

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/4/1



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** – 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.

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

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

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

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

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

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

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

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

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

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

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

Section A (6 marks)

1. What is meant by energy band gap in a solid? Draw the energy band diagrams for a conductor, an insulator and a semiconductor. [2 marks]

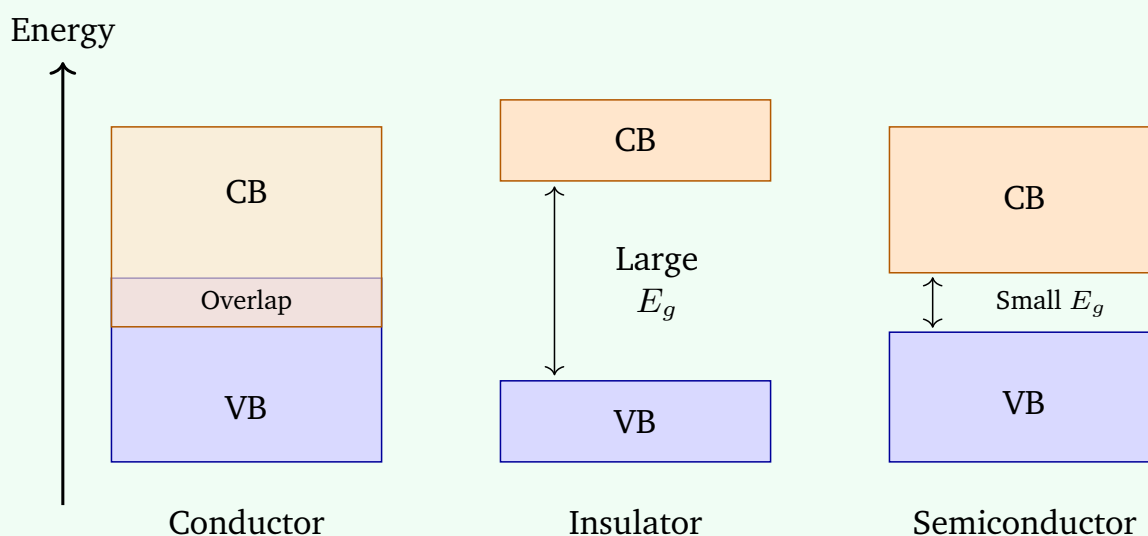
Solution:

Concept:

- In a solid, closely spaced allowed electron energies form bands. The valence band contains the valence-electron states, while electrons in the conduction band can contribute to conduction.
- The forbidden energy gap is $E_g = E_C - E_V$, where E_C is the bottom of the conduction band and E_V is the top of the valence band. No allowed electron energy states occur inside this gap.

Step 1: Define the energy band gap The energy band gap is the energy separation between the top of the valence band and the bottom of the conduction band. An electron must gain at least this energy to move from the valence-band edge to the conduction-band edge when the bands are separated.

Step 2: Compare the three band structures In a conductor, the valence and conduction bands can overlap, so electrons have nearby accessible states and there is no forbidden gap between these bands. The overlapping-band case is drawn below. An insulator has a large forbidden gap, so ordinary thermal energy cannot readily excite valence electrons into the conduction band. A semiconductor has a small gap, typically of the order of 1 eV, so some electrons can be thermally excited. The sketches show relative gap sizes schematically; CB and VB denote the conduction and valence bands.



Schematic energy-band diagrams; shaded rectangles represent allowed bands.

Step 3: Conclusion The forbidden gap separates the valence and conduction bands: it is absent in the overlapping-band conductor shown, large in an insulator and small in a semiconductor.

Quick Tip to Solve: Draw energy increasing upwards, label both bands, and compare the empty separation: overlap for a conductor, a wide gap for an insulator and a narrow gap for a semiconductor.

2(a). Name the spectral series for a hydrogen atom which lies in the visible region. Find the ratio of the maximum to the minimum wavelengths of this series. [2 marks]

Solution:

Concept:

- The Balmer series of hydrogen consists of transitions from upper levels $n = 3, 4, 5, \dots$ to the final level $n_f = 2$. Its prominent lines lie in the visible region.
- The Rydberg formula is $\lambda^{-1} = R_H(1/n_f^2 - 1/n^2)$, where λ is the emitted wavelength and R_H is the Rydberg constant for hydrogen. Since $E = hc/\lambda$, the smallest energy difference gives the longest wavelength.

Step 1: Identify the series and its longest wavelength The required series is the Balmer series, for which all transitions end at $n_f = 2$. The smallest energy separation in this series is the transition $3 \rightarrow 2$; therefore it gives the maximum wavelength:

$$\frac{1}{\lambda_{\max}} = R_H \left(\frac{1}{4} - \frac{1}{9} \right) = \frac{5R_H}{36}, \quad \lambda_{\max} = \frac{36}{5R_H}.$$

Step 2: Find the series limit and form the ratio The greatest transition energy occurs at the series limit, as the initial level tends to infinity. This gives the minimum wavelength:

$$\frac{1}{\lambda_{\min}} = R_H \left(\frac{1}{4} - 0 \right) = \frac{R_H}{4}, \quad \lambda_{\min} = \frac{4}{R_H}.$$

Thus the requested ratio follows by dividing the wavelengths, with the common Rydberg constant cancelling:

$$\frac{\lambda_{\max}}{\lambda_{\min}} = \frac{36/(5R_H)}{4/R_H} = \frac{9}{5}.$$

The series is conventionally identified with the visible spectrum, although its short-wavelength limit extends into the ultraviolet.

Step 3: Conclusion The series is the **Balmer series**, and the maximum-to-minimum wavelength ratio for the full series is $\boxed{9 : 5}$.

Quick Tip to Solve: For a series ending at level m , use $n = m + 1$ for the longest wavelength and $n \rightarrow \infty$ for the shortest; form the wavelength ratio only after taking reciprocals.

OR

2(b). What are matter waves? A proton and an alpha particle are accelerated through the same potential difference. Find the ratio of the de Broglie wavelength associated with the proton to that with the alpha particle. [2 marks]

Solution:

Concept:

- Matter waves are the waves associated with moving material particles. Their de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is the particle's momentum.
- A particle of mass m and charge q , accelerated from rest through a potential difference V , gains kinetic energy $qV = p^2/(2m)$ in the non-relativistic treatment.

Step 1: Express the wavelength in terms of the accelerating voltage Matter waves express the wave nature of material particles; they are not electromagnetic waves. From the work done by the electric field,

$$p = \sqrt{2mqV}, \quad \lambda = \frac{h}{\sqrt{2mqV}}.$$

Thus equal accelerating voltages do not give equal kinetic energies when the charges differ. The wavelength depends on both the particle mass and its charge.

Step 2: Compare the proton and alpha particle A proton has charge e and mass m_p . An alpha particle has charge $2e$ and mass approximately $4m_p$. Since both experience the same V , the common factors cancel:

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{(4m_p)(2e)}{m_p e}} = \sqrt{8}.$$

Step 3: Conclusion Matter waves are waves associated with moving material particles. The required wavelength ratio is $\lambda_p : \lambda_\alpha = 2\sqrt{2} : 1$; the lighter proton has the longer wavelength.

Quick Tip to Solve: For particles accelerated through the same voltage, compare mq under a square root, remembering that an alpha particle has twice the proton's charge.

3. Name the device which converts electrical energy into light energy. Write three advantages of the device. [2 marks]

Solution:

Concept:

- A light emitting diode (LED) is a specially designed semiconductor p - n junction which converts electrical energy into light energy when forward biased.
- Electrons and holes recombine near the junction and release energy as photons. Suitable semiconductor materials make this radiative recombination efficient.

Step 1: Identify the device and explain its action The required device is a **light emitting diode (LED)**. Under forward bias, the supply injects electrons and holes towards the junction. Their recombination produces light, so the electrical energy supplied to the junction is converted into optical energy. The photon energy is determined mainly by the semiconductor band gap.

Step 2: State three advantages 1. **Low operating voltage and power consumption:** an LED gives useful light output with a small electrical power input, making it suitable for battery-operated indicators.

2. **Fast response:** an LED switches on and off rapidly because its light production does not require a filament to heat up and cool down. It can therefore follow rapidly changing electrical signals.

3. **Long operating life:** an LED has no fragile heated filament to burn out and has a long service life when operated within its rated current and temperature limits.

Step 3: Conclusion The device is an **LED (light emitting diode)**. Its three advantages are low operating voltage and power consumption, fast switching response, and long operating life.

Quick Tip to Solve: For an LED question, name the forward-biased junction first, then give three distinct advantages: low power, fast response and long life.

Section B (24 marks)

4(a). Differentiate between nuclear fission and nuclear fusion.

[3 marks total]

Solution:

Concept:

- Nuclear fission splits a heavy nucleus into two medium-mass nuclei, usually with the emission of neutrons and energy.
- Nuclear fusion combines light nuclei to form a heavier nucleus, releasing energy when the products have greater binding energy per nucleon.

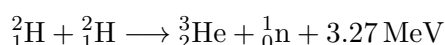
Step 1: Compare the nuclear changes In fission, a heavy nucleus such as uranium-235 breaks into lighter fragments after absorbing a neutron. In fusion, light nuclei such as two deuterium nuclei combine; the printed reaction produces helium-3 and a neutron. Thus fission proceeds by splitting a heavy nucleus, whereas fusion proceeds by combining light nuclei. In both processes the released energy corresponds to a decrease in the total rest mass of the reacting system.

Step 2: Compare the conditions and control Neutron-induced fission can occur when a suitable heavy nucleus absorbs a slow neutron. The emitted neutrons can cause further fissions, producing a chain reaction that can be controlled in a nuclear reactor. Ordinary thermonuclear fusion requires extremely high temperature so that light nuclei can overcome their electrostatic repulsion and approach within the range of the nuclear force. Fusion powers the Sun and other stars.

Step 3: Conclusion Fission is the splitting of a heavy nucleus and can sustain a neutron-induced chain reaction; fusion is the combining of light nuclei and requires very high temperature in a thermonuclear process.

Quick Tip to Solve: Compare the direction of nuclear change first: heavy nucleus splitting means fission, while light nuclei combining means fusion. Then compare their initiation conditions.

4(b). Deuterium undergoes fusion as per the reaction:



Find the duration for which an electric bulb of 500 W can be kept glowing by the fusion of 100 g of deuterium.

Solution:

Concept:

- The number of deuterium nuclei is $N = (m/M)N_A$, where m is the sample mass, $M = 2 \text{ g mol}^{-1}$ is its molar mass and N_A is Avogadro's constant.
- Each stated fusion reaction consumes two deuterium nuclei and releases 3.27 MeV. For a bulb of constant power P , the operating time is $t = E/P$, where E is the total available energy.

Step 1: Count the fusion reactions The sample contains $100/2 = 50$ moles of deuterium nuclei. Using the printed value $N_A = 6.023 \times 10^{23} \text{ mol}^{-1}$,

$$N = 50(6.023 \times 10^{23}) = 3.0115 \times 10^{25}.$$

Since two nuclei are consumed per reaction, the number of reactions is

$$N_r = \frac{N}{2} = 1.50575 \times 10^{25}.$$

Step 2: Calculate the energy in joules Convert the energy per reaction using $1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J}$:

$$E_r = 3.27(1.6 \times 10^{-13}) = 5.232 \times 10^{-13} \text{ J}.$$

For complete fusion of the sample through the stated reaction,

$$E = N_r E_r = (1.50575 \times 10^{25})(5.232 \times 10^{-13}) = 7.878084 \times 10^{12} \text{ J}.$$

Step 3: Relate the energy to the bulb power Assume all the released fusion energy is available as electrical energy to the bulb, since no conversion efficiency is specified. A 500 W bulb consumes 500 J each second, so

$$t = \frac{E}{P} = \frac{7.878084 \times 10^{12}}{500} = 1.5756168 \times 10^{10} \text{ s}.$$

Dividing by $365 \times 24 \times 3600 \text{ s}$ per year gives approximately 499.6 years.

Step 4: Conclusion The bulb can glow for approximately $1.58 \times 10^{10} \text{ s}$, or 500 years, assuming complete fuel use and conversion of the released energy into electrical energy.

Quick Tip to Solve: Divide the number of deuterium nuclei by two before multiplying by 3.27 MeV: that energy is released per pair, not per nucleus. Convert to joules before using $t = E/P$.

5. Answer the following, giving reason:

- (a) The resistance of a p-n junction is low when it is forward biased and is high when it is reverse biased.
- (b) Doping of intrinsic semiconductors is a necessity for making electronic devices.
- (c) Photodiodes are operated in reverse bias. [3 marks]

Solution:

Concept:

- A p-n junction has a depletion layer and a potential barrier. Applied bias changes the barrier and hence the ease with which charge carriers cross the junction.
- Semiconductor conductivity is $\sigma = e(n\mu_e + p\mu_h)$, where n, p are electron and hole concentrations and μ_e, μ_h their mobilities. Doping controls the carrier concentrations.
- In a photodiode, absorbed photons of sufficient energy create electron-hole pairs. The junction electric field separates these carriers and produces a photocurrent.

Step 1: (a) Compare the barrier under the two biases Forward bias opposes the built-in junction potential, lowers the potential barrier and narrows the depletion layer. Majority carriers can cross the junction readily, so even a small increase in forward voltage produces a large current. The junction therefore offers low resistance in its conducting forward-bias region.

Reverse bias reinforces the built-in potential, raises the barrier and widens the depletion layer. Majority-carrier diffusion is suppressed; only a small minority-carrier reverse current flows. Thus the reverse resistance is high, provided the applied voltage is below breakdown.

Step 2: (b) Explain why controlled doping is needed A pure intrinsic semiconductor has a low carrier concentration at ordinary temperature, so its conductivity is relatively low. Adding a small, controlled quantity of a suitable impurity supplies many additional electrons or holes and increases conductivity. Pentavalent donors produce n-type material and trivalent acceptors produce p-type material. Doping therefore provides the controlled conductivity and the p-type and n-type regions needed to form junctions in devices such as diodes and transistors.

Step 3: (c) Relate reverse bias to light detection In reverse bias, the dark current is small. Light creates additional electron-hole pairs in or near the depletion region, and its electric field sweeps electrons towards the n-side and holes towards the p-side. The resulting increase in reverse current depends on incident light intensity. Because the background current is small, this light-induced change is readily detected; in forward bias it would be difficult to distinguish from the much larger majority-carrier current.

Step 4: Conclusion (a) Forward bias reduces the barrier and allows a large current; reverse bias increases it and permits only a small current. (b) Doping gives controllable conductivity and the required p-type and n-type regions. (c) Reverse bias makes the light-induced current easy to measure against a small dark current.

Quick Tip to Solve: For bias questions, track the barrier and depletion width first; for photodiodes, compare the photocurrent with the small reverse dark current.

6. (a) In Geiger-Marsden experiment, calculate the distance of closest approach for an alpha particle with energy 2.56×10^{-12} J. Consider that the particle approaches the gold nucleus ($Z = 79$) in head-on position.

(b) If the above experiment is repeated with a proton of the same energy, then what will be the value of the distance of closest approach? [3 marks]

Solution:

Concept:

- In a head-on approach to a heavy nucleus, a positively charged projectile slows under electrostatic repulsion. At the turning point its initial kinetic energy has become electrostatic potential energy, taking the initial separation as very large and neglecting nuclear recoil.
- For a projectile of charge q approaching a nucleus of charge Ze , energy conservation gives $K = kZe q/r_{\min}$, where $k = 1/(4\pi\epsilon_0)$ and $r_{\min}$ is the centre-to-centre distance of closest approach.

Step 1: (a) Write the energy balance for the alpha particle An alpha particle has charge $+2e$, and the gold nucleus has charge $+79e$. In a head-on encounter, the alpha particle momentarily stops before reversing direction. Therefore,

$$K = \frac{k(79e)(2e)}{r_{\alpha}}, \quad r_{\alpha} = \frac{2k(79)e^2}{K}.$$

This distance is measured from the centre of the gold nucleus; it is not the distance travelled by the alpha particle.

Step 2: Substitute the given kinetic energy Use $K = 2.56 \times 10^{-12}$ J, $e = 1.6 \times 10^{-19}$ C and $k =$

$9 \times 10^9 \text{ N m}^2 \text{C}^{-2}$. Then

$$\begin{aligned} r_\alpha &= \frac{2(9 \times 10^9)(79)(1.6 \times 10^{-19})^2}{2.56 \times 10^{-12}} \\ &= \frac{3.64032 \times 10^{-26}}{2.56 \times 10^{-12}} \text{ m} \\ &= 1.422 \times 10^{-14} \text{ m}. \end{aligned}$$

The units reduce to metres because the numerator kq_1q_2 has units of energy times length.

Step 3: (b) Replace the alpha particle by a proton A proton has charge $+e$, half the alpha particle's charge. The target nucleus and the incident kinetic energy remain unchanged, so $r_{\min}$ is proportional to the projectile charge:

$$\begin{aligned} r_p &= \frac{k(79)e^2}{K} = \frac{r_\alpha}{2} \\ &= 7.11 \times 10^{-15} \text{ m}. \end{aligned}$$

Its smaller charge produces weaker repulsion, allowing it to approach closer. The different mass changes the initial speed at the same kinetic energy, but does not enter this energy-balance expression.

Step 4: Conclusion The distances of closest approach are (a) $r_\alpha \simeq 1.42 \times 10^{-14} \text{ m}$ for the alpha particle and (b) $r_p = 7.11 \times 10^{-15} \text{ m}$ for the proton.

Quick Tip to Solve: At fixed target charge and kinetic energy, use $r_{\min} \propto q$: replacing an alpha particle by a proton halves the closest-approach distance.

7. Briefly explain how bright and dark fringes are formed on the screen in Young's double slit experiment. Hence, derive the expression for the fringe width. [3 marks]

Solution:

Concept:

- Two narrow coherent slits emit waves of the same wavelength λ with a constant phase difference. Their overlapping waves produce interference on the screen.
- For two in-phase sources, constructive interference occurs at path difference $n\lambda$; destructive interference occurs at $(n + \frac{1}{2})\lambda$, where n is an integer.
- Fringe width β is the distance between consecutive bright fringes or consecutive dark fringes. Let d be the slit separation and D the distance of the screen from the slits.

Step 1: Explain the formation of bright and dark fringes Illuminate the two slits with the same monochromatic source so that they act as coherent, in-phase sources. At a point where the waves arrive in phase, their displacements reinforce, producing a bright fringe. At a point where they arrive in opposite phase, their displacements cancel, producing a dark fringe. Complete darkness requires equal amplitudes at that point; with unequal amplitudes the minimum has a nonzero intensity. The alternating maxima and minima form the fringe pattern. The point equidistant from the two slits is the central bright fringe because its path difference is zero.

Step 2: Relate path difference to position on the screen Let a point P lie a transverse distance y from the central maximum and let its direction make a small angle θ with the central axis. For $D \gg d$ and

$|y| \ll D$, the rays are nearly parallel and the small-angle approximation gives

$$\Delta = d \sin \theta \simeq d \tan \theta = \frac{dy}{D}.$$

The corresponding phase difference is $\phi = 2\pi\Delta/\lambda$. Thus $\phi = 2n\pi$ produces a bright fringe, while $\phi = (2n + 1)\pi$ produces a dark fringe.

Step 3: Find the separation of successive fringes Applying the constructive-interference condition gives the position of the n th bright fringe:

$$\frac{dy_n}{D} = n\lambda, \quad y_n = \frac{n\lambda D}{d}.$$

Therefore the separation of two consecutive bright fringes is

$$\beta = y_{n+1} - y_n = \frac{(n+1)\lambda D - n\lambda D}{d} = \frac{\lambda D}{d}.$$

Similarly, dark fringes occur at $y_n^{\text{dark}} = (n + \frac{1}{2})\lambda D/d$, so consecutive dark fringes have the same separation. The pattern is equally spaced within the small-angle region.

Step 4: Conclusion Bright and dark fringes arise from constructive and destructive interference, respectively. The fringe width is $\beta = \lambda D/d$; it increases with wavelength and screen distance, and decreases with slit separation.

Quick Tip to Solve: Subtract the positions of two successive bright fringes to find the fringe width; the distance from a bright fringe to its neighbouring dark fringe is only $\beta/2$.

8(a). (i) Draw a labelled ray diagram showing the formation of the image at infinity by an astronomical telescope.

(ii) A telescope consists of an objective of focal length 150 cm and an eyepiece of focal length 6.0 cm. If the final image is formed at infinity, then calculate:

(I) the length of the tube in this adjustment, and

(II) the magnification produced.

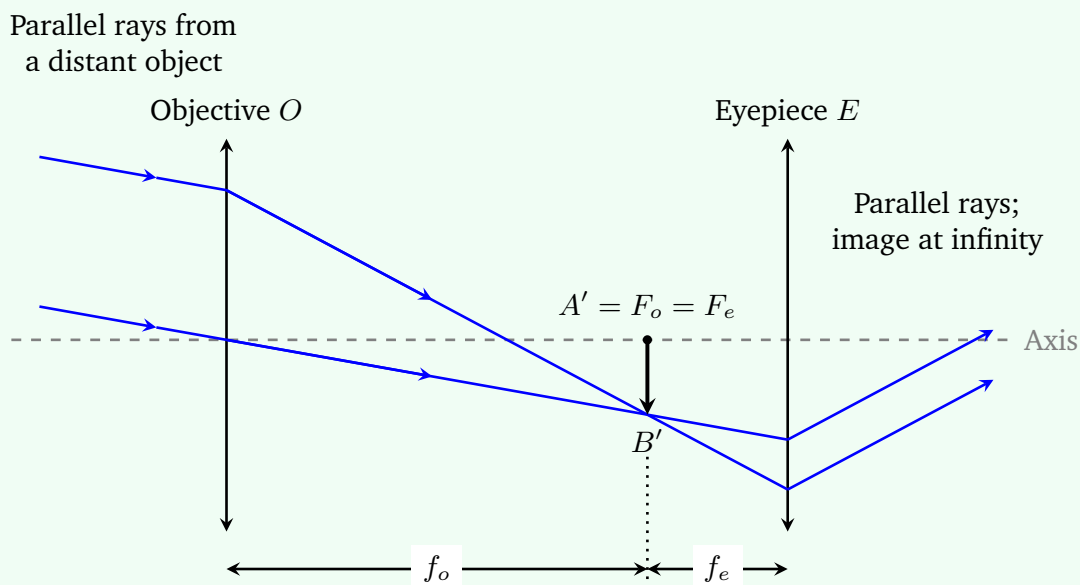
[3 marks]

Solution:

Concept:

- An astronomical telescope uses a convex objective of large focal length f_o and a convex eyepiece of small focal length f_e . The objective forms a real, inverted intermediate image of a distant object.
- In normal adjustment, this intermediate image lies in the first focal plane of the eyepiece. The emergent rays are parallel and the final virtual image is at infinity.
- For a final image at infinity, the lens separation is $L = f_o + f_e$ and the angular magnification is $M = -f_o/f_e$. The negative sign indicates inversion relative to the distant object.

Step 1: Draw the telescope in normal adjustment Parallel rays from a distant off-axis point fall on the objective O and converge at B' in its focal plane. The real intermediate image $A'B'$ is inverted. Place the eyepiece E so that its first focal plane coincides with this image plane: $F_o = F_e = A'$. The rays then emerge as a parallel bundle from the eyepiece, corresponding to a final image at infinity. The drawing shows two rays from the same distant point; the focal lengths are schematic and are not drawn to the numerical scale.



Astronomical telescope in normal adjustment; F_o and F_e coincide. Ray geometry is schematic.

Step 2: Calculate the tube length The intermediate image is f_o to the right of the objective and f_e to the left of the eyepiece. Hence their separation is the sum of the two focal lengths. With $f_o = 150$ cm and $f_e = 6.0$ cm,

$$L = f_o + f_e = 150 + 6.0 = 156 \text{ cm} = 1.56 \text{ m}.$$

Step 3: Calculate the angular magnification If the intermediate image has height of magnitude h , the small angles subtended at the objective and eyepiece have magnitudes $|\alpha| \simeq h/f_o$ and $|\beta| \simeq h/f_e$. Their ratio gives the magnifying power, with a negative sign for the inverted image:

$$M = -\frac{f_o}{f_e} = -\frac{150}{6.0} = -25.$$

Thus the apparent angular size is increased by a factor of 25. Angular magnification is dimensionless; it is not the linear magnification of the intermediate image.

Step 4: Conclusion In normal adjustment the final image is at infinity, the tube length is 156 cm, and the angular magnification is $M = -25$ (magnifying power 25, with an inverted final image).

Quick Tip to Solve: For an astronomical telescope adjusted to infinity, add the focal lengths for tube length and divide objective focal length by eyepiece focal length for magnifying power.

8(b). (i) Draw a labelled ray diagram showing the formation of the image at least distance of distinct vision by a compound microscope.

(ii) A small object is placed at a distance of 3.0 cm from a magnifier of focal length 4.0 cm. Find:

(I) the position of the image formed, and

(II) the linear magnification produced.

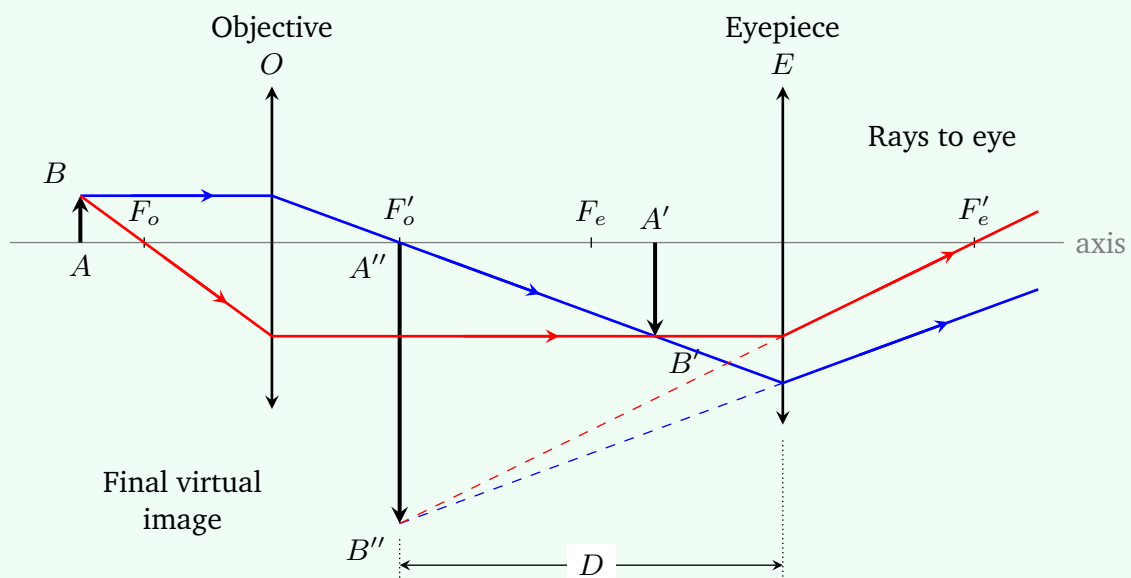
[3 marks]

Solution:

Concept:

- In a compound microscope the objective forms a real, inverted, enlarged intermediate image. The eyepiece acts as a magnifier; to form the final virtual image at the near point, its object must lie between the eyepiece and its first focus.
- For a thin lens, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$, where u and v are signed object and image distances from the optical centre and f is the focal length.
- Linear magnification is $m = \frac{h_i}{h_o} = \frac{v}{u}$. A positive value means an erect image; its magnitude gives the ratio of image height to object height.

Step 1: (i) Construct the microscope image at the near point Place the small object AB just beyond the objective's first focus F_o . The objective O forms the enlarged, real and inverted image $A'B'$. Adjust the eyepiece E so that $A'B'$ lies inside its focal length, between F_e and E . Rays reaching the eye diverge after refraction through the eyepiece. Their backward extensions intersect at B'' , giving the enlarged virtual image $A''B''$, inverted relative to the original object. The final image is at the least distance of distinct vision D , conventionally 25 cm, from the eye taken close to the eyepiece. Solid lines represent actual rays and dashed lines their backward extensions; the drawing is schematic.



Compound microscope adjusted for the final image at the near point D .

Step 2: (ii) (I) Apply the lens formula to the separate magnifier The magnifier is a converging lens, so $f = +4.0$ cm. Take incident light from left to right. The real object lies to its left, giving $u = -3.0$ cm.

Thus

$$\begin{aligned}\frac{1}{v} &= \frac{1}{f} + \frac{1}{u} \\ &= \frac{1}{4.0} - \frac{1}{3.0} = -\frac{1}{12} \text{ cm}^{-1}.\end{aligned}$$

The negative image distance signifies an image on the same side of the lens as the object. This is consistent with the object being inside the focal length, which produces a virtual image.

Step 3: (ii)(II) Calculate the linear magnification Use the signed distances in the height magnification relation:

$$m = \frac{v}{u} = \frac{-12}{-3.0} = +4.0.$$

Both distances are negative, hence the image is erect relative to this magnifier's object. The ratio is dimensionless because the distances are expressed in the same unit. This is linear magnification, so no near-point angular-magnification formula is needed for this numerical part.

Step 4: Conclusion The microscope ray diagram shows a virtual, enlarged final image at D , inverted relative to AB . For the separate magnifier, $v = -12 \text{ cm}$: the image is 12 cm from the lens on the object's side. Its linear magnification is $m = +4.0$, so it is virtual, erect and four times the object's height.

Quick Tip to Solve: Since $3.0 \text{ cm} < 4.0 \text{ cm}$, expect a virtual erect image before calculating. Retain negative u and v when evaluating $m = v/u$.

9. (a) Use Einstein's photoelectric equation to depict the variation of the maximum kinetic energy (E_k) of electrons emitted, with the frequency (ν) of the incident radiation.

(b) A photosensitive surface is illuminated with a beam of (i) yellow light, and (ii) red light, both of the same intensity. In which case will

(I) photoelectrons have more E_k ?

(II) more number of electrons be emitted?

Justify your answer in each case.

[3 marks]

Solution:

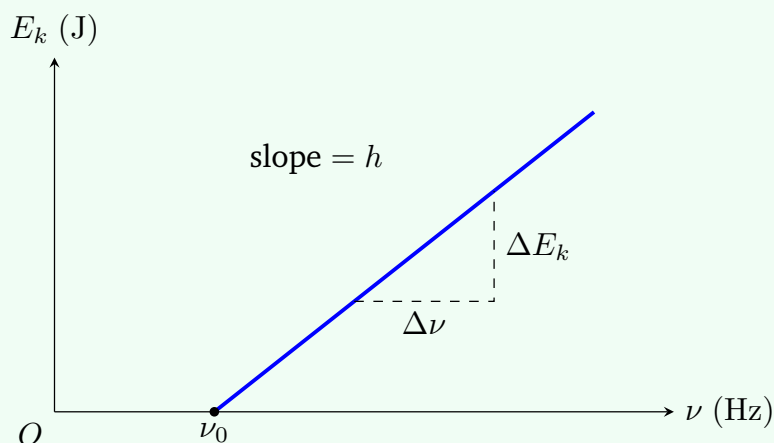
Concept:

- Einstein's photoelectric equation is $E_k = h\nu - \phi = h(\nu - \nu_0)$, where h is Planck's constant, ϕ is the work function and $\nu_0 = \phi/h$ is the threshold frequency.
- A photon transfers its energy to one electron. Intensity I is incident energy per unit area per second, so the photon flux is $I/(h\nu)$.

Step 1: (a) Plot maximum kinetic energy against frequency For a fixed photosensitive surface, ϕ remains constant. Thus the equation has the straight-line form $y = mx + c$, with frequency on the horizontal axis and maximum kinetic energy on the vertical axis:

$$E_k = h\nu - \phi, \quad \frac{dE_k}{d\nu} = h.$$

The physical graph starts at $(\nu_0, 0)$ and rises linearly with slope h . For $\nu < \nu_0$, no photoelectrons are emitted; a negative kinetic energy is not a physical continuation of the graph.



Maximum photoelectron kinetic energy versus incident frequency

Step 2: (b)(I) Compare the maximum kinetic energies Yellow light has a shorter wavelength and hence a higher frequency than red light: $\nu_y > \nu_r$. Assuming both frequencies exceed the surface's threshold, subtraction of Einstein's equations gives

$$E_{k,y} - E_{k,r} = h(\nu_y - \nu_r) > 0.$$

The higher photon energy supplies more energy to the electron after the same work function has been overcome. Equal intensity does not make the individual photon energies equal.

Step 3: (b)(II) Compare emission for equal incident intensity For equal illuminated area A and exposure time t , both beams deliver energy IAt . Under the ideal one-photon photoemission model, with the same emission efficiency for the two colours, the emitted number is proportional to the incident photon number:

$$N_y \propto \frac{IAt}{h\nu_y}, \quad N_r \propto \frac{IAt}{h\nu_r}, \quad \frac{N_r}{N_y} = \frac{\nu_y}{\nu_r} > 1.$$

Red photons carry less energy, so equal radiant intensity supplies more of them. This comparison assumes that red light also exceeds the threshold; if only yellow is above threshold, red produces no photoemission. For a real surface, wavelength-dependent emission efficiency would also be needed for an exact electron-count comparison.

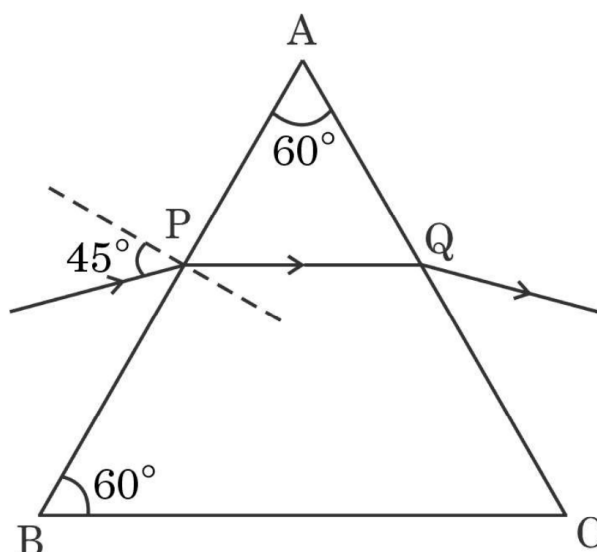
Step 4: Conclusion (a) The E_k -versus- ν graph is a straight line of slope h starting at ν_0 . (b)(I) Yellow light produces the greater maximum kinetic energy. (II) In the ideal equal-efficiency model, red light emits more electrons at the same radiant intensity, provided both colours are above threshold.

Quick Tip to Solve: Use $h\nu - \phi$ to compare electron energies, but use $I/(h\nu)$ to count photons at fixed radiant intensity; check the threshold first.

10. A ray of light is incident on a prism at an angle of 45° and passes symmetrically as shown in the figure. Calculate:

- the angle of minimum deviation,
- the refractive index of the material of the prism, and
- the angle of refraction at the point P.

[3 marks]



Solution:

Concept:

- In a prism, $r_1 + r_2 = A$ and the deviation is $\delta = i + e - A$, where A is the prism angle, i, e are the external angles and r_1, r_2 are the internal refraction angles, measured from the face normals.
- Symmetric passage is the minimum-deviation condition: $i = e$, $r_1 = r_2 = A/2$. For a prism in air, Snell's law gives $\mu = \sin i / \sin r_1$.

Step 1: Identify the symmetric path The diagram gives the apex angle $A = 60^\circ$ and the incident angle $i = 45^\circ$, measured between the incident ray and the dashed normal at P. Since the ray passes symmetrically through the prism, the emergence angle equals the incidence angle:

$$e = i = 45^\circ, \quad r_1 = r_2 = \frac{A}{2} = 30^\circ.$$

The internal angles are equal because the same optical path is obtained when the incident and emergent rays are interchanged.

Step 2: (a) Calculate the minimum deviation Add the bending at the two refracting faces. Since $r_1 + r_2 = A$, the total deviation in the symmetric position is

$$\begin{aligned} \delta_m &= (i - r_1) + (e - r_2) \\ &= i + e - A \\ &= 45^\circ + 45^\circ - 60^\circ = 30^\circ. \end{aligned}$$

The symmetric path is the minimum-deviation path, so this value is δ_m , rather than an arbitrary deviation.

Step 3: (b) Calculate the refractive index Apply Snell's law at the air-prism boundary at P, taking the

refractive index of air as unity:

$$\begin{aligned}\mu &= \frac{\sin i}{\sin r_1} = \frac{\sin 45^\circ}{\sin 30^\circ} \\ &= \frac{1/\sqrt{2}}{1/2} = \sqrt{2} \approx 1.414.\end{aligned}$$

This also agrees with the prism formula $\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$. Refractive index is a ratio, so it has no unit.

Step 4: (c) State the refraction angle at P The requested angle is between the refracted ray inside the prism and the normal to face AB at P. It is r_1 , already fixed by symmetry:

$$r_P = r_1 = \frac{60^\circ}{2} = 30^\circ.$$

The complementary angle between the refracted ray and the prism face is 60° ; it must not be confused with the angle of refraction.

Step 5: Conclusion (a) $\delta_m = 30^\circ$. (b) $\mu = \sqrt{2} \approx 1.414$. (c) The angle of refraction at P is 30° , measured from the normal.

Quick Tip to Solve: For symmetric passage, first write $e = i$ and $r_1 = r_2 = A/2$; these immediately give both the deviation and the Snell's-law substitution.

11(a). Identify electromagnetic waves which:

- (i) are used in radar system.
- (ii) affect a photographic plate.
- (iii) are used in surgery.

Write their frequency range.

[3 marks]

Solution:

Concept:

- Electromagnetic waves form a continuous spectrum. Their vacuum frequency ν and wavelength λ obey $\nu = c/\lambda$, where $c = 3 \times 10^8 \text{ m s}^{-1}$.
- The named spectral bands have approximate boundaries. Their interaction with matter determines which band is useful for radar, photography or surgical treatment.

Step 1: Identify the waves used in radar (i) **Microwaves** are used in radar systems. Their short wavelengths permit directed beams, and the reflected pulse locates the target. A usual microwave wavelength range is about 0.3 m to 10^{-3} m, giving the approximate frequency range

$$10^9 \text{ Hz to } 3 \times 10^{11} \text{ Hz.}$$

Step 2: Identify the waves that expose photographic plates (ii) **Visible light** affects an ordinary photographic plate through its photochemical action on the light-sensitive coating. Taking visible wavelengths as approximately 700 nm to 400 nm, its frequency range is

$$4.3 \times 10^{14} \text{ Hz to } 7.5 \times 10^{14} \text{ Hz.}$$

Sensitivity of photographic material is not confined to visible light: ultraviolet and X-rays can also

expose suitable plates. Visible light is the conventional identification for ordinary photography here.

Step 3: Identify the waves used for surgical treatment (iii) **Gamma rays** are used in radiosurgery, where focused high-energy radiation treats diseased tissue. Using a conventional gamma-ray wavelength boundary of about 10^{-11} m, their frequency range is approximately

$$\nu \gtrsim 3 \times 10^{19} \text{ Hz.}$$

The upper end has no fixed spectral cutoff. The term surgery also covers procedures using other bands, such as ultraviolet laser eye surgery; gamma rays specifically identify the radiosurgical application.

Step 4: Conclusion Suitable identifications are (i) microwaves, (ii) visible light and (iii) gamma rays, with the approximate frequency ranges stated above.

Quick Tip to Solve: Convert each remembered wavelength boundary with $\nu = c/\lambda$; the shorter wavelength always gives the higher frequency.

OR

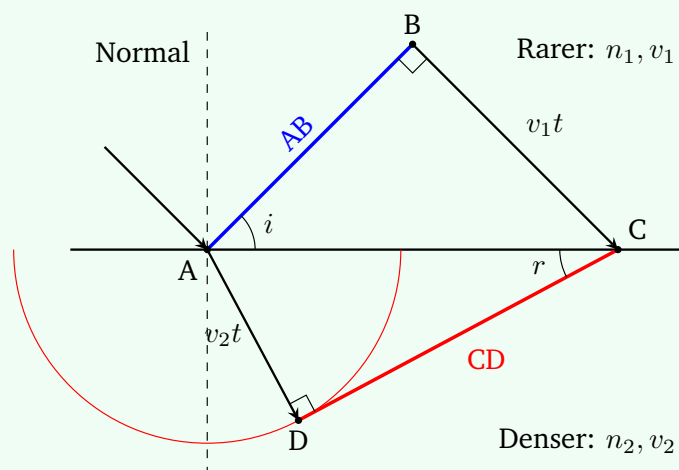
11(b). A plane wavefront is propagating from a rarer into a denser medium. Use Huygens principle to show the refracted wavefront and verify Snell's law. [3 marks]

Solution:

Concept:

- Every point on a wavefront acts as a source of secondary wavelets. The forward common tangent to the wavelets is the new wavefront.
- Rays are normal to wavefronts. In a medium of refractive index n , the wave speed is $v = c/n$, where c is the speed in vacuum.

Step 1: Construct the incident and refracted wavefronts Let AC separate the rarer medium n_1 above from the denser medium n_2 below. Incident wavefront AB touches the boundary first at A. In time t , B reaches C, so $BC = v_1 t$. The secondary wavelet from A travels $AD = v_2 t$ into the denser medium, where $v_2 < v_1$. Draw the tangent CD from C to this wavelet: CD is the refracted wavefront, perpendicular to AD.



Huygens construction: AB is the incident wavefront and CD the refracted wavefront.

Step 2: Relate the angles to the wave speeds The angle between AB and the interface AC is equal to the incidence angle i , because the incident ray and boundary normal are respectively perpendicular to these lines. Similarly, the angle between CD and CA is the refraction angle r . Triangles ABC and ADC are right-angled at B and D respectively. Therefore,

$$\sin i = \frac{BC}{AC} = \frac{v_1 t}{AC}, \quad \sin r = \frac{AD}{AC} = \frac{v_2 t}{AC}.$$

Step 3: Obtain the refractive-index relation Dividing the two equations eliminates the common time and the shared side AC:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}.$$

As $n_2 > n_1$, this also gives $r < i$: the ray bends towards the normal on entering the denser medium.

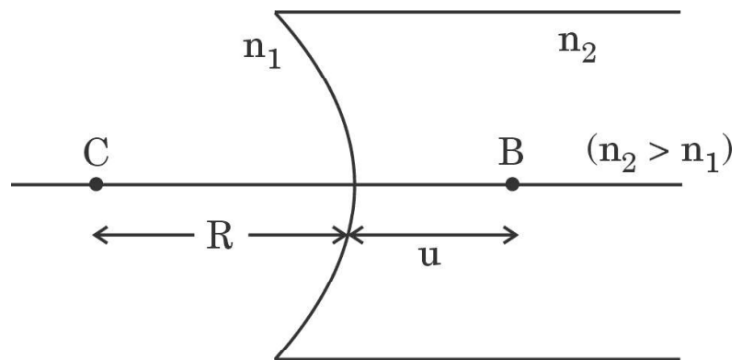
Step 4: Conclusion CD is the refracted wavefront constructed as the tangent to the secondary wavelet. The construction verifies Snell's law, $n_1 \sin i = n_2 \sin r$.

Quick Tip to Solve: Use the same travel time for BC and AD, then divide the two sine ratios; AC and the time cancel immediately.

Section C (5 marks)

12. Two transparent media of refractive indices n_1 and n_2 are separated by a spherical transparent surface. The rays of light incident on the surface get refracted into the medium on the other side. The laws of refraction are valid at each point of the spherical surface. A lens is a transparent optical medium bounded by two surfaces, at least one of which should be spherical. The focal length of a lens is determined by the radii of curvature (R_1 and R_2) of its two surfaces and the refractive index (n) of the medium of the lens with respect to the surrounding medium. Depending on R_1 and R_2 , a lens behaves as a diverging or a converging lens. The ability of a lens to diverge or converge a beam of light incident on it defines its power. [5 marks]

12(a). An object is placed at the point B as shown in the figure. The object distance (u) and the image distance (v) are related as: [1 mark]



(A) $\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2 - n_1}{n_1}\right) \frac{1}{R}$

(B) $\frac{1}{v} - \frac{1}{u} = \left(\frac{n_1 - n_2}{n_2}\right) \frac{1}{R}$

(C) $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

(D) $\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}$

Correct Answer: (D) $\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}$

Solution:**Concept:**

- Spherical refraction obeys $n_{\text{out}}/v - n_{\text{in}}/u = (n_{\text{out}} - n_{\text{in}})/R$, with Cartesian signed distances from the pole.
- The object's location identifies the incident medium; its index multiplies $1/u$.

Step 1: Identify the incident medium Object B lies in medium n_2 . Light travels from right to left into medium n_1 , so $n_{\text{in}} = n_2$ and $n_{\text{out}} = n_1$.

Step 2: Substitute the refractive indices The surface formula becomes

$$\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}.$$

Option (C) reverses the incident and refracted media. Options (A) and (B) incorrectly give equal coefficients to $1/v$ and $1/u$, although the two media have unequal indices.

Step 3: Conclusion Thus $n_1/v - n_2/u = (n_1 - n_2)/R$. Hence, the correct option is (D).

Quick Tip to Solve: Locate the object first: its medium's index multiplies $1/u$; the other medium's index multiplies $1/v$.

12(b). A point object is placed in air at a distance R in front of a convex spherical refracting surface of radius of curvature R . If the medium on the other side of the surface is glass, then the image is: [1 mark]

- (A) real and formed in glass.
- (B) real and formed in air.
- (C) virtual and formed in glass.
- (D) virtual and formed in air.

Correct Answer: (D) virtual and formed in air.

Solution:**Concept:**

- Spherical refraction obeys $n_2/v - n_1/u = (n_2 - n_1)/R$, with distances measured from the pole and positive along incident light.
- A negative image distance means that the refracted rays diverge and their backward extensions form a virtual image on the incident side.

Step 1: Assign Cartesian signs Take light as travelling from air into glass. For the real object in air, $u = -R$; the centre of curvature of the convex surface lies inside the glass, so the signed radius is $+R$. Let the refractive index of glass be n , with air of index 1.

Step 2: Calculate the image position The surface formula gives

$$\frac{n}{v} + \frac{1}{R} = \frac{n - 1}{R}, \quad v = \frac{nR}{n - 2}.$$

For ordinary glass, $n \simeq 1.5$, so $v = -3R$. The negative sign places the image in air and makes it virtual. Thus neither real-image option is possible, and a virtual image in glass would be on the wrong side of this surface.

Step 3: Conclusion The image is virtual and formed in air. Hence, the correct option is (D).

Quick Tip to Solve: Put $u = -R$ and the convex surface radius $+R$ into the surface formula before deciding which side contains the image.

12(c). An object is kept at $2F$ in front of an equiconvex lens. The image formed is:

[1 mark]

- (A) real and of the size of the object.
- (B) virtual and of the size of the object.
- (C) real and enlarged.
- (D) virtual and diminished.

Correct Answer: (A) real and of the size of the object.

Solution:

Concept:

- For a thin convex lens in air, the focal length f is positive and the lens formula is $1/f = 1/v - 1/u$, where u and v are signed object and image distances.
- The linear magnification is $m = v/u$. A negative magnification represents an inverted image, and $|m| = 1$ represents equal object and image sizes.

Step 1: Locate the image using the lens formula Choose the incident light direction as positive. An object at twice the focal distance in front of the lens has $u = -2f$. Therefore,

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{f} - \frac{1}{2f} = \frac{1}{2f}, \quad v = +2f.$$

The positive image distance places the image on the opposite side of the lens, where the refracted rays actually meet.

Step 2: Compare the size and nature with the options The magnification is

$$m = \frac{v}{u} = \frac{2f}{-2f} = -1.$$

Thus the image is inverted with the same size as the object. The virtual-image descriptions in (B) and (D) do not apply because the refracted rays meet. Option (C) incorrectly predicts enlargement: at this object position the magnitude of magnification is exactly unity.

Step 3: Conclusion The image is real, inverted and of the same size as the object. Hence, the correct option is (A).

Quick Tip to Solve: Memorise the convex-lens pair: an object at $2F$ produces its equal-size, inverted image at $2F$ on the other side.

12(d). A thin converging lens of focal length 10 cm and a thin diverging lens of focal length 20 cm are placed coaxially in contact. The power of the combination is: [1 mark]

- (A) -5 D
- (B) $+5\text{ D}$
- (C) $+15\text{ D}$
- (D) -15 D

Correct Answer: (B) $+5\text{ D}$

Solution:

Concept:

- The power of a thin lens is $P = 1/f$, where f is in metres and P is in dioptres (D). A converging lens has positive power, whereas a diverging lens has negative power.
- For thin lenses placed coaxially in contact, their signed powers add: $P_{\text{eq}} = P_1 + P_2$.

Step 1: Convert the signed focal lengths to metres Since the first lens converges light, its focal length is $f_1 = +10\text{ cm} = +0.10\text{ m}$. The second lens diverges light, so its focal length is $f_2 = -20\text{ cm} = -0.20\text{ m}$. Their powers are

$$P_1 = \frac{1}{0.10} = +10\text{ D}, \quad P_2 = \frac{1}{-0.20} = -5\text{ D}.$$

Step 2: Add the lens powers algebraically As the lenses are in contact,

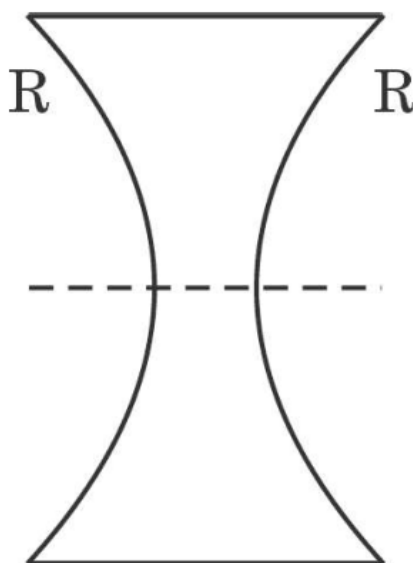
$$P_{\text{eq}} = (+10) + (-5) = +5\text{ D}.$$

The converging effect is stronger than the diverging effect, so the combination must have positive power. This eliminates (A) and (D). Option (C), $+15\text{ D}$, comes from adding the magnitudes and wrongly treating the diverging lens as converging.

Step 3: Conclusion The power of the combination is $+5\text{ D}$, so it acts as a converging lens. Hence, the correct option is (B).

Quick Tip to Solve: Put the sign on each focal length before taking its reciprocal; then add powers, never the two focal lengths.

12(e). An equiconcave lens of focal length f is cut into two identical parts along the dotted line as shown in the figure. The focal length of each part will be: [1 mark]



- (A) $\frac{f}{4}$
- (B) $\frac{f}{2}$
- (C) f
- (D) $2f$

Correct Answer: (C) f

Solution:

Concept:

- The lens-maker's formula is $1/f = (n - 1)(1/R_1 - 1/R_2)$, where n is the lens index relative to air and R_1, R_2 are signed surface radii.
- A cut along the principal axis reduces aperture but preserves the curvatures and hence focal length.

Step 1: Identify the cut direction The dotted line runs along the principal axis, separating the upper and lower halves. Each retains parts of both concave refracting surfaces; neither face becomes plane in the direction of light propagation.

Step 2: Compare the lens powers For the original lens and either half, $R_1 = -R$, $R_2 = +R$ and the material are unchanged. Thus

$$\frac{1}{f_{\text{half}}} = (n - 1) \left(-\frac{1}{R} - \frac{1}{R} \right) = \frac{1}{f}.$$

Aperture reduction does not increase power, excluding (A) and (B). Option (D) would require a perpendicular cut into plano-concave lenses.

Step 3: Conclusion Each part has focal length f . Hence, the correct option is (C).

Quick Tip to Solve: Check the cut direction: along the axis preserves both curvatures; perpendicular to it replaces one curved face.