Roll No. ☐☐☐☐☐☐☐☐

Q.P. Code 55/2/1

PHYSICS (THEORY)

CBSE Class XII Board Examination 2022 (Term 2) — with answers

Time allowed: 2 hours **Maximum Marks: 35**

General Instructions:

1. This Term-2 paper has 12 questions in three sections (A, B and C); all of them must be answered.
2. Section A: Q1–3, 2 marks each.
3. Section B: Q4–11, 3 marks each.
4. Section C: Q12 is a case-study based question of 5 marks.
5. There is no overall choice, but some questions offer an internal choice (OR); answer only one alternative. Log tables may be used; calculators are not allowed.
6. 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

Q1–3 carry 2 marks each.

1. How is the depletion region formed at a p-n junction? Explain. **2**

ANSWER

Diffusion of electrons (n→p) and holes (p→n) leaves uncovered immobile ions near the junction – this charge layer, empty of free carriers, is the depletion region.

1. When the junction is formed, the n-side has many free electrons and the p-side has many holes, so there is a concentration difference across the junction.
2. Electrons diffuse from the n-side to the p-side and holes diffuse from the p-side to the n-side (diffusion current).
3. An electron leaving the n-side leaves behind an immobile positive donor ion; a hole leaving the p-side leaves behind an immobile negative acceptor ion.
4. So a thin layer of fixed positive ions forms on the n-side and of fixed negative ions on the p-side of the junction. This layer has no free charge carriers – it is called the depletion region (width ~ 1 μm).
5. The ions create an electric field (and a barrier potential) directed from n to p, which opposes further diffusion and drives a drift current. Equilibrium is reached when drift current = diffusion current.

Tip: a labelled sketch showing + ions on the n-side and – ions on the p-side earns marks too.

2. (i) In the Geiger–Marsden α-particle scattering experiment, what is meant by (a) impact parameter and (b) distance of closest approach? **2**

(ii) What is the impact parameter when the scattering angle is (I) $\theta = 0^\circ$ and (II) $\theta = 180^\circ$?

ANSWER

(ii) θ = 0°: impact parameter is maximum (of atomic size); θ = 180°: impact parameter b = 0.

(i)(a) Impact parameter b: the perpendicular distance of the initial velocity vector (line of motion) of the α-particle from the centre of the nucleus.

(b) Distance of closest approach r_0: in a head-on approach, the minimum distance from the centre of the nucleus that the α-particle reaches, where all its kinetic energy K has become electrostatic potential energy: $K = \frac{1}{4\pi\varepsilon_0}\frac{(Ze)(2e)}{r_0} \Rightarrow r_0 = \frac{2Ze^2}{4\pi\varepsilon_0 K}$.

(ii) Smaller impact parameter → larger scattering (b ∝ cot(θ/2)).

(I) θ = 0° (undeviated): b is very large – the particle passes far from the nucleus (maximum, of the order of atomic size).

(II) θ = 180° (bounces straight back): b = 0, i.e. a head-on collision.

OR

A metal surface is irradiated with radiation of frequency ν_1 and then with radiation of frequency ν_2. The maximum kinetic energies of the photoelectrons are K and 2K respectively. Find an expression for the threshold frequency of the surface.

ANSWER

$\nu_0 = 2\nu_1 - \nu_2$

Einstein's equation: $K_{max} = h\nu - h\nu_0$.

Case 1: $K = h\nu_1 - h\nu_0$ …(1)

Case 2: $2K = h\nu_2 - h\nu_0$ …(2)

Multiply (1) by 2 and equate with (2): $2h\nu_1 - 2h\nu_0 = h\nu_2 - h\nu_0$

$\Rightarrow h\nu_0 = 2h\nu_1 - h\nu_2 \Rightarrow \nu_0 = 2\nu_1 - \nu_2$.

Check: since 2K > K, $\nu_2 > \nu_1$, and $\nu_0 < \nu_1$ requires $\nu_2 < 2\nu_1$ – consistent.

3. Explain how a solar cell produces an emf through its three basic processes. **2**

ANSWER

Generation of electron–hole pairs by light near the junction, separation of the pairs by the junction field, and collection at the contacts make the p-side positive and the n-side negative.

1. Generation: photons with energy hν greater than the band gap E_g are absorbed close to the p-n junction and create electron–hole pairs.

2. Separation: the electric field of the depletion region pushes the electrons towards the n-side and the holes towards the p-side.

3. Collection: electrons reaching the n-side are gathered by the front contact and holes reaching the p-side by the back contact.

As a result the p-side becomes positive and the n-side negative, so a photo-voltage (emf) appears across the cell and a current flows through an external load.

Marks: one point for each process plus the conclusion about the polarity of the cell.

SECTION B

Q4–11 carry 3 marks each.

4. (i) Draw a sketch of a plane electromagnetic wave travelling along the x-axis and write expressions for its oscillating electric and magnetic fields. **3**

(ii) State three characteristics of electromagnetic waves.

ANSWER

$E_y = E_0 \sin(kx - \omega t)$, $B_z = B_0 \sin(kx - \omega t)$; EM waves are transverse, travel at c in vacuum, carry energy and momentum.

(i) Sketch: x-axis as direction of travel; E drawn as a sine wave in the x-y plane (along y) and B as a sine wave in the x-z plane (along z), both in phase and perpendicular to each other and to x.
Expressions: $E_y = E_0 \sin(kx - \omega t)$, $B_z = B_0 \sin(kx - \omega t)$, with $k = 2\pi/\lambda$, $\omega = 2\pi\nu$ and $E_0/B_0 = c$.
(ii) Any three:
• They are transverse – E and B are perpendicular to each other and to the direction of propagation.
• In vacuum all travel with speed $c = 1/\sqrt{\mu_0 \varepsilon_0} = 3 \times 10^8$ m/s.
• They carry energy and momentum (and exert radiation pressure).
• They need no material medium.
• E and B oscillate in phase.

OR

Identify the electromagnetic waves produced by each source below and give one use of each:
(i) radioactive decay of nuclei
(ii) welding arcs
(iii) hot bodies

ANSWER

(i) γ-rays – cancer treatment; (ii) ultraviolet – sterilising/water purification (LASIK); (iii) infrared – night-vision devices, remote controls.

(i) Radioactive decay of nuclei → gamma rays. Use: radiotherapy to destroy cancer cells / sterilising medical equipment.
(ii) Welding arcs → ultraviolet rays (they also give visible and infrared light). Use: killing germs in water purifiers; LASIK eye surgery. (That is why welders wear special goggles.)
(iii) Hot bodies → infrared rays (heat radiation). Use: night-vision cameras, TV remote controls, physiotherapy heating.

5. (a) State the conditions needed for total internal reflection. **3**

(b) A tank holds a transparent liquid up to height H. A coin hanging from a thread is lowered slowly through the liquid until it reaches the bottom, and its apparent depth is measured for different real depths.

(i) Sketch the graph of apparent depth against real depth.

(ii) What does the slope of this graph physically represent?

ANSWER

(a) Light goes from denser to rarer medium, and angle of incidence > critical angle. (b) Straight line through origin; slope = 1/μ of the liquid.

(a) Conditions for TIR:

1. Light must travel from an optically denser medium towards a rarer medium.

2. The angle of incidence in the denser medium must be greater than the critical angle for that pair of media.

(b)(i) For near-normal viewing, apparent depth = real depth / μ. So apparent depth ∝ real depth: the graph is a straight line through the origin (real depth on x-axis from 0 to H, apparent depth on y-axis), with slope less than 1.

(ii) Slope = apparent depth / real depth = $1/\mu$, the reciprocal of the refractive index of the liquid. So μ = 1/slope.

Common mistake: plotting slope = μ – the slope is less than 1, so it is 1/μ.

6. Draw a labelled ray diagram for image formation by an astronomical (refracting) telescope in normal adjustment, and use it to derive its magnifying power. **3**

ANSWER

$m = -\dfrac{f_o}{f_e}$ (magnitude f_o/f_e), tube length $L = f_o + f_e$.

Ray diagram: parallel rays from a distant object, inclined at angle α to the axis, fall on the objective (focal length f_o) and form a real, inverted image of height h at its focal point, which is also the focus of the eyepiece (f_e). Rays leave the eyepiece parallel, making angle β with the axis, so the final image is at infinity. Label objective, eyepiece, f_o, f_e, intermediate image, α, β, arrows on rays.

Magnifying power $m = \beta/\alpha$ (angle subtended by final image / angle subtended by object).

For small angles: $\alpha \approx \tan\alpha = h/f_o$ and $\beta \approx \tan\beta = h/f_e$.

$\Rightarrow m = \dfrac{h/f_e}{h/f_o} = \dfrac{f_o}{f_e}$ (with sign, $-f_o/f_e$, as the image is inverted).

In normal adjustment the length of the telescope is $f_o + f_e$.

Tip: half a mark is lost if arrows or labels are missing.

OR

Light of wavelength λ, as a plane wavefront, falls normally on a narrow single slit of width a, and the diffraction pattern is seen on a screen at distance D.

(i) Sketch the intensity distribution of the pattern.

(ii) Derive the position of the first secondary maximum measured from the central maximum.

ANSWER

First secondary maximum at $\theta = \dfrac{3\lambda}{2a}$, i.e. $x = \dfrac{3\lambda D}{2a}$.

(i) Intensity graph: a tall, broad central maximum at θ = 0, with zeros at $\theta = \pm\lambda/a, \pm 2\lambda/a, \ldots$; between them much weaker secondary maxima near $\pm 3\lambda/2a, \pm 5\lambda/2a$, whose intensity falls off rapidly.

(ii) Divide the slit into three equal parts. When path difference between the two edges is $a\sin\theta = 3\lambda/2$, the first two thirds cancel each other (path difference λ/2 between corresponding points), and the last third adds up → a (weak) maximum.

General condition for secondary maxima: $a\sin\theta = (n + \frac{1}{2})\lambda$; first maximum, n = 1: $a\theta = 3\lambda/2$ (small θ).

$\theta = \dfrac{3\lambda}{2a}$; distance on screen $x = D\theta = \dfrac{3\lambda D}{2a}$.

7. A converging glass lens (μ = 1.5) has spherical surfaces with radii of curvature 10 cm and 20 cm. Find its focal length (a) in air, and (b) when it is immersed in a liquid of refractive index 1.25. **3**

ANSWER

(a) f = 40/3 ≈ 13.3 cm; (b) f = 100/3 ≈ 33.3 cm.

Lens maker's formula: $\frac{1}{f} = \left(\frac{\mu_g}{\mu_m} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$. A converging (biconvex) lens: $R_1 = +10$ cm, $R_2 = -20$ cm, so $\frac{1}{R_1} - \frac{1}{R_2} = \frac{1}{10} + \frac{1}{20} = \frac{3}{20}$ cm^{-1}.

(a) In air: $\frac{1}{f} = (1.5 - 1) \times \frac{3}{20} = \frac{3}{40} \Rightarrow f = \frac{40}{3} \approx 13.3$ cm.

(b) In liquid: $\frac{\mu_g}{\mu_l} = \frac{1.5}{1.25} = 1.2$; $\frac{1}{f_l} = (1.2 - 1) \times \frac{3}{20} = \frac{3}{100} \Rightarrow f_l = \frac{100}{3} \approx 33.3$ cm.

The lens is still converging but weaker, since the liquid's refractive index is closer to that of glass.

8. In the first excited state, a hydrogen atom has energy −3.4 eV. Find, for the electron in this orbit: **3**

(a) the orbit radius (Bohr radius = 0.53 Å)

(b) its angular momentum

(c) its kinetic energy and potential energy.

ANSWER

(a) r = 2.12 Å; (b) L = h/π ≈ 2.11 × 10^{-34} J s; (c) K = +3.4 eV, U = −6.8 eV.

First excited state means n = 2.

(a) $r_n = n^2 r_0 = 4 \times 0.53 = 2.12$ Å.

(b) Bohr's quantisation: $L = \frac{nh}{2\pi} = \frac{2 \times 6.63 \times 10^{-34}}{2 \times 3.14} = \frac{6.63 \times 10^{-34}}{3.14} \approx 2.11 \times 10^{-34}$ J s (kg m^2 s^{-1}).

(c) In a Bohr orbit, K = −E and U = 2E.

K = +3.4 eV; U = 2 × (−3.4) = −6.8 eV. (Check: K + U = −3.4 eV.)

Common mistake: taking n = 1 for 'first excited' – the ground state is n = 1.

9. (a) Sketch how the potential energy of a pair of nucleons changes with the distance between them. **3**

(b) Suppose a $^{56}_{26}\mathrm{Fe}$ nucleus splits into two equal $^{28}_{13}\mathrm{Al}$ nuclei. Work out the Q value and decide whether this fission is energetically possible.

Given: m($^{56}_{26}\mathrm{Fe}$) = 55.93494 u, m($^{28}_{13}\mathrm{Al}$) = 27.98191 u.

ANSWER

Q = −0.02888 u × 931.5 MeV/u ≈ −26.9 MeV < 0, so the fission is not possible.

(a) Graph of U vs r: for r greater than about 0.8 fm the PE is negative and has a minimum near $r_0 \approx 0.8$ fm (strongly attractive force); beyond ~2–3 fm it rises quickly to zero (short range). For r < 0.8 fm the PE rises steeply and becomes positive (strong repulsion).

(b) Q = [m(Fe) − 2 m(Al)] c².

2 m(Al) = 2 × 27.98191 = 55.96382 u.

Δm = 55.93494 − 55.96382 = −0.02888 u.

Q = −0.02888 × 931.5 MeV ≈ −26.9 MeV.

Q is negative: the products have more mass than the parent, so energy would have to be supplied. The fission is not energetically possible (Fe-56 is near the peak of the binding-energy curve and is very stable).

Note: some printed keys show the mass difference as −0.02442 u; the correct arithmetic gives −0.02888 u – the conclusion is the same.

10. Find the ratio of the de Broglie wavelength of an α-particle to that of a proton when both **3**

(a) move with the same speed,

(b) have the same kinetic energy,

(c) are accelerated through the same potential difference.

ANSWER

λα : λp = (a) 1 : 4, (b) 1 : 2, (c) 1 : 2√2.

Use $m_\alpha = 4m_p$, $q_\alpha = 2q_p$.

(a) $\lambda = \dfrac{h}{mv}$: same v ⇒ $\dfrac{\lambda_\alpha}{\lambda_p} = \dfrac{m_p}{m_\alpha} = \dfrac{1}{4}$.

(b) $\lambda = \dfrac{h}{\sqrt{2mK}}$: same K ⇒ $\dfrac{\lambda_\alpha}{\lambda_p} = \sqrt{\dfrac{m_p}{m_\alpha}} = \dfrac{1}{2}$.

(c) Through potential V, K = qV, so $\lambda = \dfrac{h}{\sqrt{2mqV}} \Rightarrow \dfrac{\lambda_\alpha}{\lambda_p} = \sqrt{\dfrac{m_p q_p}{m_\alpha q_\alpha}} = \sqrt{\dfrac{1}{4\times 2}} = \dfrac{1}{2\sqrt{2}}$.

Common mistake: forgetting that the α-particle has double charge in part (c).

11. Using a circuit diagram, explain how p-n junction diodes work as a full-wave rectifier. Also sketch the input and output waveforms. **3**

ANSWER

Centre-tap transformer with two diodes: each diode conducts on alternate half-cycles, current through the load is always in the same direction – a pulsating DC output for both halves.

Circuit: AC input to the primary of a centre-tapped transformer. Secondary ends A and B connect to the p-sides of diodes D_1 and D_2; their n-sides are joined and go to one end of the load resistor R_L; the other end of R_L goes to the centre tap.

Working:

• Positive half-cycle: A is positive and B negative relative to the centre tap. D_1 is forward biased and conducts; D_2 is reverse biased. Current flows through R_L in a fixed direction.

• Negative half-cycle: A is negative and B positive. Now D_2 conducts and D_1 is off. Current through R_L flows in the same direction as before.

So output is obtained during both halves of the input cycle.

Waveforms: input – a full sine wave; output – a series of positive half-sine humps with no gaps (D_1 and D_2 humps alternate), i.e. pulsating unidirectional voltage, frequency twice the input.

SECTION C

Q12 is a case-study based question of 5 marks (five 1-mark MCQs).

12. *Thomas Young explained interference of light with the superposition principle. In his double-slit experiment, light from a single slit S illuminates two slits S_1 and S_2, and a pattern of bright and dark bands (fringes) appears on a screen; the spacing between consecutive bright (or dark) fringes is the fringe width.* **5**

(a) (a) If the screen is moved closer to the plane of the slits S_1 and S_2, the fringe width:

(A) decreases, but the intensity of the bright fringes stays the same

(B) increases, but the intensity of the bright fringes decreases

(C) decreases, but the intensity of the bright fringes increases

(D) and the intensity of the bright fringes both stay the same

ANSWER

(C) decreases, but the intensity of the bright fringes increases

(iii) fringe width decreases and bright fringes become more intense

Fringe width $\beta = \frac{\lambda D}{d}$. Moving the screen closer reduces D, so β decreases.

The same light energy now falls on a smaller area of the screen (fringes are packed closer), so each bright fringe appears brighter. Hence option (iii).

(b) (b) What happens to the pattern on the screen if S_1 and S_2 are replaced by two independent but identical light sources?

(A) The intensity of the pattern increases

(B) The intensity of the pattern decreases

(C) The number of fringes doubles

(D) No pattern is seen on the screen

ANSWER

(D) No pattern is seen on the screen

(iv) No interference pattern is observed

Two independent sources emit light with randomly and rapidly changing phases, so they are not coherent. The positions of maxima and minima shift billions of times a second and the eye sees uniform illumination. Hence no sustained interference pattern – option (iv).

(c) (c) Two light sources are called coherent when the waves they emit have:

(A) the same amplitude and a varying phase difference

(B) the same wavelength and a constant phase difference

(C) different wavelengths and the same intensity

(D) different wavelengths and a constant phase difference

ANSWER

(B) the same wavelength and a constant phase difference

(ii) same wavelength (frequency) and constant phase difference

Coherence means the phase difference between the two waves stays constant in time. This is possible only if both have the same frequency (hence the same wavelength in a medium). Amplitude/intensity need not be equal. Option (ii).

(d) (d) The fringe width is β in air. If the whole apparatus is immersed in a liquid of refractive index μ, the new fringe width is:

(A) β **(B)** $\beta\mu$

(C) $\frac{\beta}{\mu}$ **(D)** $\frac{\beta}{\mu^2}$

ANSWER

(C) $\frac{\beta}{\mu}$

(iii) β/μ

In the liquid the wavelength becomes $\lambda' = \lambda/\mu$. So $\beta' = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}$. Option (iii).

(e) (e) At points P_1 and P_2 on the screen, the path differences between the two interfering waves are $\frac{3\lambda}{2}$ and 2λ respectively. Then:

(A) bright fringes form at both points

(B) dark fringes form at both points

(C) a bright fringe forms at P_1 and a dark fringe at P_2

(D) a bright fringe forms at P_2 and a dark fringe at P_1

ANSWER

(D) a bright fringe forms at P_2 and a dark fringe at P_1

(iv) bright at P_2, dark at P_1

Bright fringe: path difference = nλ (whole number of wavelengths). Dark fringe: path difference = (2n − 1)λ/2 (odd multiple of λ/2).

P_1: 3λ/2 = odd multiple of λ/2 → dark.

P_2: 2λ = whole number of λ → bright. Option (iv).

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Questions restated from the CBSE Class XII Board Examination 2022 (set 55/2/1) for practice. Reading passages and map items are described, not reproduced.