

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

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.

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

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

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

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

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

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

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

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

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

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

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

Section A (6 marks)

1(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:

- Rutherford scattering is the repulsion of a positively charged α -particle by a positively charged nucleus. A smaller impact parameter gives a larger scattering angle.
- For incident kinetic energy E , nuclear charge Ze , and α -particle charge $2e$, the relation is $b = \frac{1}{4\pi\epsilon_0} \frac{Ze^2}{E} \cot(\theta/2)$, where b is the impact parameter and θ is the scattering angle.

Step 1: Define the two distances 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 nucleus during its approach. In a head-on encounter, the particle momentarily comes to rest there, with its initial kinetic energy fully converted into electrostatic potential energy.

Step 2: Relate the limiting angles to the path For $\theta = 0^\circ$, the particle is undeflected; in the ideal Rutherford model this occurs in the limit of an infinitely large impact parameter, where the nuclear repulsion has negligible effect. For $\theta = 180^\circ$, the particle reverses along its incident line. This is a head-on encounter, so its initial line passes through the nuclear centre.

Step 3: Conclusion The impact parameter measures the initial sideways offset, whereas the closest-approach distance measures the minimum nuclear separation. The requested values are (I) $b \rightarrow \infty$ for $\theta = 0^\circ$, and (II) $b = 0$ for $\theta = 180^\circ$.

Quick Tip to Solve: Remember the two extremes: a distant pass gives almost no deflection, while a zero-offset, head-on approach gives complete backward scattering.

OR

1(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 emitting surface.
- The threshold frequency ν_0 satisfies $\phi = h\nu_0$. The same surface has the same work function in both experiments, so $K_{\max} = h(\nu - \nu_0)$.

Step 1: Write the equations for the same surface At frequency ν_1 , the maximum kinetic energy is K ;

at frequency ν_2 , it is $2K$. Hence,

$$K = h(\nu_1 - \nu_0), \quad 2K = h(\nu_2 - \nu_0).$$

Doubling the kinetic energy does not in general double the incident frequency, because the same nonzero energy $h\nu_0$ must first be spent in liberating each electron.

Step 2: Eliminate the unknown kinetic energy Multiply the first equation by two and equate its right-hand side to that of the second equation. Cancel the common factor h :

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

This equation isolates the threshold frequency using only the two given incident frequencies.

Step 3: Conclusion The threshold frequency of the surface is $\nu_0 = 2\nu_1 - \nu_2$. Since $K > 0$, the two cases also imply $\nu_2 > \nu_1 > \nu_0$.

Quick Tip to Solve: When two photoelectric energies have a known ratio, write $K_{\max} = h(\nu - \nu_0)$ for each and eliminate the common energy scale.

2. Briefly explain the working of a light emitting diode. Mention its two uses.

[2 marks]

Solution:

Concept:

- A light emitting diode (LED) is a heavily doped p - n junction made from a suitable semiconductor that emits light when operated under forward bias.
- Light is produced by radiative recombination: a conduction electron fills a hole and releases energy as a photon. The photon energy is approximately the semiconductor band gap, $h\nu \simeq E_g$.

Step 1: Explain carrier injection and light emission Connect the p -side to the positive terminal and the n -side to the negative terminal of a supply, with a suitable current-limiting resistance. Forward bias reduces the junction barrier, allowing electrons from the n -side and holes from the p -side to enter the junction region. When these carriers recombine, energy is emitted as light. The semiconductor band gap determines the colour, while increasing the forward current within the rated range increases the light output.

Step 2: Identify two practical applications **Use 1:** LEDs serve as power-on or status indicators in electronic appliances because they respond quickly and consume little power. **Use 2:** They form numerical and alphanumeric displays, such as the segments of digital clocks and electronic display panels; selected LEDs are switched on to form the required character.

Step 3: Conclusion An LED converts electrical energy into light through electron-hole recombination at a forward-biased junction. Two uses are appliance status indicators and digital display panels.

Quick Tip to Solve: Link LED operation to forward bias and radiative recombination; for the uses, give two distinct applications such as an indicator and a display.

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

[2 marks]

Solution:

Concept:

- In a p -type semiconductor holes are the majority carriers, whereas in an n -type semiconductor electrons are the majority carriers.
- Diffusion carries mobile charge carriers from a region of higher concentration to one of lower concentration. Recombination removes a free electron and a hole as mobile carriers.

Step 1: Follow diffusion across the junction When a p - n junction is formed, electrons diffuse from the n side to the p side and holes diffuse from the p side to the n side because of the concentration gradients. Near the junction, the diffusing electrons and holes recombine. Thus the thin region on either side of the junction loses its mobile majority charge carriers.

Step 2: Identify the fixed charges and the barrier Electrons leaving the n side expose positively charged donor ions, while holes leaving the p side expose negatively charged acceptor ions. These ions are fixed in the crystal lattice and cannot carry current. Their space charge establishes an electric field directed from the n side to the p side and a potential barrier opposing further majority-carrier diffusion. At equilibrium, the field-driven drift current balances the diffusion current, so the net current is zero.

Step 3: Conclusion The thin space-charge region near the junction, depleted of mobile charge carriers and containing immobile positive donor ions on the n side and negative acceptor ions on the p side, is called the depletion region.

Quick Tip to Solve: Track the carriers that leave each side: electrons leave positive ions on the n side, and holes leave negative ions on the p side.

Section B (24 marks)

4. 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.

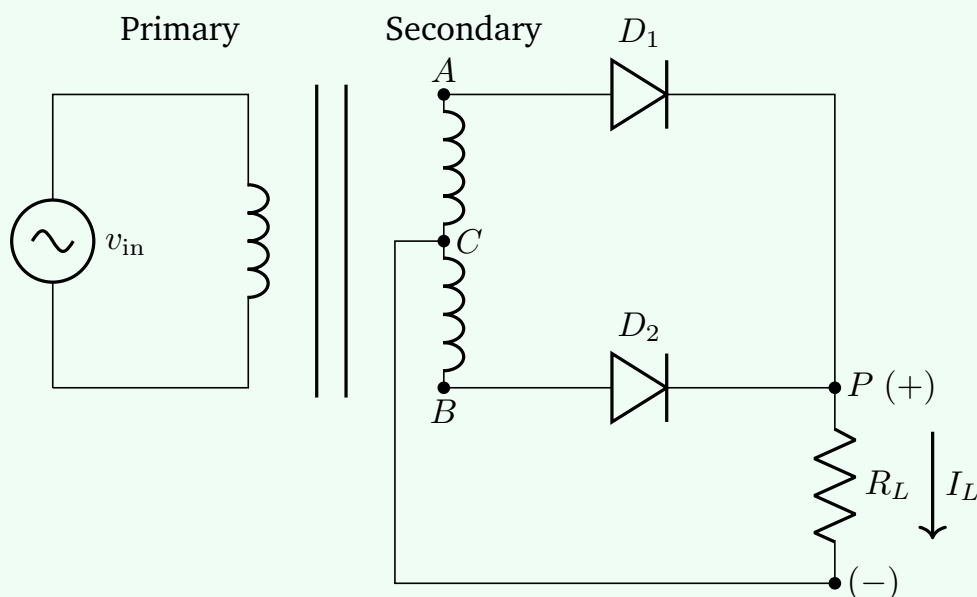
[3 marks]

Solution:

Concept:

- A p - n junction diode conducts readily in forward bias and offers a very large resistance in reverse bias. It can therefore pass current preferentially in one direction.
- A centre-tapped transformer supplies two equal secondary voltages of opposite phase relative to its centre tap C . Two diodes use alternate half-cycles to send current through the same load R_L in the same direction.

Step 1: Connect the full-wave rectifier Connect the secondary ends A and B to the anodes of diodes D_1 and D_2 , respectively. Join their cathodes at the positive output terminal P . Connect the load resistance R_L between P and the centre tap C . Apply the alternating input to the transformer's primary. In the circuit, the arrow beside R_L shows the conventional load-current direction during both half-cycles.



Centre-tapped full-wave rectifier; both diode cathodes meet at P.

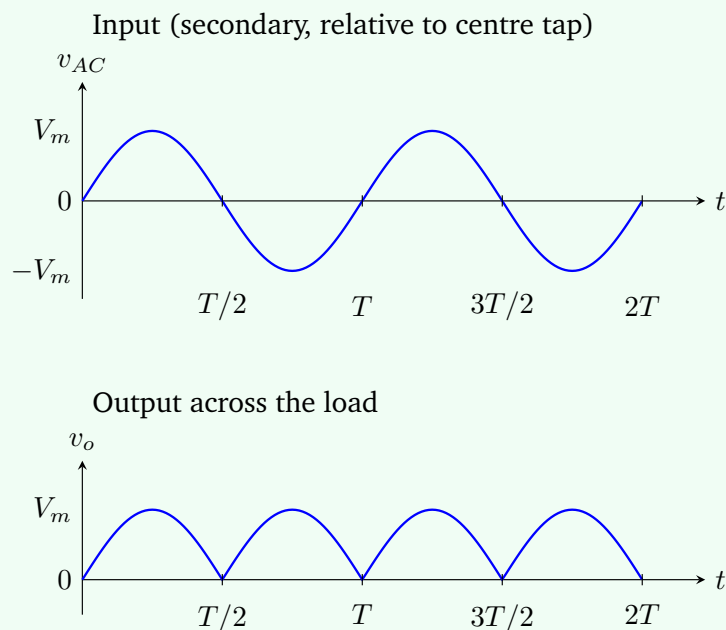
Step 2: Trace current during the positive half-cycle When A is positive relative to C, B is negative relative to C. Diode D_1 is forward biased and conducts, while D_2 is reverse biased and blocks current. The conducting path is $A \rightarrow D_1 \rightarrow P \rightarrow R_L \rightarrow C$, returning through the upper half of the secondary winding. The load current flows from P towards C.

Step 3: Trace current during the negative half-cycle In the next half-cycle, B becomes positive relative to C and A becomes negative. Now D_2 conducts and D_1 is reverse biased. Current follows $B \rightarrow D_2 \rightarrow P \rightarrow R_L \rightarrow C$, returning through the lower half of the secondary. Its direction through R_L is again from P towards C.

Step 4: Relate the input and output waveforms The input alternates above and below zero, but the output across R_L , measured at P relative to C, remains positive during both half-cycles. For ideal diodes, if the voltage of end A relative to C is $v_{AC} = V_m \sin \omega t$, then

$$v_o = V_m |\sin \omega t|.$$

The transformer changes amplitude without changing frequency. Hence the plotted secondary input has the same sinusoidal shape as the primary input. Two output pulses occur in each input period T , so the ripple frequency is $2f$, where $f = 1/T$. The output is pulsating DC; without a smoothing filter it is not constant.



Sinusoidal input and full-wave output; T is the input period.

Step 5: Conclusion The two diodes conduct alternately, utilising both halves of the AC cycle. Current through the load is unidirectional, producing a full-wave rectified output with frequency $2f$.

Quick Tip to Solve: For each half-cycle, first identify the secondary end positive relative to the centre tap; its diode conducts, while the load-current direction stays the same.

5. 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. Thus a wavelength ratio is the inverse momentum ratio.
- For non-relativistic particles, $p = mv = \sqrt{2mK}$, with mass m , speed v and kinetic energy K . A particle starting from rest and accelerated through potential difference V gains $K = qV$.
- An alpha particle has approximately four times the proton mass and twice its charge: $m_\alpha = 4m_p$, $q_\alpha = 2e$, and $q_p = e$.

Step 1: (a) Compare wavelengths at equal speeds Put $v_\alpha = v_p = v$. Since the same speed multiplies each mass in the momentum, the alpha particle has four times the proton's momentum. Taking the ratio directly,

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

The mass enters to the first power when the speeds are fixed; charge has no role in this part.

Step 2: (b) Compare wavelengths at equal kinetic energies Put $K_\alpha = K_p = K$ in $\lambda = h/\sqrt{2mK}$. Equal kinetic energies do not imply equal speeds or momenta, so the result of part (a) cannot be

reused.

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

At fixed kinetic energy the wavelength is inversely proportional to the square root of the mass.

Step 3: (c) Include both mass and charge at equal accelerating potentials For acceleration from rest through the same potential difference V , the proton gains eV whereas the alpha particle gains $2eV$. Substituting $K = qV$ gives $\lambda = h/\sqrt{2mqV}$, so

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

Both the larger mass and the larger energy gain increase the alpha particle's momentum in this case.

Step 4: Conclusion The requested 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 equal accelerating potential differences.

Quick Tip to Solve: Write the ratio in the requested order first. Use $1/m$, $1/\sqrt{m}$, or $1/\sqrt{mq}$ according as speed, kinetic energy, or accelerating voltage is fixed.

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

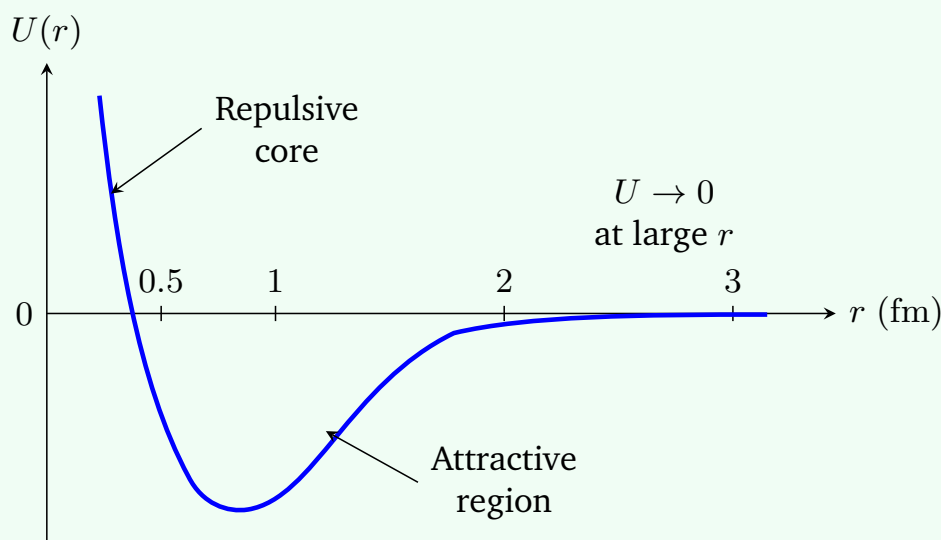
[3 marks]

Solution:

Concept:

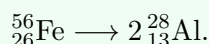
- The nuclear interaction is strongly repulsive at very small nucleon separations, attractive over a short intermediate range, and negligible beyond a few femtometres. Potential energy $U(r)$ is measured relative to $U(\infty) = 0$.
- The radial force is $F_r = -dU/dr$. A negative slope gives outward repulsion, while the rising side of a negative potential well gives inward attraction.
- The energy released in a nuclear reaction is $Q = (m_{\text{initial}} - m_{\text{final}})c^2$, with $1 \text{ u } c^2 = 931.5 \text{ MeV}$. Positive Q releases energy; negative Q requires energy input.

Step 1: (a) Sketch the nucleon potential-energy curve At very small separation, U rises steeply to positive values, representing the repulsive core. It falls to a negative minimum at a separation of order 1 fm, then rises towards zero as the particles move farther apart. Beyond roughly 2 to 3 fm, the nuclear interaction is negligible. The curve below is schematic: its minimum represents a stable separation because a displacement to either side produces a restoring force. The attractive region is on the rising side of the well, where $dU/dr > 0$.



Schematic nuclear potential energy versus nucleon separation; $1 \text{ fm} = 10^{-15} \text{ m}$.

Step 2: (b) Write the proposed reaction and mass difference The process is



Both the mass number $56 = 2 \times 28$ and the charge number $26 = 2 \times 13$ are conserved. Using the supplied masses,

$$\begin{aligned} m_{\text{final}} &= 2(27.98191) = 55.96382 \text{ u}, \\ \Delta m &= 55.93494 - 55.96382 = -0.02888 \text{ u}. \end{aligned}$$

If the supplied masses are neutral-atom masses, their electron contributions cancel since the total atomic number is unchanged.

Step 3: Calculate the energy balance Convert the mass difference into energy:

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

The products have a larger total rest mass than the original nucleus. Therefore energy must be supplied to create them; the proposed splitting does not release energy. This agrees with iron being near the maximum of the binding-energy-per-nucleon curve, so splitting it into these lighter nuclei lowers their total binding energy.

Step 4: Conclusion The potential-energy graph has a steep repulsive core, a negative well and a short-range tail approaching zero. For the proposed fission, $Q \approx -26.9 \text{ MeV}$, so it is not energetically possible as a spontaneous energy-releasing process; at least 26.9 MeV must be supplied for the mass-energy balance alone.

Quick Tip to Solve: Subtract the total product mass from the initial mass before converting units. A negative mass difference immediately identifies an endothermic nuclear reaction.

7(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.

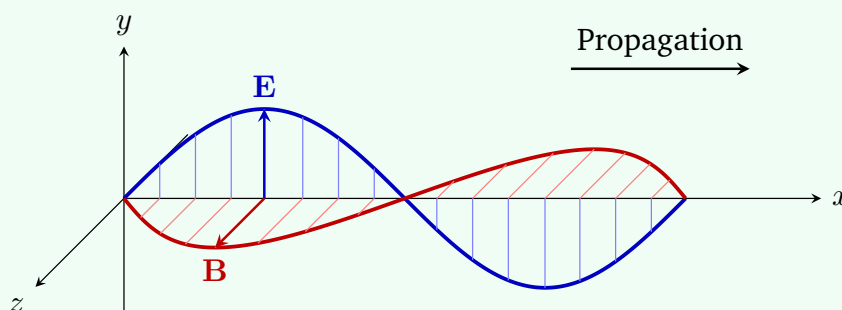
[3 marks]

Solution:

Concept:

- A plane electromagnetic wave consists of time-varying electric and magnetic fields that are mutually perpendicular and perpendicular to the direction of propagation.
- In vacuum, the field amplitudes satisfy $E_0 = cB_0$, where $c = 1/\sqrt{\mu_0\epsilon_0}$. The wave number is $k = 2\pi/\lambda$ and angular frequency is $\omega = 2\pi f$, with $\omega/k = c$.

Step 1: Choose the field directions and depict the wave For propagation along the positive x -axis, choose the electric field along y and the magnetic field along z . Then $\hat{y} \times \hat{z} = \hat{x}$, so the direction of energy flow, $\mathbf{E} \times \mathbf{B}$, is along positive x . The snapshot shows in-phase sinusoidal fields: corresponding maxima and zeros occur together. Separate amplitude scales are used because the field units differ.



Snapshot of an electromagnetic wave; blue: electric field, red: magnetic field (separate amplitude scales).

Step 2: Write the oscillating field expressions A suitable pair of expressions is

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

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

The common phase shows that the fields oscillate in phase. At a fixed phase, $kx - \omega t$ is constant, so x increases with time: these expressions represent propagation along positive x . Here E_0 and B_0 are the maximum field magnitudes, x is position and t is time.

Step 3: State three characteristics (1) Electromagnetic waves are transverse: $\mathbf{E} \perp \mathbf{B}$, and both fields are perpendicular to the propagation direction.

(2) They need no material medium and travel through vacuum with speed $c = 1/\sqrt{\mu_0\epsilon_0} = 3.0 \times 10^8 \text{ m s}^{-1}$.

(3) They carry energy and momentum; consequently, they exert radiation pressure on a surface that absorbs or reflects them.

Step 4: Conclusion For a wave travelling along positive x , the in-phase fields can be $\mathbf{E} = E_0 \sin(kx - \omega t) \hat{y}$ and $\mathbf{B} = (E_0/c) \sin(kx - \omega t) \hat{z}$. Such waves are transverse, propagate in vacuum, and transport energy and momentum.

Quick Tip to Solve: Choose perpendicular field directions first, then check $\mathbf{E} \times \mathbf{B}$: y crossed with z must point along the stated positive x -direction.

7(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 into spectral regions according to its frequency or wavelength. The photon energy is $E = hf$, where h is Planck's constant and f is the frequency.
- The characteristic production mechanism helps identify the radiation: nuclear energy transitions produce gamma rays, energetic atomic transitions in arcs produce ultraviolet radiation, and ordinary hot bodies are sources of infrared radiation.

Step 1: Identify the radiation from radioactive nuclear decays (i) The electromagnetic waves are **gamma rays**. A daughter nucleus left in an excited state can release its excess energy as a high-energy gamma photon. Gamma rays are electromagnetic radiation; alpha and beta emissions that may also accompany radioactive decay are particles.

One use: Gamma rays are used in radiotherapy to destroy cancerous cells under a controlled dose.

Step 2: Identify the radiation from welding arcs (ii) Welding arcs are a source of **ultraviolet rays**. The energetic processes in the electric arc excite atoms, whose subsequent transitions emit ultraviolet radiation as well as visible light. The characteristic spectral region asked for here is ultraviolet.

One use: Ultraviolet radiation is used to sterilise water by inactivating microorganisms.

Step 3: Identify the radiation from hot bodies (iii) Hot bodies are sources of **infrared rays**, commonly associated with thermal radiation. Ordinary heated objects emit strongly in the infrared region; very hot bodies may also emit visible light, so infrared is not their only possible radiation.

One use: Infrared lamps are used in physiotherapy to warm tissues and relieve muscular pain.

Step 4: Conclusion The required source–wave–use pairs are: radioactive nuclear decays–gamma rays–cancer radiotherapy; welding arcs–ultraviolet rays–water sterilisation; hot bodies–infrared rays–heat treatment in physiotherapy.

Quick Tip to Solve: Match the production mechanism first: nucleus to gamma, welding arc to ultraviolet, and ordinary thermal emission to infrared; then attach one specific use to each.

8(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]

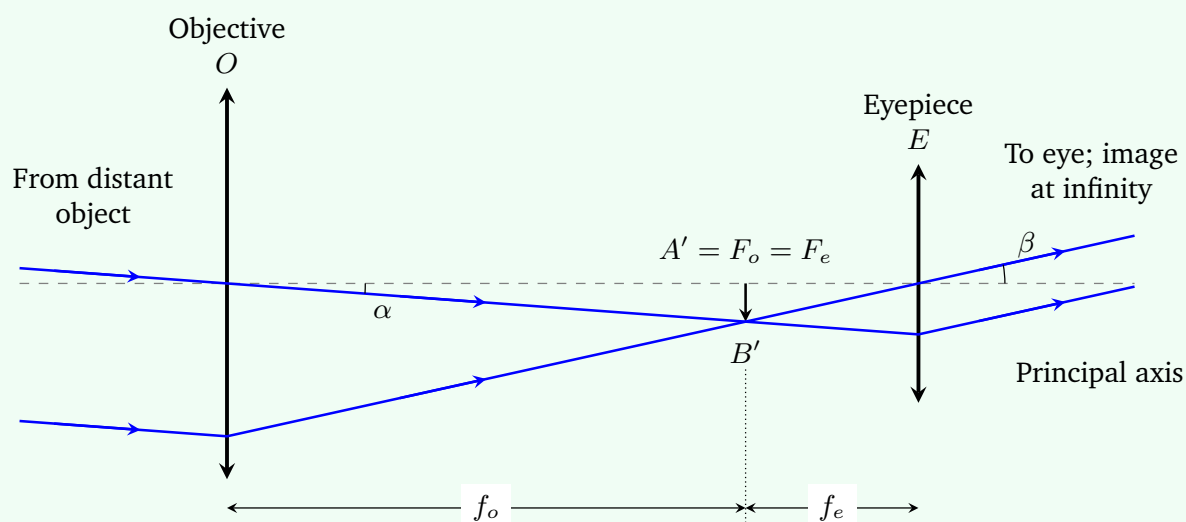
Solution:

Concept:

- An astronomical refracting telescope uses two converging lenses: an objective of large focal length f_o and an eyepiece of small focal length f_e .
- Normal adjustment means that the final image is at infinity. The objective's second focal plane coincides with the eyepiece's first focal plane, so the lens separation is $f_o + f_e$.

- Angular magnifying power is the ratio of the angle subtended by the final image at the eye to the angle subtended by the distant object at the unaided eye; small angles obey $\tan \theta \simeq \theta$.

Step 1: Form the intermediate image and arrange the eyepiece Parallel rays from a point on the distant object enter the objective O . It forms a real, inverted and diminished image $A'B'$ in its focal plane. Place the eyepiece E so that this image also lies in its first focal plane, with $F_o = F_e = A'$. The eyepiece acts as a magnifier: rays from B' emerge parallel, producing the final virtual image at infinity. Thus the eye observes without accommodation. In the diagram the two rays belong to the same off-axis object point, and the thin arrows show the direction of light.



Telescope in normal adjustment: the common focal plane contains $A'B'$; emergent rays are parallel. Angles are exaggerated for clarity.

Step 2: Relate the angular sizes to the common image height Let the magnitude of the intermediate image height be $h = A'B'$. Let α and β denote the positive magnitudes of the small angles made by the incident and emergent bundles with the principal axis, respectively. The ray through the optical centre of the objective and the ray through the optical centre of the eyepiece are undeviated. From their respective right triangles,

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

In the paraxial approximation, $\alpha \simeq h/f_o$ and $\beta \simeq h/f_e$. Taking the ratio cancels the common image height. The objective inverts the image, and the eyepiece does not reverse this inversion; hence the signed angular magnification has a negative sign.

Step 3: Conclusion For an astronomical telescope in normal adjustment,

$$M = -\frac{\beta}{\alpha} = -\frac{f_o}{f_e}, \quad |M| = \frac{f_o}{f_e}.$$

The negative sign denotes an inverted final image. The final image is at infinity and the telescope length is $L = f_o + f_e$.

Quick Tip to Solve: Put the intermediate image at the common focal plane, then divide the two angle relations: the shared height cancels, leaving f_o/f_e .

8(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.

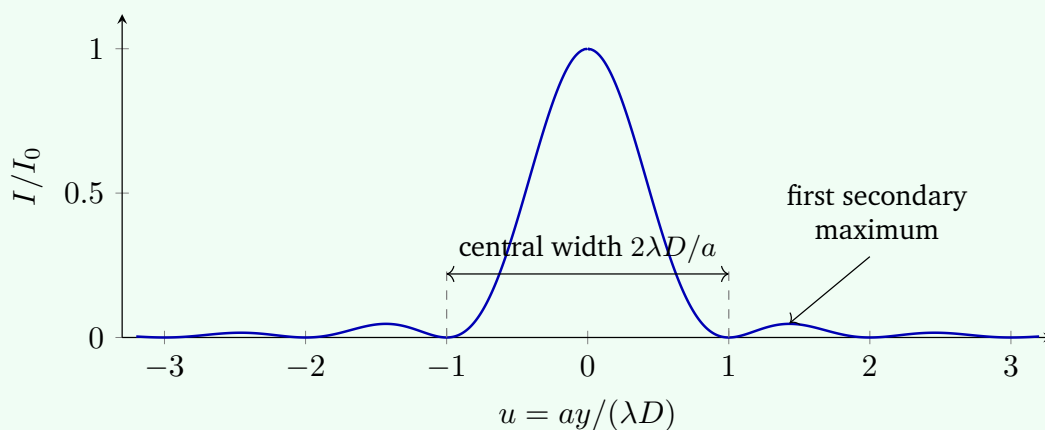
[3 marks]

Solution:

Concept:

- In single-slit diffraction, secondary wavelets from different parts of a slit interfere. For slit width a , the path difference between the extreme rays observed at angle θ is $a \sin \theta$.
- Dark fringes occur at $a \sin \theta = n\lambda$, where $n = \pm 1, \pm 2, \dots$. On a distant screen, the transverse distance is $y = D \tan \theta \simeq D \sin \theta$.

Step 1: (i) Depict the intensity distribution The central maximum is the brightest and broadest peak. Its bounding minima are at $y = \pm \lambda D/a$, so its width is $2\lambda D/a$. Weaker secondary maxima occur symmetrically on either side, and their intensities decrease away from the centre. Successive minima on either side are separated by $\lambda D/a$. The graph uses the dimensionless screen coordinate $u = ay/(\lambda D)$, with the central peak normalized to I_0 .



Single-slit intensity distribution; $u = ay/(\lambda D)$.

Step 2: (ii) Locate the first secondary maximum The first secondary maximum lies between the first and second minima, whose path differences are λ and 2λ . In the usual school-level approximation it lies near their midpoint:

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

One can understand this by dividing the slit into three equal parts: when the extreme-ray path difference is $3\lambda/2$, adjacent thirds have path difference $\lambda/2$. Contributions from two thirds cancel pairwise, while the remaining third gives a weak secondary bright fringe. With small-angle observation on the screen,

$$\frac{y_1}{D} \simeq \sin \theta_1 \simeq \frac{3\lambda}{2a}.$$

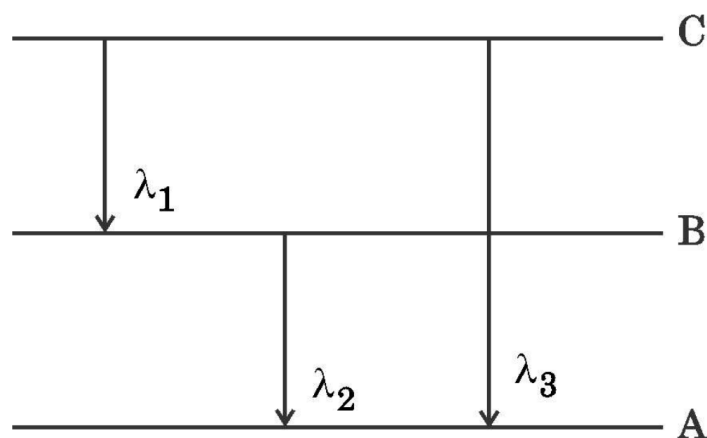
Step 3: Specify the approximation The midpoint condition gives the standard approximate position. More precisely, $I = I_0(\sin \beta/\beta)^2$, where $\beta = \pi a \sin \theta/\lambda$; its noncentral maxima obey $\tan \beta = \beta$. The first positive root is $\beta \simeq 4.493$, giving $y_1 \simeq 1.43\lambda D/a$. Thus the secondary peak in the intensity curve lies slightly inside the midpoint between the adjacent minima.

Step 4: Conclusion The first secondary maximum is approximately $y_1 = 3\lambda D/(2a)$ from the central maximum on either side; the exact diffraction formula gives approximately $1.43\lambda D/a$. The central maximum has width $2\lambda D/a$.

Quick Tip to Solve: First mark the minima at integer multiples of $\lambda D/a$; the first secondary bright fringe lies between the first two minima, not at the first minimum.

9. (a) State Bohr's quantization condition for defining stationary orbits.

(b) Use the energy level diagram shown below to obtain the relation between three wavelengths λ_1 , λ_2 and λ_3 emitted due to the transition of electron from the energy states C and B. [3 marks]



Solution:

Concept:

- Bohr's stationary orbits are allowed orbits in which an electron does not radiate energy. Their angular momenta are restricted to integral multiples of $h/(2\pi)$, where h is Planck's constant.
- A downward transition emits one photon with energy $h\nu = hc/\lambda = E_{\text{upper}} - E_{\text{lower}}$, where c is the speed of light and λ is the emitted wavelength.

Step 1: (a) State the quantization condition For an electron of mass m_e , speed v_n and orbital radius r_n , Bohr's condition is

$$m_e v_n r_n = n \frac{h}{2\pi}, \quad n = 1, 2, 3, \dots$$

Thus the orbital angular momentum cannot take arbitrary continuous values. The positive integer n labels an allowed stationary orbit; radiation occurs only when the electron changes its energy state.

Step 2: (b) Read the three transitions The diagram places the energies in the order $E_C > E_B > E_A$. The arrow labelled λ_1 joins C to B, the arrow labelled λ_2 joins B to A, and the arrow labelled λ_3 joins C directly to A. Therefore,

$$\begin{aligned} E_C - E_B &= \frac{hc}{\lambda_1}, \\ E_B - E_A &= \frac{hc}{\lambda_2}, \\ E_C - E_A &= \frac{hc}{\lambda_3}. \end{aligned}$$

Step 3: Add the energy differences The total energy difference from C to A equals the sum of the two

successive differences:

$$(E_C - E_B) + (E_B - E_A) = E_C - E_A.$$

Substitution of the photon energies gives

$$\frac{hc}{\lambda_1} + \frac{hc}{\lambda_2} = \frac{hc}{\lambda_3}.$$

Divide throughout by the nonzero common factor hc . Energies and frequencies add in this way; wavelengths themselves do not. The direct transition releases the greatest photon energy and must therefore have the shortest wavelength, providing a check on the relation.

Step 4: Conclusion Bohr's condition is $m_e v_n r_n = nh/(2\pi)$. The required wavelength relation is $1/\lambda_3 = 1/\lambda_1 + 1/\lambda_2$, or $\lambda_3 = \lambda_1 \lambda_2 / (\lambda_1 + \lambda_2)$.

Quick Tip to Solve: Follow each arrow's endpoints before writing photon energies: add energy gaps, so add reciprocal wavelengths rather than the wavelengths themselves.

10. (a) Is the speed of light in glass independent of the colour of light? Give reason.

(b) A small bulb is placed at the bottom of a tank containing water to a depth of 70 cm. Find the area of the surface of water through which light from the bulb can emerge out. Given refractive index of water is $\frac{4}{3}$. [3 marks]

Solution:

Concept:

- The speed of light in a transparent medium is $v = c/n$, where c is its speed in vacuum and n is the refractive index for that colour.
- At a water-air boundary the critical angle C obeys $\sin C = n_{\text{air}}/n_{\text{water}}$. Rays incident beyond C undergo total internal reflection.
- For a point source at depth h , the limiting rays form a cone whose intersection with the horizontal surface is a circle of radius $r = h \tan C$ and area $A = \pi r^2$.

Step 1: (a) Relate colour to speed in glass Glass is a dispersive medium: its refractive index depends on the wavelength, and hence on the colour, of light. In the visible region under normal dispersion, $n_{\text{violet}} > n_{\text{red}}$. Since $v = c/n$, violet light travels more slowly than red light in glass. The equal speed of different colours in vacuum therefore does not imply equal speeds in glass.

Step 2: (b) Find the limiting angle for emergence Take the refractive index of air as unity. A ray from the bulb that strikes the surface with incidence less than C , measured from the vertical normal, can refract into air. At the limiting angle the refracted ray grazes the surface. Thus

$$\sin C = \frac{1}{4/3} = \frac{3}{4}, \quad \cos C = \sqrt{1 - \frac{9}{16}} = \frac{\sqrt{7}}{4}, \quad \tan C = \frac{3}{\sqrt{7}}.$$

Step 3: Calculate the radius and surface area The bulb is at $h = 70 \text{ cm} = 0.70 \text{ m}$. Rotational symmetry about the vertical line through the bulb makes the escape region circular. Using the right triangle

formed by its depth and a limiting ray,

$$r = h \tan C = \frac{2.10}{\sqrt{7}} \text{ m}, \quad r^2 = \frac{4.41}{7} \text{ m}^2 = 0.63 \text{ m}^2.$$

Therefore the required area is

$$A = \pi r^2 = 0.63\pi \text{ m}^2 \simeq 1.98 \text{ m}^2.$$

Points outside this circle correspond to incidence angles exceeding the critical angle, so light directed towards them is totally internally reflected back into water.

Step 4: Conclusion (a) No. The speed depends on colour because the refractive index of glass depends on wavelength; red light is faster than violet light. (b) The area through which light emerges is $0.63\pi \text{ m}^2 \simeq 1.98 \text{ m}^2$, or approximately $1.98 \times 10^4 \text{ cm}^2$.

Quick Tip to Solve: For a point source at depth h below a water-air surface, use $A = \pi h^2/(n^2 - 1)$; keep the depth and area units consistent.

11. The refractive index of an equilateral triangular prism kept in air is $\sqrt{2}$. Calculate:

(a) the angle of minimum deviation.

(b) the critical angle for the prism.

[3 marks]

Solution:

Concept:

- At minimum deviation a prism has a symmetric ray path: the incidence and emergence angles are equal, and the internal refraction angles are $r_1 = r_2 = A/2$, where A is the prism angle.
- For a prism in air, $n = \sin[(A + \delta_m)/2] / \sin(A/2)$, where n is the refractive index relative to air and δ_m is the minimum deviation.
- At the critical angle C for light passing from the prism into air, the refracted angle is 90° . Snell's law then gives $\sin C = 1/n$.

Step 1: (a) Identify the prism angle and symmetric path The cross-section is an equilateral triangle, so the angle between the two refracting faces is $A = 60^\circ$. At minimum deviation the two internal angles add to A and are equal. Hence each internal angle is $r = 30^\circ$. The given refractive index is $n = \sqrt{2}$, relative to the surrounding air.

Step 2: Substitute in the minimum-deviation relation Substitution into the prism formula gives

$$\sqrt{2} = \frac{\sin[(60^\circ + \delta_m)/2]}{\sin 30^\circ}, \quad \sin \frac{60^\circ + \delta_m}{2} = \frac{\sqrt{2}}{2}.$$

The angle $(A + \delta_m)/2$ is the external angle of incidence at minimum deviation. Its physical range is between 0° and 90° , so the appropriate inverse-sine value is 45° , not the supplementary angle. Thus

$$\frac{60^\circ + \delta_m}{2} = 45^\circ, \quad \delta_m = 90^\circ - 60^\circ = 30^\circ.$$

Step 3: (b) Apply Snell's law at the critical angle The critical angle is measured inside the denser prism from the normal to a prism-air face. At critical incidence, the emerging ray travels along that

face. Therefore

$$n \sin C = 1 \sin 90^\circ, \quad \sin C = \frac{1}{\sqrt{2}}, \quad C = 45^\circ.$$

This critical-angle condition concerns a single prism-air interface and does not require the ray to be on the minimum-deviation path.

Step 4: Conclusion (a) The angle of minimum deviation is 30° . (b) The critical angle for the prism-air interface is 45° .

Quick Tip to Solve: Set $A = 60^\circ$ for an equilateral prism, find $(A + \delta_m)/2$ first, then double it and subtract A . Calculate the critical angle separately from $\sin C = 1/n$.

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 experiment, the fringe width is $\beta = \lambda D/d$, where λ is wavelength, D the slit-to-screen distance and d the slit separation.
- At a bright fringe the waves add constructively. For equal individual intensities I_0 , the maximum intensity is $I_{\max} = 4I_0$.

Step 1: Compare the fringe widths Moving the screen closer reduces D while λ and d stay fixed. Thus $\beta'/\beta = D'/D < 1$. The fringes move closer together; they cannot retain their width or become wider. This eliminates options (B) and (D).

Step 2: Compare the bright-fringe intensities Light from each slit spreads as it travels towards the screen. At the nearer screen the light is distributed over a smaller area, so the intensity contributed by each slit is greater. At a maximum these larger amplitudes still add in phase, increasing the bright-fringe intensity. Option (A) incorrectly holds this intensity constant. The factor of four relating maximum intensity to the intensity from either equal slit remains the same, but the individual intensity

itself changes.

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

Quick Tip to Solve: Use $\beta \propto D$ for spacing, then consider the spreading of light separately to compare brightness.

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: the same frequency and a constant relative phase.
- The resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$, where I_1, I_2 are the individual intensities and ϕ is the phase difference.

Step 1: Examine the phase relation The original slits receive light from one source and have a stable phase relation. Two independent ordinary light sources emit independently, so their relative phase varies randomly and rapidly even if their wavelengths and intensities are identical. Identical sources therefore need not be coherent.

Step 2: Average the observed intensity The eye or detector averages over the rapid phase changes, giving $\langle \cos \phi \rangle = 0$. Hence the observed intensity is $\langle I \rangle = I_1 + I_2$, without stable bright and dark interference bands. Options (A) and (B) assume a surviving fringe pattern with altered intensity, while (C) assumes a doubled number of fringes; none describes the loss of coherence. The screen is still illuminated: absence of a pattern does not mean absence of light.

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

Quick Tip to Solve: When independent sources replace two slits, check phase stability before comparing fringe spacing or intensity.

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 frequency means equal wavelength.
- A stable interference pattern requires a time-independent phase difference; equal amplitudes improve fringe contrast but are not a condition for coherence.

Step 1: Apply the coherence conditions For frequencies f_1 and f_2 , the relative phase evolves as $\Delta\phi = 2\pi(f_1 - f_2)t + \Delta\phi_0$, where t is time and $\Delta\phi_0$ the initial phase difference. A constant relative phase therefore requires equal frequencies and a stable initial phase relation. Option (B) states these conditions through the same wavelength and a constant phase difference.

Step 2: Reject the other descriptions Option (A) explicitly allows the phase difference to vary; equal amplitude cannot correct this. Options (C) and (D) give different wavelengths, hence different frequencies in the same medium. Their relative phase cannot remain constant. Equal intensity in (C) also does not imply coherence.

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

Quick Tip to Solve: Check frequency and phase stability first; equal amplitude or intensity alone never establishes coherence.

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:

- Fringe width is $\beta = \lambda D/d$, with wavelength λ , slit-to-screen distance D and slit separation d .
- In a liquid of refractive index μ , light speed is $v = c/\mu$. Its frequency f remains unchanged, so its wavelength becomes $\lambda' = \lambda/\mu$.

Step 1: Find the wavelength in the liquid Immersion changes the speed of light but not the frequency

set by the source. Using $\lambda = v/f$, the wavelength in the liquid is

$$\lambda' = \frac{c}{\mu f} = \frac{\lambda}{\mu}.$$

Both arms of the interference experiment are in this same medium.

Step 2: Substitute in the fringe-width relation The positions of the slits and screen do not change, so D and d are unchanged. Consequently,

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

Option (A) ignores the wavelength change and (B) reverses it. Option (D) introduces two factors of μ , although only the wavelength in the fringe-width expression changes.

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

Quick Tip to Solve: For complete immersion with fixed geometry, replace the wavelength by λ/μ once in the fringe-width formula.

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:

- In Young's experiment a bright fringe occurs for path difference $\Delta = n\lambda$, where n is an integer and λ is wavelength.
- A dark fringe occurs for an odd half-wavelength path difference, $\Delta = (2n + 1)\lambda/2$, because the two equal-amplitude waves arrive in opposite phase.

Step 1: Classify the path difference at the first point At P_1 , the path difference is $3\lambda/2$, an odd multiple of $\lambda/2$. The corresponding phase difference is $2\pi\Delta/\lambda = 3\pi$, equivalent to π modulo 2π . The waves therefore interfere destructively at this point.

Step 2: Classify the path difference at the second point At P_2 , the path difference is 2λ , a whole-number multiple of wavelength. The corresponding phase difference is 4π , equivalent to zero modulo 2π , so the waves interfere constructively. Options (A) and (B) incorrectly give both points the same fringe type. Option (C) reverses the assignments given by the phase conditions.

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

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