

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/2/3



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

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

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

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

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

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

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

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

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

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

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

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

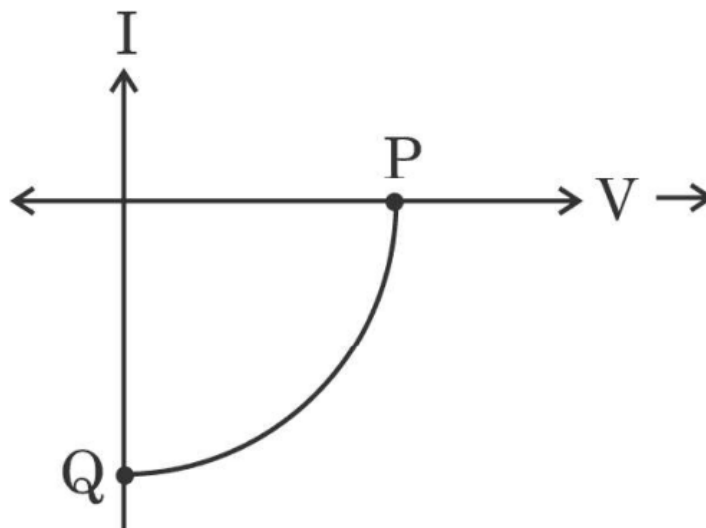
Section A (6 marks)

1. The $V - I$ characteristics of a solar cell is shown in the figure.

(a) What do the points P and Q represent?

(b) Give the circuit diagram for a solar cell.

[2 marks]



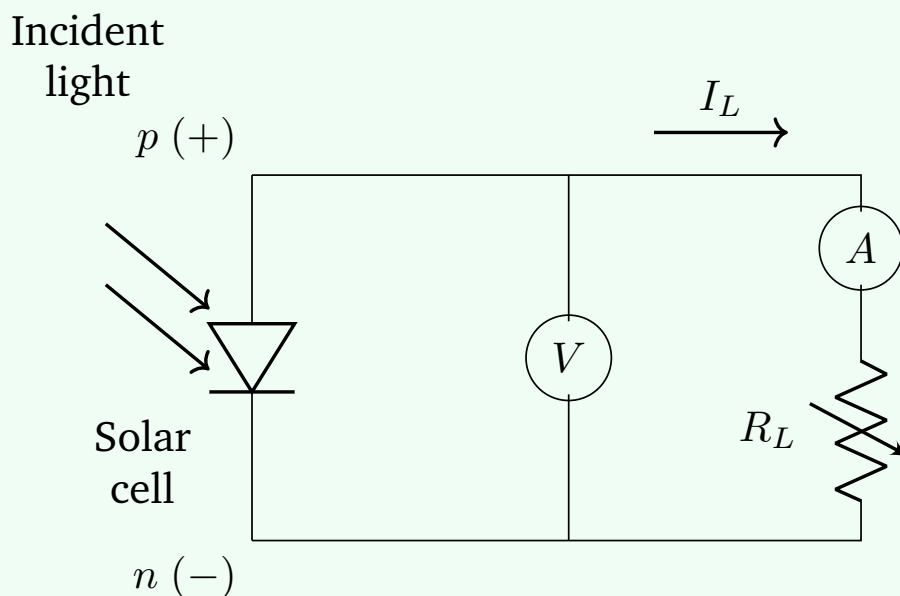
Solution:

Concept:

- A solar cell is an illuminated p - n junction that converts light energy into electrical energy without an external bias supply.
- The voltage-axis intercept gives the open-circuit voltage V_{oc} , while the magnitude of the current-axis intercept gives the short-circuit current I_{sc} .

Step 1: Identify the intercepts P and Q At P , the current is zero while the voltage is positive. This corresponds to an open external circuit, so P represents the open-circuit voltage V_{oc} . At Q , the terminal voltage is zero but current flows, as when the terminals are shorted. Thus Q represents the short-circuit current. In the sign convention of the given graph, its coordinate is $I = -I_{sc}$; the magnitude I_{sc} is positive. The negative current indicates that the illuminated cell supplies power to the external circuit.

Step 2: Connect the illuminated cell to a load Connect an ammeter and a variable load resistance in series with the solar cell, and connect a voltmeter across its terminals. The arrows pointing towards the junction represent incident light. The p -side is the positive terminal and the n -side the negative terminal; conventional current in the external circuit flows from the p -side through the load to the n -side. No external battery is connected. Varying the load gives different terminal-voltage and current readings.



Illuminated solar cell connected to a variable load, with current and voltage measurement.

Step 3: Conclusion P represents V_{oc} and Q represents the short-circuit current, plotted as $-I_{sc}$. The illuminated junction with the load and meters shown is the required solar-cell circuit.

Quick Tip to Solve: Read the zero quantity at each intercept: zero current means open circuit; zero terminal voltage means short circuit.

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

[2 marks]

Solution:

Concept:

- A concentration gradient causes majority carriers to diffuse across a newly formed p - n junction: electrons move from n to p , and holes from p to n .
- Recombination near the junction removes mobile carriers but leaves immobile ionised dopant atoms. Their space charge produces a barrier electric field.

Step 1: Follow diffusion and recombination The n -region has a large concentration of free electrons and the p -region has a large concentration of holes. On forming the junction, electrons diffuse into the p -side and recombine with holes near the junction. Similarly, holes diffuse into the n -side and recombine with electrons. Consequently, a thin region on both sides of the junction becomes depleted of mobile charge carriers.

Step 2: Identify the remaining ions and barrier field Electrons leaving the n -side expose positively charged donor ions; holes leaving the p -side expose negatively charged acceptor ions. These ions are fixed in the crystal lattice and cannot carry current. Together they form the space-charge or depletion region. The electric field points from the positive donor ions on the n -side towards the negative acceptor ions on the p -side. The resulting potential barrier opposes further majority-carrier diffusion. At thermal equilibrium, drift current balances diffusion current and the net junction current is zero.

Step 3: Conclusion The depletion region is the thin layer around a p - n junction depleted of mobile electrons and holes by diffusion and recombination, leaving fixed negative acceptor ions on the p -side

and fixed positive donor ions on the n -side.

Quick Tip to Solve: Remember the exposed ions: electrons leaving the n -side leave it positive; holes leaving the p -side leave it negative.

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

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

[2 marks]

Solution:

Concept:

- In Rutherford scattering, a positively charged α -particle is deflected by the repulsive Coulomb force of a nucleus of charge Ze .
- For incident kinetic energy E , the impact parameter and scattering angle are related by $b = \frac{Ze^2}{4\pi\epsilon_0 E} \cot(\theta/2)$, where b measures the offset of the incident trajectory.

Step 1: Define the two distances (i) The **impact parameter** b is the perpendicular distance from the centre of the nucleus to the initial straight-line path of the incident α -particle, when it is far from the nucleus. The **distance of closest approach** is the minimum separation between the α -particle and the nucleus during its motion. For a head-on approach, the particle momentarily stops there as its initial kinetic energy is completely converted into electrostatic potential energy.

Step 2: Apply the scattering-angle limits (ii) For (I) $\theta = 0^\circ$, there is no deflection. In the ideal Rutherford formula, $\cot(\theta/2)$ tends to infinity, so this is the limit $b \rightarrow \infty$: the particle passes extremely far from the nucleus. For (II) $\theta = 180^\circ$, $\cot 90^\circ = 0$. Thus the incident path is directed at the centre of the nucleus and the collision is head-on; the particle reverses its direction.

Step 3: Conclusion Impact parameter is the initial perpendicular offset, whereas closest approach is the minimum particle–nucleus separation. The required values are (I) $b \rightarrow \infty$ for 0° scattering and (II) $b = 0$ for 180° scattering.

Quick Tip to Solve: Match the two extremes physically: a very distant trajectory is undeflected; a head-on trajectory returns along its incident line.

OR

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

[2 marks]

Solution:

Concept:

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

Step 1: Write the equations for the two frequencies When the radiation frequency is ν_1 , the maximum kinetic energy is K ; when it is ν_2 , it is $2K$. Substituting the given energies and $\phi = h\nu_0$ into Einstein's equation gives

$$K = h(\nu_1 - \nu_0),$$

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

The unknown threshold frequency is common to these equations because the emitting surface has not changed.

Step 2: Eliminate the kinetic energy Multiply the first equation by two and compare it with the second. Cancelling the common nonzero factor h , we obtain

$$2(\nu_1 - \nu_0) = \nu_2 - \nu_0,$$

$$2\nu_1 - \nu_2 = \nu_0.$$

As a check, subtracting the original equations gives $K = h(\nu_2 - \nu_1)$; the higher kinetic energy therefore corresponds to the higher frequency, as expected.

Step 3: Conclusion The threshold frequency of the surface is $\nu_0 = 2\nu_1 - \nu_2$.

Quick Tip to Solve: For two photoelectric measurements on the same surface, write both Einstein equations first; doubling the equation for K eliminates the unknown energy immediately.

Section B (24 marks)

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

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

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

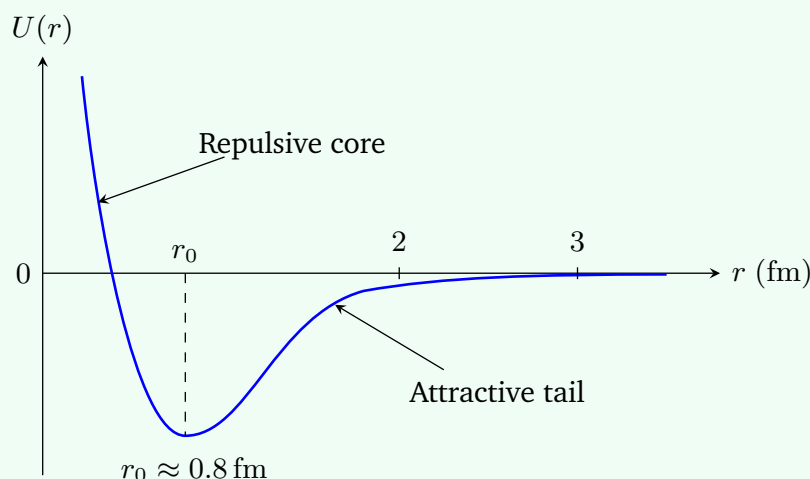
[3 marks]

Solution:

Concept:

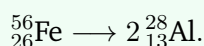
- The nuclear potential energy $U(r)$, where r is the nucleon separation, is defined with $U(\infty) = 0$. It has a short-range repulsive core and a negative potential well.
- The radial force is $F_r = -dU/dr$. A decreasing potential gives repulsion, whereas an increasing potential gives attraction.
- The energy released in a nuclear reaction is $Q = (m_i - m_f)c^2$. Use $1 \text{ u } c^2 = 931.5 \text{ MeV}$; a negative Q requires energy input.

Step 1: (a) Sketch the nucleon potential At very small separation the potential rises steeply to positive values, representing the repulsive core. It falls to a negative minimum at a separation of order $r_0 \approx 0.8 \text{ fm}$. Beyond the minimum it rises towards zero from below, representing the attractive part of the nuclear interaction. At separations of a few femtometres, the nuclear potential is practically zero, showing its short range. The sketch is schematic; the depth depends on the nucleon pair and its state. Recall that $1 \text{ fm} = 10^{-15} \text{ m}$.



Schematic nuclear potential energy versus nucleon separation.

Step 2: (b) Calculate the initial and final masses The proposed reaction conserves both mass number and atomic number:



The final rest mass is the sum of the two identical fragment masses:

$$\begin{aligned} m_i &= 55.93494 \text{ u}, \\ m_f &= 2(27.98191) \text{ u} = 55.96382 \text{ u}, \\ m_i - m_f &= -0.02888 \text{ u}. \end{aligned}$$

The products have greater rest mass than the parent. If the supplied masses are atomic masses, their electron masses cancel because the total atomic number is 26 on each side.

Step 3: Evaluate the energy balance Convert the mass difference to the reaction energy, retaining the sign:

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

A positive Q would supply kinetic energy to the fragments. Here energy must instead be supplied to create their larger combined rest mass. This agrees with iron lying near the maximum of the binding-energy-per-nucleon curve: splitting it into lighter nuclei reduces the total binding energy.

Step 4: Conclusion The potential has a steep repulsive core, a negative minimum and a short attractive tail tending to zero. For the proposed fission, $Q \approx -26.9 \text{ MeV}$; it is not energetically possible as a spontaneous energy-releasing process and requires at least 26.9 MeV of external energy.

Quick Tip to Solve: Double the aluminium mass before subtracting it from the iron mass. If the products are heavier, the fission Q value must be negative.

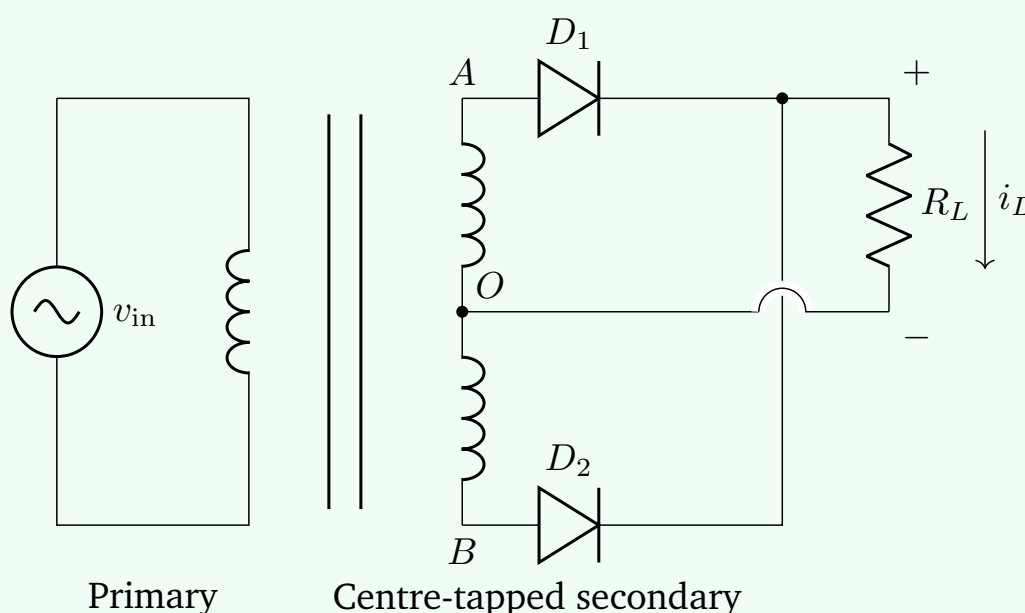
5. With the help of a circuit diagram, explain the working of a p - n junction diode as a full-wave rectifier. Also draw its input and output waveforms. [3 marks]

Solution:

Concept:

- A p - n junction diode conducts when forward biased and blocks current when reverse biased. A rectifier uses this property to convert alternating voltage into a unidirectional output.
- A full-wave rectifier uses both half-cycles of the input. In the centre-tapped arrangement, the two ends of the secondary have opposite instantaneous polarities relative to the centre tap.

Step 1: Connect the centre-tapped rectifier Connect the ends A and B of the transformer secondary to the anodes of diodes D_1 and D_2 . Join their cathodes to the upper end of the load resistance R_L , and connect the lower end of the load to the centre tap O . Apply the alternating input to the transformer primary. The drawing shows a wire crossing with a bridge, so that the centre-tap return does not connect to the cathode wire at that crossing.



Centre-tapped full-wave rectifier; the bridge at the wire crossing indicates no connection.

Step 2: Follow the positive half-cycle When A is positive and B is negative relative to O , diode D_1 is forward biased and D_2 is reverse biased. Current flows along $A \rightarrow D_1 \rightarrow R_L \rightarrow O$, returning through the upper half of the secondary. The current through the load is directed from its upper end to its lower end.

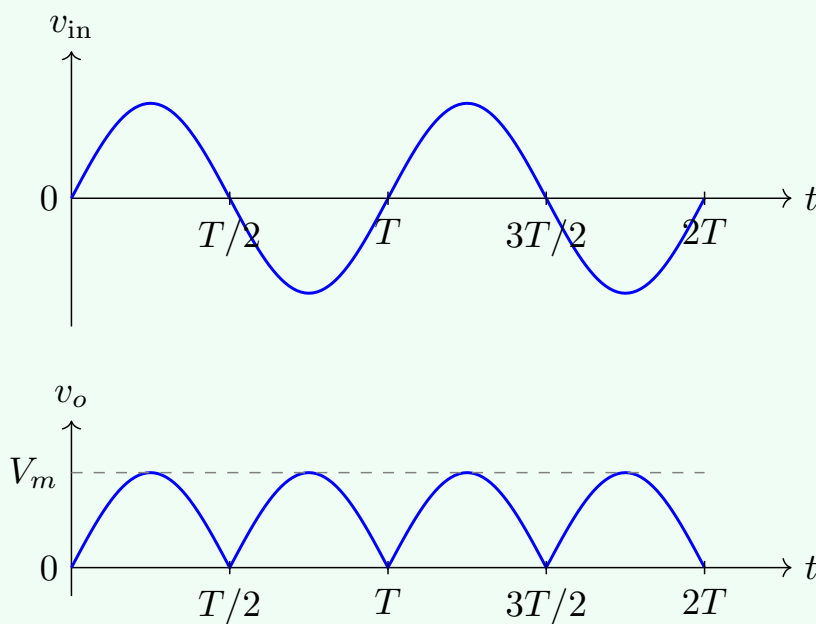
Step 3: Follow the negative half-cycle In the next half-cycle, B becomes positive and A negative relative to O . Now D_2 conducts and D_1 blocks. Current flows along $B \rightarrow D_2 \rightarrow R_L \rightarrow O$, returning through the lower half of the secondary. Thus the direction of current through R_L remains the same in both half-cycles.

Step 4: Draw the input and rectified output For ideal diodes, let the voltage of A relative to O be $v_{AO} = V_m \sin \omega t$. The other half-secondary voltage is $v_{BO} = -V_m \sin \omega t$. Each diode supplies the positive half-cycle of its own half-secondary, so

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

The input waveform is sinusoidal, while the negative half-cycles are inverted in the output. The

output has two positive pulses in each input period T , giving ripple frequency $2f$ for input frequency $f = 1/T$. It is pulsating direct current; smoothing would require an additional filter.



Sinusoidal input and ideal full-wave output over two input periods.

Step 5: Conclusion The two diodes conduct alternately, producing load current in one fixed direction during both halves of the alternating input. The circuit therefore acts as a full-wave rectifier, with a pulsating output of frequency $2f$.

Quick Tip to Solve: Trace each conducting path from the positive secondary end through its diode and the load to the centre tap; both paths must pass through the load in the same direction.

6. An equiconvex lens forms a two times enlarged real image when an object is kept 16 cm from it. The lens is cut into two identical plano-convex lenses. If the object is again kept 16 cm in front of one of these lenses, then find the nature and position of the image formed. [3 marks]

Solution:

Concept:

- With the Cartesian sign convention, the thin-lens formula is $1/f = 1/v - 1/u$ and the linear magnification is $m = v/u$, where u , v and f are the signed object distance, image distance and focal length.
- For a thin lens in air, the lensmaker's formula is $1/f = (\mu - 1)(1/R_1 - 1/R_2)$, where μ is the lens refractive index and R_1, R_2 are the signed radii of its surfaces. A plane surface has infinite radius.

Step 1: Find the original image distance Place the optical centre at the origin and take the incident light to travel from left to right. The object is on the left, so $u = -16$ cm. A real image formed by a convex lens is inverted. Hence the stated two times enlargement gives $m = -2$, rather than $+2$. Using magnification,

$$v = mu = (-2)(-16) = +32 \text{ cm.}$$

Step 2: Calculate the original focal length Substitute the signed distances in the lens formula:

$$\begin{aligned}\frac{1}{f} &= \frac{1}{v} - \frac{1}{u} \\ &= \frac{1}{32} - \frac{1}{-16} = \frac{1}{32} + \frac{2}{32} = \frac{3}{32} \text{ cm}^{-1}.\end{aligned}$$

Therefore the original focal length is $f = 32/3$ cm, consistent with a converging lens.

Step 3: Find the focal length after cutting To obtain two identical plano-convex pieces, the equiconvex lens is cut through its middle in a plane perpendicular to the principal axis. For the original lens, take $R_1 = +R$ and $R_2 = -R$. Each new piece has one curved surface of the same radius magnitude R and one plane surface. Thus

$$\begin{aligned}\frac{1}{f} &= \frac{2(\mu - 1)}{R}, \\ \frac{1}{f'} &= \frac{\mu - 1}{R} = \frac{1}{2f}.\end{aligned}$$

Each piece has half the original power and therefore twice its focal length:

$$f' = 2f = \frac{64}{3} \text{ cm}.$$

Step 4: Locate and characterise the new image For the same object distance $u = -16$ cm, apply the lens formula to one plano-convex piece:

$$\begin{aligned}\frac{1}{v'} &= \frac{1}{f'} + \frac{1}{u} \\ &= \frac{3}{64} - \frac{1}{16} = -\frac{1}{64} \text{ cm}^{-1}, \\ v' &= -64 \text{ cm}.\end{aligned}$$

The negative image distance places the image on the object side of the lens, so it is virtual. Its magnification is

$$m' = \frac{v'}{u} = \frac{-64}{-16} = +4.$$

The positive sign means erect, and the magnitude indicates four times enlargement. This agrees with the object lying within the new focal length, since $16 < 64/3$.

Step 5: Conclusion The plano-convex lens forms a **virtual, erect image enlarged four times**, at 64 cm in front of the lens on the object side ($v' = -64$ cm).

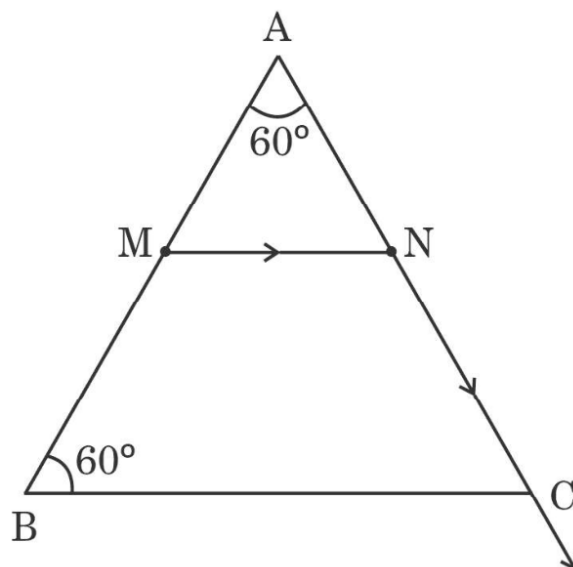
Quick Tip to Solve: Cutting an equiconvex lens into two plano-convex pieces halves its power and doubles its focal length. Use negative magnification for the original enlarged real image.

7. A ray is incident on a prism of material of refractive index $\sqrt{2}$ at point M such that it grazes along NC after emerging from the prism, as shown in the figure.

Find:

- (a) the critical angle for the prism.
(b) the angle of refraction at face AB .

[3 marks]



Solution:

Concept:

- The critical angle C is the angle of incidence in the denser medium for which the refracted ray in air makes 90° with the normal. For a prism of refractive index μ in air, $\sin C = 1/\mu$.
- Inside a prism, the angles measured from the normals obey $r_1 + r_2 = A$, where A is the prism angle, r_1 is the refracted angle at the first face and r_2 is the incidence angle at the second face.

Step 1: (a) Apply Snell's law at the grazing emergence The ray emerges along NC , which lies on the second face AC . Its angle of emergence measured from the normal is therefore $e = 90^\circ$. Applying Snell's law from the prism to air gives

$$\mu \sin r_2 = \sin e = 1.$$

This is precisely the limiting condition that defines the critical angle; the ray is not undergoing total internal reflection. With $\mu = \sqrt{2}$,

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

Thus the internal incidence angle at N is $r_2 = C$.

Step 2: (b) Use the prism-angle relation The printed apex angle at A is 60° . The normals to the two refracting faces yield the standard prism relation $r_1 + r_2 = A$. Substituting the critical incidence angle at the second face gives

$$r_1 = A - r_2 = 60^\circ - 45^\circ = 15^\circ.$$

This is the angle of refraction at AB , measured between the internal ray MN and the normal at M , rather than between the ray and the prism face. The drawn ray is schematic; the given refractive index and grazing-emergence condition determine the angles.

Step 3: Conclusion (a) The critical angle is 45° . (b) The angle of refraction at face AB is 15° , measured from the normal.

Quick Tip to Solve: Grazing emergence means $e = 90^\circ$ and $r_2 = C$. First find C from the refractive index, then subtract it from the apex angle.

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

(ii) Write three characteristics of electromagnetic waves.

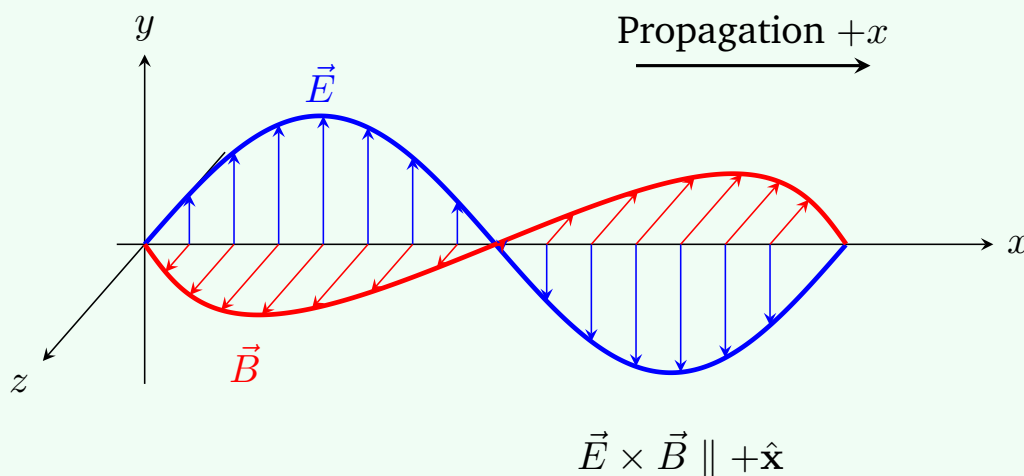
[3 marks]

Solution:

Concept:

- A plane electromagnetic wave is transverse: the electric field $\vec{E}$, magnetic field $\vec{B}$ and propagation direction are mutually perpendicular. The direction of travel is along $\vec{E} \times \vec{B}$.
- For a sinusoidal wave in vacuum, $k = 2\pi/\lambda$, $\omega = 2\pi\nu$, $\omega/k = c$, and the field amplitudes obey $E_0 = cB_0$. Here λ is wavelength and ν is frequency.

Step 1: (i) Choose the field directions and depict the wave Take the wave to travel in the positive x -direction, with the electric field oscillating parallel to the y -axis and the magnetic field parallel to the z -axis. Since $\hat{y} \times \hat{z} = \hat{x}$, this choice gives the required propagation direction. At a fixed time the fields vary sinusoidally with x , as depicted below. Their positive maxima, zeros and negative maxima occur at the same positions: the fields are in phase. The two field amplitudes are drawn on separate schematic scales.



Snapshot of a plane electromagnetic wave: $\vec{E} \parallel y$, $\vec{B} \parallel z$, propagation along $+x$. Field scales are schematic.

Step 2: Write the oscillating field expressions A suitable pair of expressions, choosing zero initial phase, is

$$\begin{aligned}\vec{E}(x, t) &= E_0 \sin(kx - \omega t) \hat{y}, \\ \vec{B}(x, t) &= B_0 \sin(kx - \omega t) \hat{z}.\end{aligned}$$

Here E_0 and B_0 are the maximum field magnitudes, x is position and t is time. A surface of constant phase satisfies $kx - \omega t = \text{constant}$, so it moves towards increasing x with speed $\omega/k = c$. Both fields are uniform over each plane perpendicular to this direction.

Step 3: (ii) State three characteristics (1) Electromagnetic waves are transverse, with $\vec{E} \perp \vec{B}$ and

both fields perpendicular to their direction of propagation.

(2) They require no material medium. In vacuum all electromagnetic waves travel with speed

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3.0 \times 10^8 \text{ m s}^{-1}.$$

(3) They transport energy and momentum and therefore exert radiation pressure when absorbed or reflected by a surface.

Step 4: Conclusion For propagation along $+x$, choose in-phase electric and magnetic fields along y and z , with $E_0 = cB_0$. Electromagnetic waves are transverse, propagate through vacuum, and carry energy and momentum.

Quick Tip to Solve: For a wave along $+x$, choose $\vec{E} \parallel y$ and $\vec{B} \parallel z$, use the same phase for both, and check $\vec{E} \times \vec{B} \parallel +x$.

OR

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

(i) Radioactive decays of nucleus

(ii) Welding arcs

(iii) Hot bodies

Write one use each of these waves.

[3 marks]

Solution:

Concept:

- Electromagnetic waves are classified by their frequency or wavelength. Their production mechanism helps identify the relevant region of the electromagnetic spectrum.
- Nuclear transitions produce gamma rays, electric arcs emit ultraviolet radiation, and thermal motion in hot bodies produces infrared radiation. These are characteristic emissions; a source can also emit other wavelengths.

Step 1: Identify radiation from radioactive nuclei (i) The electromagnetic radiation associated with radioactive decay of a nucleus is **gamma radiation**. An excited daughter nucleus can lose excess energy by emitting a gamma photon. Gamma rays are electromagnetic waves, whereas alpha and beta emissions are particles. One use of gamma rays is **destroying cancer cells in radiotherapy**.

Step 2: Identify radiation from welding arcs (ii) Welding arcs produce strong **ultraviolet radiation**. The energetic electrical discharge excites atoms and ions, whose radiation includes ultraviolet wavelengths. One use of ultraviolet radiation is **sterilising water**, because suitable ultraviolet radiation inactivates microorganisms.

Step 3: Identify radiation from hot bodies (iii) Hot bodies emit **infrared radiation** as part of their thermal emission. Infrared is associated with the heating effect of radiation, although sufficiently hot bodies also emit visible light. One use of infrared radiation is **thermal imaging**, in which the infrared

emission from objects is detected to reveal temperature differences, even in darkness.

Step 4: Conclusion The required pairs are: (i) gamma rays—cancer radiotherapy; (ii) ultraviolet rays—water sterilisation; and (iii) infrared rays—thermal imaging.

Quick Tip to Solve: Link each source to its characteristic process: nuclear transition to gamma rays, welding arc to ultraviolet, and thermal emission to infrared.

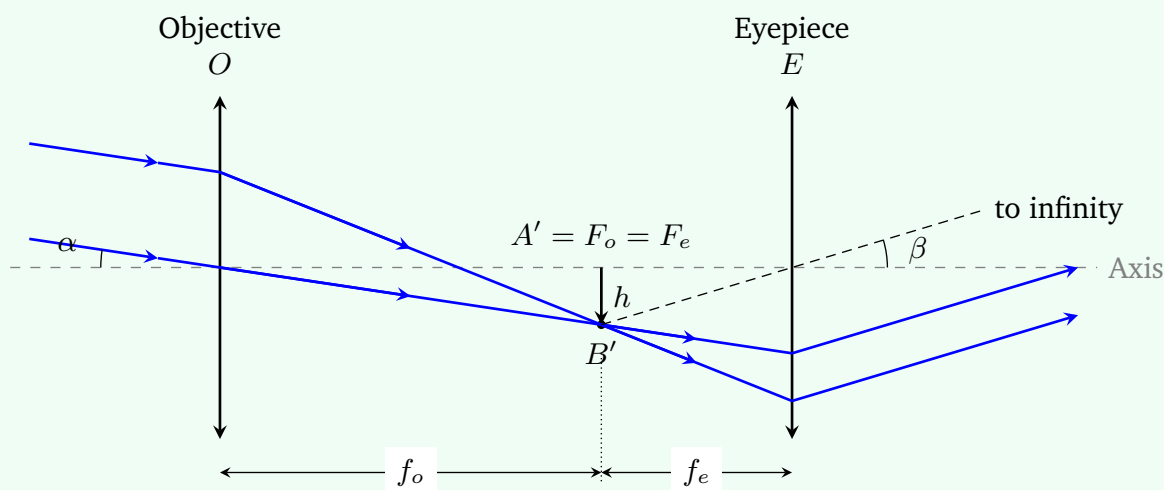
9(a). Draw a labelled ray diagram showing the formation of an image by an astronomical refracting telescope in normal adjustment. Hence, obtain the expression for its magnifying power. [3 marks]

Solution:

Concept:

- An astronomical refracting telescope uses a converging objective of focal length f_o and a converging eyepiece of focal length f_e , with $f_o > f_e$.
- In normal adjustment, the real intermediate image formed at the objective's second focal plane lies in the eyepiece's first focal plane. The final image is at infinity, and the lens separation is $L = f_o + f_e$.
- Angular magnifying power compares the angle subtended by the final image at the eye with the angle subtended by the distant object at the unaided eye. For small angles, $\tan \theta \simeq \theta$.

Step 1: Trace the rays in normal adjustment Parallel rays from one point of a distant object enter the objective at a small angle α to the principal axis. The objective brings them to B' , forming the real, inverted intermediate image $A'B'$ in its focal plane. Set the eyepiece so that A' is also at its first principal focus, F_e . Rays from B' then emerge parallel from the eyepiece, producing an enlarged angular view of the inverted image at infinity. The eye is placed just beyond the eyepiece.



Normal adjustment: $F_o = F_e = A'$; the intermediate image is $A'B'$, and the emergent rays are parallel. Angle labels indicate magnitudes.

Step 2: Relate the angular sizes to the image height Let $h = A'B'$ denote the positive magnitude of the intermediate image height. The objective and eyepiece focal triangles give the magnitudes

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

The incident ray through the objective's optical centre is undeviated; similarly, a ray from B' through

the eyepiece's optical centre fixes the emergent direction. These triangles explain why the same height h enters both ratios.

Step 3: Obtain the magnifying power Using the small-angle approximation and cancelling h , the magnitude of the angular magnification is

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

The final image is inverted relative to the object. Therefore the signed angular magnifying power is negative. A longer objective focal length and a shorter eyepiece focal length give a greater angular magnification.

Step 4: Conclusion For an astronomical refracting telescope in normal adjustment,

$$\boxed{M = -\frac{f_o}{f_e}}, \quad \boxed{|M| = \frac{f_o}{f_e}}, \quad L = f_o + f_e.$$

The negative sign denotes an inverted final image; the final image is at infinity.

Quick Tip to Solve: First make the objective's image plane coincide with the eyepiece's focal plane; then divide the two small-angle relations to cancel the same image height.

OR

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

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

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

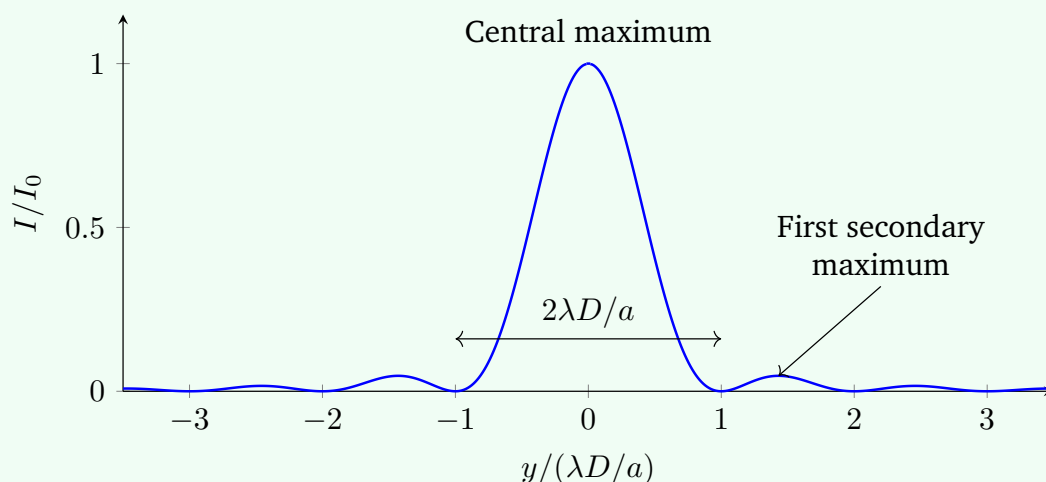
[3 marks]

Solution:

Concept:

- In single-slit diffraction, secondary wavelets from all points of the slit interfere. The path difference between the extreme rays at angle θ is $a \sin \theta$, where a is the slit width.
- For a distant screen and small angles, $y \simeq D\theta$. Minima occur at $a \sin \theta = n\lambda$, where $n = \pm 1, \pm 2, \dots$, λ is the wavelength and D is the screen distance.

Step 1: (i) Sketch and interpret the intensity distribution The central maximum at $y = 0$ is the brightest and widest. Its bounding minima lie at $y = \pm \lambda D/a$, so its width is $2\lambda D/a$. Secondary maxima occur between successive minima on either side and decrease rapidly in intensity away from the centre. Each secondary band has width approximately $\lambda D/a$. The distribution is symmetric about the central maximum.



Single-slit intensity distribution; horizontal position is measured in units of $\lambda D/a$.

Step 2: (ii) Locate the first secondary maximum The first and second minima on the positive side satisfy

$$a \sin \theta_1 = \lambda, \quad a \sin \theta_2 = 2\lambda.$$

The first secondary maximum lies between them. In the usual school-level approximation it is taken midway between these minima, giving

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

Equivalently, when the path difference is approximately $3\lambda/2$, division into three equal strips shows that two strips nearly cancel pairwise, leaving a smaller resultant from the remaining strip. With $\sin \theta \simeq \tan \theta = y/D$, its displacement from the central maximum follows by multiplying the angular position by D .

Step 3: Distinguish the approximation from the exact peak The exact intensity law is $I = I_0(\sin \beta/\beta)^2$, with $\beta = \pi a \sin \theta/\lambda$. A nonzero maximum obeys $\tan \beta = \beta$; the first root is $\beta \simeq 4.493$, so its more accurate small-angle position is $y \simeq 1.43\lambda D/a$. Thus the standard $3\lambda D/(2a)$ expression is an approximate location, not an exact equality.

Step 4: Conclusion The first secondary maxima are approximately at $y = \pm 3\lambda D/(2a)$; hence their distance from the central maximum is $3\lambda D/(2a)$. The central bright band has width $2\lambda D/a$, with weaker secondary maxima on both sides.

Quick Tip to Solve: Mark the first two minima at $\lambda D/a$ and $2\lambda D/a$; the first secondary maximum lies between them, approximately halfway.

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

[3 marks]

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is particle momentum. For nonrelativistic motion, $p = mv = \sqrt{2mK}$, with mass m , speed v and kinetic energy K .
- An alpha particle has mass $m_\alpha \simeq 4m_p$ and charge $q_\alpha = 2e$, while a proton has mass m_p and charge $q_p = e$. Acceleration from rest through potential difference V supplies kinetic energy $K = qV$.

Step 1: (a) Compare the wavelengths at equal speeds Let the common speed be v . Since wavelength is inversely proportional to momentum, the ratio in the order alpha particle to proton is

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

Thus the heavier alpha particle has four times the proton's momentum at the same speed and therefore one-quarter of its wavelength.

Step 2: (b) Compare the wavelengths at equal kinetic energies Let both kinetic energies be K . Using $\lambda = h/\sqrt{2mK}$, the common factors h , 2 and K cancel:

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

Equal kinetic energies do not mean equal speeds or momenta. The square-root mass dependence is therefore required in this part.

Step 3: (c) Compare the wavelengths after acceleration through equal potentials Taking both particles to start from rest, their gained kinetic energies are $K_\alpha = 2eV$ and $K_p = eV$. Hence

$$\begin{aligned} \frac{\lambda_\alpha}{\lambda_p} &= \sqrt{\frac{m_p q_p V}{m_\alpha q_\alpha V}} \\ &= \sqrt{\frac{m_p e}{(4m_p)(2e)}} = \frac{1}{\sqrt{8}} = \frac{1}{2\sqrt{2}}. \end{aligned}$$

The alpha particle gains twice the proton's energy because its charge is twice as large; both mass and charge must therefore enter the comparison.

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

Quick Tip to Solve: Use $\lambda \propto 1/m$ at fixed speed, $1/\sqrt{m}$ at fixed kinetic energy, and $1/\sqrt{mq}$ at fixed accelerating potential.

11. An electron is in the third excited state in a hydrogen atom. It undergoes transitions to the lower energy states.

(a) What is the maximum number of spectral lines that can be emitted?

(b) Calculate the minimum wavelength of the spectral lines emitted.

[3 marks]

Solution:

Concept:

- The ground state of hydrogen is $n = 1$; hence its third excited state is $n = 4$. Emission occurs when an electron falls from a higher to a lower energy level.
- The maximum number of distinct spectral lines from all possible downward transitions among n levels is $N = n(n - 1)/2$. Each pair of levels gives a particular photon energy.
- For hydrogen, $1/\lambda = R_H(1/n_f^2 - 1/n_i^2)$, where $R_H = 1.097 \times 10^7 \text{ m}^{-1}$ is the Rydberg constant and n_i, n_f denote the initial and final levels.

Step 1: (a) Count the possible downward transitions The available levels are 4, 3, 2, 1. The six possible transitions are $4 \rightarrow 3$, $4 \rightarrow 2$, $4 \rightarrow 1$, $3 \rightarrow 2$, $3 \rightarrow 1$ and $2 \rightarrow 1$. Thus the complete spectrum obtained over all possible decay paths has

$$N = \frac{4(4 - 1)}{2} = 6.$$

This counts the distinct lines available from atoms initially excited to this level; one electron following a single cascade does not emit all six photons.

Step 2: (b) Identify the transition of greatest energy A photon's energy is $E = hc/\lambda$, so the shortest wavelength corresponds to the largest energy difference. Of the accessible levels, $n = 4$ is the highest and $n = 1$ the lowest. The required line therefore comes from the direct transition $4 \rightarrow 1$, rather than from transitions between adjacent excited levels.

Step 3: Substitute in the Rydberg relation Putting $n_i = 4$ and $n_f = 1$,

$$\begin{aligned}\frac{1}{\lambda_{\min}} &= (1.097 \times 10^7) \left(1 - \frac{1}{16}\right) \text{ m}^{-1} \\ &= 1.0284 \times 10^7 \text{ m}^{-1}, \\ \lambda_{\min} &= 9.72 \times 10^{-8} \text{ m} = 97.2 \text{ nm}.\end{aligned}$$

This ultraviolet line belongs to the Lyman series because its final state is the ground state.

Step 4: Conclusion (a) The maximum number of distinct spectral lines is 6. (b) The minimum wavelength is $\lambda_{\min} \approx 97.2 \text{ nm}$, emitted in the $4 \rightarrow 1$ transition.

Quick Tip to Solve: Convert an excited-state number to n by adding one; then count all pairs of levels and use the direct jump to $n = 1$ for the shortest wavelength.

Section C (5 marks)

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

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

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

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

Solution:

Concept:

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

Step 1: Compare the fringe widths Moving the screen towards the slits reduces D , while λ and d remain fixed. If the new distance is $D' < D$, then

$$\frac{\beta'}{\beta} = \frac{D'}{D} < 1.$$

Thus the fringes become narrower. This eliminates (B), which predicts an increase, and (D), which predicts no change in fringe width.

Step 2: Compare the bright-fringe intensities The screen now receives light from the slits at a smaller propagation distance. The intensity contributed by each slit increases as its light is spread over a smaller area. Constructive superposition therefore gives a higher bright-fringe intensity. Option (A) incorrectly treats this intensity as unchanged when the screen is moved closer.

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

Quick Tip to Solve: Use $\beta \propto D$ for fringe spacing, then separately consider the increase in illumination when the screen approaches the slits.

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

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

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

Solution:

Concept:

- A sustained interference pattern requires coherent sources: their frequencies must be equal and their phase difference must remain constant.
- The resultant intensity is $I = I_1 + I_2 + 2\sqrt{I_1 I_2} \cos \phi$, where I_1, I_2 are the individual intensities and ϕ is the phase difference at the observation point.

Step 1: Test whether the replacement sources are coherent The original slits are illuminated by the same source, so they maintain a definite phase relationship. Two independent light sources emit through unrelated atomic processes. Even if they are identical, their relative phase changes randomly with time; identical frequency and intensity alone do not establish coherence.

Step 2: Average the interference term Over the eye's observation time, the random phase gives $\langle \cos \phi \rangle = 0$. Thus

$$\langle I \rangle = I_1 + I_2.$$

The fixed bright and dark fringes disappear. Light still reaches the screen; the absence is of a stable interference pattern. Options (A) and (B) incorrectly retain a pattern with altered intensity, and (C) incorrectly predicts extra fringes.

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

Quick Tip to Solve: When two sources are independent, check their relative phase before comparing wavelength or brightness; random phase washes out the fringes.

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

[1 mark]

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

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

Solution:

Concept:

- Coherent light waves have the same frequency and maintain a constant phase difference, so their interference maxima and minima remain stationary.
- In the same medium, wave speed v , frequency f and wavelength λ obey $v = f\lambda$; equal frequencies therefore correspond to equal wavelengths.

Step 1: Apply the definition of coherence For a definite, unchanging interference pattern, the relative phase of the two waves must remain fixed. Their amplitudes need not be equal: unequal amplitudes reduce fringe contrast, but do not by themselves destroy coherence. Option (A) is therefore wrong because it allows the phase difference to vary.

Step 2: Compare the wavelength conditions If the wavelengths differ in the same medium, the frequencies differ. Their relative phase then changes as

$$\Delta\phi(t) = 2\pi(f_1 - f_2)t + \Delta\phi(0),$$

where f_1, f_2 are the two frequencies. Options (C) and (D) fail this requirement. Equal intensity in (C) cannot compensate for changing relative phase, and the constant phase difference claimed in (D) is incompatible with unequal frequencies.

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

Quick Tip to Solve: For coherence, look for both equal frequency or wavelength and a fixed phase difference; equal amplitude is not a defining requirement.

12(d). The fringe width in a Young's double slit experiment is β . If the whole set-up is immersed in a liquid of refractive index μ , then the new fringe width will be: [1 mark]

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

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

Solution:

Concept:

- The fringe width in Young's double slit experiment is $\beta = \lambda D/d$, where D is the slit-to-screen distance and d is the separation of the slits.
- In a liquid of refractive index μ , light speed becomes c/μ while its frequency f stays unchanged. Consequently the wavelength becomes $\lambda' = \lambda/\mu$, taking air's refractive index as unity.

Step 1: Find the wavelength in the liquid Immersion changes the propagation medium but not the frequency set by the source. Since $\lambda = v/f$, the ratio of wavelengths equals the ratio of wave speeds:

$$\frac{\lambda'}{\lambda} = \frac{c/\mu}{c} = \frac{1}{\mu}.$$

Thus light has a shorter wavelength in the liquid.

Step 2: Substitute into the fringe-width formula The whole apparatus is immersed without changing its dimensions, so D and d remain the same. Therefore

$$\beta' = \frac{\lambda' D}{d} = \frac{1}{\mu} \frac{\lambda D}{d} = \frac{\beta}{\mu}.$$

Option (A) neglects the wavelength change, (B) predicts the opposite trend, and (D) introduces an extra factor of μ even though the geometry does not change.

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

Quick Tip to Solve: For complete immersion with unchanged geometry, replace the wavelength by λ/μ ; the fringe width decreases by the same factor.

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

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

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

Solution:

Concept:

- In Young's double slit experiment, a bright fringe occurs when the total path difference is $\Delta = n\lambda$, where n is an integer and λ is the wavelength.
- A dark fringe occurs for $\Delta = (2n + 1)\lambda/2$. The corresponding phase difference is $\phi = 2\pi\Delta/\lambda$, an odd multiple of π .

Step 1: Identify the fringe at the first point At P_1 , the given path difference is $3\lambda/2$, an odd multiple of half a wavelength. Its phase difference is

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

The waves therefore arrive in opposite phase and produce destructive interference, giving a dark fringe.

Step 2: Identify the fringe at the second point At P_2 , the path difference is 2λ , an integer multiple of the wavelength. Here

$$\phi_2 = \frac{2\pi}{\lambda} (2\lambda) = 4\pi.$$

The waves arrive in phase and produce constructive interference, giving a bright fringe. Thus (A) and (B) fail because the two points have different fringe types, while (C) reverses the two assignments.

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

Quick Tip to Solve: Divide each path difference by λ : an integer gives a bright fringe, while a half-integer such as $3/2$ gives a dark fringe.