

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/4/2

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

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

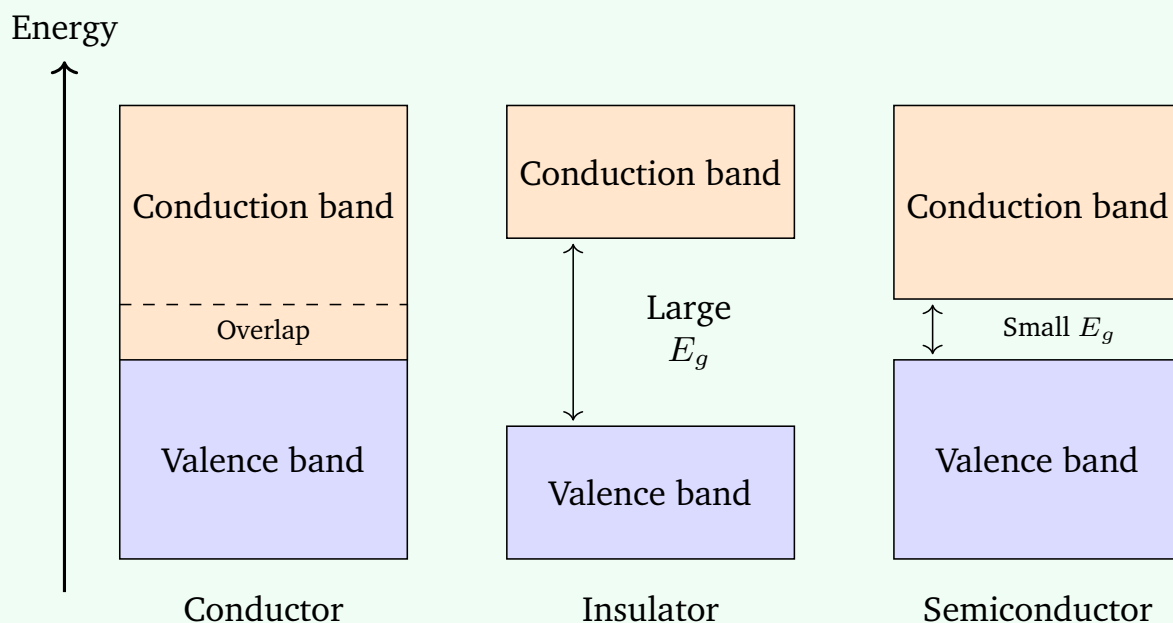
Solution:

Concept:

- A band is a range of allowed electron energies in a solid. The valence band contains valence electrons, while electrons in the conduction band can move through the solid and conduct current.
- The forbidden energy gap is $E_g = E_c - E_v$, where E_c is the lower edge of the conduction band and E_v is the upper edge of the valence band. No allowed electron energy states exist 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 acquire at least this energy to move from the valence band to the conduction band when the bands are separated.

Step 2: Compare the three band diagrams In a conductor, the valence and conduction bands overlap (or an allowed band is partially filled), so electrons can access nearby empty states without crossing a forbidden gap. In an insulator, a large forbidden gap separates the filled valence band from the empty conduction band, so ordinary thermal energy cannot readily excite electrons across it. In a semiconductor, the forbidden gap is small, typically of order 1 eV; some electrons can cross it at ordinary temperatures and leave holes in the valence band. The diagrams show these three cases with energy increasing upwards.



Energy band diagrams for a conductor, an insulator and a semiconductor; shaded rectangles represent allowed bands.

Step 3: Conclusion The energy band gap is the forbidden interval $E_g = E_c - E_v$ between the valence and conduction bands. A conductor has overlapping bands, an insulator has a large gap and a semiconductor has a small gap, as shown.

Quick Tip to Solve: Draw energy upwards and compare the separation of the two bands: overlap, large gap and small gap.

2. Name the device which converts an ac input signal into a dc output signal. Write the principle of working of the device. [2 marks]

Solution:

Concept:

- Rectification is the conversion of an alternating input into a unidirectional output. A rectifier uses one or more semiconductor p - n junction diodes.
- A diode conducts readily when forward biased because its junction barrier is reduced. It offers very high resistance under reverse bias because its barrier is increased, provided reverse breakdown is not reached.

Step 1: Identify the device The device is a rectifier, based on a semiconductor junction diode. Its operation depends on the strongly different conductivities of the diode in forward and reverse bias; this makes current through the load flow in only one direction.

Step 2: Explain its working principle For a simple half-wave rectifier, during the half-cycle that makes the diode forward biased, it conducts and a voltage appears across the load. During the opposite half-cycle, the diode is reverse biased and practically blocks current, so the load output is nearly zero. The resulting output is unidirectional, or pulsating dc. A full-wave rectifier uses both half-cycles while maintaining the same load-current direction. A filter may be added to smooth the pulsations if a steadier dc output is needed.

Step 3: Conclusion A rectifier converts ac into dc. It works on the principle that a semiconductor junction diode conducts in forward bias and practically blocks current in reverse bias, producing a unidirectional output.

Quick Tip to Solve: Link rectification directly to the diode's unequal forward and reverse resistance; remember that its raw output is pulsating dc.

3(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 consists of hydrogen transitions from initial 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 $1/\lambda = R_H(1/n_f^2 - 1/n^2)$, where R_H is the hydrogen Rydberg constant and λ is the emitted wavelength.

Step 1: Identify the longest wavelength In the Balmer series the smallest photon energy corresponds to the smallest possible energy gap, namely the transition $n = 3 \rightarrow 2$. Since $E = hc/\lambda$, this gives the maximum wavelength. Thus

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

Step 2: Identify the series limit and form the ratio The largest energy gap to level 2 occurs at the

series limit, as $n \rightarrow \infty$. This gives the minimum wavelength because $1/n^2 \rightarrow 0$:

$$\frac{1}{\lambda_{\min}} = \frac{R_H}{4}, \quad \lambda_{\min} = \frac{4}{R_H}.$$

Therefore $\lambda_{\max}/\lambda_{\min} = (36/5R_H)/(4/R_H) = 9/5$. The same Rydberg constant cancels, so its numerical value is unnecessary.

Step 3: Conclusion The series is the **Balmer series**, and $\lambda_{\max} : \lambda_{\min} = 9 : 5$. The longest line is $3 \rightarrow 2$, while the shortest wavelength is the $\infty \rightarrow 2$ series limit.

Quick Tip to Solve: For a spectral series, use the first allowed transition for the longest wavelength and the infinite initial level for the shortest.

OR

3(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 de Broglie waves associated with moving material particles. Their 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 magnitude q , accelerated from rest through a potential difference V , gains kinetic energy $K = qV$. In the nonrelativistic approximation, $p = \sqrt{2mqV}$.

Step 1: Relate wavelength to the accelerating potential Combining $p^2/(2m) = qV$ with the de Broglie relation gives

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

Matter waves represent the wave behaviour of material particles; they are not electromagnetic waves emitted by the moving particle. For the proton, $q_p = e$ and mass is m_p , so $\lambda_p = h/\sqrt{2m_p e V}$.

Step 2: Include both the alpha-particle mass and charge An alpha particle is a helium nucleus with approximately four times the proton mass and twice its charge: $m_\alpha \simeq 4m_p$, $q_\alpha = 2e$. The two particles experience the same potential difference, but the alpha particle gains twice the kinetic energy. Hence

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

Planck's constant and the common potential difference cancel from the ratio.

Step 3: Conclusion Matter waves are de Broglie waves associated with moving material particles. The required ratio is $\lambda_p : \lambda_\alpha = 2\sqrt{2} : 1$, using the standard nonrelativistic approximation and $m_\alpha \simeq 4m_p$.

Quick Tip to Solve: At equal accelerating voltage compare the product of mass and charge, since wavelength is inversely proportional to its square root.

Section B (24 marks)

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

(b) Deuterium undergoes fusion as per the reaction: ${}^2_1\text{H} + {}^2_1\text{H} \rightarrow {}^3_2\text{He} + {}^1_0\text{n} + 3.27 \text{ MeV}$. Find the duration for which an electric bulb of 500 W can be kept glowing by the fusion of 100 g of deuterium. [3 marks]

Solution:

Concept:

- Nuclear fission splits a heavy nucleus into lighter nuclei, whereas nuclear fusion combines light nuclei into a heavier nucleus. Both can release energy when the products have greater binding energy per nucleon.
- For the printed fusion reaction, two deuterium nuclei are consumed for every 3.27 MeV released. The number of nuclei in mass M is $N = (M/M_{\text{mol}})N_A$, where M_{mol} is the molar mass and N_A is Avogadro's constant.
- Electrical power is energy consumed per unit time, $P = E/t$. Use $1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$ and assume complete fusion and complete conversion of the released energy into electrical energy.

Step 1: (a) Distinguish fission and fusion In fission, a heavy nucleus such as uranium splits into two lighter nuclei, usually with neutrons and energy released. The emitted neutrons can produce a chain reaction; fission can be initiated by neutron absorption. In fusion, light nuclei such as hydrogen isotopes join to form a heavier nucleus and release energy. Fusion requires very high temperature to give nuclei enough energy to overcome their electrostatic repulsion. Thus their essential difference is the splitting of a heavy nucleus versus the combination of light nuclei.

Step 2: (b) Count the fusion reactions Taking the deuterium molar mass as 2 g mol^{-1} , the number of deuterium nuclei in 100 g is

$$N = \frac{100}{2} \times 6.022 \times 10^{23} = 3.011 \times 10^{25}.$$

The reaction consumes two deuterium nuclei, so the number of reactions is $N/2 = 1.5055 \times 10^{25}$, not N .

Step 3: Calculate the total energy and bulb duration The energy released per reaction and the total available energy are

$$\begin{aligned} E_r &= 3.27 \times 1.602 \times 10^{-13} = 5.23854 \times 10^{-13} \text{ J}, \\ E &= (1.5055 \times 10^{25})(5.23854 \times 10^{-13}) \simeq 7.887 \times 10^{12} \text{ J}. \end{aligned}$$

A 500 W bulb consumes 500 J each second. Therefore

$$t = \frac{E}{P} = \frac{7.887 \times 10^{12}}{500} \simeq 1.58 \times 10^{10} \text{ s}.$$

Dividing by $365 \times 24 \times 3600 \text{ s}$ per year gives approximately 500 years. This is the ideal duration under the stated complete-conversion assumption.

Step 4: Conclusion Fission splits a heavy nucleus; fusion joins light nuclei. Fusion of 100 g of deuterium supplies approximately 7.89×10^{12} J, so the 500 W bulb can glow for 1.58×10^{10} s $\approx$ 500 years, ideally.

Quick Tip to Solve: Divide the number of deuterium nuclei by two before multiplying by the reaction energy; each fusion event consumes two nuclei.

5. (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, electrostatic repulsion slows a positively charged projectile. At its turning point, its initial kinetic energy K has been converted into electrostatic potential energy, taking the initial separation as very large and neglecting recoil of the heavy gold nucleus.
- For projectile charge ze and nuclear charge Ze , $K = kze^2/r_{\min}$, where $k = 1/(4\pi\epsilon_0) = 9.0 \times 10^9 \text{ N m}^2\text{C}^{-2}$, $e = 1.6 \times 10^{-19} \text{ C}$, and $r_{\min}$ is the distance of closest approach.

Step 1: (a) Apply energy conservation to the alpha particle An alpha particle carries charge $+2e$, while a gold nucleus carries charge $+79e$. At closest approach the alpha particle momentarily stops, so its kinetic energy there is zero. Conservation of energy therefore gives

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

Using the given energy $K = 2.56 \times 10^{-12}$ J,

$$\begin{aligned} r_\alpha &= \frac{2(9.0 \times 10^9)(79)(1.6 \times 10^{-19})^2}{2.56 \times 10^{-12}} \\ &= 1.422 \times 10^{-14} \text{ m}. \end{aligned}$$

This is the separation of the projectile and nucleus at the turning point; it is not a measurement of the radius of the gold nucleus.

Step 2: (b) Repeat for the proton at the same energy A proton has charge $+e$, half the alpha particle's charge. The nuclear charge and incident kinetic energy are unchanged. Thus

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

The proton can approach more closely because its repulsive potential energy at any fixed separation is

half that of the alpha particle. The projectile mass does not enter this turning-point calculation when its kinetic energy, rather than its speed, is specified.

Step 3: Conclusion (a) The alpha particle's distance of closest approach is 1.42×10^{-14} m. (b) For the proton of the same energy, it is 7.11×10^{-15} m, half the alpha-particle value.

Quick Tip to Solve: For fixed nuclear charge and incident energy, closest approach is proportional to projectile charge: replacing an alpha particle by a proton halves the distance.

6. 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 reversed 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 region and a built-in potential barrier. Bias changes the width of this region and the barrier faced by majority carriers, thereby changing junction current and effective resistance.
- Doping controls the concentration of mobile charge carriers and hence conductivity. Illumination creates additional electron-hole pairs that can contribute to current.

Step 1: (a) Explain the resistance under forward and reverse bias Under forward bias the p side is connected to the positive terminal and the n side to the negative terminal. The applied field opposes the junction's built-in field, reduces the potential barrier and narrows the depletion layer. Majority carriers can cross the junction readily, so a substantial current flows for a small applied voltage and the junction offers low resistance.

Under reverse bias the connections are reversed. The applied field reinforces the built-in field, raises the potential barrier and widens the depletion layer. Majority carriers are drawn away from the junction, suppressing their current. Only a very small minority-carrier current flows, so the junction offers high resistance. This statement applies before reverse breakdown.

Step 2: (b) Explain why an intrinsic semiconductor is doped An intrinsic semiconductor has equal electron and hole concentrations, both comparatively small at ordinary temperatures, and hence low conductivity. Adding a controlled, small amount of impurity greatly increases the concentration of one carrier type. A pentavalent donor produces an n -type semiconductor with electrons as majority carriers, while a trivalent acceptor produces a p -type semiconductor with holes as majority carriers. Doping provides controllable conductivity and enables p - and n -type regions to form the junctions used in diodes and transistors.

Step 3: (c) Explain reverse-bias operation of a photodiode Incident photons of sufficient energy create electron-hole pairs in or near the depletion region. The strong electric field across the reverse-biased junction promptly separates these carriers: electrons move towards the n side and holes towards the

p side. Their collection produces a reverse photocurrent whose magnitude increases with incident light intensity.

The reverse dark current is small, so the additional current caused by light is easily detected. It also widens the depletion region and supports rapid carrier collection. In forward bias, the large majority-carrier current would make a small light-induced change harder to distinguish.

Step 4: Conclusion (a) Forward bias lowers the barrier and permits a large majority-carrier current; reverse bias raises it and permits only a small current. (b) Doping supplies controlled majority carriers and enables the required semiconductor junctions. (c) Reverse bias efficiently collects photogenerated carriers against a small dark-current background.

Quick Tip to Solve: Link each answer to its cause: bias changes the barrier, doping changes carrier density, and light adds carriers that the reverse-junction field collects.

7. (a) The interference pattern is not observed in Young's double slit experiment when the two sources S_1 and S_2 are far apart. Explain.

(b) Mention the conditions for the two sources to be coherent.

(c) What is the effect on the interference pattern in a Young's double slit experiment, if the source of wavelength λ is replaced by another source of wavelength 1.5λ , with the interference pattern still observable?

[3 marks]

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 separation of the two slits.
- Coherent sources emit waves of the same frequency and maintain a constant phase difference, so maxima and minima stay at fixed positions.
- For interference to be visibly resolved, neighbouring bright and dark fringes must be sufficiently separated on the screen.

Step 1: Explain the effect of widely separated slits (a) With wavelength and screen distance fixed, increasing the separation d between S_1 and S_2 decreases the fringe width:

$$\beta = \frac{\lambda D}{d}.$$

When the slits are far apart, the fringes become extremely narrow and crowded. The observing eye or detector cannot resolve adjacent bright and dark bands, and their intensities are effectively averaged. Thus a distinct interference pattern is not observed. Increasing separation does not by itself destroy coherence; the relevant reason here is that the fringe spacing becomes too small to distinguish.

Step 2: State the conditions for coherence (b) The two sources must have the same frequency (and hence the same wavelength in the same medium) and a constant phase difference with time. A fixed phase difference need not be zero. If the relative phase changes randomly, the positions of maxima

and minima fluctuate rapidly and the time-averaged pattern disappears. In practice, illuminating both slits from one monochromatic source provides the required coherent waves.

Step 3: Calculate the new fringe width (c) The source is replaced by one of wavelength $\lambda' = 1.5\lambda$, while D and d stay unchanged. Since the question states that the pattern remains observable, use the fringe-width relation for the new wavelength:

$$\beta' = \frac{\lambda'D}{d} = \frac{1.5\lambda D}{d},$$

$$\frac{\beta'}{\beta} = 1.5.$$

Bright and dark fringes are therefore spaced farther apart. The central bright fringe remains at zero path difference; fringe positions on either side spread away from it.

Step 4: Conclusion Widely separated slits give fringes too narrow to resolve. Coherent sources have equal frequency and a constant phase difference. Replacing λ by 1.5λ increases the fringe width to 1.5β , a 50% increase.

Quick Tip to Solve: Keep D fixed and compare λ/d : larger slit separation crowds the fringes, while a larger wavelength spreads them out.

8. The wavelength of the waves associated with a particle having kinetic energy E is λ . How and by what factor should its kinetic energy be changed so that the wavelength becomes $\left(\frac{\lambda}{2}\right)$? Also, find the ratio of the final to the initial velocity of the particle. [3 marks]

Solution:

Concept:

- The de Broglie wavelength is $\lambda = h/p$, where h is Planck's constant and p is the momentum of the particle.
- For the same non-relativistic particle of mass m , its kinetic energy is $E = p^2/(2m) = mv^2/2$, where v is its speed.
- Combining these equations gives $\lambda = h/\sqrt{2mE}$. Thus wavelength varies inversely with the square root of kinetic energy when mass is fixed.

Step 1: Relate the initial and final momenta The printed target wavelength is $\lambda_f = \lambda/2$. Let the initial momentum and speed be p_i and v_i , and the final values be p_f and v_f . Using the de Broglie relation for each state,

$$p_i = \frac{h}{\lambda},$$

$$p_f = \frac{h}{\lambda/2} = \frac{2h}{\lambda} = 2p_i.$$

Halving the wavelength therefore doubles the momentum. Planck's constant is unchanged, and we are changing the motion of the same particle, so its mass is unchanged as well.

Step 2: Determine the required kinetic energy Initially the kinetic energy is E . Denote the final

kinetic energy by E_f . Since kinetic energy is proportional to the square of momentum at fixed mass,

$$\frac{E_f}{E} = \frac{p_f^2/(2m)}{p_i^2/(2m)} = \left(\frac{p_f}{p_i}\right)^2 = 2^2 = 4,$$

$$E_f = 4E.$$

The kinetic energy must be increased to four times its initial value. Equivalently, the amount of energy added is $E_f - E = 3E$; the multiplier of the final energy is four, rather than three.

Step 3: Find the final-to-initial velocity ratio For the same mass, momentum satisfies $p = mv$, so the ratio of speed magnitudes is

$$\frac{v_f}{v_i} = \frac{p_f/m}{p_i/m} = 2.$$

The energy relation gives the same check:

$$\frac{v_f}{v_i} = \sqrt{\frac{E_f}{E}} = \sqrt{4} = 2.$$

The wavelength fixes the magnitude of momentum; no change of direction is required to produce this change in wavelength.

Step 4: Conclusion Increase the kinetic energy to $4E$, by a factor of 4 . The final-to-initial velocity magnitude ratio is $v_f/v_i = 2$, or $2 : 1$.

Quick Tip to Solve: When the wavelength is divided by a factor n , multiply the momentum and speed by n , and the non-relativistic kinetic energy by n^2 .

9(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]

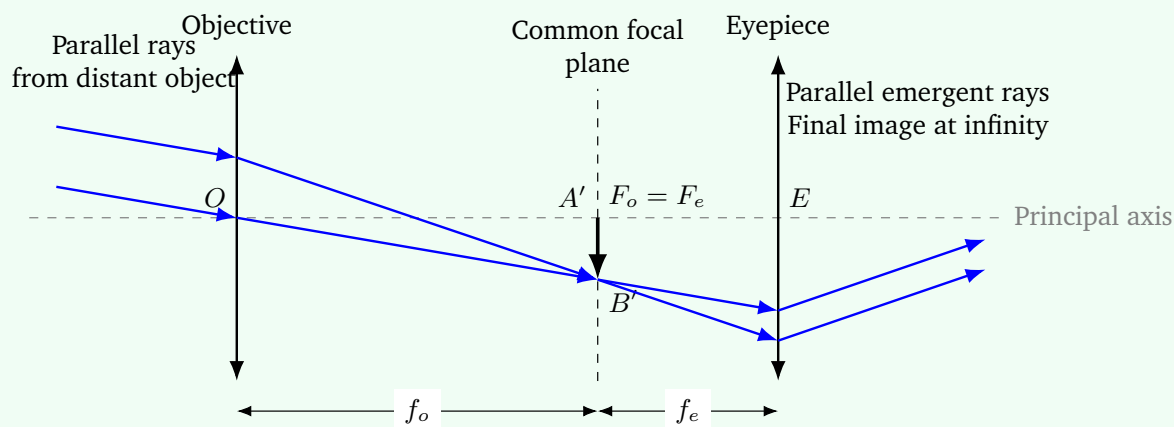
Solution:

Concept:

- An astronomical telescope uses a convex objective of long focal length f_o and a convex eyepiece of short focal length f_e . The objective forms a real, inverted image of a distant object in its focal plane.
- In normal adjustment, this intermediate image lies in the first focal plane of the eyepiece. The emergent rays are parallel, so the final image is at infinity and the eye views it without accommodation.
- The lens separation is $L = f_o + f_e$. The angular magnification is $M = \beta/\alpha = -f_o/f_e$, where α and β are the small angular sizes seen by the unaided eye and through the telescope; the negative sign denotes inversion.

Step 1: (i) Draw the telescope in normal adjustment Parallel rays from one point of a distant object enter the objective obliquely and converge at B' . The real, inverted intermediate image $A'B'$ is

formed in the common focal plane, with F_o (the objective's second focus) coinciding with F_e (the eyepiece's first focus). Since this image acts as an object at the eyepiece's focus, the eyepiece refracts the diverging rays from B' into a parallel beam. Thus the final, inverted image is at infinity. The ray sketch is schematic; its distances illustrate the common focal plane rather than the numerical focal-length ratio.



Astronomical telescope in normal adjustment; the intermediate image lies in the common focal plane and the emergent rays are parallel.

Step 2: (ii)(I) Calculate the tube length The distant object produces its image f_o behind the objective. To obtain a final image at infinity, the eyepiece must be f_e beyond this intermediate image. Hence the distance between the two lenses is

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

Both distances are added because the common focal plane lies between the lenses.

Step 3: (ii)(II) Calculate the angular magnification If the intermediate image has height h , the magnitudes of the small angles are $|\alpha| \simeq h/f_o$ and $|\beta| \simeq h/f_e$. Their ratio gives the magnifying power. Including the inversion sign,

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

Magnification is dimensionless. Its magnitude describes angular enlargement, while its sign describes orientation; it is not the linear magnification of the intermediate image.

Step 4: Conclusion In normal adjustment, the tube length is 156 cm . The angular magnification is $M = -25$, i.e. a magnifying power of 25 with the final image inverted and at infinity.

Quick Tip to Solve: When a telescope's final image is at infinity, place the intermediate image at the shared focal plane: add the focal lengths for tube length and divide objective focal length by eyepiece focal length for magnifying power.

9(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.

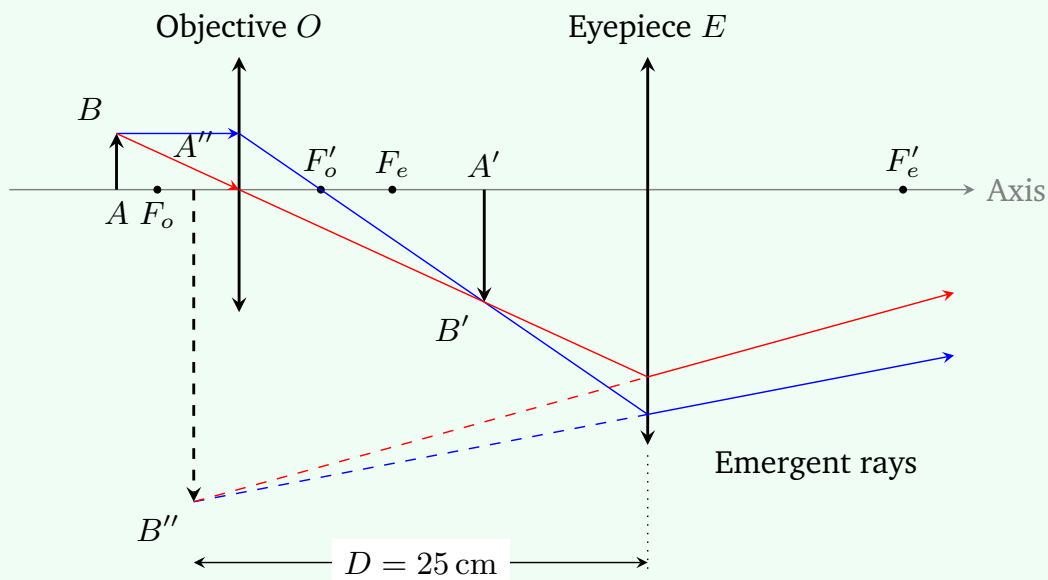
[3 marks]

Solution:

Concept:

- In a compound microscope, the objective forms a real, inverted, enlarged intermediate image; the eyepiece acts as a magnifier and forms a virtual final image.
- For the final image at the least distance of distinct vision, $v_e = -D$, where $D = 25$ cm, and the intermediate image lies between the eyepiece and its first focal point.
- With the Cartesian sign convention, a convex lens obeys $1/f = 1/v - 1/u$; linear magnification is $m = v/u$.

Step 1: Draw and explain the microscope arrangement Place the object AB just beyond the objective focus F_o . The objective O produces the enlarged, inverted real image $A'B'$. Set the eyepiece E so that $A'B'$ is inside its focal length: between F_e and E . Rays from B' emerging through the eyepiece diverge; their backward extensions meet at B'' , forming the virtual image $A''B''$ at distance D from the eyepiece. The final image is inverted relative to the original object. Solid lines in the sketch show actual rays travelling to the right; dashed lines show backward extensions. Distances in the sketch are schematic.



Compound microscope with final virtual image at D (schematic).

Step 2: Apply the lens formula to the separate magnifier The numerical part concerns a single magnifier, so use its own focal length rather than the microscope parameters. Light travels from the

object towards the lens; hence $u = -3.0$ cm and $f = +4.0$ cm. Thus

$$\begin{aligned}\frac{1}{v} &= \frac{1}{f} + \frac{1}{u} \\ &= \frac{1}{4} - \frac{1}{3} = -\frac{1}{12} \text{ cm}^{-1}, \\ v &= -12 \text{ cm}.\end{aligned}$$

A negative image distance puts the virtual image on the same side of the lens as the object. This agrees with the condition that the object is inside the focal length of a convex magnifier.

Step 3: Calculate the linear magnification The ratio of image height to object height is

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

The positive sign indicates an erect image, and the magnitude means that the image height is four times the object height. This is linear magnification, so the angular-magnification formula involving D is not used for this numerical part.

Step 4: Conclusion The labelled diagram gives a virtual final microscope image at the near point. For the single magnifier, the image is 12 cm from the lens on the object's side, with $v = -12$ cm and linear magnification $m = +4.0$: virtual, erect and enlarged.

Quick Tip to Solve: For an object inside a convex lens's focal length, expect a negative image distance and positive linear magnification; this checks both signs immediately.

10(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 are classified into frequency bands. Their vacuum speed is $c = 3.0 \times 10^8$ m s⁻¹, and frequency and wavelength obey $\nu = c/\lambda$.
- Applications depend on directionality, penetration and energy absorption. Photon energy is $E = h\nu$, where h is Planck's constant; a higher frequency gives a more energetic photon.

Step 1: Identify the waves used in radar (i) Radar systems use **microwaves**. The frequency range used for this answer is

$$10^{10} \text{ Hz to } 10^{12} \text{ Hz}.$$

Their short wavelengths allow a narrow, directional beam to be transmitted towards a target. Reflected pulses are received by the radar antenna, and the round-trip delay determines the distance. Microwaves are therefore suitable for locating aircraft, ships and other reflecting targets.

Step 2: Identify the radiation that affects a photographic plate (ii) **X-rays** affect photographic plates. Their frequency range is

$$10^{16} \text{ Hz to } 10^{20} \text{ Hz}.$$

X-rays expose a sensitive photographic emulsion. Differences in absorption by materials produce contrast on the plate, which is the basis of radiographic imaging. The plate records where the radiation reaches it; the effect does not require the radiation to be visible to the human eye. Gamma rays are also an accepted identification for this part, with range 10^{20} – 10^{24} Hz.

Step 3: Identify the radiation used in surgery (iii) **Gamma rays** are used in radiosurgery, in which focused beams deposit energy in a selected target and damage unwanted tissue. Their frequency range is

$$10^{20} \text{ Hz to } 10^{24} \text{ Hz.}$$

Their high photon energy and penetration allow the treatment of internal targets. Converging beams concentrate the dose at the target rather than requiring an ordinary mechanical incision. An accepted alternative is infrared radiation used in surgical lasers, with range 10^{12} – 10^{14} Hz. The quoted ranges are approximate school-level spectrum bands; the application uses a selected frequency within the band.

Step 4: Conclusion (i) Microwaves: 10^{10} – 10^{12} Hz. (ii) X-rays: 10^{16} – 10^{20} Hz. (iii) Gamma rays: 10^{20} – 10^{24} Hz. Gamma rays for (ii), and infrared 10^{12} – 10^{14} Hz for (iii), are also accepted alternatives.

Quick Tip to Solve: Connect each application to its interaction: microwave echoes locate targets, X-rays expose a plate, and focused gamma rays deliver a radiosurgical dose.

OR

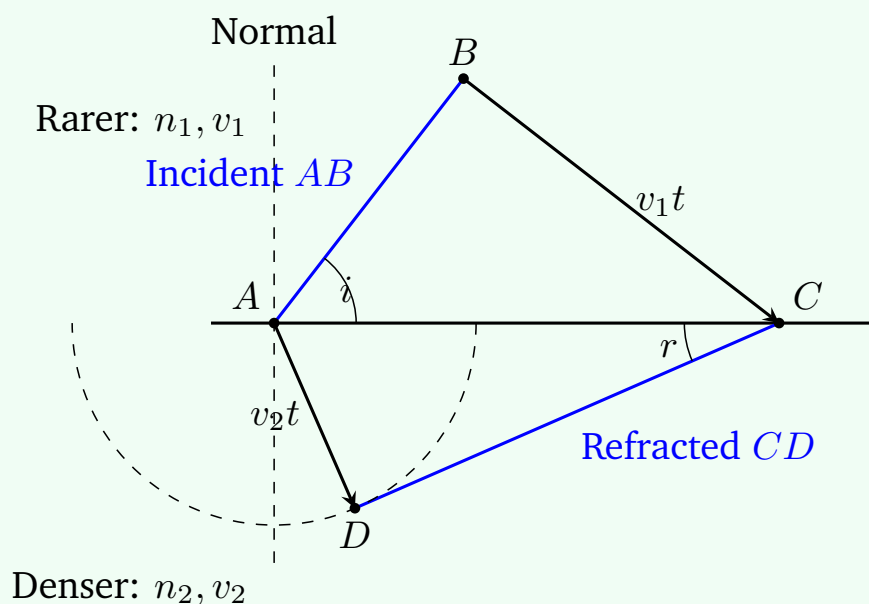
10(b). A plane wavefront is propagating from a rarer into a denser medium. Use Huygens principle to show the refracted wavefront and verify Snell's law. [3 marks]

Solution:

Concept:

- Huygens' principle: every point on a wavefront acts as a source of secondary wavelets. Their forward common tangent is the new wavefront.
- In a medium of refractive index n , the wave speed is $v = c/n$. A ray is normal to its wavefront; incident and refracted angles are measured from the interface normal.

Step 1: Construct the secondary wavelet in the denser medium Let AB be an incident plane wavefront in the rarer medium, with A just reaching the plane boundary. The point B reaches the boundary at C after time t . If the speeds in the rarer and denser media are v_1 and v_2 , respectively, then $BC = v_1 t$. During this same time, the secondary disturbance from A travels a distance $AD = v_2 t$ in the denser medium. Draw a circle of radius AD about A , and draw its forward tangent CD from C . Thus CD is the refracted plane wavefront and $AD \perp CD$.



Huygens construction: AB is incident and CD is refracted.

Step 2: Relate the construction to the angles Since rays are perpendicular to their wavefronts, the angle between AB and the boundary AC is the angle of incidence i , while that between CD and AC is the angle of refraction r . The triangles ABC and ADC are right-angled at B and D . Hence

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

Dividing eliminates the common construction length and the time:

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

Here $n_2 > n_1$, so $v_2 < v_1$, $AD < BC$, and $r < i$: the transmitted ray bends towards the normal.

Step 3: Conclusion The common tangent CD gives the refracted wavefront. The construction verifies Snell's law, $n_1 \sin i = n_2 \sin r$, and shows that the ray bends towards the normal on entering the denser medium.

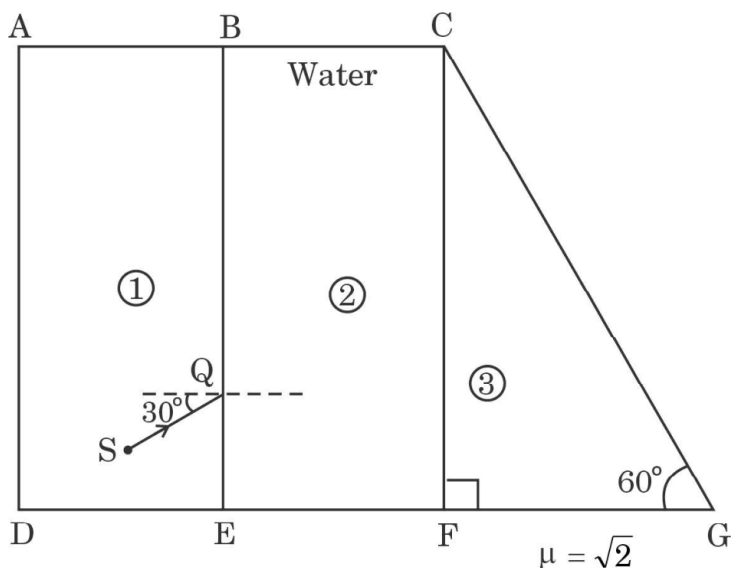
Quick Tip to Solve: Use the same travel time for $BC = v_1 t$ and $AD = v_2 t$; both sine ratios then have the common hypotenuse AC .

11. The figure shows a water column BCFE surrounded by two media (1) and (3) of the same refractive index $\sqrt{2}$. A ray of light from a point source S is incident on surface BE at an angle of 30° .

(a) Trace the path of the ray through media (2) and (3) as it emerges out of face CG.

(b) Find the angle of emergence at face CG.

[3 marks]



Solution:

Concept:

- At each interface, Snell's law gives $n_i \sin i = n_t \sin r$, with both angles measured from that interface's normal.
- Refraction through a layer bounded by parallel faces restores the original ray direction when the two external media have equal refractive indices.

Step 1: Trace refraction into and out of the water column The normals to the vertical faces BE and CF are horizontal. The ray SQ enters the water at Q with incidence 30° . Using the usual refractive index $n_w = 4/3$ of water and $n_1 = \sqrt{2}$, its refracted angle r_w satisfies

$$\sqrt{2} \sin 30^\circ = \frac{4}{3} \sin r_w, \quad \sin r_w = \frac{3\sqrt{2}}{8}.$$

Thus $r_w \simeq 32.0^\circ$. It bends away from the horizontal normal, travelling upwards and rightwards through water to CF . At CF , it enters medium (3), whose refractive index is also $\sqrt{2}$. Since the two water faces are parallel, the incidence there is r_w . Therefore

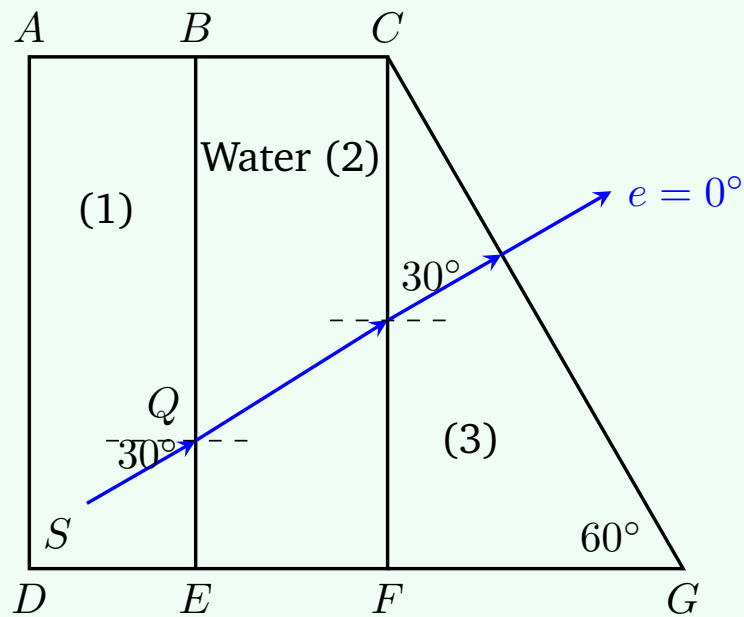
$$\frac{4}{3} \sin r_w = \sqrt{2} \sin r_3 \Rightarrow r_3 = 30^\circ.$$

The ray bends towards the normal and is parallel to SQ within medium (3). Neither water interface causes total internal reflection: each computed transmitted sine is below unity.

Step 2: Find the incidence and emergence at the sloping face Face CG makes 60° with the horizontal base FG . Its outward normal towards the upper right consequently makes 30° with the horizontal. The ray within medium (3) also travels at 30° above the horizontal. It is therefore perpendicular to CG , so its incidence at that face is 0° . Applying Snell's law at the final face gives

$$\sqrt{2} \sin 0^\circ = n_{\text{out}} \sin e = 0 \Rightarrow e = 0^\circ.$$

Thus the ray continues undeviated along the outward normal. In particular, the 60° drawn at G is a face angle, not an incidence angle.



Ray path through water (2) and medium (3); emergence is normal to CG.

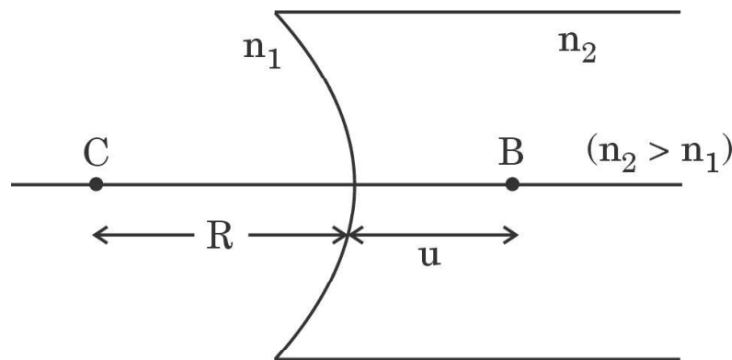
Step 3: Conclusion (a) The ray bends away from the normal in water, towards it in medium (3), and emerges straight through CG along its normal. (b) The angle of emergence is 0° .

Quick Tip to Solve: First use equal exterior indices and parallel water faces to recover 30° ; then compare this ray direction with the normal to CG.

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:

- For paraxial refraction at a spherical surface, $n_{\text{out}}/v - n_{\text{in}}/u = (n_{\text{out}} - n_{\text{in}})/R$, using signed Cartesian distances.
- The incident medium is identified from the object's position, and the positive direction follows the incident light.

Step 1: Identify the incident and refracted media The object B lies to the right of the spherical surface, in the medium of refractive index n_2 . Light from B therefore travels towards the surface from right to left and enters the medium of refractive index n_1 . Thus $n_{\text{in}} = n_2$ and $n_{\text{out}} = n_1$. The centre C lies to the left, in the direction of incident light, so R is positive with this sign convention; the real object has $u < 0$.

Step 2: Apply the correct spherical-surface relation Substitution into the refraction formula gives

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

Option (C) reverses the incident and outgoing refractive indices and would describe an object in the other medium. Options (A) and (B) give equal coefficients to $1/u$ and $1/v$, whereas refraction between unequal indices requires different coefficients. Dividing the correct equation by either index cannot produce these alternatives because the remaining index ratio must be retained.

Step 3: Conclusion The required relation is $\frac{n_1}{v} - \frac{n_2}{u} = \frac{n_1 - n_2}{R}$. Hence, the correct option is (D).

Quick Tip to Solve: Read the object's side first: the index multiplying the object-distance term belongs to the incident medium.

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:

- Refraction at a spherical surface obeys $n_2/v - n_1/u = (n_2 - n_1)/R$, where the subscripts denote the incident and refracted media.
- With light travelling from air into glass, a convex surface has positive radius and a real object in front has negative object distance.

Step 1: Substitute the object distance and refractive indices Take the pole as origin and the direction of incident light as positive. Here $u = -R$, the incident air has $n_1 = 1$, and the glass has refractive index $n_2 = n$. For the ordinary glass used in the standard school treatment, n is approximately 1.5. The spherical refraction equation becomes

$$\frac{n}{v} + \frac{1}{R} = \frac{n - 1}{R} \Rightarrow \frac{n}{v} = \frac{n - 2}{R}.$$

Step 2: Interpret the sign and compare the choices Thus $v = nR/(n - 2)$. For ordinary glass, $1 < n < 2$, so $v < 0$; specifically, $n = 1.5$ gives $v = -3R$. The refracted rays diverge in the glass, and their backward extensions meet on the incident air side. The image is therefore virtual and located in air. Options (A) and (B) are incorrect because they describe a real image, which requires the refracted rays actually to converge. Option (C) is incorrect because a virtual image here lies on the incident side, in air, rather than in glass.

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

Quick Tip to Solve: For a spherical surface, substitute the negative object distance before simplifying; a negative image distance places this image back in air.

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:

- An equiconvex lens in air is a converging lens with positive focal length f .
- The thin-lens formula is $1/v - 1/u = 1/f$, and linear magnification is $m = v/u$, using the Cartesian sign convention.

Step 1: Locate the image using the lens formula The object lies at twice the focal distance on the incident-light side, so $u = -2f$. Substituting gives

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

The positive image distance places the image on the other side of the lens, where the refracted rays actually meet; it is therefore real.

Step 2: Check its size and compare the choices The magnification is $m = v/u = (2f)/(-2f) = -1$. Its magnitude is unity, so the image has the same size as the object; the negative sign indicates inversion. The virtual-image choices (B) and (D) are incompatible with actual convergence of rays. Choice (C) is also incorrect because enlargement requires $|m| > 1$, whereas here $|m| = 1$.

Step 3: Conclusion The image is real, inverted and of the same size as the object, formed at $2F$ on the other side. Hence, the correct option is (A).

Quick Tip to Solve: For a convex lens, an object at twice the focal length gives an image at twice the focal length with magnification minus one.

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) $+5$ D
- (C) $+15$ D
- (D) -15 D

Correct Answer: (B) $+5$ D

Solution:

Concept:

- Lens power is $P = 1/f$, with f expressed in metres; its unit is the dioptre (D).
- A converging lens has positive power and a diverging lens has negative power. For thin lenses in contact, $P = P_1 + P_2$.

Step 1: Calculate the signed individual powers The converging lens has $f_1 = +10$ cm $= +0.10$ m, giv-

ing $P_1 = 1/0.10 = +10$ D. The diverging lens has $f_2 = -20$ cm $= -0.20$ m, giving $P_2 = 1/(-0.20) = -5$ D. The negative sign is essential: the second lens spreads an incident parallel beam rather than converging it.

Step 2: Add powers and test the alternatives Since the lenses are coaxial and in contact, their combined power is

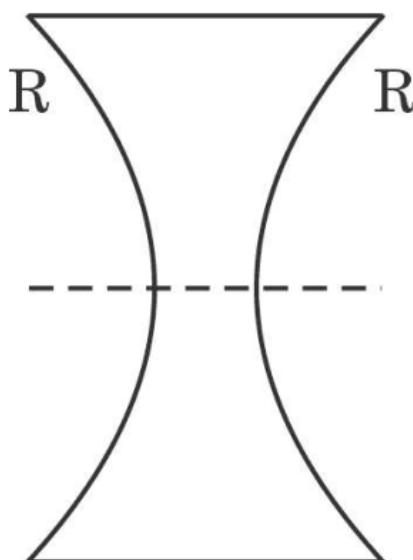
$$P = P_1 + P_2 = 10 - 5 = +5 \text{ D.}$$

Choice (A), -5 D, has the wrong sign because the stronger converging lens dominates. Choice (C), $+15$ D, incorrectly treats both lenses as converging. Choice (D), -15 D, both adds the magnitudes and assigns an incorrect negative sign. As a check, the equivalent focal length is $1/5 = +0.20$ m.

Step 3: Conclusion The combination has power $+5$ D and is converging. Hence, the correct option is (B).

Quick Tip to Solve: Convert focal lengths to metres and attach their signs before adding powers; do not add the focal lengths themselves.

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:

- For a thin lens in air, the lens-maker formula is $1/f = (n - 1)(1/R_1 - 1/R_2)$, where n is the refractive index relative to air and R_1, R_2 are signed radii of curvature.
- Cutting a lens along its principal axis reduces its aperture but leaves the curvatures of its refracting

surfaces unchanged.

Step 1: Identify the direction of the cut The dotted horizontal line in the printed figure passes along the principal axis of the equiconcave lens. The cut therefore separates upper and lower halves, each retaining portions of both original curved refracting surfaces. It does not split the lens into two plano-concave lenses. The material and the surrounding medium also remain the same.

Step 2: Compare the focal lengths using the surface curvatures With light travelling from left to right, the original equiconcave lens has $R_1 = -R$ and $R_2 = +R$. Thus,

$$\frac{1}{f} = (n - 1) \left(-\frac{1}{R} - \frac{1}{R} \right) = -\frac{2(n - 1)}{R}.$$

Each half retains these same radii and refractive index, so the expression for $1/f$ is unchanged. The reduced aperture affects the amount of transmitted light, not the focal length in the thin-lens approximation. Options (A) and (B) incorrectly increase the magnitude of the power. Option (D) would correspond to halving the power by removing one curved surface, which this cut does not do.

Step 3: Conclusion The focal length of each part remains f , including its negative sign for a diverging lens. Hence, the correct option is (C).

Quick Tip to Solve: Read the cut direction first: a cut along the principal axis changes aperture, whereas a cut perpendicular to it can change surface curvature and power.