Roll No. ☐☐☐☐☐☐☐☐

Q.P. Code 55/1/1

PHYSICS (THEORY)

CBSE Class XII Board Examination 2024 — with answers

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

General Instructions:

1. The paper has 33 questions in five sections (A to E); all of them must be answered.
2. Section A: Q1–16, multiple choice and Assertion-Reason, 1 mark each.
3. Section B: Q17–21, very short answer, 2 marks each.
4. Section C: Q22–28, short answer, 3 marks each.
5. Section D: Q29–30, case-study based, 4 marks each.
6. Section E: Q31–33, long answer, 5 marks each.
7. There is no overall choice, but some questions in Sections B to E offer an internal choice (OR). 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

Q1–16 carry 1 mark each (MCQ; Q13–16 are Assertion-Reason).

1. A thin plastic rod is bent into a circular ring of radius R and carries a uniform linear charge density λ. What is the magnitude of the electric field at the centre of the ring? **1**

(A) $\frac{\lambda}{2\varepsilon_0 R}$

(B) Zero

(C) $\frac{\lambda}{4\pi\varepsilon_0 R}$

(D) $\frac{\lambda}{4\varepsilon_0 R}$

ANSWER

(B) Zero

Divide the ring into small elements. For every element there is an identical element diametrically opposite to it.

Both are at the same distance R from the centre, so their fields at the centre are equal in magnitude but opposite in direction – they cancel.

Adding over the whole ring, the net field at the centre is zero.

Common mistake: the potential at the centre is NOT zero ($V = \lambda \cdot 2\pi R/(4\pi\varepsilon_0 R) = \lambda/(2\varepsilon_0)$); only the field vanishes.

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2. Ten capacitors of 1 μF each are joined in parallel across a 100 V source. What is the total energy stored? **1**

(A) 10^{-2} J

(B) 10^{-3} J

(C) 0.5×10^{-3} J

(D) 5.0×10^{-2} J

ANSWER

(D) 5.0×10^{-2} J

In parallel, capacitances add: $C = 10 \times 1\ \mu F = 10\ \mu F = 10^{-5}$ F.

Energy $U = \frac{1}{2}CV^2 = \frac{1}{2} \times 10^{-5} \times (100)^2 = \frac{1}{2} \times 10^{-5} \times 10^4 = 0.05$ J $= 5.0 \times 10^{-2}$ J.

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3. Points A and B are joined by two parallel branches. The upper branch has a 12 V cell in series with a 1 Ω resistor; the lower branch has a 6 V cell in series with a 0.5 Ω resistor. Both cells have their like terminals on the same side (same orientation). What is the potential difference between A and B? **1**

(A) 6 V **(B) 8 V**

(C) 9 V **(D)** 12 V

ANSWER
(B) 8 V

Two cells (emf ε_1, ε_2, internal/series resistance r_1, r_2) in parallel with the same orientation are equivalent to one cell of emf

$$\varepsilon_{eq} = \frac{\varepsilon_1/r_1 + \varepsilon_2/r_2}{1/r_1 + 1/r_2}.$$

Here $\varepsilon_1/r_1 = 12/1 = 12$, $\varepsilon_2/r_2 = 6/0.5 = 12$; $1/r_1 + 1/r_2 = 1 + 2 = 3$.
$\varepsilon_{eq} = 24/3 = 8$ V. No current is drawn from A–B externally, so $V_{AB} = 8$ V.
Check: circulating current $= (12 - 6)/(1 + 0.5) = 4$ A; $V = 12 - 4\times1 = 8$ V ✓.

4. A loop in the x–y plane carries current I in the clockwise sense and lies in a uniform magnetic field pointing along the z-axis. The loop will tend to: **1**

(A) move along the x-axis **(B)** move along the y-axis

(C) shrink **(D)** expand

ANSWER
(C) shrink

Net force on a closed loop in a uniform field is zero, so the loop does not translate (A, B wrong).
Force on each element: $d\vec{F} = I\, d\vec{l} \times \vec{B}$. Take B along +z (viewed from +z). At the top of a clockwise loop current flows along +x: $\hat{x} \times \hat{z} = -\hat{y}$, i.e. towards the centre. The same happens at every element – all forces point inward.
Hence the loop tends to shrink. (Its magnetic moment is antiparallel to B, an unstable orientation.)

5. A 10 cm wire lies along the y-axis and carries 1.0 A in the +y direction. The field in the region is $\vec{B} = (5\,\text{mT})\hat{j} - (8\,\text{mT})\hat{k}$. Find the force on the wire. **1**

(A) $\mathbf{(0.8\,mN)\hat{i}}$ **(B)** $\mathbf{-(0.8\,mN)\hat{i}}$

(C) $\mathbf{(80\,mN)\hat{i}}$ **(D)** $\mathbf{-(80\,mN)\hat{i}}$

ANSWER
(B) −(0.8 mN) î

$\vec{F} = I\vec{L} \times \vec{B}$, with $\vec{L} = 0.1\,\hat{j}$ m.
The ĵ part of B is parallel to the wire – no force.
$\vec{F} = 1.0 \times 0.1\,\hat{j} \times (-8 \times 10^{-3}\,\hat{k}) = -0.8 \times 10^{-3}(\hat{j} \times \hat{k}) = -0.8 \times 10^{-3}\,\hat{i}$ N.
F = −(0.8 mN) î.

6. A galvanometer of resistance G is converted into an ammeter of range 0 to I A. If only 0.1% of I passes through the galvanometer, the resistance of the ammeter is: **1**

(A) $\frac{G}{999}$ **(B)** $\frac{G}{1000}$

(C) $\frac{G}{1001}$ **(D)** $\frac{G}{100.1}$

ANSWER

(B) G/1000

I_g = 0.001 I, so shunt current = 0.999 I.

Shunt S: I_g G = (I − I_g)S ⇒ S = 0.001G/0.999 = G/999.

Ammeter resistance = G ∥ S = GS/(G + S) = G·(G/999)/(G + G/999) = G/(999 + 1) = G/1000.

Shortcut: the whole I flows through R_A while I_g flows through G at the same voltage: R_A = I_g G/I = 0.001G.

Common mistake: G/999 is the shunt, not the ammeter resistance.

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7. A capacitor C on an ac source of frequency ν has reactance X. If C is doubled and ν is tripled, the new reactance is: **1**

(A) $\frac{X}{6}$ **(B)** 6X

(C) $\frac{2X}{3}$ **(D)** $\frac{3X}{2}$

ANSWER

(A) X/6

$X_C = \frac{1}{2\pi\nu C}$.

New: $X' = \frac{1}{2\pi(3\nu)(2C)} = \frac{X}{6}$.

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8. The electric field in four regions is: Region I: E_x = E₀ sin(kz − ωt); Region II: E_x = E₀; Region III: E_x = E₀ sin kz; Region IV: E_x = E₀ cos kz. In which region does a displacement current exist? **1**

(A) I **(B)** IV

(C) II **(D)** III

ANSWER

(A) Region I

Displacement current $i_d = \varepsilon_0 \frac{d\Phi_E}{dt}$ exists only where the electric field changes with time.

Only in Region I does E depend on t (through ωt). Regions II, III and IV have fields that vary with position but are constant in time, so i_d = 0 there.

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9. The second line of the Balmer series of hydrogen is produced by an electron transition: **1**

(A) $n_f = 2$ and $n_i = 3$

(B) $n_f = 3$ and $n_i = 4$

(C) $n_f = 2$ and $n_i = 4$

(D) $n_f = 2$ and $n_i = \infty$

ANSWER

(C) $n_f = 2$, $n_i = 4$

Balmer series: all transitions end on $n_f = 2$.
First line (Hα): $3 \rightarrow 2$; second line (Hβ): $4 \rightarrow 2$; the series limit is $\infty \rightarrow 2$.
So the second line is $n_i = 4 \rightarrow n_f = 2$.

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10. Germanium is doped with arsenic. As a result of this doping: **1**

(A) the Ge lattice structure gets distorted

(B) the number of conduction electrons increases

(C) the number of holes increases

(D) the number of conduction electrons decreases

ANSWER

(B) conduction electrons increase

As is pentavalent (group 15). Four of its valence electrons form covalent bonds with neighbouring Ge atoms; the fifth is loosely bound and easily becomes a free (conduction) electron.
So As is a donor, giving an n-type semiconductor with more conduction electrons (holes actually decrease slightly due to recombination). The lattice is not distorted because the dopant is in tiny amount and of similar size.

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11. Photons of energy 3.3 eV (beam A) and 11.3 eV (beam B) fall one after the other on a metal of work function 2.3 eV. The ratio of the maximum speed of photoelectrons due to A to that due to B is: **1**

(A) 3

(B) 9

(C) 1/3

(D) 1/9

ANSWER

(C) 1/3

$K_{max} = h\nu - \varphi_0$.
Beam A: $3.3 - 2.3 = 1$ eV; Beam B: $11.3 - 2.3 = 9$ eV.
$K = \frac{1}{2}mv^2 \Rightarrow v \propto \sqrt{K}$.
$v_A / v_B = \sqrt{(1/9)} = 1/3$.

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12. A moving electron and a moving proton have the same de Broglie wavelength λ. They must have the same: **1**

(A) momentum

(B) angular momentum

(C) speed

(D) energy

ANSWER

(A) momentum

λ = h/p. Equal λ ⇒ equal momentum p.

Since masses differ, their speeds (v = p/m) and kinetic energies ($K = p^2/2m$) are different.

13. Assertion (A): In the photoelectric effect, the kinetic energy of emitted photoelectrons increases when the intensity of incident light is increased. **1**

Reason (R): The photoelectric current depends on the wavelength of the incident light.

(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

A is false: $K_{max} = h\nu - \varphi_0$ depends on frequency, not on intensity. Higher intensity only means more photons per second.

R is false: for light above the threshold frequency, the photocurrent depends on the intensity (number of photons), not on the wavelength.

So both are false.

14. Assertion (A): Mutual inductance of two coils is greatest when one coil is wound over the other. **1**

Reason (R): Flux linkage between two coils is greatest when they are wound over each other.

(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

$M = N_2\Phi_2/I_1$ – it is the flux linked with one coil per unit current in the other.

When the coils are wound over each other, almost all the flux of one coil passes through the other (minimum flux leakage), so flux linkage is maximum and therefore M is maximum.

R is exactly the reason for A.

15. Assertion (A): Two long parallel wires hanging freely and connected in series with a battery move away from each other. **1**

Reason (R): Two wires carrying currents in opposite directions repel each other.

(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

When two parallel wires are joined in series with a battery, the current goes down one wire and returns up the other, so the currents are antiparallel.

Antiparallel currents repel ($F/l = \mu_0 I_1 I_2 / 2\pi d$, repulsive), so the wires move apart.

R is true and correctly explains A.

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16. Assertion (A): A plane mirror or a convex mirror can never form a real image. **1**

Reason (R): A virtual image cannot act as an object to form a real image.

(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

A is false: if a converging beam (virtual object behind the mirror) falls on a plane mirror, the reflected rays meet in front of it – a real image. A convex mirror can also give a real image of a virtual object lying within its focal length.

R is false: a virtual image can serve as an object for another optical element, e.g. the virtual image formed by one lens becomes the object for the eye lens, which forms a real image on the retina.

So both are false.

SECTION B

Q17–21 carry 2 marks each.

17. At what temperature will the resistance of a silver wire become double its resistance at 20 °C? Use 20 °C as reference temperature; temperature coefficient of resistance of silver at 20 °C = $4.0 \times 10^{-3}\ K^{-1}$. **2**

ANSWER

T = 270 °C (543 K)

$R_T = R_0[1 + \alpha(T - T_0)]$, $T_0 = 20$ °C.
Given $R_T = 2R_0 \Rightarrow 2 = 1 + \alpha(T - 20)$.
$T - 20 = 1/\alpha = 1/(4.0 \times 10^{-3}) = 250$.
T = 270 °C ≈ 543 K.

18. Monochromatic light of frequency 5.0×10^{14} Hz goes from air into a medium of refractive index 1.5. Find the wavelength of (i) the reflected light and (ii) the refracted light at the interface. **2**

ANSWER

(i) 600 nm (ii) 400 nm

Frequency does not change on reflection or refraction.
(i) Reflected light stays in air: $\lambda = c/\nu = (3 \times 10^8)/(5.0 \times 10^{14}) = 6 \times 10^{-7}$ m = 600 nm.
(ii) In the medium speed $v = c/n$, so $\lambda' = \lambda/n = 600/1.5 = 400$ nm (4×10^{-7} m).
Common mistake: changing the frequency instead of the wavelength.

OR

A plano-convex lens of focal length 16 cm is made of a material of refractive index 1.4. Find the radius of curvature of its curved surface.

ANSWER

R = 6.4 cm

Lens maker's formula: $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.
For a plano-convex lens $R_1 = R$, $R_2 = \infty$:
$1/f = (n - 1)/R \Rightarrow R = (n - 1)f = 0.4 \times 16 = 6.4$ cm.

19. An object stands 30 cm in front of a concave mirror whose radius of curvature is 40 cm. Find (i) where the image is formed and (ii) the magnification. **2**

ANSWER

(i) v = −60 cm (60 cm in front, real) (ii) m = −2

f = −R/2 = −20 cm, u = −30 cm (sign convention).
(i) Mirror formula: $1/v + 1/u = 1/f \Rightarrow 1/v = 1/f - 1/u = -1/20 + 1/30 = -1/60 \Rightarrow v = -60$ cm.
Image is 60 cm in front of the mirror – real.
(ii) $m = -v/u = -(-60)/(-30) = -2$: inverted and twice the size.

20. A neutron of mass m has kinetic energy E, and a photon has the same energy E. If λ_n is the de Broglie wavelength of the neutron and λ_p the wavelength of the photon, find λ_n/λ_p. **2**

ANSWER

λ_n/λ_p = √(E/(2mc²))

Photon: E = hc/λ_p ⇒ λ_p = hc/E.

Neutron: p = √(2mE) ⇒ λ_n = h/√(2mE).

$$\frac{\lambda_n}{\lambda_p} = \frac{h}{\sqrt{2mE}} \times \frac{E}{hc} = \sqrt{\frac{E}{2mc^2}}.$$

21. Draw the current–voltage graph for gallium arsenide (GaAs). Mark on it the region where (a) the resistance is negative and (b) Ohm's law is obeyed. **2**

ANSWER

I rises, reaches a peak, falls (negative resistance), then rises again; Ohm's law holds in the initial straight part

Graph (V on x-axis, I on y-axis): starting at the origin the current first rises almost linearly with V, then bends, reaches a maximum, then decreases while V keeps increasing, and finally rises again.

(a) Negative-resistance region: the falling part of the curve after the peak, where dI/dV < 0 (current decreases as voltage increases).

(b) Ohm's law region: the initial straight-line portion near the origin, where I ∝ V.

Marks: correct shape of the graph + both regions labelled.

SECTION C

Q22–28 carry 3 marks each.

22. A cube of side 0.1 m lies in a region where $\vec{E} = 500x\,\hat{i}$ N/C (x in metres). The cube's edges are parallel to the axes, and its left face lies in the plane x = 0.1 m (so the right face is at x = 0.2 m). Calculate (a) the net electric flux through the cube and (b) the charge inside it. **3**

ANSWER

(a) 0.5 N m² C⁻¹ (b) q ≈ 4.4 × 10⁻¹² C

E is along x only, so only the two faces perpendicular to x contribute; flux through the other four faces is zero.

Area of each face A = (0.1)² = 0.01 m².

Left face (x = 0.1 m): E = 50 N/C, outward normal is −x: φ_L = −50 × 0.01 = −0.5 N m²/C.

Right face (x = 0.2 m): E = 100 N/C, outward normal +x: φ_R = +100 × 0.01 = +1.0 N m²/C.

(a) Net flux φ = −0.5 + 1.0 = 0.5 N m² C⁻¹.

(b) Gauss's law: q = ε₀φ = 8.854 × 10⁻¹² × 0.5 ≈ 4.4 × 10⁻¹² C.

23. Define current density and state whether it is a scalar or a vector. A field $\vec{E}$ is maintained in a metallic conductor having n electrons (mass m, charge −e) per unit volume with relaxation time τ. Show that the current density is $\vec{j} = \alpha\vec{E}$, where $\alpha = \dfrac{ne^2}{m}\tau$. **3**

ANSWER

j = I/A, a vector; j = (ne²τ/m)E

Current density: current flowing per unit area held normal to the direction of flow, j = I/A. It is a vector (direction of flow of positive charge).

Acceleration of an electron: a = −eE/m. Average drift velocity: v_d = −(eE/m)τ.

In time Δt, charge crossing area A: IΔt = neA|v_d|Δt ⇒ I = neA·(eEτ/m) = (ne²τ/m)AE.

j = I/A = (ne²τ/m)E. Since electrons drift opposite to E but carry negative charge, j is along E:

$\vec{j} = \dfrac{ne^2\tau}{m}\vec{E} = \alpha\vec{E}$ (this is Ohm's law, α = conductivity σ).

OR

What is a Wheatstone bridge? Derive the condition for the bridge to be balanced.

ANSWER

Balanced when $R_1/R_2 = R_3/R_4$ (no current in galvanometer)

A Wheatstone bridge is an arrangement of four resistances R_1, R_2, R_3, R_4 in a quadrilateral ABCD, with a cell across one diagonal (A–C) and a galvanometer G across the other (B–D). It is used to find an unknown resistance.

Let R_1 = AB, R_2 = BC, R_3 = AD, R_4 = DC, currents I_1 in AB, I_3 in AD, I_g in BD.

At balance I_g = 0, so by the junction rule the current in BC is I_1 and in DC is I_3.

Loop ABDA: $I_1R_1 + I_gG - I_3R_3 = 0 \Rightarrow I_1R_1 = I_3R_3$ … (1)

Loop BCDB: $I_1R_2 - I_3R_4 - I_gG = 0 \Rightarrow I_1R_2 = I_3R_4$ … (2)

Dividing (1) by (2): $R_1/R_2 = R_3/R_4$ – the balance condition (B and D are at the same potential).

24. A proton with kinetic energy 1.3384×10^{-14} J moves horizontally from north to south and enters a uniform 2.0 mT magnetic field pointing east. Find (a) its speed, (b) the magnitude of its acceleration and (c) the radius of its path. Take q/m for the proton = 1.0×10^{8} C/kg. **3**

ANSWER

(a) 4×10^{6} m/s (b) 8×10^{11} m/s² (c) 20 m

(a) $K = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{(2K/m)}$. With $m = 1.673 \times 10^{-27}$ kg:
$v = \sqrt{(2 \times 1.3384 \times 10^{-14} / 1.673 \times 10^{-27})} = \sqrt{(1.6 \times 10^{13})} = 4.0 \times 10^{6}$ m/s.
(b) $v \perp B$, so $F = qvB$ and $a = (q/m)vB = 1.0 \times 10^{8} \times 4 \times 10^{6} \times 2 \times 10^{-3} = 8 \times 10^{11}$ m/s².
(c) $r = mv/(qB) = v/[(q/m)B] = 4 \times 10^{6} / (1.0 \times 10^{8} \times 2 \times 10^{-3}) = 20$ m.

25. A series LCR circuit is connected to an ac source $v = v_m \sin \omega t$. Derive the expression for the average power dissipated in the circuit. Also find the expression for its resonant frequency. **3**

ANSWER

$P_{avg} = V_{rms} I_{rms} \cos \varphi (= I^2R)$; $\nu_0 = 1/(2\pi\sqrt{(LC)})$

Let $v = v_m \sin \omega t$ and the current $i = i_m \sin(\omega t + \varphi)$, φ = phase difference.
Instantaneous power $p = vi = v_m i_m \sin \omega t \sin(\omega t + \varphi) = (v_m i_m/2)[\cos \varphi - \cos(2\omega t + \varphi)]$.
The average of $\cos(2\omega t + \varphi)$ over a cycle is zero.
$P_{avg} = (v_m i_m/2) \cos \varphi = (v_m/\sqrt{2})(i_m/\sqrt{2}) \cos \varphi = V I \cos \varphi = I^2Z \cos \varphi = I^2R$ (since $\cos \varphi = R/Z$).
Resonance: current is maximum when Z is minimum, i.e. $X_L = X_C$:
$\omega_0 L = 1/(\omega_0 C) \Rightarrow \omega_0 = 1/\sqrt{(LC)} \Rightarrow \nu_0 = 1/(2\pi\sqrt{(LC)})$.

26. (a) It is often said that the wavelength of an electromagnetic wave is related to the typical size of the system that emits it. Give two examples supporting this. **3**
(b) (i) Why do long-distance radio broadcasts use short-wave bands?
(ii) Why are optical and radio telescopes placed on the ground while X-ray astronomy needs satellites orbiting the Earth?

ANSWER

(a) γ-rays from nuclei (~10^{-14} m), X-rays from heavy atoms, radio waves from antennas of size ~λ; (b)(i) ionosphere reflects short waves (ii) atmosphere absorbs X-rays

(a) Any two:
• Gamma rays ($\lambda \sim 10^{-14}$–10^{-15} m) come from atomic nuclei, whose size is ~10^{-14} m.
• X-rays ($\lambda \sim 10^{-10}$ m) are emitted by inner-shell transitions in heavy atoms (atomic size ~10^{-10} m).
• Radio waves are radiated by accelerated charges in antennas; an antenna radiates best at a wavelength comparable to its own length.
(b)(i) Short-wave radio is reflected back by the ionosphere, so signals can travel far beyond the horizon by sky-wave propagation.
(ii) Visible light and radio waves pass through the atmosphere (atmospheric 'windows'), but X-rays are absorbed by the atmosphere, so X-ray telescopes must be above it, on satellites.

27. State the shortcomings of Rutherford's model of the atom. How did Bohr overcome them? Show that successive orbits in Bohr's atom are not equally spaced. **3**

ANSWER

Unstable atom + continuous spectrum predicted; Bohr's stationary orbits; $r \propto n^2$, gap $r_{n+1} - r_n \propto (2n+1)$

Drawbacks of Rutherford's model:

1. An orbiting electron is accelerated and, by classical theory, should radiate energy continuously, spiral inwards and fall into the nucleus – the atom would be unstable.
2. Its frequency of revolution would change continuously, so it would emit a continuous spectrum, whereas atoms show line spectra.

Bohr's remedy: electrons revolve only in certain stationary orbits (angular momentum $mvr = nh/2\pi$) in which they do not radiate; radiation is emitted only when an electron jumps from a higher to a lower orbit, with $h\nu = E_i - E_f$ – this explains both stability and line spectra.

Spacing: $r_n = n^2h^2\varepsilon_0/(\pi me^2) = n^2a_0$, so $r \propto n^2$.

$r_{n+1} - r_n = a_0[(n+1)^2 - n^2] = a_0(2n + 1)$, which increases with n. E.g. $r_1 = a_0$, $r_2 = 4a_0$, $r_3 = 9a_0$: gaps $3a_0$, $5a_0$… – not equal.

28. (a) Write any two properties of a nucleus. **3**

(b) Why is the density of a nucleus far greater than that of an atom?

(c) Show that all nuclei have the same density of nuclear matter.

ANSWER

(a) e.g. positively charged; $R = R_0A^{1/3}$ (b) almost all mass sits in tiny nucleus, atom mostly empty (c) $\rho = 3m/(4\pi R_0^3)$, independent of A

(a) Any two: the nucleus is positively charged; it is made of protons and neutrons (nucleons); its radius $R = R_0A^{1/3}$ ($R_0 \approx 1.2$ fm); nuclear density is independent of mass number; nuclear forces are short-range and very strong.

(b) Almost the entire mass of the atom is concentrated in the nucleus, whose radius ($\sim 10^{-15}$ m) is about 10^5 times smaller than the atom ($\sim 10^{-10}$ m). The atom is mostly empty space, so the nucleus is far denser.

(c) Mass of nucleus $\approx mA$ (m = mass of one nucleon). Volume $= (4/3)\pi R^3 = (4/3)\pi R_0^3A$.

$\rho = mA / [(4/3)\pi R_0^3A] = 3m/(4\pi R_0^3)$ – A cancels, so the density is the same ($\sim 2.3 \times 10^{17}$ kg/m^3) for all nuclei.

SECTION D

Q29–30 are case-study based, 4 marks each (four 1-mark MCQs; choice in part (iv)).

29. The focal length of a lens depends on the radii of curvature of its two faces and on the refractive index of its material relative to the surrounding medium. Power is 1/f, and powers of lenses in contact add algebraically. **4**

(i) A double-convex glass lens (refractive index n) has both faces of radius R. Its power is: (A) 2(n − 1)/R (B) (2n − 1)/R (C) (n − 1)/2R (D) (2n − 1)/2R

(ii) A double-convex lens of power P (equal radii) is cut into two equal halves by a plane perpendicular to its principal axis. Power of each half: (A) 2P (B) P (C) 4P (D) P/2

(iii) The two halves from (ii) are put back in contact with their flat faces touching (re-forming the original shape). Power of the combination: (A) P/2 (B) P (C) 2P (D) P/4

(iv) A double-convex lens of power P (equal radii) is cut along its principal axis into two halves, and the two halves are placed one behind the other on the same axis, in contact. Power of the combination: (A) Zero (B) P (C) 2P (D) P/2

ANSWER

(i) (A) 2(n−1)/R (ii) (D) P/2 (iii) (B) P (iv) (C) 2P

(i) $1/f = (n-1)(1/R - 1/(-R)) = 2(n-1)/R \Rightarrow P = 2(n-1)/R \rightarrow$ (A).

(ii) Each half is plano-convex: $P' = (n-1)/R$ = half of $2(n-1)/R \rightarrow P/2 \rightarrow$ (D).

(iii) Two lenses in contact: $P/2 + P/2 = P \rightarrow$ (B).

(iv) Cutting along the axis does not change the curvature of the faces, so each half still has power P (only the aperture is halved). Two such halves in contact coaxially: $P + P = 2P \rightarrow$ (C).

Common mistake: in (iv) thinking each half has power P/2 – that happens only for a cut perpendicular to the axis.

OR

(iv) (b) Two convex lenses of focal lengths 60 cm and 20 cm are held coaxially in contact. The power of the combination is:

(A) 6.6 D **(B)** 15 D

(C) $\frac{1}{15}$ D **(D)** $\frac{1}{80}$ D

ANSWER

(A) ≈ 6.6 D

$P = 1/f_1 + 1/f_2$ with f in metres: $P = 1/0.6 + 1/0.2 = 1.67 + 5 = 6.67$ D ≈ 6.6 D.

(Equivalent focal length F = 15 cm.)

Common mistake: writing 1/15 D by using centimetres.

30. A p-n junction diode has low resistance when forward biased and very high resistance when reverse biased, so it conducts only in one direction. This lets it convert ac into dc (rectification): a half-wave rectifier uses only alternate half cycles, a full-wave rectifier uses both. **4**

(i) The rms value of the ac voltage fed to a full-wave rectifier is $V_0/\sqrt{2}$. The rms value of the rectified output is: (A) $V_0/\sqrt{2}$ (B) $V_0^2/\sqrt{2}$ (C) $2V_0/\sqrt{2}$ (D) $V_0/(2\sqrt{2})$

(ii) In a full-wave rectifier, current flows through each diode for: (A) the complete cycle of input (B) half cycle of input (C) less than half cycle of input (D) only the positive half cycle of input

(iii) In a full-wave rectifier: (A) both diodes are forward biased at the same time (B) both are reverse biased at the same time (C) one is forward biased while the other is reverse biased (D) both are forward biased in the first half cycle and reverse biased in the second

(iv) A 50 Hz alternating voltage is applied to a half-wave rectifier. The ripple frequency of the output is: (A) 100 Hz (B) 50 Hz (C) 25 Hz (D) 150 Hz

ANSWER

(i) (A) $V_0/\sqrt{2}$ (ii) (B) half cycle (iii) (C) (iv) (B) 50 Hz

(i) The full-wave output is $|V_0 \sin \omega t|$; squaring removes the sign, so its rms value equals that of the input: $V_0/\sqrt{2}$ → (A).

(ii) Each diode conducts only when it is forward biased, i.e. during one half of each cycle → (B).

(iii) The two ends of the centre-tapped secondary are always in opposite phase, so at any instant one diode is forward biased and the other reverse biased → (C).

(iv) A half-wave rectifier gives one output pulse per input cycle, so the ripple frequency equals the input frequency, 50 Hz → (B). (Full-wave would give 100 Hz.)

OR

(iv) A square-wave signal switching between +5 V and −5 V is applied to a circuit in which a

(b) p-n junction diode is in series with a load R_L (output taken across R_L; the diode conducts when the input is positive). The output across R_L is:

(A) Positive pulses of height 10 V (zero otherwise)

(B) Negative pulses of depth −10 V (zero otherwise)

(C) Negative pulses of depth −5 V (zero otherwise)

(D) Positive pulses of height +5 V (zero otherwise)

ANSWER

(D) +5 V pulses

When input = +5 V, the diode is forward biased and (ideal diode) the full +5 V appears across R_L.

When input = −5 V, the diode is reverse biased, no current flows, output = 0.

So the output is a train of +5 V pulses separated by zero – half-wave rectified square wave → (D).

Common mistake: taking the peak-to-peak value (10 V) as the output height.

SECTION E

Q31–33 carry 5 marks each.

31. (i) Derive the potential energy of an electric dipole $\vec{p}$ in a uniform external field $\vec{E}$. When is this potential energy (1) maximum and (2) minimum? **5**

(ii) A dipole is formed by charges −1.0 pC at (0, 0) and +1.0 pC at (3 mm, 4 mm) in the x–y plane. A field $\vec{E} = (1000\ \text{V/m})\,\hat{i}$ is switched on. Find the torque $\vec{\tau}$ on the dipole.

ANSWER

(i) U = −pE cos θ = −p·E; max at θ = 180°, min at θ = 0° (ii) τ = −4 × 10⁻¹² N m k̂

(i) Torque on the dipole in uniform E: τ = pE sin θ (tends to align p with E).

Work done by an external torque in rotating it slowly from θ₀ to θ₁:

W = ∫ pE sin θ dθ (θ₀ → θ₁) = pE(cos θ₀ − cos θ₁).

This work is stored as potential energy. Choosing U = 0 at θ₀ = 90°:

U(θ) = −pE cos θ = $-\vec{p}\cdot\vec{E}$.

(1) Maximum U = +pE when θ = 180° (p antiparallel to E) – unstable equilibrium.

(2) Minimum U = −pE when θ = 0° (p parallel to E) – stable equilibrium.

(ii) Dipole moment points from −q to +q: $\vec{p} = q\vec{d} = 1.0 \times 10^{-12}(3\hat{i} + 4\hat{j}) \times 10^{-3} = (3\hat{i} + 4\hat{j}) \times 10^{-15}$ C m (|p| = 5 × 10⁻¹⁵ C m).

$\vec{\tau} = \vec{p} \times \vec{E} = (3\hat{i} + 4\hat{j}) \times 10^{-15} \times 1000\,\hat{i} = 4 \times 10^{-12}(\hat{j} \times \hat{i}) = -4 \times 10^{-12}\,\hat{k}$ N m.

Magnitude 4 × 10⁻¹² N m (check: pE sin θ = 5 × 10⁻¹⁵ × 1000 × 0.8), directed along −z.

OR

(i) A dipole of moment $\vec{p} = p\,\hat{i}$, made of charges −q and +q separated by 2a, lies along the x-axis with its centre at the origin. Show that its potential at a point x on the axis (x ≫ a) is $V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}\cdot\hat{i}}{x^2}$.

(ii) Two isolated metal spheres S₁ and S₂ of radii 1 cm and 3 cm carry the same surface charge density $\left(\frac{2}{\pi} \times 10^{-9}\right)$ C/m². They are far apart and are then joined by a thin wire. Find the new charge on S₁.

ANSWER

(ii) Q₁' = 2 × 10⁻¹² C

(i) −q is at x = −a, +q at x = +a. At point P (x, 0):

V = (1/4πε₀)[q/(x − a) − q/(x + a)] = (1/4πε₀)·q·2a/(x² − a²) = (1/4πε₀)·p/(x² − a²), with p = 2qa.

For x ≫ a, a² is negligible: V = p/(4πε₀x²). Since $\vec{p} = p\hat{i}$, p = $\vec{p}\cdot\hat{i}$, so V = (1/4πε₀)($\vec{p}\cdot\hat{i}$)/x².

(ii) Initial charges Q = σ·4πr²:

Q₁ = (2/π × 10⁻⁹)(4π × 10⁻⁴) = 8 × 10⁻¹³ C; Q₂ = (2/π × 10⁻⁹)(4π × 9 × 10⁻⁴) = 72 × 10⁻¹³ C.

Total Q = 80 × 10⁻¹³ C (conserved).

When joined, they reach a common potential: kQ₁'/r₁ = kQ₂'/r₂ ⇒ Q₁'/Q₂' = r₁/r₂ = 1/3.

Q₁' = Q/4 = 20 × 10⁻¹³ = 2 × 10⁻¹² C (and Q₂' = 6 × 10⁻¹² C).

Note: charge flows from S₂ to S₁ even though σ was equal, because S₂ was at the higher potential (V = σr/ε₀).

32. (i) A resistor R and a capacitor C are in series with an ac source $v = v_m \sin \omega t$. Derive the impedance of the circuit. **5**

(ii) When does an inductor behave like a plain conductor in a circuit? Give the reason.

(iii) An electric lamp is rated for 110 V dc and 11 A. It is to be run on a 220 V, 50 Hz ac supply by putting a coil in series. Find the inductance of the coil.

ANSWER

(i) $Z = \sqrt{(R^2 + 1/(\omega^2C^2))}$ (ii) for dc ($\nu = 0$, $X_L = 0$) (iii) $L \approx 0.055$ H

(i) The same current $i = i_m \sin(\omega t + \varphi)$ flows through R and C. Voltage across R ($v_R = i_mR$) is in phase with i; voltage across C ($v_C = i_mX_C$) lags i by 90°.

Phasor addition: $v_m^2 = v_R^2 + v_C^2 = i_m^2(R^2 + X_C^2)$.

$Z = v_m/i_m = \sqrt{(R^2 + X_C^2)} = \sqrt{(R^2 + 1/(\omega^2C^2))}$, and $\tan \varphi = X_C/R$ (current leads voltage).

(ii) An inductor acts as a pure conductor for direct current: $X_L = \omega L = 2\pi\nu L$ and for dc $\nu = 0$, so $X_L = 0$. (Equivalently, for steady current $dI/dt = 0$, so the back emf $L\, dI/dt = 0$.) Only its small wire resistance remains.

(iii) Lamp resistance $R = 110/11 = 10\ \Omega$. Required current 11 A from 220 V rms: $Z = 220/11 = 20\ \Omega$.

$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(400 - 100)} = \sqrt{300} = 10\sqrt{3} \approx 17.3\ \Omega$.

$L = X_L/(2\pi\nu) = 17.3/(2\pi \times 50) = 17.3/314 \approx 0.055$ H (55 mH).

OR

(i) Draw a labelled diagram of a step-up transformer and explain its working principle. Explain any three reasons for energy loss in a real transformer.

(ii) A step-up transformer changes a low voltage into a high voltage. Does this go against the law of conservation of energy? Explain.

(iii) A step-up transformer has 200 turns in the primary and 3000 in the secondary. The primary input is 90 V. Find (1) the secondary output voltage and (2) the primary current if the secondary current is 2.0 A.

ANSWER

(ii) No – current falls in the same ratio (iii) (1) 1350 V (2) 30 A

(i) Diagram: a laminated soft-iron core with a primary coil of few turns (N_p, connected to ac input) and a secondary coil of many turns ($N_s > N_p$, connected to the load).

Principle: mutual induction. The alternating primary current produces an alternating flux in the core which links the secondary and induces an emf in it. With the same flux per turn, $V_s/V_p = N_s/N_p$.

Energy losses (any three): (a) flux leakage – not all primary flux links the secondary; (b) copper (I^2R) loss in the resistance of the windings; (c) eddy currents in the core (reduced by laminating); (d) hysteresis loss in repeated magnetisation of the core; (e) humming/vibration.

(ii) No. For an ideal transformer $V_pI_p = V_sI_s$; when the voltage is stepped up, the current is stepped down in the same ratio, so output power never exceeds input power.

(iii) (1) $V_s = V_p(N_s/N_p) = 90 \times 3000/200 = 90 \times 15 = 1350$ V.

(2) $I_p = I_s(N_s/N_p) = 2.0 \times 15 = 30$ A (ideal transformer).

33. (i) A light ray passes through a triangular prism. Sketch how the angle of deviation varies with the angle of incidence and hence define the angle of minimum deviation. **5**

(ii) A ray falls normally on one refracting face of a prism of angle A and is deviated by angle δ. Prove that the refractive index is $n = \frac{\sin(A+\delta)}{\sin A}$.

(iii) A prism of refracting angle 60° has refractive index √2. Find (1) the angle of minimum deviation and (2) the corresponding angle of incidence.

ANSWER

(iii) (1) δ_m = 30° (2) i = 45°

(i) Graph of δ (y-axis) against i (x-axis): a U-shaped curve – δ first decreases as i increases, reaches a minimum δ_m, and then increases again.

Angle of minimum deviation: the smallest deviation produced by the prism; at this position the angle of incidence equals the angle of emergence (i = e) and the ray inside the prism is parallel to the base.

(ii) At the first face incidence is normal, so the ray enters undeviated ($r_1 = 0$). Since $r_1 + r_2 = A$, it meets the second face at $r_2 = A$.

It emerges at angle e. All the deviation occurs at the second face: $\delta = e - r_2 = e - A \Rightarrow e = A + \delta$.

Snell's law at the second face (glass to air): $n \sin A = \sin e = \sin(A + \delta) \Rightarrow n = \sin(A + \delta)/\sin A$.

(iii) (1) $n = \frac{\sin\frac{A+\delta_m}{2}}{\sin\frac{A}{2}} \Rightarrow \sin((60° + \delta_m)/2) = \sqrt{2} \times \sin 30° = 1/\sqrt{2} \Rightarrow (60° + \delta_m)/2 = 45° \Rightarrow \delta_m = 30°$.

(2) At minimum deviation i = (A + δ_m)/2 = 45°.

OR

(i) State Huygens' principle. A plane wavefront strikes a reflecting surface at angle i. Construct the reflected wavefront and use it to prove that the angle of reflection equals the angle of incidence.

(ii) What are coherent sources of light? Can two independent sodium lamps behave as coherent sources? Explain.

(iii) Light containing a known wavelength 520 nm and an unknown wavelength λ is used in Young's double-slit experiment. The 4th bright fringe of λ falls exactly on the 5th bright fringe of 520 nm. Find λ.

ANSWER

(i) i = r (ii) No (iii) λ = 650 nm

(i) Huygens' principle: every point on a wavefront acts as a source of secondary wavelets that spread out in all directions with the speed of the wave; the common forward tangent (envelope) to these wavelets gives the new wavefront at a later time.

Construction: plane wavefront AB meets the mirror MN at A, at angle i. While the disturbance from B travels BC = vt to reach the mirror at C, the wavelet from A spreads to a sphere of radius AE = vt. The tangent CE from C to this sphere is the reflected wavefront.

In right triangles ABC and AEC: AC is common, BC = AE = vt, ∠ABC = ∠AEC = 90°, so the triangles are congruent ⇒ ∠BAC = ∠ECA ⇒ i = r.

(ii) Coherent sources: sources whose phase difference stays constant with time (and having the same frequency).

> Two independent sodium lamps cannot be coherent: light from each comes from random, independent emissions by millions of atoms lasting ~10^{-8} s, so the phase difference between the two lamps changes randomly and rapidly; no steady interference pattern is seen.
> (iii) Position of nth bright fringe $y = n\lambda D/d$. Coincidence: $4\lambda D/d = 5 \times 520 \times D/d \Rightarrow \lambda = 5 \times 520/4 = 650$ nm.

— END —

Questions restated from the CBSE Class XII Board Examination 2024 (set 55/1/1) for practice. Reading passages and map items are described, not reproduced.