

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

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** : 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. Nos. **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. Explain the formation of depletion layer and barrier potential in a p-n junction diode. [2 marks]

Solution:

Concept:

- Diffusion carries electrons and holes from regions of high concentration to regions of low concentration across a p-n junction.
- Uncovered, immobile dopant ions form a space-charge region. Its electric field opposes further diffusion and establishes a built-in potential barrier.

Step 1: Explain the formation of the depletion layer On forming a p-n junction, majority electrons diffuse from the n-side to the p-side and recombine with holes. Similarly, holes diffuse from the p-side to the n-side and recombine with electrons. Near the junction this removes mobile majority carriers, leaving positively charged donor ions on the n-side and negatively charged acceptor ions on the p-side. These ions are fixed in the crystal lattice. The thin region depleted of mobile charge carriers is called the depletion layer.

Step 2: Explain the development of barrier potential The fixed positive and negative ions create an electric field directed from the n-side to the p-side. The force due to this field opposes further diffusion of the majority carriers: it drives electrons towards the n-side and holes towards the p-side. The associated potential difference, with the n-side at higher potential, is the barrier potential. As the layer develops, the drift current caused by this field grows until it balances the diffusion current, giving zero net current at equilibrium.

Step 3: Conclusion Recombination near the junction leaves a layer of fixed, oppositely charged ions depleted of mobile carriers. Their electric field produces the barrier potential that opposes further majority-carrier diffusion.

Quick Tip to Solve: Remember the sequence: diffusion, recombination, fixed ions, electric field, then barrier potential. The field points from the positive n-side ions to the negative p-side ions.

2. 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]

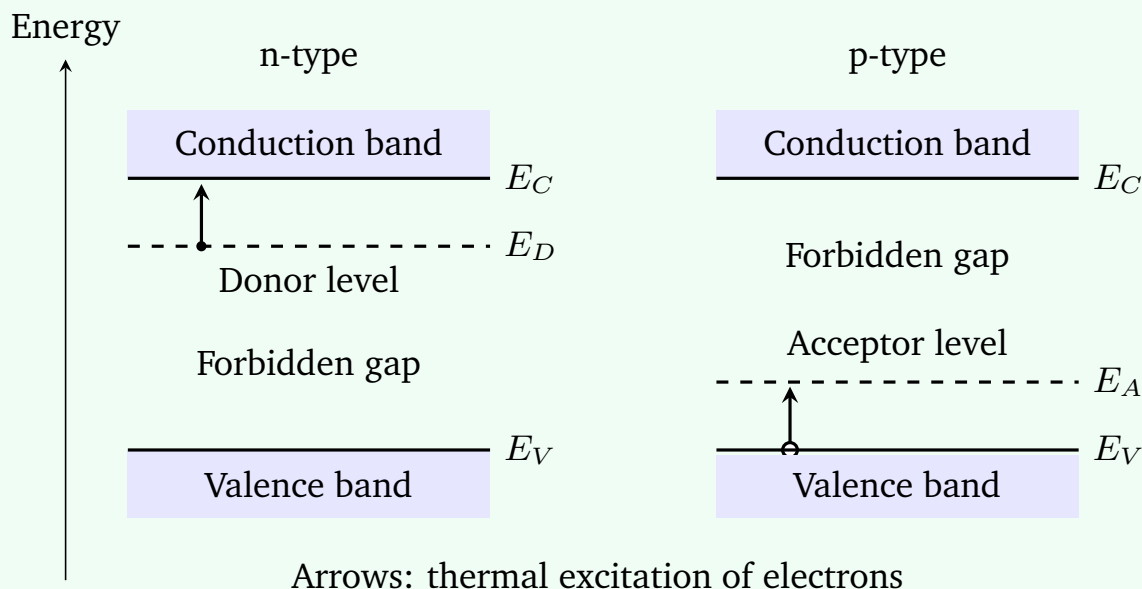
Solution:

Concept:

- Doping introduces impurity energy levels in the forbidden gap between the valence-band edge E_V and the conduction-band edge E_C .
- Donor levels E_D lie just below E_C , whereas acceptor levels E_A lie just above E_V . The small energy separations allow thermal excitation of carriers.

Step 1: Draw the donor level for an n-type semiconductor A pentavalent impurity supplies a weakly bound extra electron. Its donor level E_D lies slightly below the conduction band. At a finite temperature, thermal energy can promote donor electrons through the small energy difference $E_C - E_D$ into the conduction band, leaving fixed positive donor ions. Thus electrons become the majority carriers. The extent of donor ionisation depends on temperature; complete ionisation is not implied at every $T > 0$ K.

Step 2: Draw the acceptor level for a p-type semiconductor A trivalent impurity introduces an acceptor level E_A slightly above the valence band. It can accept a valence electron when thermal energy supplies the small difference $E_A - E_V$. This leaves a mobile hole in the valence band and a fixed negative acceptor ion. Consequently, holes become the majority carriers. The diagrams show these small excitation energies relative to the much larger forbidden energy gap; they are schematic and not to scale.



Impurity energy levels and electron excitation at $T > 0K$ (schematic).

Step 3: Conclusion Donor levels near the conduction band facilitate the supply of conduction electrons in n-type material. Acceptor levels near the valence band facilitate the production of valence-band holes in p-type material.

Quick Tip to Solve: Place a donor level just below the conduction band and an acceptor level just above the valence band; show electron excitation upward in energy in both cases.

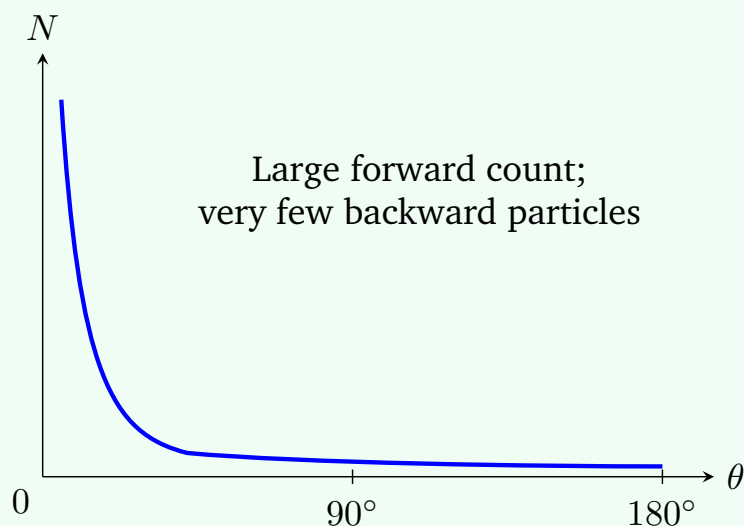
3(a). Draw the graph showing the variation of the number (N) of scattered alpha particles with scattering angle (θ) in Geiger-Marsden experiment. Infer two conclusions from the graph. [2 marks]

Solution:

Concept:

- In the Geiger–Marsden experiment, positively charged alpha particles are scattered by the repulsive electric field of a small, positively charged atomic nucleus.
- For a fixed incident beam and detector geometry, the Rutherford scattering law gives $N(\theta) \propto 1/\sin^4(\theta/2)$, where N is the detected number at scattering angle θ . Thus large-angle scattering is much less frequent than small-angle scattering.

Step 1: Sketch the angular distribution Put the number N of scattered alpha particles on the vertical axis and the scattering angle θ on the horizontal axis. The count is very large near the forward direction and falls steeply as θ increases. Only a very small number are scattered through large angles, including angles near 180° . The graph is qualitative; the exact forward direction includes the undeviated beam.



Qualitative variation of scattered count with angle (not to scale).

Step 2: Infer the atomic structure **First conclusion:** most alpha particles travel straight through the foil or undergo only small deflections, so most of an atom's volume is empty space.

Second conclusion: the very few particles scattered through large angles or backwards encounter a very strong repulsive field. The atom's positive charge and almost all its mass must therefore be concentrated in a tiny, dense central nucleus. Such rare encounters also show that the nucleus occupies only a small fraction of the atomic volume.

Step 3: Conclusion N decreases sharply with increasing θ . The atom is mostly empty space, with its positive charge and nearly all its mass concentrated in a very small nucleus.

Quick Tip to Solve: Link the high forward count to empty space and the tiny backward count to a small, dense positive nucleus; do not draw the curve reaching zero at a finite angle.

OR

3(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]

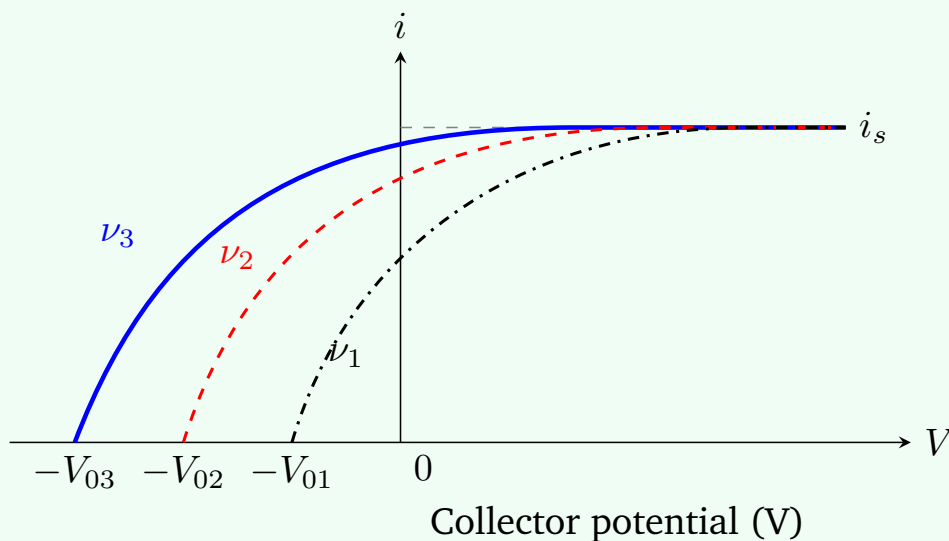
Solution:

Concept:

- The stopping potential magnitude V_0 is determined by Einstein's equation $eV_0 = h\nu - \phi$, where ν is the incident frequency and ϕ is the metal's work function. Assume all three frequencies exceed the threshold frequency.
- In the standard photoelectric-current graphs, saturation current is set by incident intensity, while stopping potential is set by frequency. A negative collector potential retards photoelectrons; a sufficiently positive potential collects all emitted electrons.

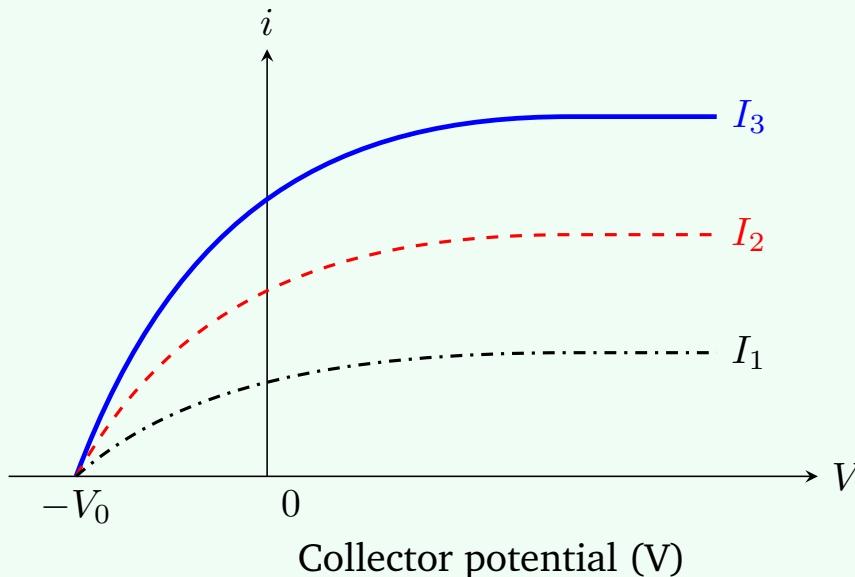
Step 1: Keep intensity fixed and vary frequency For $\nu_1 < \nu_2 < \nu_3$, the maximum kinetic energies and hence the stopping-potential magnitudes obey $V_{01} < V_{02} < V_{03}$. The intercepts on the negative-

potential axis are consequently ordered $-V_{03} < -V_{02} < -V_{01}$. Draw the three curves approaching the same saturation-current level, since the intensity is the same. The curve for the highest frequency starts furthest to the left.



Same intensity, different frequencies: equal saturation currents and different stopping potentials.

Step 2: Keep frequency fixed and vary intensity For incident intensities $I_1 < I_2 < I_3$, the emission rate increases with intensity, so the saturation currents obey $i_{s1} < i_{s2} < i_{s3}$. All three curves have the same negative-potential intercept $-V_0$, because the maximum energy $h\nu - \phi$ is unchanged. Distinguish incident intensity I from the measured photoelectric current i on the vertical axis.



Same frequency, different intensities: one stopping potential and increasing saturation currents.

Step 3: Conclusion At fixed intensity, increasing frequency moves the stopping intercept left while the saturation level remains the same. At fixed frequency, increasing intensity raises the saturation level while the stopping intercept remains fixed.

Quick Tip to Solve: Check two features of each graph: frequency changes the negative-axis intercept; intensity changes the positive-voltage plateau.

Section B (24 marks)

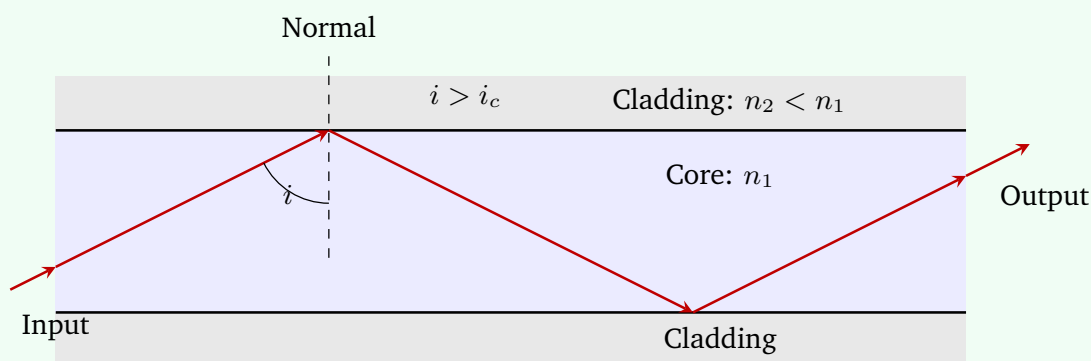
4. Explain with the help of a suitable diagram, the phenomenon on which an optical fibre works. Mention any two uses of optical fibres. [3 marks]

Solution:

Concept:

- Total internal reflection (TIR) is the complete reflection of a light ray back into the optically denser medium at its boundary with a rarer medium.
- TIR requires light to travel from refractive index n_1 to $n_2 < n_1$, with incidence angle i greater than the critical angle i_c . Angles are measured from the normal, and $\sin i_c = n_2/n_1$.

Step 1: Explain the construction and guiding of light An optical fibre has a thin transparent core of refractive index n_1 , surrounded by cladding of slightly lower refractive index n_2 . Light entering the core at a suitable angle strikes the core–cladding boundary with $i > i_c$. It is therefore totally internally reflected back into the core instead of refracting into the cladding. Repeated total internal reflections at successive points guide the light along the fibre, as shown below. The ray arrows show energy travelling from the input end towards the output end; the dashed line is the normal at a reflection point.



Repeated total internal reflection guides light through the higher-index core.

Step 2: State two applications **Optical communication:** Fibres carry light pulses encoding telephone or internet data over long distances with low loss and large information capacity.

Medical endoscopy: Fibre bundles transmit illumination into internal organs and carry the image back to the observer, allowing examination of regions that cannot be viewed directly from outside the body.

Step 3: Conclusion An optical fibre works by repeated total internal reflection at a core–cladding boundary, where $n_1 > n_2$ and $i > i_c$. Two uses are optical communication and medical endoscopy.

Quick Tip to Solve: In an optical-fibre sketch, label the higher-index core, lower-index cladding and normal; measure the incidence angle from the normal, not the fibre wall.

5. Ultra-violet light of wavelength 200 nm from a source is incident on a metal surface. If the stopping potential is -2.5 V , (a) calculate the work function of the metal, and (b) How would the surface respond to a high intensity red light of wavelength $6328\text{ \AA}$ produced by a laser? [3 marks]

Solution:

Concept:

- Einstein's photoelectric equation is $h\nu = \phi + K_{\max}$, where ϕ is the metal's work function and $K_{\max}$ is the maximum kinetic energy of the emitted electrons.
- The stopping potential is retarding. Its magnitude gives $K_{\max} = e|V_s|$; photon energy is $E = hc/\lambda$, and emission requires $E \geq \phi$.

Step 1: Calculate the ultraviolet photon energy Convert the wavelength to SI units: $200\text{ nm} = 2.00 \times 10^{-7}\text{ m}$. Taking $h = 6.63 \times 10^{-34}\text{ J s}$, $c = 3.00 \times 10^8\text{ m s}^{-1}$ and $e = 1.60 \times 10^{-19}\text{ C}$, the incident photon energy is

$$E_{\text{UV}} = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{2.00 \times 10^{-7}} = 9.945 \times 10^{-19}\text{ J} \simeq 6.22\text{ eV}.$$

Step 2: Determine the work function for part (a) The negative sign of -2.5 V indicates a retarding potential; it does not mean that kinetic energy is negative. Thus

$$K_{\max} = e(2.5\text{ V}) = 4.00 \times 10^{-19}\text{ J} = 2.5\text{ eV}.$$

Subtract this energy from the photon energy using Einstein's equation:

$$\phi = E_{\text{UV}} - K_{\max} = (9.945 - 4.00) \times 10^{-19}\text{ J} = 5.945 \times 10^{-19}\text{ J} \simeq 3.72\text{ eV}.$$

Step 3: Compare the red photon energy with the work function for part (b) For the laser, $6328\text{ \AA} = 6.328 \times 10^{-7}\text{ m}$. Hence

$$E_{\text{red}} = \frac{hc}{\lambda_{\text{red}}} = \frac{1.989 \times 10^{-25}}{6.328 \times 10^{-7}} \simeq 3.14 \times 10^{-19}\text{ J} = 1.96\text{ eV}.$$

Each red photon therefore has less energy than the work function. In the photoelectric model, one electron absorbs the energy of one photon; increasing intensity increases the number of photons incident per second, but not the energy of each photon. It cannot overcome the frequency threshold for emission.

Step 4: Conclusion (a) The work function is approximately $5.94 \times 10^{-19}\text{ J}$, or 3.7 eV . (b) The red laser produces no photoelectric emission, even at high intensity, because its photon energy 1.96 eV is below the work function.

Quick Tip to Solve: Use the magnitude of a negative stopping potential in $K_{\max} = e|V_s|$. Then compare photon energy with the work function before considering intensity.

- 6(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:

- In single-slit diffraction, dark fringes satisfy $a \sin \theta = n\lambda$, where a is the slit width, λ is the wavelength and $n = 1, 2, \dots$
- For a distant screen and small diffraction angles, $y = D \tan \theta \simeq D \sin \theta$, where D is the slit-to-screen distance and y is measured from the central maximum.
- Secondary maxima lie approximately midway between successive minima. The second secondary maximum is between the second and third minima, so its approximate position is $y = 5\lambda D/(2a)$.

Step 1: Express the data in SI units The wavelength, slit width and screen distance are

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

First calculate the useful diffraction length scale:

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

Since $\lambda/a = 0.003$, the angles of the first few fringes are small, as required by the screen-position approximation.

Step 2: Locate the first minimum For part (i), put $n = 1$ in the minimum condition. The waves from corresponding points in the two halves of the slit cancel at this angle. Hence the distance from the central maximum is

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

Step 3: Locate the second secondary maximum For part (ii), use the standard approximate position of a secondary bright fringe. The first secondary maximum lies near $3\lambda D/(2a)$; therefore the second lies near $5\lambda D/(2a)$:

$$y_{\max,2} \simeq \frac{5}{2} \frac{\lambda D}{a} = \frac{5}{2} \times 3.0 \text{ mm} = 7.5 \text{ mm}.$$

This midpoint rule is an approximation for secondary maxima, whereas the minima follow the exact angular zero-intensity condition. The pattern is symmetric, so equal distances occur on either side of the centre.

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

Quick Tip to Solve: Calculate $\lambda D/a$ once: multiply it by 1 for the first minimum and by $5/2$ for the second secondary maximum. Convert both wavelength and slit width to metres first.

6(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:

- (i) the ratio of their powers, and
(ii) 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 as $P = 1/f = (\mu - 1)(1/R_1 - 1/R_2)$, where μ is the lens refractive index and R_1, R_2 are the signed surface radii.
- Taking light to travel from left to right, a surface radius is positive when its centre of curvature is to the right of the surface. Positive power denotes a converging lens and negative power a diverging lens.
- The equivalent power of thin lenses in contact is the algebraic sum $P = P_1 + P_2$. Power is in dioptres when the radii and focal lengths are in metres.

Step 1: Find the individual lens powers Let $R > 0$ denote the common magnitude of the radii. For the equiconvex lens, the first surface has $R_1 = +R$ and the second has $R_2 = -R$. Thus

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

For the equiconcave lens, the signs are reversed: $R_1 = -R$ and $R_2 = +R$. Therefore

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

These opposite signs express the converging and diverging actions of the respective lenses in air.

Step 2: Form the ratio of powers For part (i), divide the convex lens power by the concave lens power. The common factor $2/R$ cancels, while the negative sign must be retained:

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

Equivalently, the signed ratio is $P_1 : P_2 = (\mu_1 - 1) : -(\mu_2 - 1)$. The ratio of magnitudes alone would omit the minus sign and would not describe the opposite optical actions.

Step 3: Add the powers and identify the combination For part (ii), the lenses are thin and in contact, so their powers add algebraically:

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

The given inequality $\mu_2 > \mu_1$ makes this power negative. The concave lens has the larger power magnitude, so the combination acts as a diverging lens. Its equivalent focal length is $f = R/[2(\mu_1 - \mu_2)] < 0$.

Step 4: Conclusion $\frac{P_1}{P_2} = -\frac{\mu_1 - 1}{\mu_2 - 1}$, and $P = \frac{2(\mu_1 - \mu_2)}{R} < 0$. With R in metres, P is in dioptres. The combination is diverging.

Quick Tip to Solve: Assign $(+R, -R)$ to the convex lens and $(-R, +R)$ to the concave lens before substituting. Add signed powers; the larger refractive index gives the concave lens the stronger action here.

7(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 1.0×10^{11} Hz. Identify the radiation and mention its two uses. [3 marks]

Solution:

Concept:

- The frequency ν is fixed by the oscillating source. At a stationary interface the transmitted wave must oscillate at the same frequency as the incident wave.
- Wave speed, frequency and wavelength are related by $v = \nu\lambda$. In a medium of refractive index n , the speed is $v = c/n$, where c is the speed of light in vacuum.

Step 1: (i) Explain why the frequency remains unchanged The oscillating electric field of the incident light drives charges in the second medium at the incident frequency. Their response produces the refracted wave at the same frequency. Thus refraction at a stationary surface cannot change the time period fixed by the source: $\nu_1 = \nu_2 = \nu$. A change in frequency would also prevent the wave oscillations from matching continuously at the boundary.

Step 2: Relate the wavelength change to the change in speed The optical properties of the two media determine different propagation speeds. Since frequency remains constant, the wavelength adjusts according to

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

Therefore, on entering a medium of higher refractive index, light travels more slowly and its wavelength decreases; entering a lower-index medium produces the reverse change.

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

$$\lambda_0 = \frac{c}{\nu} = \frac{3.0 \times 10^8}{1.0 \times 10^{11}} = 3.0 \times 10^{-3} \text{ m} = 3.0 \text{ mm}.$$

This frequency lies in the **microwave** region of the electromagnetic spectrum. Two uses of microwaves are: (1) radar systems for detecting objects and measuring their range, using reflected microwave pulses; (2) satellite communication, in which microwaves carry information between ground stations and satellites.

Step 4: Conclusion The source fixes the frequency during refraction, while a change in speed changes the wavelength through $\lambda = v/\nu$. Radiation of frequency 1.0×10^{11} Hz is microwave radiation, used in radar and satellite communication.

Quick Tip to Solve: Keep frequency fixed when applying $v = \nu\lambda$ across a stationary interface. A vacuum wavelength of a few millimetres identifies the microwave region.

7(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 $\angle \delta = \angle i + \angle e - \angle A$.

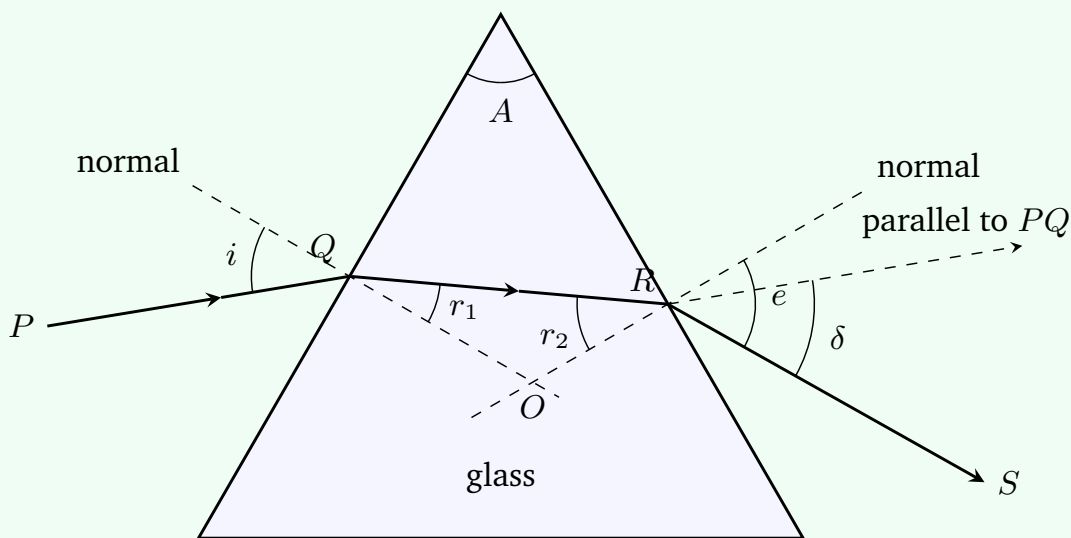
(ii) What will be the minimum value of δ if the ray passes symmetrically through the prism? [3 marks]

Solution:

Concept:

- Refraction occurs at both faces of a prism. The angles i, r_1, r_2, e are measured from the corresponding normals, where r_1, r_2 are the internal refraction angles.
- The prism geometry gives $r_1 + r_2 = A$, where A is the prism angle. The total deviation δ is the sum of the deviations at the two faces.
- For a prism in the same external medium on both sides, minimum deviation occurs for the symmetric path: $i = e$ and $r_1 = r_2 = A/2$.

Step 1: (i) Trace the refracted ray and mark the angles In the ray diagram, PQ is incident on the first face, QR travels through the glass, and RS emerges from the second face. At Q , the ray bends towards the normal; at R , it bends away from the normal. The dashed lines through Q and R are the normals. The additional dashed line through R , parallel to PQ , shows the original direction against which the deviation δ is measured.



Refraction through a prism; dashed normals intersect at O .

Step 2: Use the geometry inside the prism Let the two normals intersect at O . In the quadrilateral formed by the prism apex, Q , O and R , the angles at Q and R are right angles. Hence $\angle QOR = 180^\circ - A$. Applying the angle sum to triangle QOR ,

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

The deviation at the first surface is $i - r_1$, and that at the second surface is $e - r_2$. Both turn the ray towards the base of the prism, so their contributions add:

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

Step 3: (ii) Apply the condition for a symmetric path When the ray passes symmetrically through the prism, the internal angles are equal and therefore $r_1 = r_2 = A/2$. Snell's law at the two faces, with the same surrounding medium, then gives equal incidence and emergence angles, $i = e$. This is the minimum-deviation position. Substituting in the relation just obtained,

$$\delta_{\min} = i + i - A = 2i - A.$$

Here i is the angle of incidence in the symmetric position. No numerical value can be assigned without additional values for the prism angle and incidence angle (or refractive index).

Step 4: Conclusion The prism deviation is $\delta = i + e - A$. For symmetric passage, $i = e$, $r_1 = r_2 = A/2$, and the minimum deviation is $\delta_{\min} = 2i - A$.

Quick Tip to Solve: Measure all four refraction angles from the normals. Add the two surface deviations, then replace $r_1 + r_2$ by A ; use $i = e$ only at minimum deviation.

8. State the working principle of an LED. Write any two important advantages and two disadvantages of LED.

[3 marks]

Solution:

Concept:

- A light emitting diode (LED) is a heavily doped p-n junction that emits light when forward biased. Its principle is electroluminescence: electrical energy is converted into light by radiative electron-hole recombination.
- The photon energy is approximately the semiconductor band gap: $h\nu \simeq E_g$, or $\lambda \simeq hc/E_g$, where h is Planck's constant, c is the speed of light and E_g is the band-gap energy.

Step 1: Explain the working principle In forward bias, the junction barrier is reduced. Electrons from the n-region and holes from the p-region are injected across the junction. Near the junction, electrons recombine with holes and release energy. In a suitable direct-band-gap semiconductor, a substantial part of this energy emerges as photons rather than heat. Thus the forward current produces light; the band gap determines its approximate colour. Ordinary silicon diodes are poor light emitters because their recombination is mainly non-radiative.

Step 2: State two advantages (i) LEDs consume little electrical power and operate at low voltage, making them useful in battery-operated indicators. (ii) They have a long working life and are mechanically robust because they contain no delicate filament that must be heated until it glows.

Step 3: State two disadvantages (i) Their operation is temperature-sensitive: excessive junction temperature reduces light output and can damage the device, so heat dissipation must be controlled. (ii) LEDs tolerate only a small reverse voltage; an incorrectly applied reverse bias can cause breakdown and damage, so correct polarity and reverse-voltage protection are important.

Step 4: Conclusion An LED works by radiative electron-hole recombination in a forward-biased p-n junction. Two advantages are low power consumption and long working life; two disadvantages are temperature sensitivity and low reverse-voltage tolerance.

Quick Tip to Solve: Link forward bias to carrier injection and then to photon emission; state exactly two distinct advantages and two distinct disadvantages.

9. (a) Sketch the energy level diagram for hydrogen atom.

(b) Find the ratio of the longest and the shortest wavelength in Lyman series in hydrogen atom.

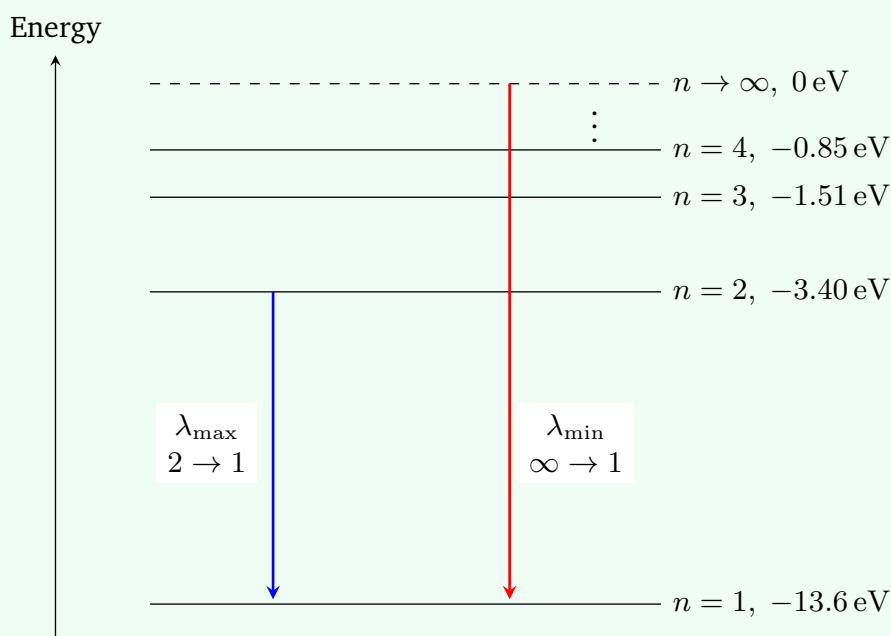
[3 marks]

Solution:

Concept:

- The allowed energies of hydrogen are $E_n = -13.6/n^2$ eV, where $n = 1, 2, \dots$ is the principal quantum number. The zero of energy is the ionisation limit $n \rightarrow \infty$.
- For emission, $hc/\lambda = E_i - E_f$. Lyman-series transitions end at $n_f = 1$, and the Rydberg formula is $1/\lambda = R_H(1 - 1/n_i^2)$, with $n_i \geq 2$ and R_H the hydrogen Rydberg constant.

Step 1: (a) Draw the energy levels of hydrogen The ground state is $n = 1$, with energy -13.6 eV. The first three excited levels have energies $E_2 = -3.40$ eV, $E_3 = -1.51$ eV and $E_4 = -0.85$ eV. The levels become progressively closer together and approach 0 eV as $n \rightarrow \infty$. Negative energies indicate bound states. The sketch shows the longest-wavelength Lyman transition and the limiting transition producing the shortest wavelength.



Hydrogen energy levels and the two limiting Lyman transitions (level spacing schematic).

Step 2: (b) Identify the longest Lyman wavelength Since wavelength varies inversely with the emitted photon energy, the longest wavelength corresponds to the smallest energy gap ending at $n = 1$, namely $n_i = 2 \rightarrow 1$. Thus

$$\frac{1}{\lambda_{\max}} = R_H \left(1 - \frac{1}{4} \right) = \frac{3R_H}{4}, \quad \lambda_{\max} = \frac{4}{3R_H}.$$

Step 3: Obtain the shortest wavelength and form the ratio The largest Lyman energy gap is approached as the initial level tends to the ionisation limit, $n_i \rightarrow \infty$. Therefore

$$\frac{1}{\lambda_{\min}} = R_H(1 - 0) = R_H, \quad \lambda_{\min} = \frac{1}{R_H}.$$

Dividing in the requested order gives

$$\frac{\lambda_{\max}}{\lambda_{\min}} = \frac{4/(3R_H)}{1/R_H} = \frac{4}{3}.$$

The constant cancels, so the ratio is dimensionless. Its value exceeds unity, as required for longest wavelength divided by shortest wavelength.

Step 4: Conclusion The hydrogen energy levels obey $E_n = -13.6/n^2$ eV and converge to 0 eV. For the Lyman series, the ratio of longest to shortest wavelength is $\lambda_{\max} : \lambda_{\min} = 4 : 3$.

Quick Tip to Solve: First fix the final level at $n = 1$; the nearest upper level gives the longest wavelength, while the infinite upper level gives the shortest.

10. Find the two possible positions of an object kept in front of a lens of +5.0 D, so that the image formed in both cases is four times magnified. [3 marks]

Solution:

Concept:

- Lens power is $P = 1/f$, with f in metres. Positive power denotes a converging lens, whose focal length is positive in the Cartesian sign convention.
- For a thin lens, $1/f = 1/v - 1/u$ and linear magnification is $m = v/u$, where u and v are signed object and image distances from the optical centre. A real object in front of the lens has $u < 0$.
- Fourfold magnification means $|m| = 4$: an inverted real image has $m = -4$, whereas an erect virtual image has $m = +4$.

Step 1: Convert the given power into focal length Use the power in dioptres and then convert metres to centimetres:

$$f = \frac{1}{+5.0} \text{ m} = +0.20 \text{ m} = +20 \text{ cm}.$$

Both possible positions must be found with this same positive focal length; the image orientation determines the sign of magnification.

Step 2: Find the position for an inverted real image Here $m = -4$, so $v = -4u$. Substitution into the lens formula gives

$$\begin{aligned} \frac{1}{20} &= \frac{1}{-4u} - \frac{1}{u} = -\frac{5}{4u}, \\ u &= -25 \text{ cm}, \quad v = +100 \text{ cm}. \end{aligned}$$

The object lies between f and $2f$, as expected for a magnified real image. The positive image distance puts this image on the opposite side of the lens.

Step 3: Find the position for an erect virtual image Here $m = +4$, so $v = 4u$. Again apply the lens formula:

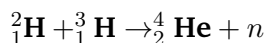
$$\begin{aligned} \frac{1}{20} &= \frac{1}{4u} - \frac{1}{u} = -\frac{3}{4u}, \\ u &= -15 \text{ cm}, \quad v = -60 \text{ cm}. \end{aligned}$$

This object lies within the focal length. The negative image distance places the erect virtual image on the object's side, consistent with $v/u = +4$.

Step 4: Conclusion The two object positions are 25 cm and 15 cm in front of the lens, i.e. $u = -25$ cm and $u = -15$ cm. They produce fourfold inverted real and erect virtual images, respectively.

Quick Tip to Solve: When only the magnitude of magnification is specified for a convex lens, solve with both signs: $m = -4$ and $m = +4$.

11. 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 positive Q-value: $Q = (m_{\text{initial}} - m_{\text{final}})c^2 = \Delta mc^2$, where Δm is the decrease in total rest mass.
- The mass-energy conversion is $1 \text{ u } c^2 \simeq 931.5 \text{ MeV}$. Thus a mass defect expressed in atomic mass units is multiplied by 931.5 to obtain energy in MeV.

Step 1: Add the masses of the reacting nuclei Deuterium and tritium fuse to produce helium and a neutron. Use both reactant masses supplied in the question:

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

The total mass number is $2 + 3 = 4 + 1$ and total charge number is $1 + 1 = 2 + 0$, so the written reaction conserves both nucleon number and charge.

Step 2: Add the product masses and obtain the mass defect Include the emitted neutron in the product mass; omitting it would greatly overestimate the energy released.

$$\begin{aligned} m_{\text{final}} &= (4.002603 + 1.008665) \text{ u} \\ &= 5.011268 \text{ u}, \\ \Delta m &= 5.030151 - 5.011268 \\ &= 0.018883 \text{ u}. \end{aligned}$$

The positive difference means that the products have less rest mass than the reactants. If the supplied values are treated as atomic masses, electron rest masses cancel: two hydrogen atoms and one helium

atom each account for two electrons in total.

Step 3: Convert the lost rest mass to released energy Apply mass-energy equivalence to the mass difference, keeping the unrounded difference until the final multiplication:

$$Q = 0.018883 \times 931.5 \text{ MeV} = 17.5895145 \text{ MeV}.$$

This is the energy released per fusion reaction, mainly as kinetic energy of the helium nucleus and neutron. A positive Q-value denotes an exothermic reaction, rather than energy that must be supplied as net reaction energy.

Step 4: Conclusion The energy released is $Q \simeq 17.59 \text{ MeV}$, or approximately 17.6 MeV , per reaction.

Quick Tip to Solve: Add all masses on each side before subtracting; in this fusion reaction the neutron must be included on the product side.

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_1S_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:

- Sustained interference requires coherent sources: the waves have equal frequencies and a constant phase difference.
- In $y = a \sin(\Omega t + \delta)$, the coefficient Ω of time is the angular frequency and δ is the initial phase. Equal amplitude alone does not establish coherence.

Step 1: Compare the angular frequencies The four waves have angular frequencies ω , 2ω , 2ω and 4ω , respectively. Only waves (ii) and (iii) share the same frequency. Their instantaneous phase difference is

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

which is constant, so their superposition can produce a stable interference pattern.

Step 2: Reject the other listed pairs Pair (i), (ii) in (A) has frequencies ω and 2ω ; pair (iii), (iv) in (C) has 2ω and 4ω ; pair (iv), (i) in (D) has 4ω and ω . In each of these pairs the phase difference changes with time, so they do not give sustained interference fringes. The fixed initial phase $\pi/2$ in wave (iv) cannot compensate for its different frequency.

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

Quick Tip to Solve: Compare coefficients of t before comparing initial phases: only the two $2\omega t$ waves have the same frequency here.

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 $\delta = 2\pi\Delta x/\lambda$, where λ is the wavelength.
- For two coherent waves, resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta$. Here each wave has intensity I_0 .

Step 1: Convert path difference to phase difference Substitute the given quarter-wavelength path difference:

$$\delta = \frac{2\pi}{\lambda} \frac{\lambda}{4} = \frac{\pi}{2}.$$

Thus the waves arrive in phase quadrature, with $\cos \delta = 0$. They are neither exactly in phase nor in opposite phase.

Step 2: Evaluate the resultant intensity Since $I_1 = I_2 = I_0$,

$$I = I_0 + I_0 + 2I_0 \cos \frac{\pi}{2} = 2I_0.$$

Option (A), zero, requires a phase difference of π ; option (D), $4I_0$, requires zero phase difference modulo 2π . Option (B), I_0 , also disagrees with the interference formula at $\pi/2$. Here only the

interference cross term vanishes, leaving the sum of the two individual intensities.

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

Quick Tip to Solve: A path difference of $\lambda/4$ gives 90° phase difference; the cosine term vanishes 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, fringe width is $\omega = \lambda D/d$, where λ is the wavelength, D the screen distance and d the slit separation.
- With the apparatus unchanged, fringe width is proportional to wavelength. Visible wavelengths increase from green to orange to red.

Step 1: Identify the wavelength order The wavelengths obey $\lambda_{\text{red}} > \lambda_{\text{orange}} > \lambda_{\text{green}}$. The widths $\omega_1, \omega_2, \omega_3$ correspond respectively to orange, green and red light, so their numerical subscripts are not the order of their wavelengths.

Step 2: Compare the given alternatives The common positive factor D/d preserves the wavelength ordering. Red therefore produces the widest fringes, orange intermediate fringes and green the narrowest. Options (A) and (C) incorrectly make green widest, while (B) incorrectly makes red narrowest. The printed option (D) alone follows the wavelength order.

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

Quick Tip to Solve: Write the colour beside each subscript before ranking widths; larger wavelength means larger fringe width for the same apparatus.

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 slit separation and D is screen distance.
- For the first bright fringe $n = 1$, so its distance from the centre equals the fringe width and $\lambda = y_1 d/D$. All lengths must use consistent units.

Step 1: Convert the given distances to SI units The first bright fringe corresponds to $n = 1$, not the central bright fringe $n = 0$. The given distances become

$$y_1 = 0.4 \times 10^{-3} \text{ m}, \quad d = 0.8 \times 10^{-3} \text{ m}, \quad D = 0.50 \text{ m}.$$

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

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

Since $1 \text{ nm} = 10^{-9} \text{ m}$, this is 640 nm. Options (A), (B) and (D) would predict first-fringe distances of 0.30, 0.35 and 0.425 mm, respectively, rather than the stated 0.4 mm.

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

Quick Tip to Solve: The first bright fringe lies one fringe width from the centre; use $\lambda = y_1 d/D$ after converting all three distances to metres.

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, angular fringe separation is $\Delta\theta = \beta/D = \lambda/d$. It is independent of the screen distance but inversely proportional to slit separation.

Step 1: Move the screen farther from the slits In operation (i), D increases while λ and d stay fixed. The linear spacing β increases in the same proportion as D ; hence the angular spacing β/D is unchanged. Confusing linear width with angular width gives an incorrect dependence on screen distance.

Step 2: Increase the slit separation In operation (ii), increasing d at fixed wavelength decreases λ/d , so angular fringe separation decreases while fringes remain observable. Option (A) overlooks this change. Options (B) and (D) incorrectly predict a decrease when the screen moves away. Only option (C) describes both operations correctly.

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

Quick Tip to Solve: Divide linear fringe width by the screen distance first: $\Delta\theta = \lambda/d$ immediately shows which changes affect angular spacing.