥ field).
(2) Minimum F = 0 when θ = 0° or 180° (conductor ∥ field).
(ii) Force per length: F/l = $\mu_0 I_1 I_2/(2\pi d)$.
F = $(2\times10^{-7} \times 5.0 \times 2.5 \times 0.10)/(2.5\times10^{-2}) = (2.5\times10^{-7})/(2.5\times10^{-2}) = 1.0\times10^{-5}$ N.
Opposite currents ⇒ the force is repulsive.

33. (i) (1) Give two differences between an interference pattern and a diffraction pattern. **5**

(2) Name any two factors that affect the fringe width in Young's double-slit experiment.

(ii) In a Young's double-slit experiment the slit separation is 100 times the wavelength of the light used. Find:

(1) the angular separation (in radians) between the central maximum and the next maximum;

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

ANSWER

(ii)(1) $\theta = 0.01$ rad; (2) 5 mm

(i)(1) Any two:

• Interference: equally spaced bright and dark fringes; diffraction: central maximum twice as wide as the others.

• Interference: all bright fringes of (nearly) equal intensity; diffraction: intensity of maxima falls rapidly away from the centre.

• Interference comes from superposition of waves from two coherent sources; diffraction from waves from different points of the same wavefront (single slit).

(2) Fringe width $\beta = \lambda D/d$ – depends on wavelength λ, slit-to-screen distance D and slit separation d (any two).

(ii)(1) First maximum: $d \sin\theta = \lambda \Rightarrow \theta \approx \lambda/d = 1/100 = 0.01$ rad.

(2) $y = D\theta = 0.50\ \text{m} \times 0.01 = 5\times10^{-3}\ \text{m} = 5$ mm.

OR

(i) A spherical surface of radius of curvature R separates media of refractive indices n_1 and n_2. A point object in medium n_1 is at distance u from the surface and its image forms in medium n_2 at distance v. Derive the relation between u and v.

(ii) A solid glass sphere (radius 6.0 cm, n = 1.5) has a tiny air bubble at point O, 3.0 cm from its centre C. An observer at point E outside, on the line through C and O on the bubble's side, looks at the bubble through the nearest surface. Find where the bubble appears to be.

ANSWER

(i) $n_2/v - n_1/u = (n_2 - n_1)/R$; (ii) $v = -2.4$ cm: bubble appears 2.4 cm inside the surface (3.6 cm from C)

(i) Take a convex surface, pole M, centre C, object O on the axis, ray ON hitting at N, image I. Small-angle approximation.

Angles: $i = \angle NOM + \angle NCM \approx MN/OM + MN/MC$; $r = \angle NCM - \angle NIM \approx MN/MC - MN/MI$.

Snell (small angles): $n_1 i = n_2 r \Rightarrow n_1/OM + n_2/MI = (n_2 - n_1)/MC$.

Sign convention: OM = −u, MI = +v, MC = +R $\Rightarrow \dfrac{n_2}{v} - \dfrac{n_1}{u} = \dfrac{n_2 - n_1}{R}$.

(ii) Light goes from the bubble (inside glass, $n_1 = 1.5$) out to air ($n_2 = 1$) through the surface nearest E. Distance of bubble from that surface = 6 − 3 = 3 cm ⇒ u = −3 cm. Centre C is on the glass side ⇒ R = −6 cm.

$1/v - 1.5/(-3) = (1 - 1.5)/(-6)$

$1/v + 0.5 = 1/12 \Rightarrow 1/v = -5/12 \Rightarrow v = -2.4$ cm.

The image is virtual, 2.4 cm from the surface inside the sphere (i.e. 3.6 cm from C). So the bubble appears closer to the viewing surface (2.4 cm instead of its real 3 cm).

> Common mistake: taking R = +6 cm – the centre lies on the incoming-light (glass) side, so R is negative.

SECTION E

Q34–35 are case-based questions carrying 4 marks each.

34. A cell of emf E = 6.0 V and internal resistance r = 1.0 Ω (branch a–h) feeds two parallel branches: branch b–g has R_1 = 10 Ω (points i and j on either side of it), and branch c–f has R_2 = 5.0 Ω and R_3 = 5.0 Ω in series (points d and e between them). The top wire is a–b–c and the bottom wire is h–g–f. Kirchhoff's rules can give the currents and voltages. **4**

(a) Which points of the circuit are at the same potential?

(b) What is the current in arm bg?

(c) Find the potential difference across R_3.

ANSWER

(a) {a,b,c}, {d,e}, {h,g,f} (also i with b, j with g); (b) 0.5 A; (c) 2.5 V

(a) Points joined by plain wire (no resistance) are at the same potential: a, b, c (and i); d and e; h, g, f (and j).

(b) $R_2 + R_3 = 10\ \Omega$, in parallel with $R_1 = 10\ \Omega \Rightarrow R_{ext} = 5\ \Omega$.

Total current $I = E/(R_{ext} + r) = 6/(5 + 1) = 1$ A.

Kirchhoff check: loop abgha: $10I_2 + 1 \cdot I = 6$; loop acfha: $10(I - I_2) + I = 6 \Rightarrow I = 1$ A, $I_2 = 0.5$ A.

Current in bg = 0.5 A.

(c) Current in branch c–f = 1 − 0.5 = 0.5 A $\Rightarrow V(R_3) = 0.5 \times 5 = 2.5$ V.

OR

(c) Find the power dissipated in R_2.

ANSWER

P = 1.25 W

External resistance: 10 Ω ∥ 10 Ω = 5 Ω; total current = 6/(5 + 1) = 1 A.

It splits equally: 0.5 A through R_2–R_3 branch.

$P(R_2) = I^2R = (0.5)^2 \times 5 = 1.25$ W.

35. Strontium titanate, a rare natural oxide, is used as a diamond substitute because its refractive index (2.41) and critical angle (24.5°) are almost the same as diamond's, so even experts find it hard to tell them apart. A ray falls normally on face AB of an equilateral prism ABC (angle A = 60°) made of this material. **4**

(a) Trace the path of the ray through the prism.

(b) Find the speed of light in the prism.

(c) Briefly explain two applications of total internal reflection.

ANSWER

(a) Enters AB undeviated, hits AC at 60° > 24.5° → TIR, then meets BC normally and emerges undeviated; (b) $v \approx 1.24 \times 10^8$ m/s; (c) optical fibres, brilliance of diamond (also mirage, totally reflecting prisms)

(a) At AB the ray is normal ⇒ no bending.
Geometry of an equilateral prism: the ray then meets face AC at an angle of incidence of 60°.
60° > critical angle 24.5° ⇒ total internal reflection at AC.
The reflected ray travels perpendicular to BC, so it leaves through BC without deviation.
(b) $v = c/n = 3\times10^8/2.41 \approx 1.24\times10^8$ m/s.
(c) Any two:
• Optical fibres – light repeatedly totally reflected at the core–cladding boundary travels long distances with little loss (communication, endoscopy).
• Sparkling of diamond – small critical angle (≈24°) causes multiple TIR inside a well-cut diamond.
• Mirage; totally reflecting prisms in periscopes/binoculars.

OR

(c) Define total internal reflection of light and state two conditions necessary for it.

ANSWER

TIR: complete reflection of light back into a denser medium at its boundary with a rarer medium; needs denser→rarer travel and i > critical angle.

Definition: when light going from an optically denser medium to a rarer medium strikes the boundary at an angle greater than the critical angle, it is entirely reflected back into the denser medium – total internal reflection.
Conditions:
1. Light must travel from the optically denser medium towards the rarer medium.
2. The angle of incidence must be greater than the critical angle for that pair of media.

— END —

Questions restated from the CBSE Class XII Board Examination 2023 (set 55/1/1) for practice. Reading passages and map items are described, not reproduced.