

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

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

- (i) This question paper contains **12** questions. **All** questions are compulsory.
- (ii) This question paper is divided into three sections – Section A, B and C.
- (iii) **Section A:** 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. 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]

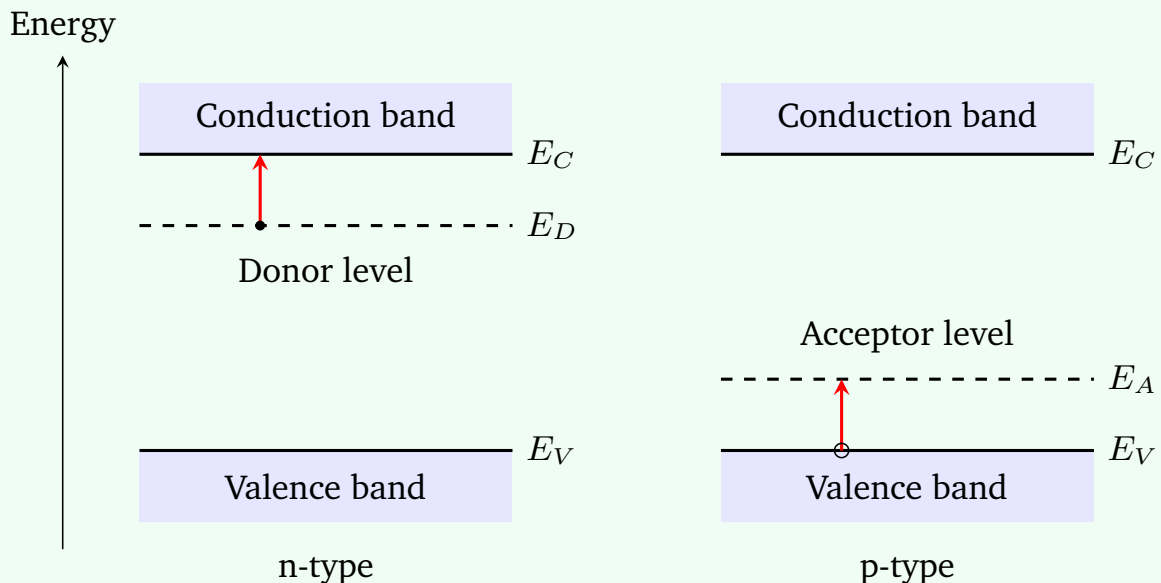
Solution:

Concept:

- The valence-band edge E_V and conduction-band edge E_C enclose the forbidden energy gap. Doping introduces permitted impurity levels within this gap.
- A donor level E_D lies just below E_C ; an acceptor level E_A lies just above E_V . Their small separation from the corresponding band makes thermal excitation possible at ordinary temperatures.

Step 1: Draw and interpret the n-type energy bands A pentavalent impurity contributes a weakly bound extra electron at the donor level. The small energy $E_C - E_D$ is sufficient to transfer this electron into the conduction band, leaving an immobile positive donor ion. Thus the donor level supplies mobile electrons without requiring excitation across the entire band gap. Electrons are the majority carriers in the usual extrinsic conduction range.

Step 2: Draw and interpret the p-type energy bands A trivalent impurity introduces an acceptor level that can receive an electron from the valence band. Only the small energy $E_A - E_V$ is needed for this transfer. It leaves a mobile hole in the valence band and an immobile negative acceptor ion. Holes are therefore the majority carriers in the usual extrinsic conduction range. At $T > 0$, thermal excitation can occur; this does not imply that all impurity atoms are ionised at every nonzero temperature.



Impurity energy levels at $T > 0$. Upward arrows denote electron excitation; energy spacings are schematic.

Step 3: Conclusion Donor levels just below the conduction band facilitate electron conduction in n-type material; acceptor levels just above the valence band facilitate hole conduction in p-type material. The diagrams show the relevant levels and the electron transitions.

Quick Tip to Solve: Remember: donors donate upward into the conduction band; acceptors accept upward from the valence band.

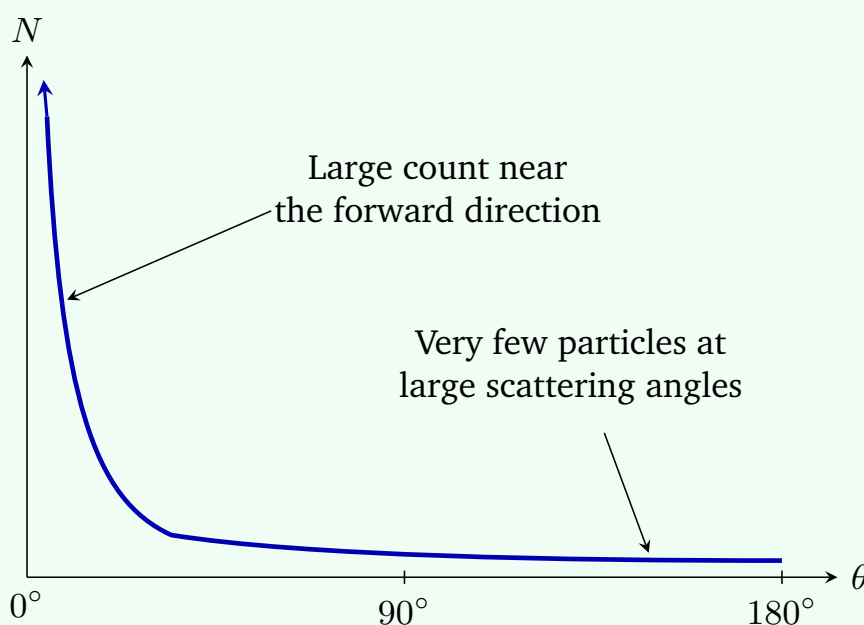
2(a). Draw the graph showing the variation of the number (N) of scattered alpha particles with scattering angle (θ) in Geiger-Marsden experiment. Infer two conclusions from the graph. [2 marks]

Solution:

Concept:

- In the Geiger–Marsden experiment, alpha particles incident on a thin metal foil are scattered by the electrostatic repulsion of the atom’s positive nucleus.
- For a detector subtending the same small solid angle at each angle, Rutherford scattering gives $N(\theta) \propto 1/\sin^4(\theta/2)$. Thus the count is very large near the forward direction and falls sharply as the scattering angle increases.

Step 1: Sketch the angular distribution Plot the number N of detected scattered alpha particles vertically and the scattering angle θ horizontally. The curve is sharply peaked near 0° , decreases rapidly, and has a very small but nonzero tail at large angles, including near 180° . The drawing is schematic: the ideal Rutherford expression diverges at exactly zero angle, where the directly transmitted beam and experimental angular resolution must also be considered.



Schematic Geiger–Marsden angular distribution. The large-angle count is small but nonzero; vertical scale is arbitrary.

Step 2: Infer the structure of the atom First, the overwhelming predominance of particles travelling straight through or with only small deflection shows that most of the atom is empty space. Second, the very small number of particles deflected through large angles or scattered backwards shows that strong repulsion occurs only in a tiny central region. The positive charge and practically the entire atomic mass are concentrated in this small, dense nucleus, which can reverse the motion of an energetic alpha particle.

Step 3: Conclusion The scattering count decreases steeply with increasing angle. Its dominant forward peak implies that the atom is mostly empty space, while the rare large-angle events imply a small, dense, positively charged nucleus.

Quick Tip to Solve: Link the large forward count to empty space and the rare backward events to the compact positive nucleus; keep the large-angle tail above zero.

2(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 ($I_1 < I_2 < I_3$)

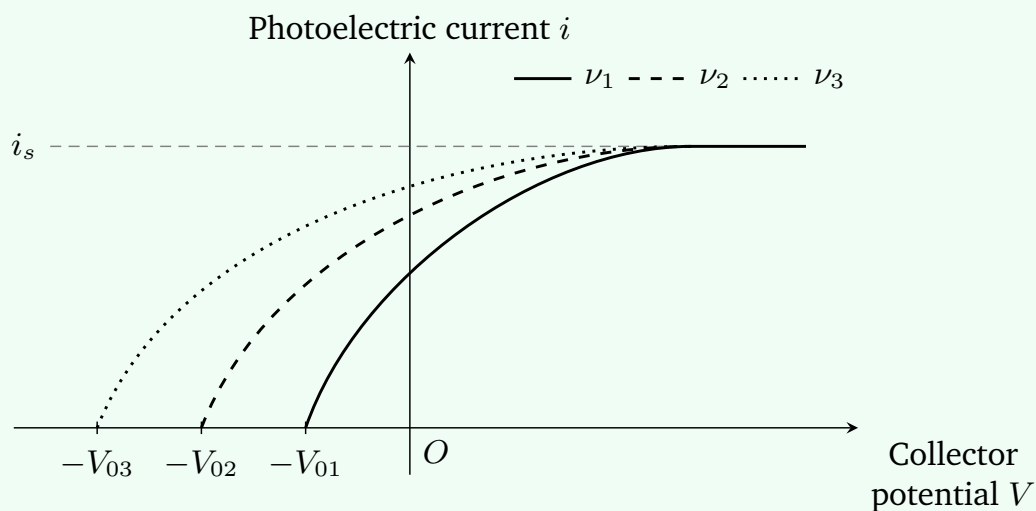
[2 marks]

Solution:

Concept:

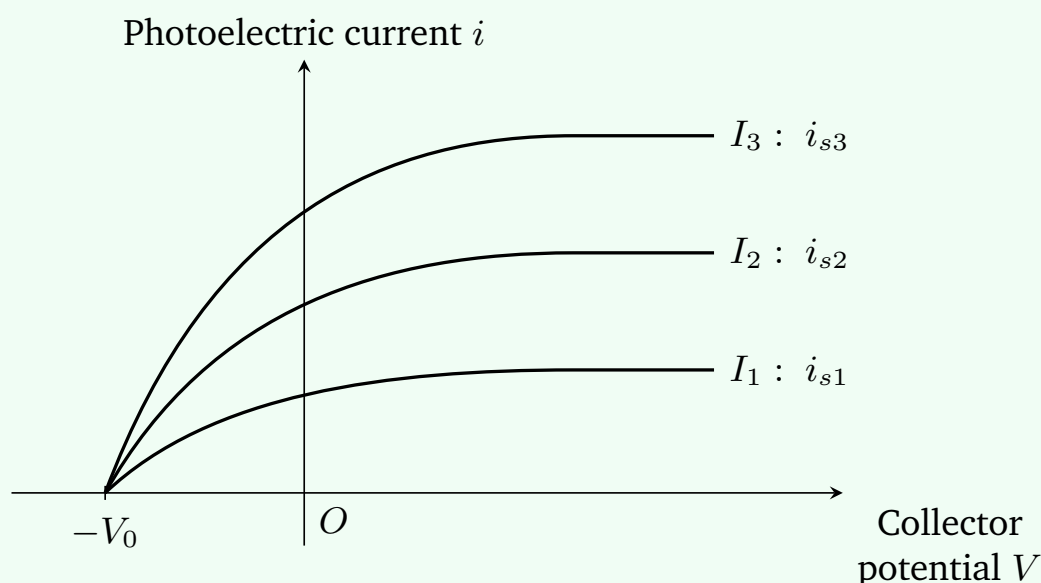
- The stopping potential magnitude V_0 satisfies $eV_0 = K_{\max} = h\nu - \phi$, where e is the elementary charge, h is Planck's constant and ϕ is the emitter's work function. The current becomes zero at collector potential $-V_0$.
- In the standard photoelectric characteristic, saturation current increases with incident intensity, whereas stopping potential depends on frequency. Assume all three frequencies exceed the threshold frequency of the emitter.

Step 1: (i) Keep intensity fixed and vary frequency Draw the three curves with the same saturation-current level. Increasing frequency increases the maximum kinetic energy, so a larger retarding potential is needed to stop even the fastest electrons. Thus $V_{01} < V_{02} < V_{03}$: the zero-current intercept for ν_3 lies farthest to the left. The negative sign on each intercept is essential because the collector must be negative relative to the emitter to stop the photoelectrons.



Same intensity: $\nu_1 < \nu_2 < \nu_3$; common saturation current.

Step 2: (ii) Keep frequency fixed and vary intensity Increasing intensity at fixed frequency increases the rate of photoelectron emission and hence the saturation current. It does not change the maximum kinetic energy of an emitted electron, so all three curves have the same negative stopping-potential intercept. For $I_1 < I_2 < I_3$, draw successively higher plateaus: $i_{s1} < i_{s2} < i_{s3}$. A sufficiently positive collector collects essentially all emitted photoelectrons, giving each plateau.



Same frequency: $I_1 < I_2 < I_3$; common stopping potential.

Step 3: Conclusion At fixed intensity, the graphs have a common saturation current and different stopping potentials. At fixed frequency, they have different saturation currents and a common stopping potential, as shown.

Quick Tip to Solve: Frequency moves the stopping intercept; intensity changes the saturation height. Always mark stopping potential on the negative side of the voltage axis.

3. Write the characteristics of a p-n junction which make it suitable for rectification.

[2 marks]

Solution:

Concept:

- Rectification converts an alternating input into a unidirectional output. It requires a device that conducts readily for one polarity of applied voltage and offers very high resistance for the opposite polarity.
- A p-n junction has an asymmetric current-voltage characteristic: forward bias lowers the junction potential barrier, while reverse bias raises it and widens the depletion region.

Step 1: Conduction in forward bias When the p-side is connected to the positive terminal and the n-side to the negative terminal, the diode is forward biased. Once the applied voltage is sufficient for appreciable conduction, the reduced barrier allows majority carriers to cross the junction. A substantial current flows, so the junction offers low forward resistance and passes the corresponding half-cycle of an alternating input.

Step 2: Blocking in reverse bias With the supply polarity reversed, the depletion region widens and the barrier increases. The diode offers very high reverse resistance; only a small reverse saturation current due to minority carriers flows, provided the reverse voltage is below breakdown. It therefore substantially blocks current during the opposite half-cycle. The resulting load current flows in one direction, although it may vary in magnitude and remain pulsating.

Step 3: Conclusion A p-n junction is suitable for rectification because it has low resistance in forward bias and very high resistance in reverse bias, giving effectively one-way conduction within its normal operating range.

Quick Tip to Solve: State both contrasting resistance properties and connect them to passing one polarity and blocking the other; a rectifier's output can still be pulsating.

Section B (24 marks)

4. 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:

- An α -particle has charge $+2e$, while a nucleus of atomic number Z has charge $+Ze$. Their electrostatic interaction is repulsive.
- For a head-on approach to a heavy nucleus, conservation of mechanical energy relates the incident kinetic energy K to electrostatic potential energy at the turning point. Take potential energy to be zero at infinity and neglect nuclear recoil.

Step 1: Define the distance of closest approach The distance of closest approach r_0 is the minimum separation between the centre of the nucleus and an incident α -particle in a head-on collision. As the particle approaches, electrostatic repulsion slows it down. At the closest point, it momentarily comes to rest and then reverses its motion. Thus its initial kinetic energy is completely converted into electrostatic potential energy.

Step 2: Obtain its dependence on incident energy If ϵ_0 is the permittivity of free space and e is the elementary charge, energy conservation gives

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

For the same nucleus and the same particle charge, all factors other than K are fixed, so $r_0 \propto 1/K$.

Step 3: Compare the two incident energies Write the new energy as $K' = 2K$ and the new closest separation as r'_0 . Taking the ratio eliminates the nuclear charge and electrostatic constant:

$$\frac{r'_0}{r_0} = \frac{K}{K'} = \frac{K}{2K} = \frac{1}{2}.$$

A more energetic particle can approach more closely because it can gain more electrostatic potential energy before stopping. Doubling energy must therefore decrease, rather than increase, the turning-point separation.

Step 4: Conclusion The distance of closest approach is the minimum nucleus–particle separation in a head-on encounter. When the α -particle's kinetic energy is doubled, this distance is halved:

$$r'_0 = r_0/2.$$

Quick Tip to Solve: For the same nucleus, use $Kr_0 = \text{constant}$; compare kinetic energies directly, without first calculating the particle's speed.

5. A point source in air is kept 24 cm in front of a concave spherical glass surface (${}_a\mu_g = 1.5$) and radius of curvature 60 cm. Find the nature of the image formed and its distance from the point source. [3 marks]

Solution:

Concept:

- For paraxial refraction at a spherical surface, $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$, where u and v are the signed object and image distances from the pole, and R is the signed radius of curvature.
- In the Cartesian sign convention, take the incident light direction as positive. A negative image distance places the image on the incident side; the backward extensions of refracted rays meet there to form a virtual image.

Step 1: Assign signs to the given distances Let light travel from the source in air towards the glass in the positive direction, with the pole at the origin. The source is in front of the surface, so $u = -24$ cm. Since the surface is concave as viewed from the incident air side, its centre of curvature also lies on that side, giving $R = -60$ cm. The refractive indices are $n_1 = 1$ for air and $n_2 = 1.5$ for glass.

Step 2: Apply refraction at the spherical surface Substituting these signed quantities in the refraction formula gives

$$\begin{aligned}\frac{1.5}{v} - \frac{1}{-24} &= \frac{1.5 - 1}{-60}, \\ \frac{1.5}{v} + \frac{1}{24} &= -\frac{1}{120}, \\ \frac{1.5}{v} &= -\frac{1}{120} - \frac{5}{120} = -\frac{1}{20}, \\ v &= -30 \text{ cm}.\end{aligned}$$

All distances in this substitution are in centimetres. The negative sign locates the image in air, on the same side of the surface as the source. Thus the emergent refracted rays diverge, and their backward extensions intersect at the image position.

Step 3: Measure the distance from the source The source and image coordinates are -24 cm and -30 cm, respectively. Their separation is the absolute difference, not the sum of their distances from the pole:

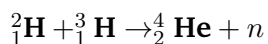
$$d = |v - u| = |-30 - (-24)| = 6 \text{ cm}.$$

The image lies farther from the surface than the source does. The value 30 cm is the image distance from the surface and must not be mistaken for the requested distance from the point source.

Step 4: Conclusion The image is virtual, located 30 cm in front of the glass surface. Its distance from the point source is 6 cm, farther into the air away from the surface.

Quick Tip to Solve: For a concave refracting surface viewed from air, set $R < 0$; when source and image lie on the same side, use $|v - u|$ for their separation.

6. 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.
- Use $1 \text{ u} c^2 = 931.5 \text{ MeV}$ to convert a mass difference in atomic mass units directly into energy. A positive Q-value means that energy is released.

Step 1: Add the reactant masses One deuterium nucleus and one tritium nucleus fuse. Their total initial mass, using the supplied values, is

$$m_i = 2.014102 + 3.016049 = 5.030151 \text{ u}.$$

The supplied atomic masses may be used consistently because the two hydrogen atoms together contain two electrons and the helium atom also contains two electrons; the electron rest masses cancel in the mass difference.

Step 2: Add all product masses and find the mass loss Both the helium nucleus and the emitted neutron must be included on the product side. Thus

$$m_f = 4.002603 + 1.008665 = 5.011268 \text{ u}.$$

The decrease of rest mass is

$$\Delta m = m_i - m_f = 5.030151 - 5.011268 = 0.018883 \text{ u}.$$

Since the final rest mass is smaller, the reaction releases energy, principally as kinetic energy of the products.

Step 3: Convert the mass difference into MeV Applying mass-energy equivalence gives

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

Keeping the mass difference unrounded until this multiplication avoids unnecessary loss of accuracy.

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

Quick Tip to Solve: Include the neutron in the final mass sum, then multiply the initial-minus-final mass difference in u by 931.5 to obtain MeV directly.

7. 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]

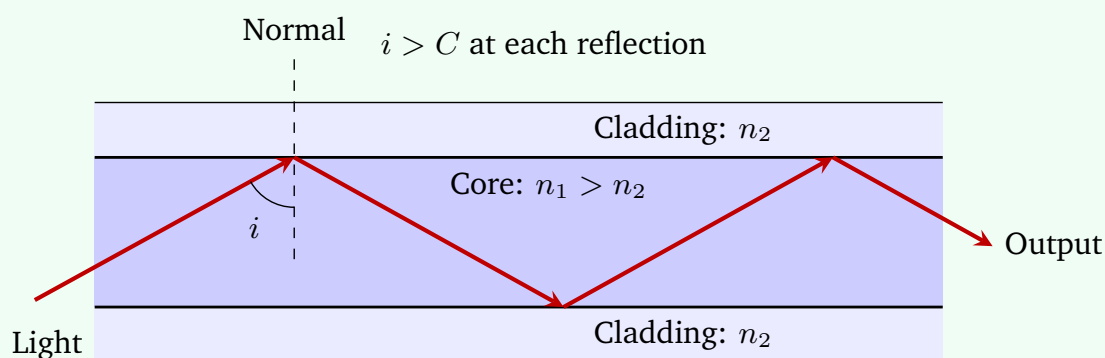
Solution:

Concept:

- An optical fibre guides light by repeated total internal reflection at the boundary between its transparent core and surrounding cladding.
- Total internal reflection requires light to travel from an optically denser medium to a rarer medium, with incidence angle i greater than the critical angle C . Angles are measured from the normal to the boundary.
- For core refractive index n_1 and cladding refractive index n_2 , $n_1 > n_2$ and $\sin C = n_2/n_1$.

Step 1: Explain total internal reflection Consider a ray travelling from the core towards the cladding. As its incidence angle increases, the refracted ray bends farther away from the normal. At the critical angle C , the refracted ray grazes the boundary. For $i > C$, there is no propagating refracted ray into the cladding: the light is reflected back into the core. This is total internal reflection.

Step 2: Apply the phenomenon to an optical fibre An optical fibre is a thin transparent strand with a core of higher refractive index surrounded by cladding of lower refractive index. Light entering at a suitable angle strikes the core-cladding boundary with $i > C$. It undergoes successive total internal reflections, as shown by the ray path, and travels along the fibre to its other end with little loss. The cladding maintains the required refractive-index boundary. Gentle bending can guide light around a curve provided the total-internal-reflection condition continues to hold.



Repeated total internal reflection in an optical fibre (schematic).

Step 3: State two applications **Communication:** Optical fibres carry light pulses encoding telephone and internet data over long distances with low attenuation.

Medical endoscopy: Fibre bundles carry light into internal organs and transmit an image back, enabling doctors to inspect otherwise inaccessible regions of the body.

Step 4: Conclusion Optical fibres work by repeated total internal reflection, requiring $n_1 > n_2$ and $i > C$ at the core-cladding interface. Two uses are optical communication and medical endoscopy.

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

8(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 single-slit diffraction, destructive interference gives minima at $a \sin \theta = n\lambda$, where a is the slit width, λ the wavelength and $n = 1, 2, \dots$
- At small angles, the distance from the central maximum is $y = D \tan \theta \simeq D \sin \theta$, with D the screen distance. Secondary maxima lie approximately halfway between adjacent minima.

Step 1: Convert the data and identify the scale Express all lengths in metres before substituting:

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

The characteristic distance between adjacent minima on the same side is

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

Here $\lambda/a = 0.003 \ll 1$, so the small-angle approximation is appropriate for the requested positions.

Step 2: Locate the first minimum For the first minimum, $n = 1$, so the path difference between light from the extreme edges of the slit is one wavelength. Pairing corresponding points in the two halves of the slit gives cancellation. Its distance 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 Count secondary maxima outward from the central maximum. The first lies between the first and second minima; the second lies between the second and third minima. Using the standard approximate midpoint condition $a \sin \theta \simeq 5\lambda/2$,

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

The midpoint rule is an approximation for diffraction maxima, whereas $a \sin \theta = n\lambda$ gives the minimum condition. The pattern is symmetric, so matching positions occur on both sides of the centre.

Step 4: Conclusion The distances from the central maximum are (i) 3.0 mm for the first minimum and (ii) approximately 7.5 mm for the second secondary maximum.

Quick Tip to Solve: First compute $\lambda D/a$. Multiply it by 1 for the first minimum and by $5/2$ for the second secondary maximum; do not count the central peak as a secondary maximum.

8(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:

- The lens-maker formula for a thin lens in air is $P = 1/f = (\mu - 1)(1/R_1 - 1/R_2)$. Here μ is the refractive index and R_1, R_2 are signed radii of the first and second surfaces.
- For thin lenses in contact, powers add algebraically: $P_{eq} = P_1 + P_2$. A positive power converges light, while a negative power diverges it. Power is in dioptres when radii and focal lengths are in metres.

Step 1: Assign signs and calculate each lens power Let light travel from left to right and let $R > 0$ denote the common radius magnitude. For the equiconvex lens, the centres of curvature give $R_1 = +R$ and $R_2 = -R$. Therefore,

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

For the equiconcave lens the signs reverse: $R_1 = -R, R_2 = +R$. Its power is

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

Step 2: Form the requested ratio Divide the convex-lens power by the concave-lens power; the common factor $2/R$ cancels:

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

The ratio is signed; its minus sign records the opposite optical effects of the two lenses.

Step 3: Add the powers and determine the nature Since the lenses are thin and in contact, their equivalent power is

$$\begin{aligned} P_{eq} &= \frac{2(\mu_1 - 1)}{R} - \frac{2(\mu_2 - 1)}{R} \\ &= \frac{2(\mu_1 - \mu_2)}{R}. \end{aligned}$$

The given inequality $\mu_2 > \mu_1$ makes the numerator negative. Hence the concave lens has the larger power magnitude and the combination diverges an initially parallel beam.

Step 4: Conclusion (i) $P_1/P_2 = -(\mu_1 - 1)/(\mu_2 - 1)$. (ii) $P_{eq} = 2(\mu_1 - \mu_2)/R$, in dioptres for R in metres. The combination is **diverging**.

Quick Tip to Solve: Keep the concave lens power negative before adding. Equal radius magnitudes cancel the geometric factor in the ratio, and the larger refractive index makes the concave lens dominate here.

9. Photoelectrons are emitted from a metal surface when illuminated with UV light of wavelength 330 nm. The minimum amount of energy required to emit the electrons from the surface is 3.5×10^{-19} J. Calculate:

- (i) the energy of the incident radiation, and
(ii) the kinetic energy of the photoelectron.

[3 marks]

Solution:

Concept:

- A photon of frequency ν and wavelength λ carries energy $E = h\nu = hc/\lambda$, where h is Planck's constant and c is the speed of light.
- The work function ϕ is the minimum energy needed to liberate an electron from the metal. Einstein's photoelectric equation is $K_{\max} = E - \phi$, where $K_{\max}$ is the maximum kinetic energy of an emitted electron.

Step 1: Express the data in SI units The incident wavelength and the work function are

$$\lambda = 330 \text{ nm} = 3.30 \times 10^{-7} \text{ m}, \quad \phi = 3.5 \times 10^{-19} \text{ J}.$$

Use $h = 6.63 \times 10^{-34} \text{ J s}$ and $c = 3.00 \times 10^8 \text{ m s}^{-1}$. The specified minimum emission energy is the work function; it is not the kinetic energy of the electron.

Step 2: (i) Calculate the incident photon energy Substitute the wavelength into the photon-energy relation:

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{3.30 \times 10^{-7}} = 6.03 \times 10^{-19} \text{ J}.$$

Here the energy of the incident radiation means the energy per photon. It exceeds the work function, so the radiation can produce photoelectric emission.

Step 3: (ii) Apply conservation of energy to the electron Part of the absorbed photon energy is used in overcoming the work function. The remaining energy gives the maximum kinetic energy:

$$\begin{aligned} K_{\max} &= E - \phi \\ &= (6.03 - 3.50) \times 10^{-19} \\ &= 2.53 \times 10^{-19} \text{ J}. \end{aligned}$$

The result is positive, as expected for emission. Electrons that lose energy before escaping can emerge with smaller kinetic energies; Einstein's equation gives the maximum value sought here.

Step 4: Conclusion (i) The incident energy per photon is $6.03 \times 10^{-19} \text{ J}$. (ii) The photoelectron's maximum kinetic energy is $2.53 \times 10^{-19} \text{ J}$.

Quick Tip to Solve: Convert nanometres to metres before using hc/λ , then subtract the work function once to obtain $K_{\max}$.

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

[3 marks]

Solution:

Concept:

- An LED (light emitting diode) is a semiconductor p - n junction that emits light when it is forward biased. Its working principle is electroluminescence.
- In a suitable direct-band-gap semiconductor, electron-hole recombination releases energy as photons. Approximately $h\nu = E_g$, where E_g is the band gap, h is Planck's constant and ν is the emitted light frequency.

Step 1: Explain the working principle Under forward bias, electrons are injected from the n -side and holes from the p -side into the junction region. Electrons recombine with holes and release energy. In an LED material, a significant part of this energy appears as light rather than heat. Thus electrical energy is converted into light by radiative recombination. The semiconductor band gap determines the colour of the emitted light.

Step 2: State two advantages (1) Low power consumption: an LED requires relatively little electrical power to produce useful light, making it suitable for efficient indicators and displays.

(2) Long operating life: it has no fragile heated filament, so it offers a long service life and reliable operation when used within its rated current and temperature limits.

Step 3: State two disadvantages (1) Temperature sensitivity: excessive junction temperature reduces light output and can shorten the LED's life. High-power LEDs therefore require suitable heat removal.

(2) Low reverse-voltage tolerance: an LED can be damaged if a sufficiently large reverse voltage is applied. Correct polarity and, where necessary, reverse-voltage protection are therefore required.

Step 4: Conclusion An LED works by electroluminescence due to electron-hole recombination in a forward-biased junction. Its advantages include low power consumption and long life; its disadvantages include temperature sensitivity and low reverse-voltage tolerance.

Quick Tip to Solve: Link LED emission to forward bias and radiative recombination, then give two distinct benefits and two distinct practical limitations.

11(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 of a light wave is fixed by the oscillating source. At a stationary boundary, the transmitted wave must oscillate with the same frequency as the incident wave.
- Wave speed, frequency and wavelength satisfy $v = \nu\lambda$. In a medium of refractive index n , the speed is $v = c/n$, where c is the speed in vacuum.

Step 1: (i) Explain why the frequency is unchanged The incident wave drives the charges of the second medium at its own frequency. These charges produce the transmitted wave at that same frequency. Thus, crossing a stationary interface does not change the rate of oscillation: $\nu_2 = \nu_1$. A

change in frequency would also prevent the incident and transmitted oscillations from remaining matched at the boundary.

Step 2: Relate the wavelength change to the speed change Different optical media generally have different refractive indices and hence different speeds of light. Since the frequency stays 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, the wavelength decreases on entering an optically denser medium and increases on entering an optically rarer medium.

Step 3: (ii) Identify the radiation and give two uses For the given frequency, the 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 belongs to the microwave region of the electromagnetic spectrum. Two uses of microwaves are radar, in which reflected pulses locate objects and determine their range, and satellite communication, in which microwaves carry signals between ground stations and satellites.

Step 4: Conclusion (i) Frequency remains fixed by the source; wavelength changes because light travels at different speeds in the two media. (ii) The radiation is **microwave radiation**, used in radar and satellite communication.

Quick Tip to Solve: At a stationary interface keep frequency fixed and use $\lambda = v/\nu$; a wavelength of a few millimetres identifies the microwave region.

OR

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

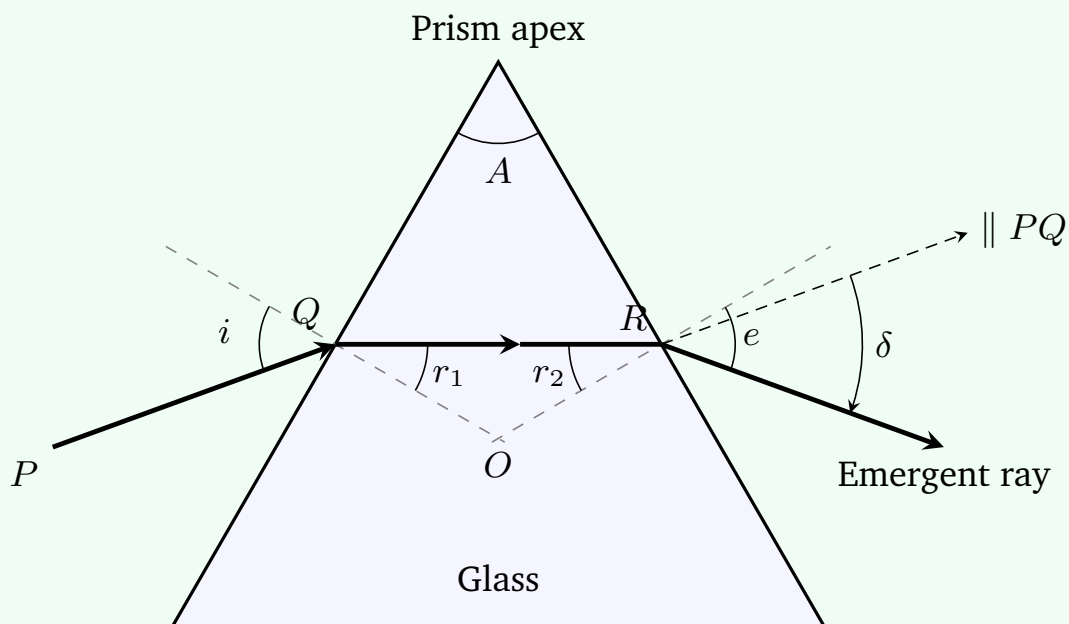
(ii) What will be the minimum value of δ if the ray passes symmetrically through the prism? [3 marks]

Solution:

Concept:

- Angles of incidence and refraction are measured from the normal to the relevant face. For a prism of angle A , the internal angles of refraction obey $r_1 + r_2 = A$.
- The deviation δ is the angle between the incident direction produced and the emergent direction. The deviations at successive refracting faces add.
- At minimum deviation the ray passes symmetrically through the prism: $i = e$ and $r_1 = r_2 = A/2$.

Step 1: (i) Trace the ray and label the angles Let PQ be incident on the first face at Q . Draw a normal there and label the incidence angle i . On entering glass from air the ray bends towards this normal, making angle r_1 with it, and travels along QR . At the second face, draw its normal through R . The internal incidence angle is r_2 ; the ray bends away from the normal on emergence and makes angle e with it. The dashed direction through R parallel to PQ lets us mark the total deviation δ at R .



Prism ray path; normals are dashed, and the reference direction through R is parallel to PQ.

Step 2: Relate the prism angle to the internal angles The two inward normals intersect at O. Since each normal is perpendicular to its prism face, their angle inside the quadrilateral formed with the prism apex is $180^\circ - A$. In triangle QOR, the other two angles are r_1 and r_2 . Hence

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

Step 3: Add the deviations at the two faces At entry the ray turns through $i - r_1$ towards the base of the prism. At exit it turns further towards the base through $e - r_2$. Both turns have the same sense, so

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

Step 4: (ii) Apply the condition for symmetric passage For the symmetric ray path, $i = e = i_m$ and $r_1 = r_2 = A/2$, where i_m denotes the incidence angle at minimum deviation. Substitution in the deviation relation gives

$$\delta_{\min} = 2i_m - A.$$

Equivalently, if μ is the refractive index of the glass relative to air, Snell's law gives $\sin i_m = \mu \sin(A/2)$, so

$$\delta_{\min} = 2 \sin^{-1}[\mu \sin(A/2)] - A.$$

No numerical value is determined because the prism angle and refractive index are not specified numerically.

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

Quick Tip to Solve: First use $r_1 + r_2 = A$, then add the two turns. Set $i = e$ only when the path is symmetric and the deviation is minimum.

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:

- A stable interference pattern requires coherent sources: the waves must have the same frequency and a constant phase difference.
- In $y = a \sin(\Omega t + \alpha)$, a is amplitude, Ω is angular frequency and α is the initial phase.

Step 1: Compare the angular frequencies The coefficients of t in the four phases are respectively ω , 2ω , 2ω and 4ω . Only waves (ii) and (iii) have the same angular frequency. Equal amplitudes alone do not guarantee coherence.

Step 2: Check the phase difference For waves (ii) and (iii), the phase difference is $(2\omega t + \phi) - 2\omega t = \phi$, a constant. For each pair in (A), (C) and (D), the frequencies differ, so its relative phase changes with time and cannot produce the stationary interference pattern intended here.

Step 3: Conclusion Waves (ii) and (iii) form the coherent pair. Hence, the correct option is (B).

Quick Tip to Solve: Compare the coefficients of time first; then subtract the phases to check that no time-dependent term remains.

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 phase difference $\delta = 2\pi\Delta x/\lambda$, where λ is the wavelength.
- Interference gives $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \delta$, where I_1 and I_2 are the individual intensities.

Step 1: Convert the path difference to phase The given path difference is one quarter of a wavelength. Therefore,

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

The two waves arrive in phase quadrature, not in phase or in opposite phase.

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

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

Zero and $4I_0$ correspond to complete destructive and constructive interference respectively. The value I_0 is only one wave's intensity and does not include the second wave's contribution here.

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

Quick Tip to Solve: For a quarter-wavelength path difference, the cosine interference term vanishes, so add the two individual intensities.

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:

- Young's double-slit fringe width is $\beta = \lambda D/d$, with wavelength λ , screen distance D and slit separation d .
- For an unchanged apparatus, fringe width is proportional to wavelength. Red light has a longer wavelength than orange light, which has a longer wavelength than green light.

Step 1: Associate each width with its colour The question assigns ω_1 to orange, ω_2 to green and ω_3 to

red. The same slit separation and screen distance apply in the successive observations, so the common factor D/d does not affect their ordering.

Step 2: Transfer the wavelength order to the widths Since $\lambda_{\text{red}} > \lambda_{\text{orange}} > \lambda_{\text{green}}$, the corresponding widths satisfy $\omega_3 > \omega_1 > \omega_2$. Options (A) and (C) wrongly place green first. Option (B) places red last, despite red having the largest wavelength.

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

Quick Tip to Solve: Write the colour beside each indexed width before ordering them: red widest, orange intermediate, green narrowest.

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 bright fringes in Young's experiment occur at $y_n = n\lambda D/d$, where n is fringe order, D is screen distance and d is slit separation.
- The first bright fringe next to the central maximum has $n = 1$, hence its distance from the centre is the fringe width $\beta = \lambda D/d$.

Step 1: Express the data in SI units Here $d = 0.8 \text{ mm} = 8 \times 10^{-4} \text{ m}$, $D = 50 \text{ cm} = 0.50 \text{ m}$, and $y_1 = 0.4 \text{ mm} = 4 \times 10^{-4} \text{ m}$. The central maximum is order zero, so the stated fringe is order one, not a first dark fringe.

Step 2: Calculate the wavelength Rearranging $y_1 = \lambda D/d$ gives

$$\lambda = \frac{y_1 d}{D} = \frac{(4 \times 10^{-4})(8 \times 10^{-4})}{0.50} \text{ m} = 6.4 \times 10^{-7} \text{ m} = 640 \text{ nm}.$$

Substituting the other proposed wavelengths gives first-bright distances 0.300, 0.350, and 0.425 mm, respectively; none equals the given 0.400 mm.

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

Quick Tip to Solve: For the first bright fringe use its distance directly as the fringe width, and convert both millimetre quantities to metres before multiplying.

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 separation is $\beta = \lambda D/d$, with wavelength λ , slit separation d and screen distance D .
- In the small-angle approximation, the angular fringe separation is $\Delta\theta = \beta/D = \lambda/d$; it is independent of the screen distance.

Step 1: Move the screen away Operation (i) increases D . Although the linear separation β increases in the same proportion, the angular separation β/D remains unchanged. Options (B) and (D) incorrectly predict a decrease when the screen is moved away.

Step 2: Increase the slit separation In operation (ii), increasing d while retaining the same light reduces λ/d . Thus the angular separation decreases while the fringes remain observable. Option (A) incorrectly treats the angular separation as independent of slit separation.

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

Quick Tip to Solve: Before changing any distances, distinguish linear width from angular width: divide the linear width by the screen distance to get λ/d .