

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/1/3



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** : Q. Nos. **1** to **3** are of **2** marks each.
- (iv) **Section B** : Q. Nos. **4** to **11** are of **3** marks each.
- (v) **Section C** : Q. 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)

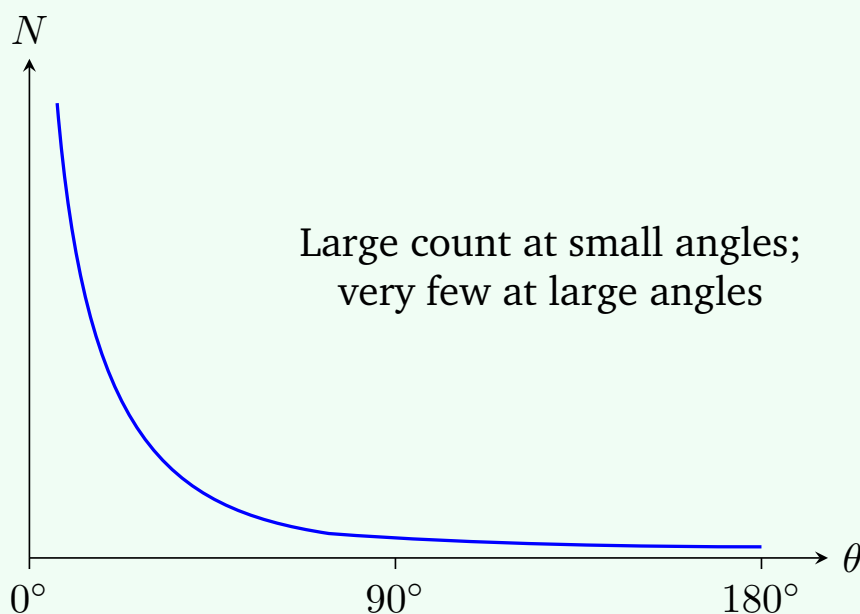
1(a). Draw the graph showing the variation of the number (N) of scattered alpha particles with scattering angle (θ) in Geiger-Marsden experiment. Infer two conclusions from the graph. [2 marks]

Solution:

Concept:

- In the Geiger-Marsden experiment, alpha particles are scattered by the electric field of the positively charged nucleus. The scattering angle θ measures the deviation from the initial direction.
- For equal detector solid angles and otherwise identical conditions, Rutherford scattering gives $N(\theta) \propto 1/\sin^4(\theta/2)$. Thus the count decreases sharply as the scattering angle increases.

Step 1: Draw the angular distribution Plot the number N of scattered alpha particles on the vertical axis and the scattering angle θ on the horizontal axis. The distribution is strongly concentrated near the forward direction: the curve is very high for small angles and falls rapidly, with only a small, nonzero count at large angles. The schematic graph shows this trend; the forward beam at exactly 0° is not a finite point of the ideal Rutherford formula.



Schematic angular distribution of scattered alpha particles

Step 2: Infer the atomic structure First, the overwhelming majority of alpha particles pass through with little or no deviation. Therefore, most of an atom is empty space. Second, only a very small fraction undergo large deflections or turn back. Since an alpha particle is relatively massive and positively charged, such deflections require a strong repulsive field in a very small region. This shows that the atom's positive charge and nearly all its mass are concentrated in a tiny, dense nucleus.

Step 3: Conclusion The count falls steeply with increasing θ . The two conclusions are: most of the atom is empty space, and its positive charge and nearly all its mass occupy a very small, dense nucleus.

Quick Tip to Solve: Connect the large forward count to empty space and the rare backward counts to a tiny, dense nucleus.

1(b). Plot suitable graphs to show the variation of photoelectric current with the collector plate potential for the incident radiation of

(i) the same intensity but different frequencies ν_1, ν_2 and ν_3 ($\nu_1 < \nu_2 < \nu_3$)

(ii) the same frequency but different intensities I_1, I_2 and I_3 ($I_1 < I_2 < I_3$)

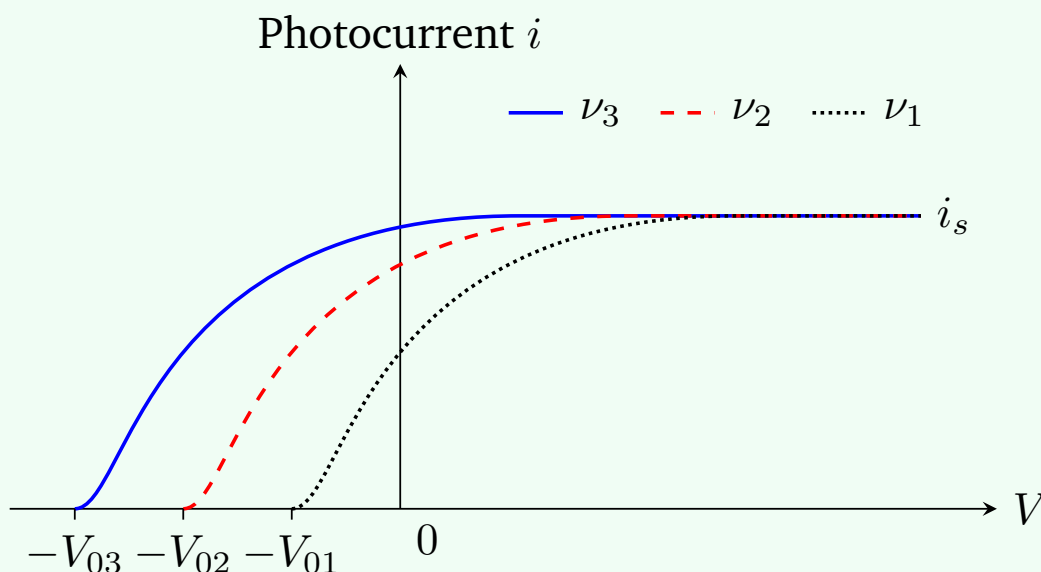
[2 marks]

Solution:

Concept:

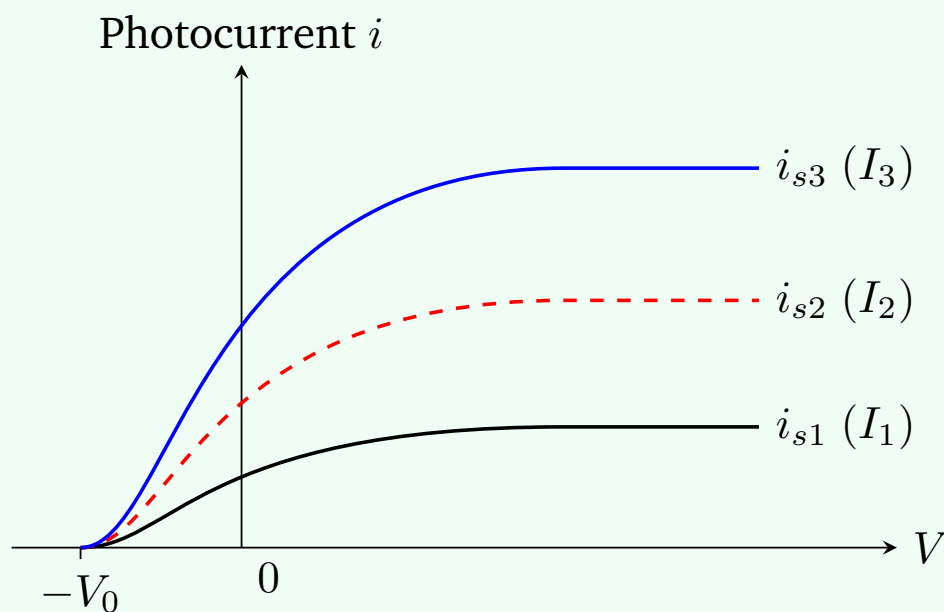
- Einstein's photoelectric equation is $eV_0 = K_{\max} = h\nu - \phi$, where V_0 is the positive magnitude of stopping potential, ν is frequency and ϕ is the metal's work function.
- In the standard school-level comparison, saturation photocurrent depends on incident intensity, while stopping potential depends on frequency. All three incident frequencies must exceed the threshold frequency for photoemission.

Step 1: Same intensity and different frequencies For $\nu_1 < \nu_2 < \nu_3$, the maximum kinetic energies and stopping-potential magnitudes satisfy $V_{01} < V_{02} < V_{03}$. Hence, on an axis of collector potential V , the zero-current intercepts occur in the order $-V_{03} < -V_{02} < -V_{01}$. The highest-frequency curve extends farthest to the left. At sufficiently positive collector potential all emitted electrons are collected; for the specified equal-intensity comparison the curves reach the same saturation current i_s .



Equal intensity: $\nu_1 < \nu_2 < \nu_3$

Step 2: Same frequency and different intensities The frequency is unchanged, so $K_{\max}$ and the stopping-potential magnitude V_0 are unchanged. All curves therefore start at the same intercept $-V_0$. Increasing intensity increases the rate of electron emission and therefore increases the saturation current. For $I_1 < I_2 < I_3$, the saturation levels obey $i_{s1} < i_{s2} < i_{s3}$. The graphs below use i for photocurrent and I for incident light intensity to distinguish the two quantities.



Equal frequency: $I_1 < I_2 < I_3$

Step 3: Conclusion (i) Equal intensity: a common saturation current, with increasingly negative stopping intercepts as frequency increases. (ii) Equal frequency: a common stopping intercept, with higher saturation currents as intensity increases.

Quick Tip to Solve: Label the negative stopping intercepts first: frequency moves them, while intensity changes the saturation height.

2. Distinguish between intrinsic and extrinsic semiconductors. Although in an extrinsic semiconductor $n_e \neq n_h$, yet it is electrically neutral. Why? [2 marks]

Solution:

Concept:

- An intrinsic semiconductor is a pure semiconductor; an extrinsic semiconductor is formed by adding a small, controlled amount of impurity to the pure crystal (doping).
- Electrical neutrality concerns the total charge of mobile carriers and fixed impurity ions, not merely equality of the mobile electron and hole densities n_e and n_h .

Step 1: Compare the charge carriers In an intrinsic semiconductor, thermal excitation generates electrons and holes in pairs, so $n_e = n_h = n_i$, where n_i is the intrinsic carrier density. Both carriers contribute to conduction. In an extrinsic semiconductor, doping produces unequal carrier densities: electrons are majority carriers in an n-type material ($n_e > n_h$), whereas holes are majority carriers in a p-type material ($n_h > n_e$). Doping increases the conductivity compared with the pure material at the same temperature.

Step 2: Include the charge of the impurity ions A donor atom releases an electron and becomes an immobile positive ion, so the additional negative mobile charge is balanced by positive donor charge. An acceptor atom accepts an electron from the valence band, leaving a mobile hole, and becomes an immobile negative ion. Thus the extra positive hole charge is balanced by negative acceptor charge. If

N_D^+ and N_A^- denote the number densities of ionised donors and acceptors, charge neutrality is

$$n_h + N_D^+ = n_e + N_A^-.$$

Step 3: Conclusion Intrinsic material is pure with equal electron and hole densities; extrinsic material is doped with majority and minority carriers. It remains electrically neutral because the fixed impurity-ion charge balances the excess mobile-carrier charge, even though $n_e \neq n_h$.

Quick Tip to Solve: When checking neutrality in a doped crystal, count the fixed donor or acceptor ions as well as the mobile electrons and holes.

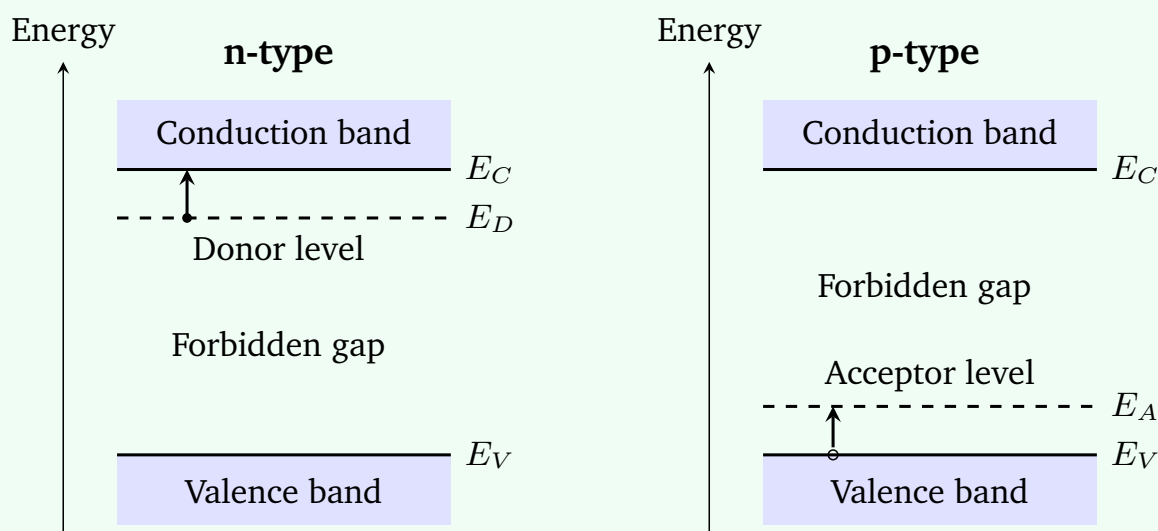
3. Draw energy band diagrams of n-type and p-type semiconductors at temperature $T > 0$ K, depicting the donor and acceptor energy levels. Mention the significance of these levels. [2 marks]

Solution:

Concept:

- The conduction-band edge E_C lies above the valence-band edge E_V , separated by the forbidden energy gap $E_g = E_C - E_V$.
- Doping creates impurity levels inside the gap: the donor level E_D is just below E_C , while the acceptor level E_A is just above E_V .

Step 1: Draw and identify the impurity levels The diagrams show the energy levels for $T > 0$ K. The upward arrows indicate the small energy needed to promote an electron from a donor level into the conduction band, or from the valence band into an acceptor level. The levels are schematic and not drawn to scale.



Impurity energy levels and electron excitation for n-type and p-type semiconductors at $T > 0$ K.

Step 2: Explain their significance for conduction In an n-type semiconductor, a donor's extra electron occupies a level just below the conduction band. Since $E_C - E_D \ll E_g$, a small amount of thermal energy can release it into the conduction band, leaving a fixed positive donor ion. Electrons are therefore the majority carriers.

In a p-type semiconductor, the acceptor level is vacant and lies just above the valence band. Since $E_A - E_V \ll E_g$, an electron can readily be thermally excited from the valence band into this level.

The acceptor becomes a fixed negative ion, and the vacancy left in the valence band is a mobile hole. Holes are therefore the majority carriers. These nearby impurity levels allow carriers to be supplied without excitation across the full band gap.

Step 3: Conclusion The donor level just below E_C supplies conduction electrons; the acceptor level just above E_V creates valence-band holes. Their small ionisation energies explain the increased conductivity of doped semiconductors.

Quick Tip to Solve: Place donor levels near the conduction band and acceptor levels near the valence band; draw electron-excitation arrows upward in both diagrams.

Section B (24 marks)

4(a). A parallel beam of light of wavelength 600 nm is incident normally on a slit of width 0.2 mm. If the resulting diffraction pattern is observed on a screen 1 m away, find the distance of

(i) first minimum, and

(ii) second maximum, from the central maximum.

[3 marks]

Solution:

Concept:

- For Fraunhofer diffraction at a single slit of width a , minima occur at $a \sin \theta = m\lambda$, where $m = 1, 2, \dots$ and λ is the wavelength.
- At small angles, the distance from the central maximum is $y \simeq D\theta$. Secondary maxima lie approximately halfway between successive minima, at $y_n \simeq (2n + 1)\lambda D / (2a)$, where $n = 1, 2, \dots$ counts secondary maxima on either side.

Step 1: Convert the given quantities to SI units The wavelength, slit width and slit-to-screen distance are

$$\lambda = 600 \times 10^{-9} \text{ m}, \quad a = 0.2 \times 10^{-3} \text{ m}, \quad D = 1 \text{ m}.$$

The scale $\lambda D / a$ determines the separation of successive minima. Since the resulting distances are much smaller than D , the small-angle approximation is appropriate.

Step 2: Locate the first minimum For the first minimum, set $m = 1$. The contributions from corresponding points in the two halves of the slit cancel because their path difference is half a wavelength. Thus

$$y_{\min,1} = \frac{\lambda D}{a} = \frac{600 \times 10^{-9} \times 1}{0.2 \times 10^{-3}} = 3.0 \times 10^{-3} \text{ m}.$$

Step 3: Locate the second secondary maximum Counting secondary maxima outward from the central maximum, the second lies between the second and third minima. Using the usual school-level midpoint approximation,

$$y_{\max,2} \simeq \frac{5\lambda D}{2a} = \frac{5}{2} (3.0 \times 10^{-3}) = 7.5 \times 10^{-3} \text{ m}.$$

The midpoint rule for secondary maxima is approximate, whereas the minimum condition follows directly from destructive interference. Distances have equal magnitudes on the two sides of the centre.

Step 4: Conclusion The first minimum is 3.0 mm from the central maximum, and the second secondary maximum is approximately 7.5 mm from it, on either side.

Quick Tip to Solve: Calculate $\lambda D/a$ first: multiply it by 1 for the first minimum and by $5/2$ for the second secondary maximum.

OR

4(b). A thin equiconvex lens of radius of curvature R made of material of refractive index μ_1 is kept coaxially, in contact with an equiconcave lens of the same radius of curvature and refractive index μ_2 ($\mu_2 > \mu_1$). Find:

- the ratio of their powers, and
- the power of the combination and its nature.

[3 marks]

Solution:

Concept:

- For a thin lens in air, the lens-maker's formula gives its power: $P = 1/f = (\mu - 1)(1/R_1 - 1/R_2)$. Here f is the focal length and R_1, R_2 are signed surface radii.
- Thin lenses in contact have equivalent power $P = P_1 + P_2$. Positive power denotes a converging lens and negative power denotes a diverging lens. Radii must be in metres for power in dioptres.

Step 1: Find the equiconvex lens power Take light from left to right and let R be the positive radius magnitude. For the equiconvex lens, $R_1 = +R, R_2 = -R$. Therefore

$$P_1 = (\mu_1 - 1) \left(\frac{1}{R} - \frac{1}{-R} \right) = \frac{2(\mu_1 - 1)}{R}.$$

Step 2: Find the equiconcave lens power and their ratio For the equiconcave lens the signs reverse: $R_1 = -R, R_2 = +R$. Its power is

$$P_2 = (\mu_2 - 1) \left(\frac{1}{-R} - \frac{1}{R} \right) = -\frac{2(\mu_2 - 1)}{R}.$$

Dividing the signed powers gives the answer to part (i):

$$\frac{P_1}{P_2} = -\frac{\mu_1 - 1}{\mu_2 - 1}.$$

The negative sign expresses their opposite actions on a parallel beam.

Step 3: Add the powers and determine the nature For coaxial thin lenses in contact, add the signed

powers. For part (ii),

$$\begin{aligned} P &= P_1 + P_2 \\ &= \frac{2(\mu_1 - 1)}{R} - \frac{2(\mu_2 - 1)}{R} \\ &= \frac{2(\mu_1 - \mu_2)}{R}. \end{aligned}$$

Since $\mu_2 > \mu_1$, the net power is negative: the concave lens has the greater power magnitude, so parallel incident rays emerge diverging.

Step 4: Conclusion (i) $P_1/P_2 = -(\mu_1 - 1)/(\mu_2 - 1)$. (ii) The combination has power $P = 2(\mu_1 - \mu_2)/R$, in dioptres if R is in metres. It behaves as a diverging (concave) lens.

Quick Tip to Solve: Equal radius magnitudes make both powers proportional to $\mu - 1$; keep the concave power negative before adding or taking the ratio.

5. Define the term — Distance of closest approach. How will it be affected, for an α -particle, if kinetic energy of the particle is doubled? [3 marks]

Solution:

Concept:

- In a head-on approach, an α -particle of charge $+2e$ is repelled by a nucleus of charge $+Ze$, where Z is its atomic number and e is the elementary charge.
- Conservation of mechanical energy gives $K + U = \text{constant}$. The electrostatic potential energy at separation r is $U(r) = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{r}$, taking zero potential energy at infinity.

Step 1: Define the closest approach The distance of closest approach is the minimum separation between the centres of an incident α -particle and the target nucleus in a head-on collision. As the positively charged particle approaches the positively charged nucleus, electrostatic repulsion slows it down. At the closest point it comes momentarily to rest before reversing its motion. In the usual Rutherford model, the heavy nucleus is treated as stationary and nuclear forces are neglected.

Step 2: Relate the distance to incident energy Let the initial kinetic energy far from the nucleus be K , and denote the closest distance by r_0 . Initially the electrostatic potential energy is negligible. At the turning point the particle's kinetic energy is zero, so its initial kinetic energy has become electrostatic potential energy:

$$K = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{r_0}, \quad r_0 = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{K}.$$

Thus, for a given nucleus and the same kind of incident particle, the closest distance is inversely proportional to the initial kinetic energy. A more energetic particle can approach further against the repulsive force.

Step 3: Double the incident kinetic energy With the nuclear charge unchanged and $K' = 2K$, apply

the same energy relation:

$$r'_0 = \frac{1}{4\pi\epsilon_0} \frac{2Ze^2}{2K} = \frac{r_0}{2}.$$

Step 4: Conclusion The distance of closest approach is the minimum centre-to-centre separation in a head-on approach. Doubling the α -particle's initial kinetic energy **halves this distance**: $r'_0 = r_0/2$.

Quick Tip to Solve: For the same nucleus and projectile, use $Kr_0 = \text{constant}$; multiply the kinetic energy by any factor and divide the closest distance by that factor.

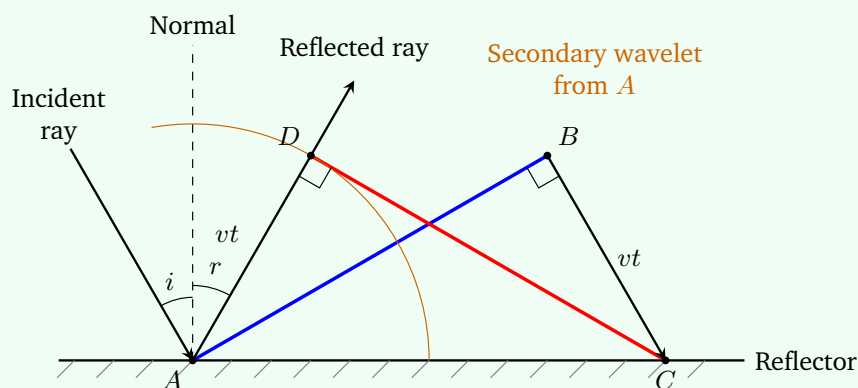
6. Using Huygen's principle, for a plane wavefront incident on a plane reflecting surface, draw the reflected wavefront. Hence prove laws of reflection. [3 marks]

Solution:

Concept:

- Huygens' principle: every point of a wavefront acts as a source of secondary wavelets. The forward envelope of these wavelets gives the wavefront at a later time.
- A ray is normal to its wavefront. During reflection the incident and reflected waves travel in the same medium with the same speed v ; in time t each travels a distance vt .

Step 1: Construct the reflected wavefront Let AB be a plane wavefront incident obliquely on the plane reflecting surface AC . The end A reaches the surface first. In time t , the disturbance at B reaches C , so $BC = vt$. Meanwhile, a secondary wavelet from A has radius $AD = vt$. Draw the tangent CD from C to this wavelet. This tangent is the reflected wavefront, the envelope of the secondary wavelets from the surface. The reflected ray AD is normal to it.



Huygens construction: AB is incident, CD is reflected, and $BC = AD = vt$.

Step 2: Compare the two right triangles Since the incident ray BC is perpendicular to AB , $\angle ABC = 90^\circ$. The radius AD is perpendicular to the tangent CD , so $\angle ADC = 90^\circ$. Triangles ABC and CDA have common hypotenuse AC and equal sides $BC = AD = vt$. They are therefore congruent by the right-angle-hypotenuse-side criterion, giving

$$\angle BAC = \angle DCA.$$

Let i and r be the angles made by the incident and reflected rays with the surface normal. Because each ray is perpendicular to its wavefront, while the normal is perpendicular to the surface, $\angle BAC = i$ and $\angle DCA = r$. Hence the equality proves the first law.

Step 3: Establish the common plane The construction lies in the plane of the incident ray and surface normal. For plane wavefronts and a plane reflector, it is unchanged along the direction perpendicular to this plane. Thus the normal to the reflected wavefront, namely the reflected ray, also lies in this plane, proving the second law.

Step 4: Conclusion The tangent CD is the reflected plane wavefront. The two laws of reflection are: $i = r$, and the incident ray, reflected ray and normal at the point of incidence lie in the same plane.

Quick Tip to Solve: In the Huygens construction, first label $BC = AD = vt$. The two right triangles then share AC , immediately giving the equality of the incidence and reflection angles.

7. The de-Broglie wavelength associated with an electron is 0.30 nm. Calculate: (a) the speed, and (b) the kinetic energy (in eV), of the electron. [3 marks]

Solution:

Concept:

- The de-Broglie relation is $\lambda = h/p$, where λ is the matter wavelength, h is Planck's constant and p is the particle's momentum.
- For a non-relativistic electron, $p = m_e v$ and $K = p^2/(2m_e) = \frac{1}{2}m_e v^2$, where m_e is its mass, v its speed and K its kinetic energy. Also, $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$.

Step 1: Convert the wavelength and find the momentum Convert nanometres into metres before combining the wavelength with SI constants. Using $h = 6.63 \times 10^{-34} \text{ J s}$,

$$\lambda = 0.30 \times 10^{-9} = 3.0 \times 10^{-10} \text{ m},$$

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{3.0 \times 10^{-10}} = 2.21 \times 10^{-24} \text{ kg m s}^{-1}.$$

Step 2: (a) Calculate the electron's speed With $m_e = 9.1 \times 10^{-31} \text{ kg}$, the speed follows directly from $p = m_e v$:

$$v = \frac{p}{m_e} = \frac{2.21 \times 10^{-24}}{9.1 \times 10^{-31}} = 2.43 \times 10^6 \text{ m s}^{-1}.$$

This is only about $0.0081c$, so using non-relativistic momentum and kinetic energy is justified.

Step 3: (b) Calculate the kinetic energy and convert to electronvolts Use the momentum already obtained, avoiding extra rounding of the speed:

$$K = \frac{p^2}{2m_e} = \frac{(2.21 \times 10^{-24})^2}{2(9.1 \times 10^{-31})} = 2.684 \times 10^{-18} \text{ J},$$

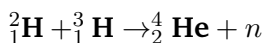
$$K \text{ (in eV)} = \frac{2.684 \times 10^{-18}}{1.6 \times 10^{-19}} = 16.77 \text{ eV}.$$

Division by the joule equivalent of one electronvolt changes only the energy unit; it does not change the physical energy.

Step 4: Conclusion The electron's speed is approximately $2.43 \times 10^6 \text{ m s}^{-1}$, and its kinetic energy is 16.8 eV. To two significant figures, these are $2.4 \times 10^6 \text{ m s}^{-1}$ and 17 eV.

Quick Tip to Solve: First find $p = h/\lambda$; then use the same momentum for both $v = p/m_e$ and $K = p^2/(2m_e)$. Divide joules by 1.6×10^{-19} to get eV.

8. Calculate the energy released in MeV in the following reaction:



Given: $m({}^2_1\text{H}) = 2.014102 \text{ u}$

$m({}^3_1\text{H}) = 3.016049 \text{ u}$

$m({}^4_2\text{He}) = 4.002603 \text{ u}$

$m_n = 1.008665 \text{ u}$

[3 marks]

Solution:

Concept:

- The energy released in a nuclear reaction is its Q -value: $Q = (m_i - m_f)c^2$, where m_i and m_f are the total initial and final rest masses, and c is the speed of light.
- The mass-energy conversion is $1 \text{ u } c^2 = 931.5 \text{ MeV}$. A positive mass difference means that rest-mass energy is released, chiefly as kinetic energy of the reaction products.

Step 1: Add the masses of the reacting nuclei One deuterium nucleus and one tritium nucleus combine in the given fusion reaction. The total initial mass is therefore

$$\begin{aligned} m_i &= m({}^2_1\text{H}) + m({}^3_1\text{H}) \\ &= 2.014102 + 3.016049 \\ &= 5.030151 \text{ u.} \end{aligned}$$

The quoted isotope masses may be used consistently as atomic masses: the two hydrogen atoms contain two electrons altogether, matching the two electrons in the helium atom, so electron masses cancel in the difference.

Step 2: Add the product masses and find the mass decrease Both the helium nucleus and the emitted neutron must be included in the final mass. Omitting the neutron would greatly overestimate the released energy.

$$\begin{aligned} m_f &= m({}^4_2\text{He}) + m_n \\ &= 4.002603 + 1.008665 \\ &= 5.011268 \text{ u,} \\ \Delta m &= m_i - m_f \\ &= 5.030151 - 5.011268 = 0.018883 \text{ u.} \end{aligned}$$

The initial mass exceeds the final mass, establishing that this reaction releases energy rather than requiring a net energy input.

Step 3: Convert the mass decrease into released energy Multiplying the mass decrease in atomic mass units by the energy equivalent of one atomic mass unit gives the energy directly in MeV:

$$Q = \Delta mc^2 = 0.018883 \times 931.5 \text{ MeV} = 17.5895 \text{ MeV}.$$

This is the total energy released per fusion reaction, shared by the helium nucleus and neutron according to conservation of energy and momentum.

Step 4: Conclusion The energy released in the fusion reaction is $Q \approx 17.6 \text{ MeV}$ per reaction.

Quick Tip to Solve: Include the outgoing neutron in the final mass, subtract final mass from initial mass, and multiply the result in u by 931.5 to obtain MeV directly.

9(a). (i) Monochromatic light is incident on a surface separating two media. The frequency of the light after refraction remains unaffected but its wavelength changes. Why?

(ii) The frequency of an electromagnetic radiation is $1.0 \times 10^{11} \text{ Hz}$. Identify the radiation and mention its two uses. [3 marks]

Solution:

Concept:

- The frequency ν of light is fixed by its source. At a stationary boundary, the transmitted wave oscillates with the same frequency as the incident wave.
- Wave speed, frequency and wavelength obey $v = \nu\lambda$. In a medium of refractive index n , the speed is $v = c/n$, where c is the vacuum speed of light.

Step 1: (i) Explain why frequency stays constant The incident electromagnetic field drives the charges of the second medium at its own frequency. Their response produces the refracted wave with that same frequency. The fields at the boundary must remain matched at every instant; different incident and transmitted frequencies would not satisfy this condition. Thus refraction at a stationary interface does not change the rate of oscillation fixed by the source.

Step 2: Relate the changed speed to the wavelength Different optical media have different refractive indices, so the speed changes on refraction. Since the frequency remains constant, the distance travelled during one oscillation changes:

$$\frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} = \frac{n_1}{n_2}.$$

Hence light entering an optically denser medium has a smaller speed and a shorter wavelength, while entering a rarer medium produces the reverse change.

Step 3: (ii) Identify the radiation and state two uses For the given frequency, calculate the wavelength in vacuum:

$$\lambda = \frac{c}{\nu} = \frac{3.0 \times 10^8}{1.0 \times 10^{11}} = 3.0 \times 10^{-3} \text{ m} = 3.0 \text{ mm}.$$

A frequency of 100 GHz, or a millimetre wavelength, lies in the microwave region. Microwaves are used in radar systems to detect objects and determine their position or speed, and in satellite communication to transmit information. These are uses of the microwave band; individual systems

choose their operating frequency within it.

Step 4: Conclusion The frequency remains source-controlled, while the wavelength changes because the speed changes. The given radiation is **microwave radiation**; two uses are radar and satellite communication.

Quick Tip to Solve: Keep frequency fixed at refraction and use $\lambda \propto 1/n$. Convert an unfamiliar electromagnetic frequency to wavelength before identifying its band.

OR

9(b). (i) Trace the path of a ray of light PQ which is incident at an angle i on one face of a glass prism of angle A . It then emerges out from the other face at an angle e . Use the ray diagram to prove that the angle through which the ray is deviated is given by $\angle \delta = \angle i + \angle e - \angle A$.

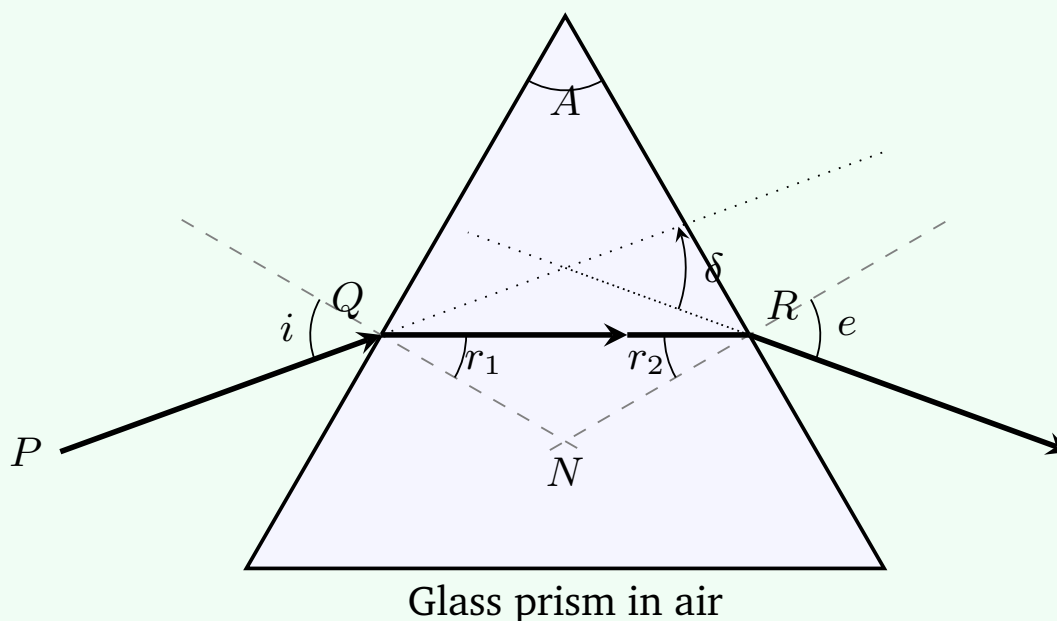
(ii) What will be the minimum value of δ if the ray passes symmetrically through the prism? [3 marks]

Solution:

Concept:

- The incidence angle i , emergence angle e , and internal refraction angles r_1, r_2 are measured from the normals to the prism faces.
- For a prism of apex angle A , geometry gives $r_1 + r_2 = A$. The total deviation is the sum of the deviations at the two faces.
- At minimum deviation, the ray travels symmetrically: $i = e$ and $r_1 = r_2 = A/2$.

Step 1: (i) Trace the ray and label the angles The incident ray PQ enters the glass at Q , bends towards the normal, travels along QR , and emerges at R , bending away from the normal. The dashed lines through Q and R are the face normals. The dotted extensions show the angle δ between the original direction and the emergent direction. The sketch illustrates the symmetric ray path; the angle relations derived below also apply to an unsymmetric path.



Prism ray path, face normals and deviation; the illustrated path is symmetric.

Step 2: Relate the refraction angles to the prism angle Let the inward normals at Q and R meet at N . In the quadrilateral formed by the apex, Q, N, R , the angles at Q and R are right angles. Therefore $\angle QNR = 180^\circ - A$. In triangle QNR , the other two angles are r_1 and r_2 , so

$$r_1 + r_2 + (180^\circ - A) = 180^\circ, \quad r_1 + r_2 = A.$$

Step 3: Add the deviations at the two surfaces The first refraction turns the ray through $i - r_1$; the second turns it in the same sense through $e - r_2$. Hence the total deviation is

$$\begin{aligned} \delta &= (i - r_1) + (e - r_2) \\ &= i + e - (r_1 + r_2) \\ &= i + e - A. \end{aligned}$$

The ray is thus deviated towards the base of the prism.

Step 4: (ii) Apply the symmetric-path condition At minimum deviation, $i = e$. Substituting this equality gives $\delta_{\min} = 2i - A$, with i evaluated for the symmetric path. Also $r_1 = r_2 = A/2$. If the prism refractive index relative to air is n , Snell's law gives the equivalent expression

$$\delta_{\min} = 2 \sin^{-1} \left(n \sin \frac{A}{2} \right) - A.$$

No numerical value can be obtained because neither a numerical incidence angle nor the refractive index and apex angle are supplied.

Step 5: Conclusion The prism deviation is $\delta = i + e - A$. For symmetric passage, the minimum deviation is $\delta_{\min} = 2i - A$, where $i = e$.

Quick Tip to Solve: Measure all ray angles from the normals. First use $r_1 + r_2 = A$, then add the two face deviations; set $i = e$ only for minimum deviation.

10. State the working principle of an LED. Write any two important advantages and two disadvantages of LED. [3 marks]

Solution:

Concept:

- An LED is a light-emitting semiconductor p - n junction operated in forward bias. It converts electrical energy into light by electroluminescence.
- Radiative recombination of an electron and a hole releases energy as a photon: $h\nu \simeq E_g$, where E_g is the semiconductor band gap, h is Planck's constant and ν is the emitted frequency.

Step 1: Explain the working principle Connect the p -side to the positive terminal and the n -side to the negative terminal of a supply, with suitable current limitation. Forward bias reduces the junction barrier, so electrons and holes are injected across the junction. In a suitable direct-band-gap semiconductor, their recombination near the junction emits photons. The band gap mainly determines the colour of the light, while the forward current controls its intensity within the rated operating range.

Step 2: State two advantages (i) **Low power consumption:** An LED produces useful light with comparatively little electrical power and operates at a small forward voltage.

(ii) **Long operating life:** It has no fragile heated filament, so a correctly driven LED is reliable and can operate for a long time.

Step 3: State two disadvantages (i) **Temperature sensitivity:** Excessive junction temperature reduces light output and can shorten the LED's life; suitable heat removal is necessary.

(ii) **Poor reverse-voltage tolerance:** An LED can withstand only a small reverse voltage. Reverse breakdown can damage the junction, so correct polarity and protection against excessive reverse voltage are needed.

Step 4: Conclusion An LED works by photon emission during electron-hole recombination in a forward-biased junction. Low power consumption and long life are advantages; temperature sensitivity and low reverse-voltage tolerance are disadvantages.

Quick Tip to Solve: Link the working to forward bias and radiative recombination; keep the two advantages and the two limitations explicitly separate.

11. For a glass prism of refractive index $\sqrt{3}$, the value of angle of minimum deviation δ is equal to the angle of prism A . Find the angle of prism A . How will the angle δ be affected if the prism were immersed in water? [3 marks]

Solution:

Concept:

- At minimum deviation a ray passes symmetrically through a prism: $i = e$, $r_1 = r_2 = A/2$ and $\delta_m = 2i - A$. Here A is the prism angle and i, e are the angles of incidence and emergence.
- The prism formula is $\mu_{\text{rel}} = \sin[(A + \delta_m)/2] / \sin(A/2)$, where μ_{rel} is the refractive index of the prism relative to the surrounding medium.

Step 1: Insert the minimum-deviation condition Initially the prism is in air, so its relative refractive index is $\sqrt{3}$. The stated deviation δ is its minimum deviation. Substitute $\delta_m = A$ in the prism formula:

$$\sqrt{3} = \frac{\sin A}{\sin(A/2)}.$$

Use $\sin A = 2 \sin(A/2) \cos(A/2)$. A physical prism has a nonzero prism angle, so $\sin(A/2)$ may be cancelled.

Step 2: Solve for the prism angle The resulting equation gives

$$\begin{aligned} 2 \cos(A/2) &= \sqrt{3}, \\ \cos(A/2) &= \frac{\sqrt{3}}{2}, \\ A/2 &= 30^\circ. \end{aligned}$$

The solution lies in the physical range of prism angles; the given equality also fixes the initial minimum deviation once the prism angle is known.

Step 3: Compare the minimum deviation in water Immersion does not change the prism angle. If n_w is the refractive index of water, the relative refractive index becomes $\sqrt{3}/n_w$, smaller than its value in air. Hence

$$\delta_{m,w} = 2 \sin^{-1} \left[\frac{\sqrt{3}}{n_w} \sin 30^\circ \right] - 60^\circ.$$

Because $n_w > 1$, the argument of the inverse sine is smaller. The minimum-deviation incidence angle therefore falls, and so does the minimum deviation. Physically, the smaller optical contrast between glass and water produces less bending at each face.

Step 4: Conclusion The angle of the prism is $A = 60^\circ$, and its minimum deviation in air is also 60° . When immersed in water, its minimum deviation δ decreases.

Quick Tip to Solve: When $\delta_m = A$, simplify the prism formula directly to $\mu = 2 \cos(A/2)$; on immersion replace μ by the relative refractive index.

Section C (5 marks)

CASE STUDY

12. The principle of superposition is used to understand the phenomenon of interference of light waves. The principle states that at a particular point, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each wave. Light waves from two coherent sources produce interference pattern. Thomas Young devised a way to obtain two coherent sources using two identical pinholes (S_1 and S_2) illuminated by a single monochromatic pinhole source S . Using these sources in his experiment known as Young's double slit experiment, Young studied the interference pattern. The pattern consists of alternate bright and dark fringes. The distance between two successive bright or dark fringes depends on the distance between S_1 and S_2 , the distance of the screen from the plane of $S_1 S_2$ and the wavelength of light used. [5 marks]

12(I). Consider the following waves:

- (i) $y_1 = a \sin \omega t$
- (ii) $y_2 = a \sin 2\omega t$
- (iii) $y_3 = a \sin(2\omega t + \phi)$
- (iv) $y_4 = a \sin\left(4\omega t + \frac{\pi}{2}\right)$

Which pair of the waves coming from two sources S_1 and S_2 will produce interference? [1 mark]

- (A) (i) and (ii)
- (B) (ii) and (iii)
- (C) (iii) and (iv)
- (D) (iv) and (i)

Correct Answer: (B) (ii) and (iii)

Solution:

Concept:

- A sustained interference pattern requires coherent sources: the waves must have the same frequency and a constant phase difference.
- For phases $\omega_1 t + \phi_1$ and $\omega_2 t + \phi_2$, their difference is $(\omega_2 - \omega_1)t + \phi_2 - \phi_1$; unequal frequencies make this change with time.

Step 1: Compare the frequencies and phases The angular frequencies of waves (i), (ii), (iii) and (iv) are respectively ω , 2ω , 2ω and 4ω . Only (ii) and (iii) have equal angular frequency. Their phase difference is

$$(2\omega t + \phi) - 2\omega t = \phi,$$

which is constant, so these sources are coherent.

Step 2: Check the other proposed pairs In (A), the frequencies are ω and 2ω ; in (C), they are 2ω and 4ω ; in (D), they are 4ω and ω . Each of these pairs has a time-dependent phase difference and cannot produce the sustained interference pattern described in the passage. Equal amplitudes alone do not establish coherence.

Step 3: Conclusion Waves (ii) and (iii) produce sustained interference. Hence, the correct option is (B).

Quick Tip to Solve: Compare the coefficients of t first: they must match; a fixed added phase such as ϕ does not destroy coherence.

12(II). Two light waves of the same intensity I_0 each, having a path difference of $\lambda/4$, emanating from two coherent sources, meet at a point. The resultant intensity at the point will be [1 mark]

- (A) Zero
- (B) I_0
- (C) $2I_0$
- (D) $4I_0$

Correct Answer: (C) $2I_0$

Solution:

Concept:

- A path difference Δx corresponds to a phase difference $\Delta\phi = 2\pi\Delta x/\lambda$, where λ is the wavelength.
- The interference intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \Delta\phi$, where I_1, I_2 are the individual intensities.

Step 1: Convert path difference into phase difference With $\Delta x = \lambda/4$,

$$\Delta\phi = \frac{2\pi}{\lambda} \frac{\lambda}{4} = \frac{\pi}{2}.$$

The waves are in phase quadrature, rather than exactly in phase or exactly out of phase.

Step 2: Substitute the equal intensities Put $I_1 = I_2 = I_0$ and $\cos(\pi/2) = 0$:

$$I = I_0 + I_0 + 2I_0 \cos(\pi/2) = 2I_0.$$

The interference term vanishes at this point. Zero intensity, option (A), would require phase difference π ; the maximum $4I_0$, option (D), would require phase difference zero modulo 2π . Option (B) incorrectly gives only one source's intensity.

Step 3: Conclusion The resultant intensity is $2I_0$. Hence, the correct option is (C).

Quick Tip to Solve: A quarter-wavelength path difference gives a right-angle phase difference, so the interference term is zero and the two intensities add.

12(III). Vandana performs Young's double slit experiment by using orange, green and red lights successively. If the fringe widths measured in the three cases are ω_1, ω_2 and ω_3 respectively, then which of the following is correct? [1 mark]

(A) $\omega_2 > \omega_1 > \omega_3$

(B) $\omega_1 > \omega_2 > \omega_3$

(C) $\omega_2 > \omega_3 > \omega_1$

(D) $\omega_3 > \omega_1 > \omega_2$

Correct Answer: (D) $\omega_3 > \omega_1 > \omega_2$

Solution:

Concept:

- In Young's double slit experiment, the fringe width is $\omega = \lambda D/d$, where λ is the wavelength, D the screen distance and d the slit separation.
- For the same apparatus, D and d remain fixed, so fringe width is directly proportional to wavelength.

Step 1: Arrange the wavelengths The order of wavelengths in the visible spectrum is red greater than orange greater than green. Thus $\lambda_{\text{red}} > \lambda_{\text{orange}} > \lambda_{\text{green}}$. Red produces the widest fringes and green the narrowest.

Step 2: Match the colours to their symbols Orange, green and red correspond respectively to ω_1, ω_2 and ω_3 . Multiplication by the same positive factor D/d preserves the wavelength order. Options (A) and (C) incorrectly make the green fringe width largest; option (B) incorrectly makes the red fringe width smallest.

Step 3: Conclusion The required ordering is $\omega_3 > \omega_1 > \omega_2$. Hence, the correct option is (D).

Quick Tip to Solve: First rank the colours by wavelength, then replace each colour with its assigned fringe-width symbol.

12(IV). In a Young's double slit experiment, the slit separation is 0.8 mm and the interference pattern is obtained on a screen kept 50 cm from the plane of the slits S_1 and S_2 . If the first bright fringe is formed 0.4 mm from the central maximum, the wavelength of light used is [1 mark]

(A) 480 nm

(B) 560 nm

(C) 640 nm

(D) 680 nm

Correct Answer: (C) 640 nm

Solution:

Concept:

- The position of the n th bright fringe measured from the central maximum is $y_n = n\lambda D/d$, where D is screen distance and d is slit separation.
- The first bright fringe has $n = 1$; therefore its distance from the centre equals the fringe width and $\lambda = y_1 d/D$.

Step 1: Convert the distances into metres The given quantities are $d = 0.8 \times 10^{-3}$ m, $D = 0.50$ m

and $y_1 = 0.4 \times 10^{-3}$ m. The first bright fringe is a full fringe width from the central bright fringe; the half-width relation applies to the first dark fringe.

Step 2: Substitute in the bright-fringe relation Rearranging $y_1 = \lambda D/d$ gives

$$\lambda = \frac{(0.4 \times 10^{-3})(0.8 \times 10^{-3})}{0.50} = 6.4 \times 10^{-7} \text{ m.}$$

Since $1 \text{ nm} = 10^{-9} \text{ m}$, the wavelength is 640 nm. Options (A), (B) and (D) would give first-bright positions of 0.30, 0.35 and 0.425 mm, respectively, rather than the specified 0.4 mm.

Step 3: Conclusion The wavelength is 640 nm. Hence, the correct option is (C).

Quick Tip to Solve: Use the first bright fringe's distance directly as the fringe width, and convert all distances to metres before substitution.

12(V). Consider the effect on the angular separation of the fringes in a Young's double slit experiment due to the following operations:

- (i) the screen is moved away from the plane of the slits,
- (ii) the separation between the two slits is increased till fringes are observed.

Which of the following options is correct?

[1 mark]

- (A) It remains constant in both cases.
- (B) It decreases in both cases.
- (C) It remains constant in (i) but decreases in (ii).
- (D) It decreases in (i) but remains constant in (ii).

Correct Answer: (C) It remains constant in (i) but decreases in (ii).

Solution:

Concept:

- The linear fringe width in Young's double slit experiment is $\beta = \lambda D/d$, with wavelength λ , screen distance D and slit separation d .
- In the small-angle approximation, the angular separation of consecutive fringes is $\Delta\theta = \beta/D = \lambda/d$, measured in radians.

Step 1: Move the screen away Increasing D increases the linear separation β in the same proportion. However, the angular separation is their ratio β/D . The factor D cancels, so moving the screen away leaves the angular separation unchanged. This rules out options (B) and (D), which predict a decrease in case (i).

Step 2: Increase the slit separation The wavelength remains fixed, while $\Delta\theta = \lambda/d$ is inversely proportional to d . Increasing the slit separation therefore reduces the angular separation while the fringes remain observable. Option (A) is incorrect because it predicts no change when d increases.

Step 3: Conclusion The angular separation remains constant in (i) but decreases in (ii). Hence, the correct option is (C).

Quick Tip to Solve: For angular fringe separation use λ/d ; for linear fringe width use $\lambda D/d$, which also depends on screen distance.