

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/2/1



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

- (i) This question paper contains **12** questions. **All** questions are compulsory.
- (ii) This question paper is divided into **three** sections – **Section A, B, and C.**
- (iii) **Section A** – Questions no. **1 to 3** are of **2** marks each.
- (iv) **Section B** – Questions no. **4 to 11** are of **3** marks each.
- (v) **Section C** – Question no. **12** is a Case Study-Based Question of **5** marks.
- (vi) There is no overall choice in the question paper. However, internal choice has been provided in some of the questions. Attempt any one of the alternatives in such questions.
- (vii) Use of log tables is permitted, if necessary, but use of calculator is **not** permitted.

$$c = 3 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ J s}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ T m A}^{-1}$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$$

$$\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$$

$$\text{Mass of electron } (m_e) = 9.1 \times 10^{-31} \text{ kg}$$

$$\text{Mass of neutron} = 1.675 \times 10^{-27} \text{ kg}$$

$$\text{Mass of proton} = 1.673 \times 10^{-27} \text{ kg}$$

$$\text{Avogadro's number} = 6.023 \times 10^{23} \text{ per gram mole}$$

$$\text{Boltzmann constant} = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

Section A (6 marks)

1. Explain the formation of depletion region in a p - n junction.

[2 marks]

Solution:

Concept:

- Diffusion carries majority charge carriers from a region of higher concentration to one of lower concentration across a newly formed p - n junction.
- Electrons and holes can move, but the ionised donor and acceptor atoms remain fixed in the crystal lattice. These fixed ions produce the junction's internal electric field.

Step 1: Follow diffusion and recombination On forming the junction, electrons diffuse from the n -side to the p -side, while holes diffuse from the p -side to the n -side. Near the junction, electrons recombine with holes, removing mobile charge carriers from a narrow region on both sides.

Step 2: Identify the fixed space charge The n -side near the junction is left with positively charged donor ions after electrons leave. The p -side is left with negatively charged acceptor ions after holes leave. These immobile ions form a space-charge region. Their electric field points from the n -side to the p -side and produces a potential barrier opposing further majority-carrier diffusion. At equilibrium the drift and diffusion currents balance.

Step 3: Conclusion The narrow region near the junction, depleted of mobile electrons and holes by diffusion and recombination, is called the depletion region. It contains fixed negative acceptor ions on the p -side and fixed positive donor ions on the n -side.

Quick Tip to Solve: Track which carrier leaves each side: electrons leaving the n -side expose positive donors; holes leaving the p -side expose negative acceptors.

2(a). (i) Define the terms: 'impact parameter' and 'distance of closest approach' for an α -particle in Geiger-Marsden scattering experiment.

(ii) What will be the value of the impact parameter for scattering angle (I) $\theta = 0^\circ$ and (II) $\theta = 180^\circ$?

[2 marks]

Solution:

Concept:

- In Rutherford scattering, an α -particle is repelled by the positively charged nucleus. The impact parameter specifies how far its initial line of motion misses the nuclear centre.
- For an incident kinetic energy E and nuclear charge Ze , the scattering relation is $b = \frac{kZe^2}{E} \cot(\theta/2)$, where $k = 1/(4\pi\epsilon_0)$, b is the impact parameter and θ the deflection angle.

Step 1: Define the two distances (i) The **impact parameter**, b , is the perpendicular distance between the initial straight-line direction of motion of the incident α -particle and the centre of the target nucleus.

The **distance of closest approach** is the minimum separation between the α -particle and the nuclear centre during its encounter. For a head-on approach, the particle momentarily stops at this separation, with its initial kinetic energy entirely converted into electrostatic potential energy: $E = 2kZe^2/r_0$.

Step 2: Evaluate the limiting scattering angles (ii) For (I) $\theta = 0^\circ$, $\cot(\theta/2)$ tends to infinity, so $b \rightarrow \infty$. This is the ideal limiting case of an undeflected particle passing very far from the nucleus.

For (II) $\theta = 180^\circ$, $\cot 90^\circ = 0$, so $b = 0$. The incident particle is aimed directly at the nuclear centre and returns along its initial line after a head-on encounter.

Step 3: Conclusion The impact parameter measures the initial sideways offset; closest approach measures the minimum actual separation. The required values are $b \rightarrow \infty$ for $\theta = 0^\circ$ and $b = 0$ for $\theta = 180^\circ$.

Quick Tip to Solve: Remember the two extremes: a distant trajectory is almost straight, while zero sideways offset gives head-on backscattering.

OR

2(b). Photoelectric emission occurs when a surface is irradiated with the radiation of frequency (i) ν_1 and (ii) ν_2 . The maximum kinetic energy of the electrons emitted in the two cases are K and $2K$ respectively. Obtain the expression for the threshold frequency for the surface. [2 marks]

Solution:

Concept:

- Einstein's photoelectric equation is $K_{\max} = h\nu - \phi$, where h is Planck's constant, ν is the incident frequency and ϕ is the work function of the surface.
- At the threshold frequency ν_0 , the maximum kinetic energy is zero, so $\phi = h\nu_0$. The same surface has the same work function in both observations.

Step 1: Write the energy equation for each frequency For incident frequency ν_1 , the given maximum kinetic energy is K . For frequency ν_2 , it is $2K$. Hence,

$$\begin{aligned}K &= h(\nu_1 - \nu_0), \\2K &= h(\nu_2 - \nu_0).\end{aligned}$$

The incident photon energy supplies the work function first; the remaining energy appears as the maximum kinetic energy of an emitted electron.

Step 2: Eliminate the kinetic energy Twice the first equation has the same left-hand side as the second. Equating their right-hand sides and cancelling the nonzero constant h gives

$$\begin{aligned}2(\nu_1 - \nu_0) &= \nu_2 - \nu_0, \\2\nu_1 - 2\nu_0 &= \nu_2 - \nu_0.\end{aligned}$$

Thus the threshold can be determined using only the two frequencies; neither K nor h needs a numerical value.

Step 3: Conclusion The threshold frequency of the surface is $\nu_0 = 2\nu_1 - \nu_2$, expressed in the same frequency units as ν_1 and ν_2 .

Quick Tip to Solve: When one maximum kinetic energy is twice the other, double its photoelectric equation and equate the results; keep the work-function term in both equations.

3. How is an emf generated by a solar cell due to the three basic processes involved? Explain.

[2 marks]

Solution:

Concept:

- A solar cell is a p-n junction that converts incident light energy directly into electrical energy by the photovoltaic effect, without an external bias.
- A photon can generate an electron-hole pair when its energy satisfies $h\nu \geq E_g$, where h is Planck's constant, ν is the light frequency and E_g is the semiconductor band gap.

Step 1: Generate electron-hole pairs Light absorbed in or near the depletion region supplies sufficient energy to excite electrons from the valence band into the conduction band. Each excited electron leaves a hole, so illumination generates electron-hole pairs.

Step 2: Separate the photogenerated carriers The built-in electric field of the depletion region points from the n-side to the p-side. It drives electrons opposite to the field, towards the n-side, and holes along the field, towards the p-side. This separation prevents immediate recombination of these carriers.

Step 3: Collect the separated charges Electrons reaching the n-side and holes reaching the p-side are collected by the respective metal contacts. The n-contact becomes negative and the p-contact becomes positive. Their charge separation develops a potential difference across the open-circuit terminals; when a load is connected, the cell supplies current to it.

Step 4: Conclusion The three processes are generation, separation and collection of electron-hole pairs. Together they produce a photovoltaic emf with the p-side positive relative to the n-side.

Quick Tip to Solve: Remember the sequence generation, separation, collection; use the junction field direction to identify the positive p-terminal and negative n-terminal.

Section B (24 marks)

4(a). (i) Depict a plane electromagnetic wave propagating along the x -axis. Write the expressions for its oscillating electric and magnetic fields.

(ii) Write three characteristics of electromagnetic waves.

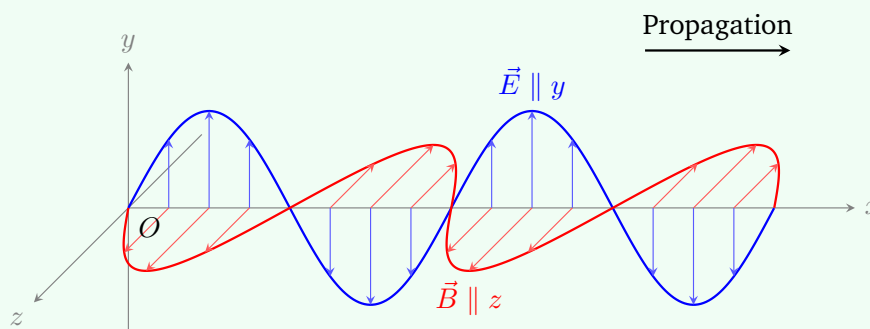
[3 marks]

Solution:

Concept:

- In a plane electromagnetic wave, $\vec{E}$ and $\vec{B}$ are mutually perpendicular and transverse to propagation, whose direction is given by $\vec{E} \times \vec{B}$.
- In vacuum, $c = 1/\sqrt{\mu_0\epsilon_0}$ and $E_0 = cB_0$, where E_0 and B_0 are the field amplitudes and μ_0, ϵ_0 are the permeability and permittivity of free space.

Step 1: Depict the fields for propagation along the positive x-axis Choose the electric field along the y -axis and the magnetic field along the z -axis. Since $\hat{y} \times \hat{z} = \hat{x}$, this orientation gives propagation along $+x$. The snapshot at $t = 0$ shows the fields in the xy - and xz -planes, respectively, on separate schematic amplitude scales.



A plane electromagnetic wave travelling along $+x$; the fields are in phase and mutually perpendicular.

Step 2: Write the oscillating electric and magnetic fields One consistent choice for a monochromatic plane wave in vacuum is

$$\vec{E}(x, t) = E_0 \sin(kx - \omega t) \hat{y},$$

$$\vec{B}(x, t) = B_0 \sin(kx - \omega t) \hat{z}.$$

Here $k = 2\pi/\lambda$ is the wave number, $\omega = 2\pi\nu$ is the angular frequency, λ is the wavelength and ν is the frequency. The fields oscillate in phase, with speed $\omega/k = c$, and are uniform over planes perpendicular to x .

Step 3: State three characteristics of electromagnetic waves 1. **Transverse nature:** Both fields oscillate perpendicular to the propagation direction and to each other; thus electromagnetic waves can be polarised.

2. **Propagation without a material medium:** They travel through vacuum at $c \simeq 3.0 \times 10^8 \text{ m s}^{-1}$.

3. **Transport of energy and momentum:** They carry energy through space and exert radiation pressure on surfaces that absorb or reflect them.

Step 4: Conclusion The depicted wave has $\vec{E} \perp \vec{B} \perp \hat{x}$, in-phase fields and $E_0 = cB_0$. It is transverse, propagates through vacuum, and carries energy and momentum.

Quick Tip to Solve: Check the direction using $\vec{E} \times \vec{B}$; use the same sine phase in both fields and $kx - \omega t$ for travel along $+x$.

OR

4(b). Name the electromagnetic waves which are produced by the following:

(i) Radioactive decays of nucleus

(ii) Welding arcs

(iii) Hot bodies

Write one use each of these waves.

[3 marks]

Solution:

Concept:

- Electromagnetic radiation is classified by frequency or wavelength. Different physical processes characteristically produce different regions of the spectrum.
- Nuclear transitions produce gamma rays; energetic electronic transitions in electric arcs produce ultraviolet radiation; thermal motion in hot bodies produces infrared radiation prominently at ordinary hot-body temperatures.

Step 1: Identify the radiation from nuclear decay (i) The electromagnetic waves associated with radioactive decays of a nucleus are **gamma rays**. An excited nucleus can release its excess energy as a high-frequency photon. Gamma rays are used in **radiotherapy to destroy cancer cells**. Alpha and beta emissions may also accompany radioactive decay, but they are particles and are not the electromagnetic waves requested here.

Step 2: Identify the radiation from welding arcs (ii) Welding arcs produce intense **ultraviolet rays**, along with visible radiation. The energetic processes in the arc excite atoms, whose electronic transitions generate ultraviolet radiation. One use of ultraviolet rays is **sterilising surgical instruments**: suitable ultraviolet radiation damages microorganisms and helps disinfect exposed surfaces.

Step 3: Identify the radiation from hot bodies (iii) Hot bodies characteristically emit **infrared rays**. This is thermal electromagnetic radiation associated with the temperature of the body; it can be emitted even when the body does not visibly glow. Infrared rays are used in **thermal imaging**, where differences in emitted infrared radiation reveal differences in surface temperature. A hot body's spectrum is broad, so the identification does not mean that it emits infrared alone.

Step 4: Conclusion (i) Gamma rays: cancer radiotherapy. (ii) Ultraviolet rays: sterilising surgical instruments. (iii) Infrared rays: thermal imaging.

Quick Tip to Solve: Match the source to its characteristic region: nucleus to gamma, welding arc to ultraviolet, and thermal emission from hot bodies to infrared.

5. (a) State the conditions for total internal reflection to take place.

(b) A tank is filled with a transparent liquid to height ' H '. A coin suspended by a thread in the liquid is gradually lowered till it touches the bottom. The apparent depth is determined corresponding to different positions of the coin.

(i) Plot a graph showing variation of the apparent depth with the real depth of the coin.

(ii) What is the physical significance of the slope of the graph?

[3 marks]

Solution:

Concept:

- Total internal reflection is possible only when light travels from an optically denser medium to an optically rarer medium and the angle of incidence exceeds the critical angle for that pair of media.
- For an object in a liquid viewed from air nearly normally through a plane surface, its apparent depth d and real depth D obey $\mu = D/d$, where μ is the refractive index of the liquid relative to air.

Step 1: State both conditions for total internal reflection (a) First, the incident ray must travel from the optically denser medium of refractive index n_1 towards the optically rarer medium of index $n_2 < n_1$. Second, its angle of incidence i , measured from the normal, must satisfy $i > i_c$, where

$$\sin i_c = \frac{n_2}{n_1}.$$

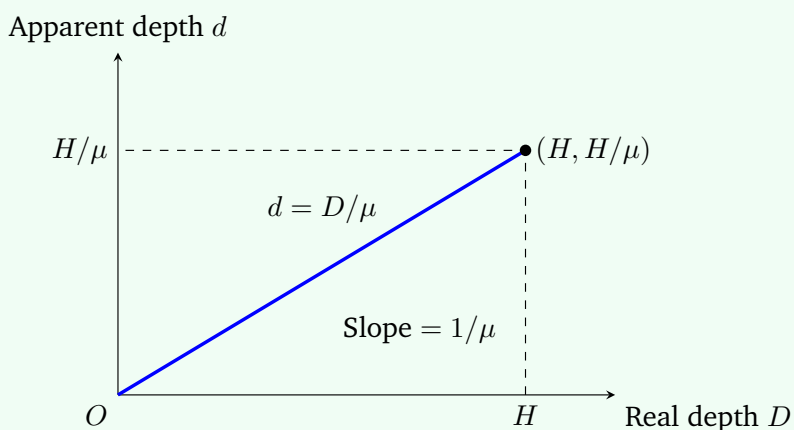
At $i = i_c$, the refracted ray just grazes the interface; total internal reflection requires an angle strictly greater than this critical angle.

Step 2: Obtain the apparent-depth graph (b)(i) Take real depth D along the horizontal axis and apparent depth d along the vertical axis, measuring both downwards from the liquid surface. For

observation from air nearly along the normal,

$$d = \frac{D}{\mu}, \quad 0 \leq D \leq H.$$

The liquid is uniform, so μ stays constant as the coin is lowered. Thus the graph is a straight line through the origin, ending at $(H, H/\mu)$ when the coin reaches the bottom. Since $\mu > 1$, the coin appears shallower than its actual position.



Apparent depth versus real depth for a coin in a uniform liquid, viewed nearly normally from air.

Step 3: Interpret the slope (b)(ii) The slope of apparent depth plotted against real depth is

$$m = \frac{\Delta d}{\Delta D} = \frac{1}{\mu}.$$

It is the reciprocal of the refractive index of the liquid relative to air, equivalently the refractive index of air relative to the liquid. Therefore, measuring this slope determines the liquid's relative refractive index as $\mu = 1/m$. The slope is dimensionless when both depths use the same unit.

Step 4: Conclusion Total internal reflection requires denser-to-rarer propagation and $i > i_c$. The apparent-depth graph is the straight line $d = D/\mu$, from $(0, 0)$ to $(H, H/\mu)$, with slope $1/\mu$.

Quick Tip to Solve: Put apparent depth on the vertical axis: its slope is apparent divided by real depth, so take the reciprocal of the slope to obtain the liquid's refractive index.

6(a). Draw a labelled ray diagram showing the formation of an image by an astronomical refracting telescope in normal adjustment. Hence, obtain the expression for its magnifying power. [3 marks]

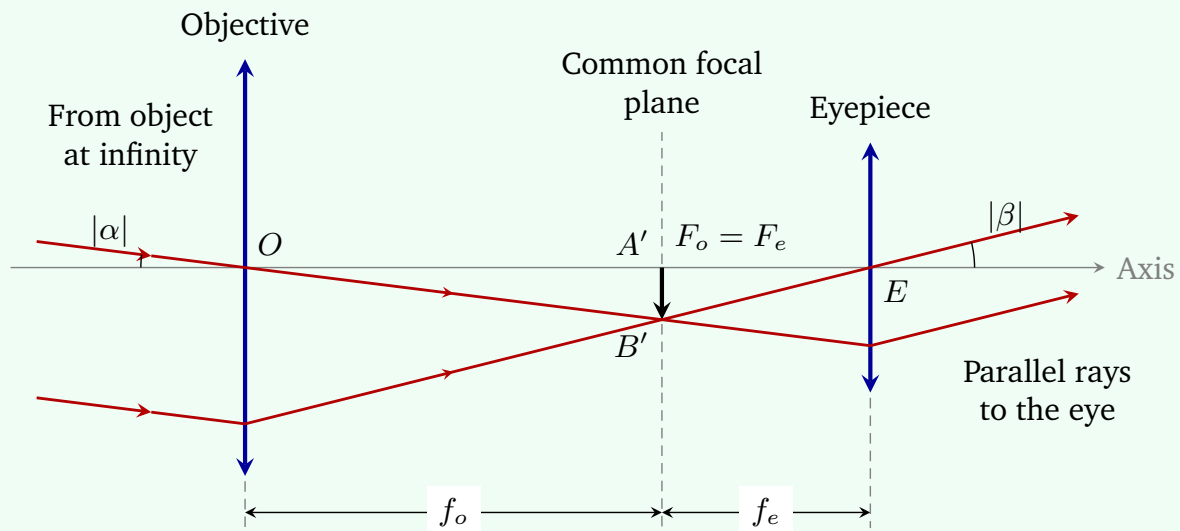
Solution:

Concept:

- An astronomical refracting telescope uses a converging objective of long focal length f_o and a converging eyepiece of short focal length f_e .
- In normal adjustment, the objective's real image lies in the first focal plane of the eyepiece, so the final image is at infinity and the relaxed eye receives parallel rays.
- Angular magnifying power is $M = \beta/\alpha$, where α is the angle subtended by the distant object at the unaided eye and β is the angle subtended by the final image at the eye through the telescope.

Step 1: Construct the image in normal adjustment Parallel rays from a point near the top of a distant

object enter the objective at a small inclination to the principal axis. The objective brings them to the point B' , forming a real, inverted, diminished image $A'B'$ in its focal plane. Place the eyepiece so that this same plane is its first focal plane: $A' = F_o = F_e$. The rays diverging from B' then emerge parallel from the eyepiece. Thus the final image is inverted and at infinity. The lens separation in this adjustment is $L = f_o + f_e$.



Astronomical telescope in normal adjustment. The angles shown are magnitudes; $A'B'$ is the real, inverted intermediate image.

Step 2: Relate the angular sizes to the intermediate image Let the magnitude of the intermediate image height be $h = A'B'$. The ray through the optical centre O of the objective gives a right triangle with base $OA' = f_o$. The ray through the optical centre E of the eyepiece gives a second triangle with base $A'E = f_e$. Therefore, for the small angles used in a telescope,

$$|\alpha| \simeq \tan |\alpha| = \frac{h}{f_o}, \quad |\beta| \simeq \tan |\beta| = \frac{h}{f_e}.$$

Dividing eliminates the intermediate image height:

$$|M| = \frac{|\beta|}{|\alpha|} = \frac{h/f_e}{h/f_o} = \frac{f_o}{f_e}.$$

The final image has the opposite orientation to the object, so its signed angular magnification is negative. A longer objective focal length and a shorter eyepiece focal length increase the angular enlargement.

Step 3: Conclusion In normal adjustment, the magnifying power is $M = -f_o/f_e$, or $|M| = f_o/f_e$ in magnitude. The minus sign denotes an inverted final image, which is formed at infinity; the telescope length is $f_o + f_e$.

Quick Tip to Solve: For normal adjustment, first make the objective's second focal plane coincide with the eyepiece's first focal plane; the same image height then cancels in the ratio of the two small angles.

6(b). A plane wavefront of light of wavelength ' λ ' is incident normally on a narrow slit of width ' a ' and a diffraction pattern is observed on a screen at a distance ' D ' from the slit.

(i) Depict the intensity distribution in the pattern observed.

(ii) Obtain the expression for the first maximum from the central maximum.

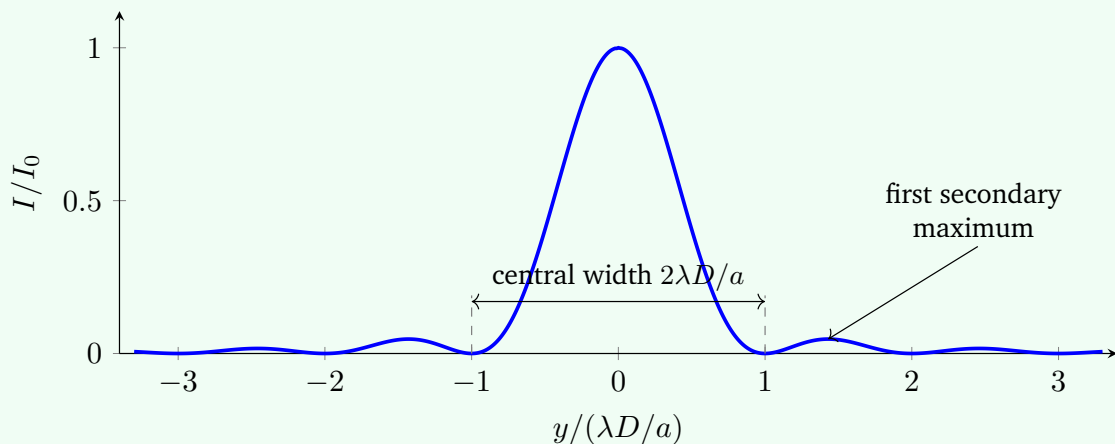
[3 marks]

Solution:

Concept:

- In single-slit diffraction, secondary wavelets from different points of a slit of width a interfere. The path difference between the extreme rays at angle θ is $a \sin \theta$.
- For incident wavelength λ , the intensity is $I = I_0(\sin \beta / \beta)^2$, where $\beta = \pi a \sin \theta / \lambda$ and I_0 is the central intensity. On a distant screen, $y \simeq D\theta$.

Step 1: (i) Sketch and explain the intensity distribution At the centre, $\theta = 0$, all contributions arrive in phase and the intensity is greatest. Minima occur when $a \sin \theta = n\lambda$, for nonzero integers n . Thus, for small angles, the first minima are at $y = \pm \lambda D / a$. The central maximum extends between them and has width $2\lambda D / a$. Weaker secondary maxima appear symmetrically on both sides; their intensities decrease with distance from the centre. Each secondary bright region between consecutive minima has approximately half the width of the central bright region.



Single-slit intensity: the first secondary maxima lie between the first and second minima.

Step 2: (ii) Locate the first secondary maximum The first secondary maximum lies between the first and second minima, for which the extreme-ray path differences are λ and 2λ . In the usual school-level estimate, take the maximum approximately midway between these minima:

$$a \sin \theta_1 \simeq \frac{3\lambda}{2}.$$

At this path difference, division into three equal slit strips permits cancellation of contributions from two strips, leaving a smaller resultant than at the centre. Using $\sin \theta_1 \simeq \tan \theta_1 = y_1 / D$,

$$\frac{ay_1}{D} \simeq \frac{3\lambda}{2}.$$

This midpoint rule is an approximation. The exact intensity formula gives $\tan \beta = \beta$ for noncentral maxima; the first root is $\beta \simeq 4.493$, giving $|y_1| \simeq 1.430\lambda D / a$. The plotted curve follows that intensity formula.

Step 3: Conclusion The pattern has a broad, brightest central maximum with weaker symmetric side maxima. The usual approximate distance of the first secondary maximum from the centre is $|y_1| \simeq 3\lambda D/(2a)$, with angular position $|\theta_1| \simeq 3\lambda/(2a)$. Its exact small-angle value is about $1.430\lambda D/a$.

Quick Tip to Solve: First mark the minima at integer multiples of $\lambda D/a$; the first secondary maximum lies between the first two minima, approximately at their midpoint.

7. A converging lens made of glass ($\mu = 1.5$) has its spherical faces of 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 marks]

Solution:

Concept:

- For a thin lens of refractive index μ_g in a surrounding medium of refractive index μ_m , the lens maker's formula is $\frac{1}{f} = (\mu_g/\mu_m - 1)(1/R_1 - 1/R_2)$. Here R_1, R_2 are signed radii and f is the focal length in that medium.
- With light travelling from left to right through the converging double-convex lens, the first surface has $R_1 > 0$ and the second has $R_2 < 0$. A positive focal length denotes convergence.

Step 1: Assign the signs of the radii Use the Cartesian sign convention, with distances measured positively along the incident light. Take $R_1 = +10$ cm and $R_2 = -20$ cm. The two curvatures therefore contribute with the same sign to the lens power:

$$\frac{1}{R_1} - \frac{1}{R_2} = \frac{1}{10} - \frac{1}{-20} = \frac{3}{20} \text{ cm}^{-1}.$$

Interchanging the two faces gives the same curvature sum, as expected for a thin lens.

Step 2: (a) Calculate the focal length in air In air, $\mu_m \simeq 1$, so the relative refractive index is 1.5. Substituting into the lens maker's formula gives

$$\begin{aligned} \frac{1}{f_{\text{air}}} &= (1.5 - 1) \frac{3}{20} = \frac{3}{40} \text{ cm}^{-1}, \\ f_{\text{air}} &= \frac{40}{3} \text{ cm} \simeq +13.3 \text{ cm}. \end{aligned}$$

Step 3: (b) Recalculate using the relative index in liquid Immersion changes the refractive index contrast but leaves both radii unchanged. The index of glass relative to the liquid is $\mu_g/\mu_m = 1.5/1.25 = 1.2$. Hence,

$$\begin{aligned} \frac{1}{f_{\text{liquid}}} &= (1.2 - 1) \frac{3}{20} = \frac{3}{100} \text{ cm}^{-1}, \\ f_{\text{liquid}} &= \frac{100}{3} \text{ cm} \simeq +33.3 \text{ cm}. \end{aligned}$$

Since the liquid's index is closer to that of glass, refraction is weaker and the focal length increases. The glass still has the greater index, so the lens remains converging.

Step 4: Conclusion The focal lengths are $f_{\text{air}} = +13.3 \text{ cm}$ and $f_{\text{liquid}} = +33.3 \text{ cm}$. Immersion increases the focal length by a factor of 2.5.

Quick Tip to Solve: For immersion, replace the glass index by μ_g/μ_m , keeping the signed radii unchanged. A smaller positive index contrast means a longer positive focal length.

8. The energy of a hydrogen atom in the first excited state is -3.4 eV . Find:

(a) the radius of this orbit. (Take Bohr radius $= 0.53 \text{ \AA}$)

(b) the angular momentum of the electron in the orbit.

(c) the kinetic and potential energy of the electron in the orbit.

[3 marks]

Solution:

Concept:

- For hydrogen, the radius of the Bohr orbit with principal quantum number n is $r_n = n^2 a_0$, where $a_0 = 0.53 \text{ \AA}$ is the Bohr radius.
- Bohr's angular-momentum condition is $L_n = m_e v_n r_n = n\hbar = nh/(2\pi)$, where h is Planck's constant and $\hbar = h/(2\pi)$.
- For an electron bound by the Coulomb force, $U = -2K$ and $E = K + U = -K = U/2$, where K , U and E denote kinetic, potential and total energy; potential energy is zero at infinite separation.

Step 1: Identify the orbit and calculate its radius in part (a) The ground state has $n = 1$, so the first excited state has $n = 2$. Its given energy is consistent with $E_n = -13.6/n^2 \text{ eV}$. Therefore,

$$r_2 = 2^2 a_0 = 4(0.53) = 2.12 \text{ \AA} = 2.12 \times 10^{-10} \text{ m}.$$

The radius increases as the square of the orbit number, so this orbit has four times the ground-state radius.

Step 2: Apply angular-momentum quantisation in part (b) Substituting $n = 2$ into Bohr's condition gives

$$L_2 = \frac{2h}{2\pi} = \frac{h}{\pi} = 2\hbar.$$

Using $h = 6.63 \times 10^{-34} \text{ J s}$, the magnitude is

$$L_2 = \frac{6.63 \times 10^{-34}}{\pi} \simeq 2.11 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}.$$

This is the orbital angular momentum in the Bohr model, independent of the electron's spin.

Step 3: Separate kinetic and potential energies in part (c) The Coulomb force supplies the centripetal force: $m_e v^2/r = ke^2/r^2$. Thus $K = ke^2/(2r)$, while $U = -ke^2/r = -2K$. It follows that $E = -K$. With the given total energy,

$$K = -E = -(-3.4) = +3.4 \text{ eV},$$

$$U = 2E = 2(-3.4) = -6.8 \text{ eV}.$$

The check $K + U = 3.4 - 6.8 = -3.4 \text{ eV}$ recovers the stated energy. Kinetic energy is positive; the negative potential energy describes the attractive bound state.

Step 4: Conclusion (a) $r_2 = 2.12 \text{ \AA} = 2.12 \times 10^{-10} \text{ m}$. (b) $L_2 = 2\hbar = h/\pi \simeq 2.11 \times 10^{-34} \text{ kg m}^2 \text{ s}^{-1}$. (c) $K = +3.4 \text{ eV}$ and $U = -6.8 \text{ eV}$.

Quick Tip to Solve: First excited means $n = 2$, not $n = 1$. Once the total Bohr energy is given, use $K = -E$ and $U = 2E$ before doing any numerical force calculation.

9. (a) Depict the variation of the potential energy of a pair of nucleons with the separation between them.

(b) Imagine the fission of a ${}^{56}_{26}\text{Fe}$ into two equal fragments of ${}^{28}_{13}\text{Al}$ nucleus. Is the fission energetically possible? Justify your answer by working out Q value of the process.

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

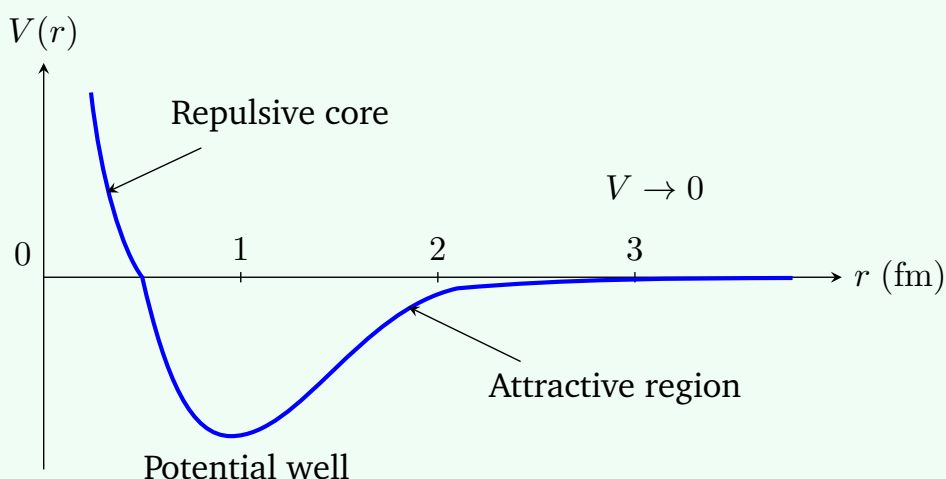
[3 marks]

Solution:

Concept:

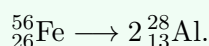
- The nucleon-nucleon potential $V(r)$, defined to be zero at infinite separation r , has a strongly repulsive core, a negative attractive well and a negligible value beyond the short range of the nuclear force.
- The energy released in a nuclear reaction is $Q = (m_{\text{initial}} - m_{\text{final}})c^2$. Use $1 \text{ u } c^2 = 931.5 \text{ MeV}$; a negative Q means that energy must be supplied.

Step 1: Draw and interpret the potential-energy curve in part (a) At very small separation, below roughly 0.5 fm , the potential rises steeply to positive values, showing the hard repulsive core that prevents nucleons from collapsing together. It falls into a negative potential well at separations of order 1 fm , where a bound pair can have lower energy than separated nucleons. Beyond the well, V rises towards zero and is practically zero after a few femtometres, reflecting the short range of the interaction. The force is related to the slope by $F_r = -dV/dr$: the inner descending side is repulsive and the outer rising side is attractive. The graph is schematic; its minimum represents a stable separation, where the force is zero.



Schematic nucleon-nucleon potential: a repulsive core and a short-range attractive well.

Step 2: Calculate the mass change for part (b) The proposed process is



Both nucleon number and charge are conserved. The combined mass of the fragments and the initial-minus-final mass difference are

$$m_f = 2(27.98191) = 55.96382 \text{ u},$$

$$\Delta m = 55.93494 - 55.96382 = -0.02888 \text{ u}.$$

The products are heavier than the original nucleus. If the tabulated masses are neutral-atom masses, the electron masses cancel because the total atomic number is unchanged.

Step 3: Convert the mass difference to the reaction energy Substituting the mass difference into the energy balance gives

$$Q = (-0.02888)(931.5) \text{ MeV} = -26.90172 \text{ MeV} \simeq -26.9 \text{ MeV}.$$

The negative sign means that this division cannot release energy. At least the mass-energy deficit of about 26.9 MeV would have to be supplied; the isolated iron nucleus cannot undergo the proposed spontaneous fission. This agrees with iron being near the maximum of binding energy per nucleon.

Step 4: Conclusion (a) The potential has a steep repulsive core, a negative well and a tail approaching zero at a few femtometres, as plotted. (b) $Q \simeq -26.9 \text{ MeV}$; the proposed fission is not energetically possible without supplying external energy.

Quick Tip to Solve: Compare the parent mass with twice the fragment mass first. If the fragments are heavier, Q is negative and the proposed fission cannot release energy.

- 10. Find the ratio of the de Broglie wavelengths associated with an alpha particle and a proton, if both**
- have the same speeds,
 - have the same kinetic energy,
 - are accelerated through the same potential difference.
- [3 marks]

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is the particle's momentum. In the non-relativistic regime, $p = mv = \sqrt{2mK}$, with mass m , speed v and kinetic energy K .
- For an alpha particle, $m_\alpha \simeq 4m_p$ and $q_\alpha = 2e$; for a proton, $q_p = e$. A particle accelerated from rest through potential difference V gains kinetic energy $K = qV$.

Step 1: (a) Compare wavelengths at equal speeds For the common speed v , momentum is proportional to mass. Taking the ratio in the order alpha particle to proton, the common factors h and v cancel:

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{h/(m_\alpha v)}{h/(m_p v)} = \frac{m_p}{m_\alpha} = \frac{1}{4}.$$

The heavier alpha particle has four times the momentum and therefore one-fourth the wavelength.

Step 2: (b) Compare wavelengths at equal kinetic energies Write $\lambda = h/\sqrt{2mK}$. When K is the

same, wavelength varies inversely as the square root of mass, rather than inversely as mass:

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p K}{m_\alpha K}} = \sqrt{\frac{1}{4}} = \frac{1}{2}.$$

Equal kinetic energies do not imply equal speeds: the alpha particle moves at half the proton's speed.

Step 3: (c) Include charge for the same accelerating potential For acceleration from rest through the same V , use $K = qV$, giving $\lambda = h/\sqrt{2mqV}$. The alpha particle gains twice the proton's kinetic energy because it has twice the charge:

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p V}{m_\alpha q_\alpha V}} = \sqrt{\frac{m_p e}{(4m_p)(2e)}} = \frac{1}{2\sqrt{2}}.$$

Step 4: Conclusion The required ratios $\lambda_\alpha : \lambda_p$ are $\boxed{1 : 4}$ for equal speeds, $\boxed{1 : 2}$ for equal kinetic energies and $\boxed{1 : 2\sqrt{2}}$ for the same accelerating potential difference.

Quick Tip to Solve: First identify what is held equal: use $\lambda \propto 1/m$ at fixed speed, $1/\sqrt{m}$ at fixed kinetic energy and $1/\sqrt{mq}$ at fixed accelerating voltage.

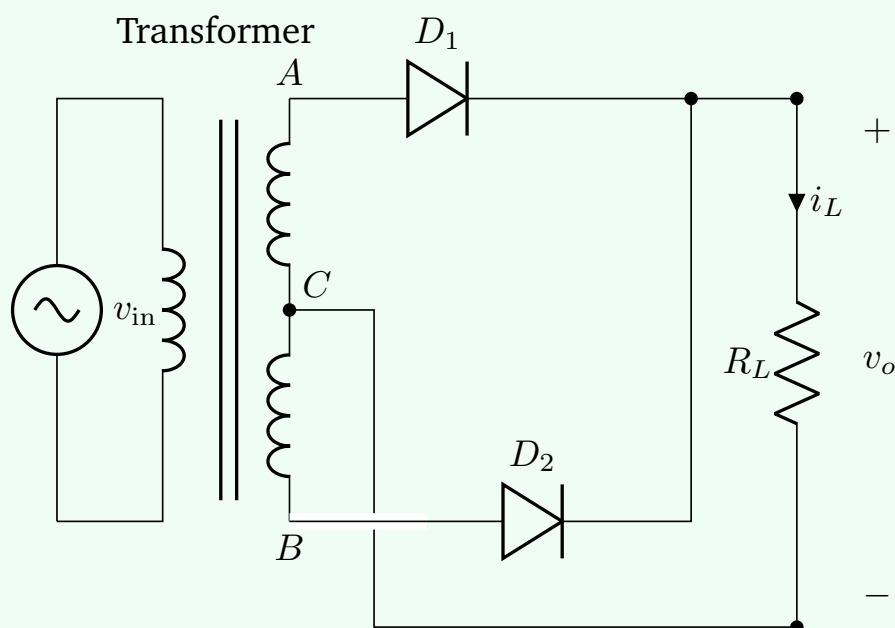
11. With the help of a circuit diagram, explain the working of a p - n junction diode as a full-wave rectifier. Also draw its input and output waveforms. [3 marks]

Solution:

Concept:

- A p - n junction diode conducts appreciable current when forward biased and blocks current when reverse biased. Rectification uses this directional conduction to produce a unidirectional output from an alternating input.
- A centre-tapped full-wave rectifier uses two diodes and a load resistance R_L . The secondary end voltages relative to the centre tap C have equal amplitudes and opposite signs, so the diodes conduct alternately.

Step 1: Connect the two-diode rectifier Connect the ends A and B of a centre-tapped transformer secondary to the anodes of D_1 and D_2 . Join their cathodes to the positive output terminal, and connect R_L between this junction and centre tap C . The alternating supply is applied to the primary. The dot at C denotes the secondary tap; crossing wires without a dot are not joined.



Centre-tapped full-wave rectifier; the two cathodes join the positive load terminal.

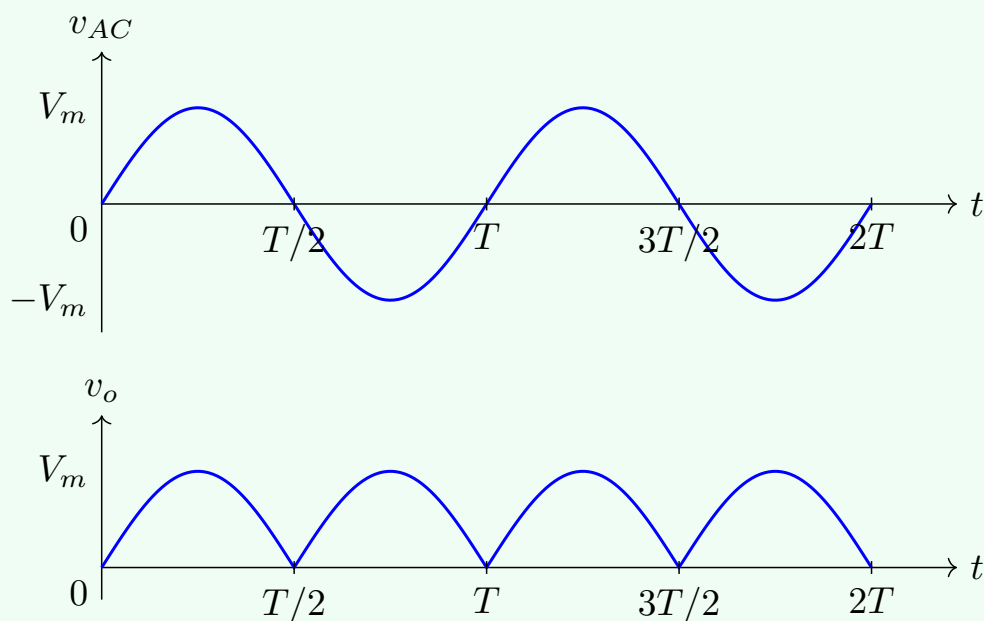
Step 2: Follow the positive half-cycle When A is positive relative to C , B is negative relative to C . Thus D_1 is forward biased and conducts, while D_2 is reverse biased and blocks. Conventional current follows $A \rightarrow D_1 \rightarrow R_L \rightarrow C$, passing downwards through the load in the circuit shown.

Step 3: Follow the negative half-cycle During the next half-cycle, B becomes positive and A negative relative to C . Now D_2 conducts and D_1 blocks. Current follows $B \rightarrow D_2 \rightarrow R_L \rightarrow C$, again downwards through the load. Both halves of the alternating input therefore contribute to the output without reversing the load current.

Step 4: Relate the input and output waveforms For ideal diodes, write the input across one half of the secondary as $v_{AC} = V_m \sin \omega t$, with $v_{BC} = -V_m \sin \omega t$. The output across the load is

$$v_o = V_m |\sin \omega t|, \quad i_L = \frac{v_o}{R_L}.$$

The input and output shapes are shown below; the primary input is also sinusoidal, with amplitude determined by the turns ratio. The output has two positive pulses per input period T , so its ripple frequency is $2f$, where $f = 1/T$. Without a filter, the output varies with time and is pulsating dc.



Sinusoidal input and full-wave output for ideal diodes, plotted over two input periods.

Step 5: Conclusion The two diodes conduct on alternate half-cycles, keeping the current through R_L in the same direction. The circuit gives full-wave, pulsating dc output with frequency $2f$.

Quick Tip to Solve: Trace each conducting path back to the centre tap: both paths must cross the load in the same direction. Draw every negative input half-cycle reflected above the time axis in the output.

Section C (5 marks)

12. The British physicist Thomas Young explained the interference of light using the principle of superposition of waves. He observed the interference pattern on the screen, in his experimental set-up, known now as Young's double slit experiment. The two slits S_1 and S_2 were illuminated by light from a slit S . The interference pattern consists of dark and bright bands of light. Such bands are called fringes. The distance between two consecutive bright and dark fringes is called fringe width. [5 marks]

12(a). If the screen is moved closer to the plane of slits S_1 and S_2 , then the fringe width: [1 mark]

- (A) will decrease, but the intensity of bright fringe remains the same.
- (B) will increase, but the intensity of bright fringe decreases.
- (C) will decrease, but the intensity of bright fringe increases.
- (D) and the intensity both remain the same.

Correct Answer: (C) will decrease, but the intensity of bright fringe increases.

Solution:

Concept:

- In Young's double slit experiment, the fringe width is $\beta = \lambda D/d$, where λ is the wavelength, D the slit-screen distance and d the slit separation.
- At a bright fringe the waves add constructively: $I_{\max} = (\sqrt{I_1} + \sqrt{I_2})^2$, where I_1, I_2 are the individual intensities at the screen.

Step 1: Compare the fringe widths Moving the screen closer reduces D , while λ and d remain unchanged. Thus $\beta \propto D$, so the fringes become more closely spaced. This excludes options (B) and (D), which require an increase or no change in fringe width.

Step 2: Compare the bright-fringe intensities The light from each slit spreads as it travels to the screen. At the closer screen, the individual intensities are greater, and constructive superposition therefore gives a larger bright-fringe intensity. For equal contributions $I_1 = I_2 = I_0$, one has $I_{\max} = 4I_0$; increasing I_0 increases the maximum. Option (A) incorrectly keeps this intensity unchanged.

Step 3: Conclusion The fringe width decreases, while the intensity of a bright fringe increases. Hence, the correct option is (C).

Quick Tip to Solve: Check spacing and brightness separately: a nearer screen reduces D and receives less-spread light from the slits.

12(b). What will happen to the pattern on the screen, when the two slits S_1 and S_2 are replaced by two independent but identical sources? [1 mark]

- (A) The intensity of pattern will increase
- (B) The intensity of pattern will decrease
- (C) The number of fringes will become double
- (D) No pattern will be observed on the screen

Correct Answer: (D) No pattern will be observed on the screen

Solution:

Concept:

- Sustained interference requires coherent sources: they must maintain a constant phase difference and have the same frequency.
- The resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$, where ϕ is the phase difference at the observation point.

Step 1: Test coherence of the replacement sources The original slits are illuminated by one source, which gives their emitted waves a fixed phase relationship. Two independent ordinary light sources do not maintain this relationship, even if their nominal frequency, intensity and other properties are identical. Their relative phase varies randomly with time.

Step 2: Average the rapidly varying interference term Over the response time of the eye or detector, the random phase gives $\langle \cos \phi \rangle = 0$. Therefore the observed intensity is $\langle I \rangle = I_1 + I_2$, without stable alternating interference maxima and minima. Options (A) and (B) incorrectly describe a persistent pattern of changed intensity; option (C) incorrectly assumes that a definite fringe pattern survives.

Step 3: Conclusion No sustained interference pattern will be observed on the screen, although the screen remains illuminated. Hence, the correct option is (D).

Quick Tip to Solve: Identical sources need not be coherent: check whether their relative phase stays fixed before applying fringe formulae.

12(c). Two sources of light are said to be coherent, when both emit light waves of:

[1 mark]

- (A) same amplitude and have a varying phase difference.
- (B) same wavelength and a constant phase difference.
- (C) different wavelengths and same intensity.
- (D) different wavelengths and a constant phase difference.

Correct Answer: (B) same wavelength and a constant phase difference.

Solution:

Concept:

- Coherent sources emit waves of the same frequency with a constant phase difference; in the same medium, equal frequencies imply equal wavelengths.
- If the source phases are $\omega_1 t + \phi_1$ and $\omega_2 t + \phi_2$, their relative phase is $(\omega_1 - \omega_2)t + (\phi_1 - \phi_2)$.

Step 1: Apply the constant-phase condition A phase difference that remains constant in time requires $\omega_1 = \omega_2$, together with a stable initial phase relation. Since $v = f\lambda$ and both waves travel in the same medium, equal frequency means equal wavelength. Equal amplitude is not a necessary condition for coherence; it only affects fringe contrast.

Step 2: Examine the alternatives Option (A) allows the phase difference to vary, so it fails the coherence condition despite equal amplitudes. Option (C) specifies different wavelengths, and equal intensity cannot compensate for the changing phase difference. Option (D) also gives different wavelengths, inconsistent with a constant relative phase for the waves in the same medium. Option (B) supplies both required properties.

Step 3: Conclusion Coherent sources emit waves of the same wavelength with a constant phase difference. Hence, the correct option is (B).

Quick Tip to Solve: For coherence, look for equal frequency and fixed relative phase; equal amplitude is a separate condition for perfectly dark minima.

12(d). The fringe width in a Young's double slit experiment is β . If the whole set-up is immersed in a liquid of refractive index ' μ ', then the new fringe width will be:

[1 mark]

- (A) β
- (B) $\beta\mu$
- (C) $\frac{\beta}{\mu}$
- (D) $\frac{\beta}{\mu^2}$

Correct Answer: (C) $\frac{\beta}{\mu}$

Solution:

Concept:

- Young's fringe width is $\beta = \lambda D/d$, where D is the slit-screen distance and d is the slit separation.
- In a liquid of refractive index μ , light has speed c/μ . Its frequency f remains unchanged, so its wavelength becomes $\lambda' = \lambda/\mu$.

Step 1: Identify the quantity changed by immersion Immersing the whole arrangement changes the

optical medium between the slits and the screen. The physical distances D and d remain the same, but the wavelength decreases by the factor μ . The frequency does not decrease on entering the liquid.

Step 2: Substitute the wavelength in the fringe formula Using the new wavelength gives

$$\beta' = \frac{\lambda' D}{d} = \frac{\lambda D}{\mu d} = \frac{\beta}{\mu}.$$

Option (A) neglects the wavelength change; option (B) reverses the refractive-index factor. Option (D), β/μ^2 , incorrectly introduces a second factor of μ , even though neither geometrical distance changes.

Step 3: Conclusion The new fringe width is $\boxed{\beta' = \beta/\mu}$. Hence, the correct option is (C).

Quick Tip to Solve: On immersing the entire setup, replace only λ by λ/μ in $\beta = \lambda D/d$.

12(e). The total path difference between two waves meeting at points P_1 and P_2 on the screen are $\left(\frac{3\lambda}{2}\right)$ and (2λ) respectively. Then: [1 mark]

- (A) bright fringes are formed at both points.
- (B) dark fringes are formed at both points.
- (C) a bright fringe is formed at P_1 and a dark fringe is formed at P_2 .
- (D) a bright fringe is formed at P_2 and a dark fringe is formed at P_1 .

Correct Answer: (D) a bright fringe is formed at P_2 and a dark fringe is formed at P_1 .

Solution:

Concept:

- Constructive interference occurs for total path difference $\Delta = n\lambda$, producing a bright fringe, where n is an integer.
- Destructive interference occurs for $\Delta = (2n + 1)\lambda/2$, an odd multiple of half a wavelength, producing a dark fringe for equal slit intensities.

Step 1: Test the path difference at the first point At P_1 , the total path difference is $3\lambda/2$, an odd multiple of $\lambda/2$. The associated phase difference is

$$\phi_1 = \frac{2\pi}{\lambda} \frac{3\lambda}{2} = 3\pi,$$

equivalent to π modulo 2π . The waves therefore arrive in opposite phase and interfere destructively.

Step 2: Test the path difference at the second point At P_2 , the total path difference is 2λ , a whole-number multiple of λ . Here $\phi_2 = (2\pi/\lambda)(2\lambda) = 4\pi$, equivalent to zero modulo 2π , so the interference is constructive. Options (A) and (B) incorrectly assign the same type to both points, while option (C) reverses the two assignments.

Step 3: Conclusion A dark fringe forms at P_1 , and a bright fringe forms at P_2 . Hence, the correct option is (D).

Quick Tip to Solve: Divide each total path difference by λ : an integer gives bright, and a half-integer gives dark.