

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/5/3



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

- (i) This question paper contains **12** questions. **All** questions are compulsory.
- (ii) This question paper is divided into **THREE** sections, **Section - A, B and C**.
- (iii) **Section A** - Question number 1 to 3 are of **2** marks each.
- (iv) **Section B** - Question number 4 to 11 are of **3** marks each.
- (v) **Section C** - Question number 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. Give two differences between a half wave rectifier and a full wave rectifier.

[2 marks]

Solution:

Concept:

- A rectifier converts an alternating input into a unidirectional, pulsating output. The polarity of the load current remains the same during the conducting intervals.
- The ripple frequency is the number of output pulses per second. Let the frequency of the alternating supply be f , so that its period is $T = 1/f$.

Step 1: Compare the use of the input half-cycles A half-wave rectifier conducts through the load during only one half-cycle of the alternating input; during the other half-cycle, its diode is reverse biased and the output is zero. A full-wave rectifier uses both half-cycles: its diodes direct current through the load in the same direction in each half-cycle. Thus half-wave rectification leaves an entire alternate half-cycle unused, whereas full-wave rectification supplies a pulse in each half-cycle.

Step 2: Compare the output ripple frequencies A half-wave rectifier gives one output pulse in each input period T , so its ripple frequency is f . A full-wave rectifier gives two output pulses in that same period, with successive pulses separated by $T/2$, so its ripple frequency is $2f$. For example, with a 50 Hz supply the respective ripple frequencies are 50 Hz and 100 Hz.

Step 3: Conclusion The two differences are: a half-wave rectifier uses only one half-cycle and has ripple frequency f ; a full-wave rectifier uses both half-cycles and has ripple frequency $2f$.

Quick Tip to Solve: Count the output pulses in one complete input cycle: one for half-wave and two for full-wave rectification.

2. Why a photo-diode is operated in reverse bias whereas current in the forward bias is much larger than that in the reverse bias? Explain. Mention its two uses.

[2 marks]

Solution:

Concept:

- Light with photon energy at least equal to the band gap creates electron-hole pairs in a photodiode. The electric field in its depletion region separates these carriers and produces a photocurrent.
- Reverse current is carried by minority carriers. At a fixed reverse bias, the photocurrent increases with the intensity of incident light; the small dark current provides the background against which it is detected.

Step 1: Explain the advantage of reverse bias Reverse bias strengthens the junction electric field and widens the depletion region. Electrons and holes generated by incident light are swept to opposite sides of the junction and contribute to the reverse current. In the dark this current is small, so illumination causes a large fractional change in the measured current. The light signal is consequently easy to detect and its intensity can be measured from the current change.

Step 2: Compare with forward bias and state two uses In forward bias, the large majority-carrier current already flows even without illumination. The additional light-generated current is relatively small compared with this background, so a large total current does not mean better sensitivity to light. Two uses of a reverse-biased photodiode are as the detector in an optical-fibre communication

receiver, where light pulses are converted into electrical signals, and in a light-intensity meter, where photocurrent indicates incident illumination.

Step 3: Conclusion A photodiode is operated in reverse bias because illumination produces an easily measurable change above a small dark current. It is used in optical-fibre receivers and light-intensity meters.

Quick Tip to Solve: Compare the light-induced change with the dark current; a larger total current alone does not make a better light detector.

3(a). What results do you expect if α -particle scattering experiment is repeated using a thin sheet of hydrogen in place of a gold foil? Explain. (Hydrogen is a solid at temperature below 14 K) [2 marks]

Solution:

Concept:

- Rutherford scattering arises from electrostatic repulsion between a positively charged alpha particle and a positive target nucleus. The force at separation r is $F = k(2e)(Ze)/r^2$, where Z is the target atomic number.
- An alpha particle has mass approximately $4m_p$, while a hydrogen nucleus is a proton of mass m_p . Unlike a heavy gold nucleus, the proton recoils appreciably during a collision.

Step 1: Compare the electrostatic deflection Hydrogen has nuclear charge $+e$, whereas gold has nuclear charge $+79e$. At the same separation the repulsive force on the alpha particle is therefore much smaller for hydrogen. Most alpha particles would pass through the thin hydrogen sheet with little deviation, and those scattered would show small forward deflections rather than the large-angle scattering seen with gold.

Step 2: Explain why backward scattering is absent The hydrogen nucleus is lighter than the incident alpha particle and can recoil, so it cannot be treated as a fixed heavy scattering centre. For an elastic head-on collision with a proton initially at rest, conservation of momentum and kinetic energy gives the outgoing alpha-particle velocity

$$v'_\alpha = \frac{4m_p - m_p}{4m_p + m_p} v_\alpha = \frac{3}{5} v_\alpha.$$

This velocity is still forward: even a head-on encounter does not reverse the alpha particle. A substantial part of its kinetic energy goes into proton recoil. Thus the backward-scattered alpha particles characteristic of a heavy gold target would not be observed.

Step 3: Conclusion With a thin hydrogen sheet, alpha particles would emerge mainly undeviated or scattered through small forward angles, with recoiling protons. Large-angle and backward scattering would be absent because the target nuclei are much lighter and have much smaller charge than gold nuclei.

Quick Tip to Solve: For a hydrogen target, consider both its small nuclear charge and its recoil; the stationary heavy-nucleus assumption no longer applies.

3(b). Why it is the frequency and not the intensity of light source that determines whether emission of photoelectrons will occur or not? Explain. [2 marks]

Solution:

Concept:

- Light consists of photons, each carrying energy $E = h\nu$, where h is Planck's constant and ν is the light frequency.
- The work function ϕ is the minimum energy needed to free an electron from the metal surface. Einstein's equation is $K_{\max} = h\nu - \phi$, where $K_{\max}$ is the maximum photoelectron kinetic energy.

Step 1: Compare one photon's energy with the work function In the ordinary photoelectric effect, a surface electron absorbs the energy of one incident photon. It can escape only if that photon's energy is at least the work function:

$$h\nu \geq \phi, \quad \nu \geq \nu_0 = \frac{\phi}{h}.$$

Here ν_0 is the threshold frequency of the metal. For $\nu < \nu_0$, an individual photon cannot supply enough energy to release an electron. For $\nu > \nu_0$, the energy left after overcoming the work function appears as the electron's kinetic energy.

Step 2: Distinguish intensity from photon energy At a fixed frequency, increasing intensity increases the number of photons incident per unit area per unit time, while the energy $h\nu$ of each photon remains unchanged. Thus brighter light below threshold still cannot cause photoelectric emission. Above threshold, increasing intensity can release more electrons per second and increase the photocurrent, but it does not change the maximum kinetic energy. Photon energies are not accumulated by an electron from successive arrivals in this usual single-photon process.

Step 3: Conclusion Frequency determines whether $h\nu \geq \phi$ and hence whether photoelectric emission is possible. Intensity controls the incident photon rate and, above threshold, the emission rate; it cannot compensate for a frequency below threshold.

Quick Tip to Solve: First compare $h\nu$ with ϕ . Only after the threshold condition is met should greater intensity be linked to a larger photocurrent.

Section B (24 marks)

4(a)(i). Define SI unit of power of a lens. [3 marks total]

Solution:

Concept:

- The power of a lens measures its ability to converge or diverge light and is defined as $P = 1/f$, where f is the focal length expressed in metres.
- The SI expression for lens power is m^{-1} , conventionally called the dioptre and denoted by D.

Step 1: Relate the unit to focal length Since power is the reciprocal of focal length, a lens whose focal-length magnitude is one metre has a power of magnitude

$$|P| = \frac{1}{1\text{ m}} = 1\text{ m}^{-1}.$$

Step 2: State the sign convention A converging lens with focal length $+1\text{ m}$ has power $+1\text{ D}$. A diverging lens with focal length -1 m has power -1 D . The sign describes the action of the lens and does not change the unit.

Step 3: Conclusion The SI unit of lens power is the dioptre: $1\text{ D} = 1\text{ m}^{-1}$. One dioptre is the power of a lens of focal length one metre.

Quick Tip to Solve: Always express focal length in metres before taking its reciprocal to obtain power in dioptres.

4(a)(ii) A plano convex lens is made of glass of refractive index 1.5. The radius of curvature of the convex surface is 25 cm.

4(a)(ii.i). Calculate the focal length of the lens.

Solution:

Concept:

- For a thin lens in air, the lens maker formula is $\frac{1}{f} = (\mu - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$, where μ is the refractive index of glass relative to air.
- A plane surface has infinite radius of curvature and therefore contributes zero reciprocal curvature. A plano-convex glass lens in air has positive focal length.

Step 1: Assign the surface radii Take the convex surface as the first surface encountered by light travelling from left to right. Its centre of curvature is to its right, so $R_1 = +25\text{ cm}$. For the plane second surface, $R_2 = \infty$, hence $1/R_2 = 0$.

Step 2: Substitute in the lens maker formula Using the given refractive index $\mu = 1.5$,

$$\begin{aligned}\frac{1}{f} &= (1.5 - 1) \left(\frac{1}{25} - 0 \right) \text{ cm}^{-1} \\ &= \frac{1}{50} \text{ cm}^{-1}.\end{aligned}$$

The positive reciprocal focal length is consistent with the converging action of this glass lens in air.

Step 3: Conclusion The focal length is $f = +50\text{ cm} = +0.50\text{ m}$.

Quick Tip to Solve: For a plano-convex lens in air, use $f = R/(\mu - 1)$; the plane face contributes no curvature.

4(a)(ii.ii). If an object is placed 50 cm in front of the lens, find the nature and position of the image formed.

Solution:

Concept:

- The thin-lens formula is $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$, using the Cartesian sign convention. Here u and v are object and image distances from the optical centre.
- An object at the principal focus of a converging lens produces parallel emergent rays. The image is described as lying at infinity, with magnification unbounded in the limiting ray-optics construction.

Step 1: Assign the signed distances The previous part gives $f = +50$ cm. The object is 50 cm in front of the lens, so $u = -50$ cm. Thus the object lies exactly at the first principal focus.

Step 2: Apply the lens formula and interpret the rays Rearranging and substituting gives

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{50} - \frac{1}{50} = 0 \text{ cm}^{-1}.$$

Therefore the emerging rays from each object point are parallel and do not meet at any finite distance. In the standard convex-lens image table this is the limiting case of a real, inverted image with very large magnification as an object approaches the focus from beyond it.

Step 3: Conclusion The image is at infinity on the emergent side of the lens and is conventionally described as real, inverted and highly enlarged. No sharp image is obtained on a screen at a finite distance.

Quick Tip to Solve: Check whether $|u| = f$ before calculating: an object at the focus sends out parallel rays and gives an image at infinity.

OR

A slit of width 0.6 mm is illuminated by a beam of light consisting of two wavelengths 600 nm and 480 nm. The diffraction pattern is observed on a screen 1.0 m from the slit. Find :

4(b)(i). The distance of the second bright fringe from the central maximum pertaining to light of 600 nm. [3 marks total]

Solution:

Concept:

- For a single slit of width a , diffraction minima occur at $a \sin \theta = m\lambda$. Secondary bright fringes lie approximately midway between successive minima; they do not obey the double-slit bright-fringe formula.
- For a distant screen, $y \simeq D\theta$. The n -th secondary maximum is approximately at $y_n \simeq (n + \frac{1}{2})\lambda D/a$, where $n = 1, 2, \dots$, and D is the slit-to-screen distance.

Step 1: Identify the second secondary maximum The central maximum is at $y = 0$. The first secondary bright fringe lies between the first and second minima, and the second lies between the second and third minima. Hence its approximate position is found with $n = 2$, giving the factor $5/2$. Convert the printed data to SI units:

$$a = 0.6 \times 10^{-3} \text{ m}, \quad \lambda = 600 \times 10^{-9} \text{ m}, \quad D = 1.0 \text{ m}.$$

Step 2: Substitute the slit width and wavelength The characteristic distance on the screen is

$$\frac{\lambda D}{a} = \frac{600 \times 10^{-9} \times 1.0}{0.6 \times 10^{-3}} = 1.0 \times 10^{-3} \text{ m}.$$

Thus the second bright fringe lies approximately 2.5 times this distance from the central maximum on either side. This midpoint rule is the usual school-level approximation. More precisely, the intensity maxima satisfy $\tan \beta = \beta$, where $\beta = \pi a \sin \theta / \lambda$; the second positive secondary root is $\beta \simeq 7.725$, corresponding to about 2.459 mm.

Step 3: Conclusion Using the standard single-slit approximation, the required distance is $y_2 \simeq 2.5 \text{ mm}$ from the central maximum. The exact diffraction maximum is approximately 2.459 mm.

Quick Tip to Solve: Count secondary maxima from the central peak: the second secondary bright fringe is between the second and third minima, so use approximately $5\lambda D/(2a)$.

4(b)(ii). The least distance from the central maximum at which bright fringes due to both the wavelengths coincide.

Solution:

Concept:

- For the printed single-slit experiment, secondary bright fringes have approximate positions $y_m \simeq (2m + 1)\lambda D/(2a)$, with $m = 1, 2, \dots$. The central maximum at $y = 0$ is common to all wavelengths.
- Coincident secondary maxima must have equal distances from the centre for the two wavelengths. Thus the appropriate equality involves odd multiples of the wavelengths, rather than the integer multiples used for double-slit interference.

Step 1: Write the condition for coincident secondary maxima Let the secondary fringe orders for 600 nm and 480 nm be m and n , respectively. The screen distance D and slit width a are the same for both patterns. Equating the approximate bright-fringe positions and cancelling these common factors gives

$$(2m + 1)600 = (2n + 1)480,$$

or

$$5(2m + 1) = 4(2n + 1).$$

Step 2: Check whether integer fringe orders can satisfy the condition The left side is odd, since it is five times an odd integer; the right side is even, since it is four times an odd integer. They therefore cannot be equal for any integer orders. The standard single-slit approximation consequently gives no common secondary bright fringe away from the centre. The central maxima do coincide, since the path difference across the slit vanishes on the axis for both wavelengths.

In particular, $y = 4 \text{ mm}$, obtained by using integer bright-fringe orders, is not a valid answer here: $ay/D = 2400 \text{ nm}$, equal to $4\lambda_1 = 5\lambda_2$. It locates coincident single-slit minima, not bright fringes. A positive coincidence distance based on the double-slit formula would change the printed experiment.

Step 3: Conclusion The common central maximum is at $y = 0$. If the question intends a noncentral bright-fringe coincidence, there is **no such distance in the standard single-slit approximation**; the printed request is inconsistent with that model. It must not be answered as a double-slit interference problem.

Quick Tip to Solve: Test the parity of the odd-order coincidence equation first. For the wavelength ratio 5 : 4, the familiar 4 mm coincidence belongs to dark single-slit fringes.

An electron in a hydrogen atom makes transitions from orbits of higher energies to orbits of lower energies.

5(i)(a). When will such transitions result in Lyman series ?

[3 marks total]

Solution:

Concept:

- In hydrogen, emission occurs when an electron drops from an initial level n_i to a lower final level n_f . The photon energy is $h\nu = E_{n_i} - E_{n_f} > 0$.
- A spectral series is identified by its common final level. The Lyman series has $n_f = 1$, the ground state.

Step 1: Identify the final orbit For a Lyman line, the electron must end in the first orbit, $n_f = 1$. Ending in the second orbit would instead produce a Balmer line, so a downward transition alone does not identify the series.

Step 2: Specify the allowed initial levels The electron can initially occupy any higher bound orbit, $n_i = 2, 3, 4, \dots$. Thus the transitions are $2 \rightarrow 1$, $3 \rightarrow 1$, $4 \rightarrow 1$, and so on. Each transition emits a photon of a distinct energy; together these ultraviolet lines form the Lyman series.

Step 3: Conclusion Lyman emission results from transitions $n_i = 2, 3, 4, \dots \rightarrow n_f = 1$.

Quick Tip to Solve: Identify a hydrogen series by the destination orbit: transitions ending at $n = 1$ belong to Lyman.

5(i)(b). When will such transitions result in Balmer series ?

Solution:

Concept:

- An emitted photon carries the energy difference between the higher initial orbit n_i and the lower final orbit n_f : $h\nu = E_{n_i} - E_{n_f}$.
- All lines of a hydrogen spectral series share a final orbit. For the Balmer series, this orbit is $n_f = 2$.

Step 1: Choose the final energy level To obtain the Balmer series, the electron must fall into the second orbit of hydrogen, $n_f = 2$. The final orbit, rather than the starting orbit alone, determines the series name.

Step 2: Identify the permitted downward transitions Since the electron loses energy, its initial orbit must be above the second: $n_i = 3, 4, 5, \dots$. The transitions $3 \rightarrow 2$, $4 \rightarrow 2$, $5 \rightarrow 2$, and so on therefore generate Balmer lines. The transition $2 \rightarrow 1$ belongs to Lyman because it ends at the ground state.

Step 3: Conclusion Balmer emission results from transitions $n_i = 3, 4, 5, \dots \rightarrow n_f = 2$.

Quick Tip to Solve: For Balmer emission, fix the lower level at $n = 2$ and allow the initial level to be any integer greater than 2.

5(ii). Find the ratio of the longest wavelength in Lyman series to the shortest wavelength in Balmer series.

Solution:

Concept:

- The hydrogen spectrum obeys the Rydberg formula $1/\lambda = R_H(1/n_f^2 - 1/n_i^2)$, where R_H is the hydrogen Rydberg constant and $n_i > n_f$.
- Within a series, the longest wavelength corresponds to the smallest energy gap; the shortest wavelength is the series limit, obtained as $n_i \rightarrow \infty$.

Step 1: Obtain the longest Lyman wavelength The Lyman series ends at $n_f = 1$. Its smallest energy gap is the transition $2 \rightarrow 1$, giving

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

Step 2: Obtain the shortest Balmer wavelength and compare The Balmer series ends at $n_f = 2$. Its largest photon energy is approached at the series limit, $n_i \rightarrow \infty$:

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

Divide the Lyman wavelength by the Balmer wavelength in the order requested. The common Rydberg constant cancels:

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

Step 3: Conclusion The ratio of the longest Lyman wavelength to the shortest Balmer wavelength is $\boxed{1:3}$.

Quick Tip to Solve: Use the first line for the longest wavelength and the series limit for the shortest; invert the wavenumbers before forming the wavelength ratio.

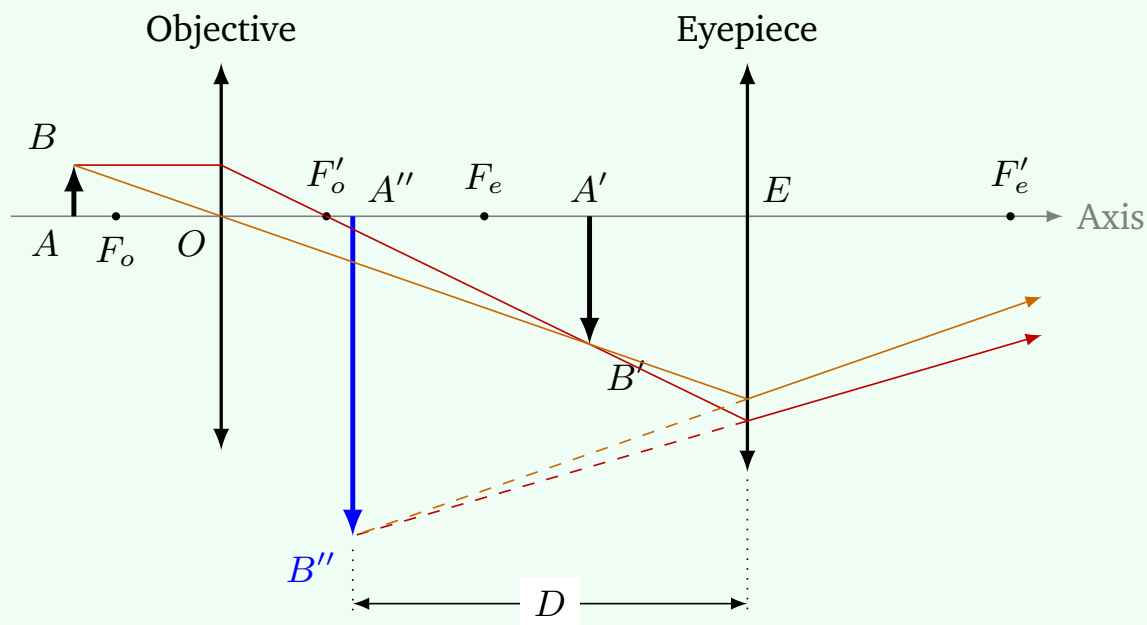
6. With the help of a ray diagram, show how a compound microscope forms a magnified image of a tiny object, at least distance of distinct vision. Hence derive an expression for the magnification produced by it. [3 marks]

Solution:

Concept:

- A compound microscope uses a short-focal-length objective to form a real, inverted, enlarged intermediate image. The eyepiece acts as a magnifying glass for this image.
- The magnifying power is the product of the objective's linear magnification and the eyepiece's angular magnification: $M = m_o m_e$. Here D is the least distance of distinct vision and f_o, f_e are the focal lengths.

Step 1: Construct the two successive images Place the tiny object AB just beyond the objective's first principal focus F_o . A ray parallel to the principal axis refracts through F'_o , while a ray through the optical centre O travels undeviated. They meet at B' , forming the real, inverted and enlarged image $A'B'$. Adjust the eyepiece so that $A'B'$ lies between its first focus F_e and optical centre E . The emergent rays diverge; their backward extensions intersect at B'' . Thus the final image $A''B''$ is virtual, enlarged and inverted relative to AB , at distance D from the eyepiece.



Compound microscope adjusted for a final virtual image at distance D ; dashed lines are backward extensions of emergent rays.

Step 2: Obtain the objective magnification Let $u_o < 0$ and $v_o > 0$ be the objective's object and image distances, using the Cartesian sign convention. Similar triangles give

$$m_o = \frac{A'B'}{AB} = \frac{v_o}{u_o}, \quad |m_o| = \frac{v_o}{|u_o|}.$$

The negative sign of m_o represents the inversion. Since the object is very close to the objective focus, $|u_o| \simeq f_o$. In the usual long-tube approximation, $v_o \simeq L$, where L is the effective tube length, so $|m_o| \simeq L/f_o$.

Step 3: Derive the eyepiece magnification at the near point The final image is virtual, so $v_e = -D$. Apply the thin-lens formula to the eyepiece:

$$\frac{1}{f_e} = \frac{1}{v_e} - \frac{1}{u_e} = -\frac{1}{D} + \frac{1}{|u_e|}, \quad \frac{D}{|u_e|} = 1 + \frac{D}{f_e}.$$

For small angles, the intermediate image of height $|A'B'|$ subtends angle $\beta \simeq |A'B'|/|u_e|$ through the

eyepiece. Viewed directly at the near point, the same image would subtend $\alpha \simeq |A'B'|/D$. Hence

$$m_e = \frac{\beta}{\alpha} = \frac{D}{|u_e|} = 1 + \frac{D}{f_e}.$$

Step 4: Conclusion The magnitude of the microscope's magnifying power for the final image at the near point is

$$|M| = \frac{v_o}{|u_o|} \left(1 + \frac{D}{f_e}\right) \simeq \frac{L}{f_o} \left(1 + \frac{D}{f_e}\right).$$

With the inversion represented by a sign, $M \simeq -(L/f_o)(1 + D/f_e)$. The final image is virtual and inverted relative to the original object.

Quick Tip to Solve: For a near-point final image, use the eyepiece factor $1 + D/f_e$; the factor D/f_e belongs to a final image at infinity. Multiply by the objective magnification.

Give an example each of a metal from which photoelectric emission takes place when irradiated by

7(a)(i). UV light.

[3 marks total]

Solution:

Concept:

- Photoelectric emission occurs when a photon's energy $h\nu$ is at least the metal's work function ϕ , the minimum energy needed to remove an electron.
- The threshold frequency is $\nu_0 = \phi/h$. Ultraviolet photons have greater energies than visible photons.

Step 1: Select a metal with a suitable threshold Zinc is a standard example of a metal that emits photoelectrons when exposed to ultraviolet radiation of sufficiently high frequency. Its work function is too large for ordinary visible light to cause emission.

Step 2: Apply the emission condition For incident UV radiation above zinc's threshold frequency, $h\nu > \phi$. A photon supplies the energy needed to free an electron, and the excess appears as its kinetic energy, according to $K_{\max} = h\nu - \phi$.

Step 3: Conclusion An example is zinc, irradiated with UV light above its threshold frequency.

Quick Tip to Solve: Recall zinc for UV-induced emission; always require the incident frequency to exceed the metal's threshold.

7(a)(ii). visible light.

Solution:

Concept:

- A metal emits photoelectrons only if the incident photon energy satisfies $h\nu \geq \phi$, where ϕ is its work function.
- Alkali metals have relatively small work functions, so suitable visible photons can eject electrons from their surfaces.

Step 1: Select a low-work-function metal Caesium is an example of a metal that shows photoelectric emission with visible light. Its low work function means that the energy required to liberate a surface electron is within the energy range of suitable visible photons.

Step 2: Check the physical condition When the chosen visible light has a frequency greater than caesium's threshold frequency $\nu_0 = \phi/h$, each absorbed photon can release an electron. The remaining photon energy becomes electron kinetic energy: $K_{\max} = h\nu - \phi$. Merely increasing intensity would not cause emission if the frequency were below threshold.

Step 3: Conclusion An example is caesium, which can emit photoelectrons under suitable visible light.

Quick Tip to Solve: Associate visible-light photoemission with low-work-function alkali metals such as caesium or potassium.

7(b). The work function of a metal is 4.50 eV. Find the frequency of light to be used to eject electrons from the metal surface with a maximum kinetic energy of 6.06×10^{-19} J.

Solution:

Concept:

- Einstein's photoelectric equation is $h\nu = \phi + K_{\max}$, where ϕ is the work function and $K_{\max}$ is the maximum kinetic energy of emitted electrons.
- Use consistent energy units: $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$, with Planck's constant $h = 6.63 \times 10^{-34} \text{ J s}$.

Step 1: Convert the work function to joules The energy used to free an electron is

$$\phi = 4.50 \times 1.60 \times 10^{-19} = 7.20 \times 10^{-19} \text{ J}.$$

This must be added to the electron's specified maximum kinetic energy; it is not the total incident photon energy.

Step 2: Calculate the required photon frequency Substituting into Einstein's equation gives

$$\begin{aligned} h\nu &= (7.20 + 6.06) \times 10^{-19} \text{ J} \\ &= 1.326 \times 10^{-18} \text{ J}, \\ \nu &= \frac{1.326 \times 10^{-18}}{6.63 \times 10^{-34}} = 2.00 \times 10^{15} \text{ Hz}. \end{aligned}$$

The photon supplies both the escape energy and the kinetic energy, so this frequency exceeds the threshold frequency of the metal.

Step 3: Conclusion The required frequency is $\nu = 2.00 \times 10^{15} \text{ Hz}$.

Quick Tip to Solve: Convert the work function from eV to joules before adding kinetic energy, then divide the total by Planck's constant.

8. In a fission event of ${}^{238}_{92}\text{U}$ by fast moving neutrons, no neutrons are emitted and final products, after the beta decay of the primary fragments, are ${}^{140}_{58}\text{Ce}$ and ${}^{99}_{44}\text{Ru}$. Calculate Q for this process. Neglect the masses of electrons/positrons emitted during the intermediate steps.

Given: $m({}^{238}_{92}\text{U}) = 238.05079 \text{ u}$; $m({}^{140}_{58}\text{Ce}) = 139.90543 \text{ u}$; $m({}^{99}_{44}\text{Ru}) = 98.90594 \text{ u}$; $m({}^1_0\text{n}) = 1.008665 \text{ u}$.

[3 marks]

Solution:

Concept:

- The energy released in a nuclear process is its mass defect times c^2 : $Q = (M_i - M_f)c^2$, where M_i and M_f are the total initial and final rest masses.
- The incident neutron is part of the initial system. Use $1 \text{ u } c^2 = 931.5 \text{ MeV}$; a positive Q means energy is released.

Step 1: Identify the initial and final particles One fast neutron is absorbed by the uranium nucleus. The mass numbers balance as $238 + 1 = 140 + 99 = 239$, so the initial mass must include one neutron. The final masses are those of cerium and ruthenium after the intermediate beta decays. As specified, neglect the masses of the emitted electrons or positrons; no emitted neutron mass is to be subtracted.

Step 2: Evaluate the total masses and their difference Add the given rest masses separately for the reactants and products:

$$\begin{aligned} M_i &= 238.05079 + 1.008665 \\ &= 239.059455 \text{ u}, \\ M_f &= 139.90543 + 98.90594 \\ &= 238.811370 \text{ u}. \end{aligned}$$

Therefore, the decrease in rest mass is

$$\Delta M = 239.059455 - 238.811370 = 0.248085 \text{ u}.$$

Retaining these digits until the final conversion avoids unnecessary rounding error.

Step 3: Convert the mass defect into released energy Multiplying by the mass-energy conversion factor gives

$$Q = 0.248085 \times 931.5 \text{ MeV} = 231.0911775 \text{ MeV}.$$

The final rest mass is less than the initial rest mass. Thus the missing rest energy appears as energy released in the overall fission and subsequent decay process, rather than energy that must be supplied as a threshold.

Step 4: Conclusion The overall energy release is $Q \simeq +231.1 \text{ MeV}$ per fission event, under the stated neglect of emitted electron or positron masses.

Quick Tip to Solve: Include the absorbed neutron in the initial mass: the check $238 + 1 = 140 + 99$ prevents omitting it. Convert to MeV only after subtracting the total masses in u.

9(a)(i). Arrange the following electromagnetic radiation in the ascending order of their frequencies:

X-rays, microwaves, gamma rays, radio waves

[3 marks total]

Solution:

Concept:

- All electromagnetic waves travel in vacuum at the same speed c , with $c = \nu\lambda$, where ν is frequency and λ is wavelength.
- Frequency increases as wavelength decreases. The standard electromagnetic spectrum runs from radio waves through microwaves, infrared, visible light, ultraviolet and X-rays to gamma rays.

Step 1: Compare the longer-wavelength radiations Radio waves occupy the lowest-frequency end of the standard spectrum. Microwaves have shorter wavelengths and hence higher frequencies than the radio waves referred to separately in this question. Thus radio waves must appear before microwaves in an ascending-frequency list.

Step 2: Compare the higher-frequency radiations X-rays and gamma rays lie beyond ultraviolet in the standard spectrum and have much shorter wavelengths than microwaves. In the conventional CBSE ordering, gamma rays occupy the highest-frequency end and follow X-rays. Retain only the four named radiations when writing the requested sequence; the intervening infrared, visible and ultraviolet regions are not part of the given list.

Step 3: Conclusion The ascending order of frequencies is

$$\text{Radio waves} < \text{Microwaves} < \text{X-rays} < \text{Gamma rays}.$$

Quick Tip to Solve: Read the standard spectrum from its longest-wavelength end and omit every radiation not named in the question.

9(a)(ii). Write two uses of any two of these radiation.

Solution:

Concept:

- Electromagnetic radiations are used according to their frequency, propagation and interaction with matter. Radio waves and microwaves are two of the radiations named in the preceding part.
- Communication systems carry information by modulating an electromagnetic wave. Microwave reflection is also used to detect objects, and microwave absorption can produce heating.

Step 1: State two uses of radio waves **Radio broadcasting:** Radio-frequency waves carry modulated audio signals from a transmitting station to receivers, as in AM and FM broadcasting.

Television transmission: Radio-frequency waves carry picture and sound signals in terrestrial television broadcasting. These uses exploit the ability of electromagnetic waves to transfer information over a distance without a conducting wire between transmitter and receiver.

Step 2: State two uses of microwaves **Radar:** A transmitter sends microwave pulses towards a distant object. The reflected signal helps detect the object, and its round-trip travel time gives the distance.

Microwave ovens: Microwaves are absorbed by food, particularly through its water content, and their energy is converted into thermal energy for heating and cooking. This is an absorption application, whereas radar depends on reflection.

Step 3: Conclusion Radio waves are used for radio broadcasting and television transmission. Microwaves are used in radar and microwave ovens. Thus two uses of each of two specified radiations have been given.

Quick Tip to Solve: Choose radio waves and microwaves: remember broadcasting for radio waves, and radar plus cooking for microwaves.

OR

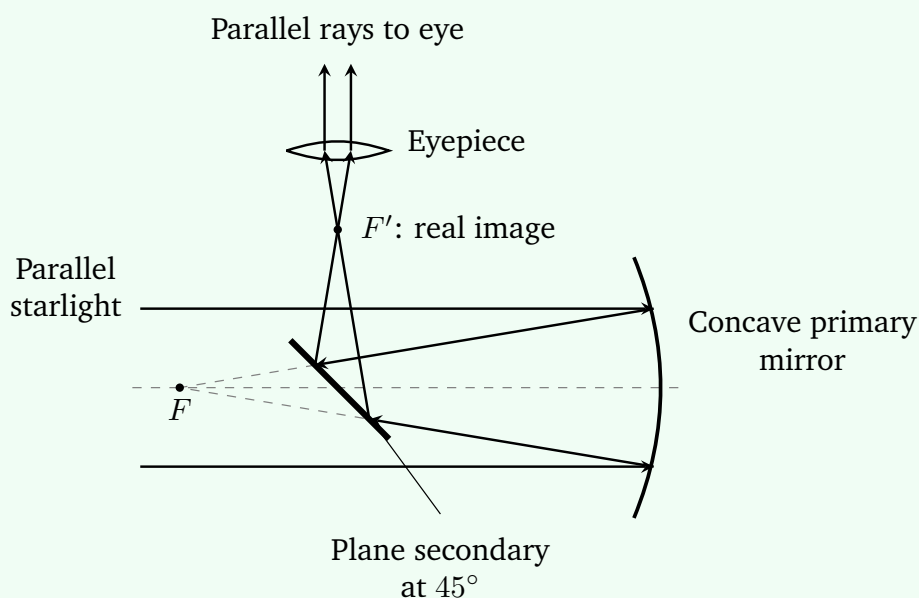
9(b). With the help of a ray diagram explain the working of a reflecting telescope. Mention two advantages of a reflecting telescope over a refracting telescope. [3 marks]

Solution:

Concept:

- A reflecting telescope uses a large concave primary mirror as its objective. Parallel light from a distant object is reflected towards its focal plane, producing a real image.
- The eyepiece acts as a magnifier. For normal adjustment the intermediate image lies in its first focal plane, so the emergent rays are parallel and the final image is at infinity.

Step 1: Trace the light through a reflecting telescope In the Newtonian arrangement shown, parallel rays from a distant star enter the open end of the telescope and strike the concave primary mirror. The primary reflects them towards its focus. A small plane secondary mirror inclined at 45° to the principal axis intercepts the converging beam and turns it through 90° , towards an eyepiece mounted at the side. The real intermediate image is therefore formed at the displaced focus F' . The dashed point F shows the focus the primary would produce without the secondary mirror.



Newtonian reflecting telescope in normal adjustment (schematic).

Step 2: Explain how the eyepiece magnifies the image Place the intermediate image at the first focal plane of the convex eyepiece. Rays from each point of this image then emerge as a parallel bundle, and the observer sees a magnified angular view with relaxed eyes. For normal adjustment, the magnitude of the angular magnifying power is $M = f_o/f_e$, where f_o is the focal length of the primary mirror and f_e is that of the eyepiece. Thus a long-focal-length objective and a short-focal-length

eyepiece give high angular magnification.

Step 3: State two advantages over a refracting telescope First, the reflecting objective is free from chromatic aberration: the law of reflection is independent of wavelength, so it does not separate colours into different focal points as a lens does. Second, a large-aperture mirror can be supported from its back and made more easily than a large objective lens. Its large aperture collects more light and gives greater resolving power, allowing fainter and more closely spaced celestial objects to be observed.

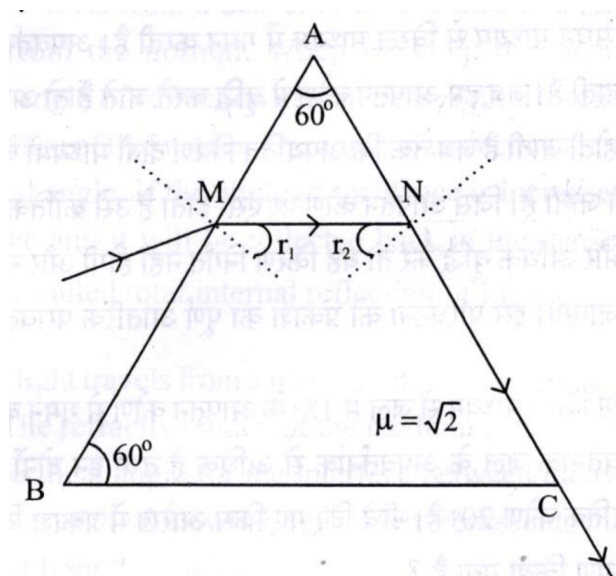
Step 4: Conclusion A concave primary mirror collects and focuses starlight; the secondary redirects it to an eyepiece, which provides angular magnification. The reflecting objective avoids chromatic aberration and permits a large, well-supported aperture with high light-gathering and resolving power.

Quick Tip to Solve: In a Newtonian telescope sketch, turn the converging beam with a small 45° plane mirror, and place the intermediate image one eyepiece focal length below the eyepiece.

A ray of light passes through a prism of refractive index $\sqrt{2}$ as shown in the figure. Find:

10(i). The angle of incidence ($\angle r_2$) at face AC.

[3 marks total]



Solution:

Concept:

- Snell's law at the prism–air boundary is $\mu \sin r_2 = \sin e$, where r_2 is the incidence angle inside the prism and e is the emergence angle in air, both measured from the normal.
- At the critical angle C , the refracted ray grazes the surface: $e = 90^\circ$ and $\sin C = 1/\mu$ for a prism in air.

Step 1: Identify grazing emergence The ray emerging at N travels along face AC in the printed figure. Thus its angle with the surface is zero, but its angle with the normal is 90° . The incident ray is travelling from the optically denser prism into air, so this is the limiting condition for refraction: $r_2 = C$. The sketch is schematic; the angle should be calculated from the grazing condition, not measured from the drawing.

Step 2: Apply Snell's law at AC Substitute the given refractive index $\mu = \sqrt{2}$ and the emergence angle $e = 90^\circ$:

$$\sqrt{2} \sin r_2 = \sin 90^\circ = 1, \quad \sin r_2 = \frac{1}{\sqrt{2}}.$$

The physically relevant incidence angle lies between 0° and 90° , so take the acute inverse sine. The prism angle is not needed to obtain this angle at the exit face.

Step 3: Conclusion The angle of incidence at face AC is $r_2 = 45^\circ$, equal to the critical angle of the prism material in air.

Quick Tip to Solve: An emergent ray along a prism face means $e = 90^\circ$, not zero; immediately use $\sin C = 1/\mu$.

10(ii). The angle of minimum deviation for this prism.

Solution:

Concept:

- For a prism of angle A , the internal refraction angles obey $r_1 + r_2 = A$. At minimum deviation the path is symmetric: $r_1 = r_2 = A/2$ and the incidence angle equals the emergence angle.
- The refractive index in air is related to the minimum deviation δ_m by $\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$. Angles are measured from the corresponding surface normals.

Step 1: Set up the minimum-deviation condition From the printed figure, the prism angle is $A = 60^\circ$, and its refractive index is $\mu = \sqrt{2}$. Minimum deviation is a property found by varying the incident direction until the internal path is symmetric. The particular grazing-emergence ray in part (i) is not this symmetric path. At minimum deviation,

$$r_1 = r_2 = \frac{A}{2} = 30^\circ.$$

Step 2: Find the incidence angle and deviation Apply Snell's law at the entrance face for the symmetric path:

$$\sin i_m = \mu \sin \frac{A}{2} = \sqrt{2} \sin 30^\circ = \frac{1}{\sqrt{2}}.$$

Thus $i_m = 45^\circ$, and symmetry also gives $e_m = 45^\circ$. Use the prism deviation relation $\delta = i + e - A$:

$$\delta_m = 2i_m - A = 2(45^\circ) - 60^\circ.$$

Step 3: Conclusion The angle of minimum deviation for this prism is $\delta_m = 30^\circ$.

Quick Tip to Solve: For minimum deviation, replace the given ray by a symmetric path: set $r = A/2$, find i by Snell's law, then use $\delta_m = 2i - A$.

11(i). Draw V-I characteristics of a p-n junction diode.

[3 marks total]

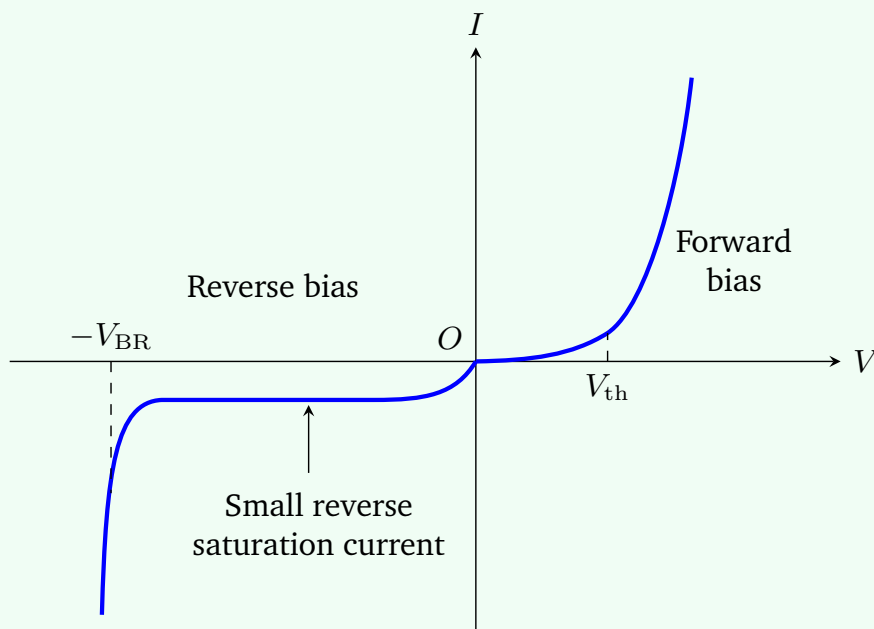
Solution:

Concept:

- A diode's V-I characteristic plots the current I through its p-n junction against the applied voltage V . Forward bias corresponds to positive voltage and current.
- Forward current rises rapidly beyond the threshold voltage V_{th} . Reverse current remains very small until the reverse breakdown voltage of magnitude V_{BR} is reached.

Step 1: Draw the forward characteristic Take voltage along the horizontal axis and current along the vertical axis. In forward bias the current is initially small; beyond the knee near V_{th} , the current increases steeply for a small increase in voltage.

Step 2: Complete the reverse characteristic In reverse bias, draw a small, nearly constant negative reverse saturation current. At $V = -V_{BR}$, show a sharp increase in the magnitude of reverse current. The reverse-current branch below is enlarged for visibility; the sketch is not to scale.



V-I characteristic of a p-n junction diode (schematic; reverse current enlarged).

Step 3: Conclusion The characteristic has a steep forward conducting branch beyond V_{th} , a nearly flat reverse leakage branch, and a steep reverse breakdown branch near $-V_{BR}$.

Quick Tip to Solve: Label both knees: the forward threshold is on the positive voltage side and reverse breakdown on the negative side.

11(ii). Differentiate between the threshold voltage and the breakdown voltage for a diode.

Solution:

Concept:

- A junction diode behaves differently under forward and reverse bias, so the threshold voltage and the breakdown voltage refer to different branches of its V-I characteristic.
- The threshold voltage is associated with appreciable forward conduction, whereas breakdown is

associated with a sharp increase in reverse current.

Step 1: Define threshold voltage The threshold or knee voltage V_{th} is the forward-bias voltage beyond which the forward current begins to increase rapidly. It is approximately 0.7 V for a silicon diode and 0.3 V for a germanium diode. Small forward current can exist below this voltage; it is not a perfectly abrupt switch.

Step 2: Define breakdown voltage The breakdown voltage V_{BR} is the magnitude of the reverse-bias voltage at which the reverse current rises sharply owing to breakdown of the junction. Its value depends on the diode construction and doping. On a signed voltage axis it occurs near $V = -V_{BR}$.

Step 3: Conclusion Threshold voltage marks the onset of rapid current increase in forward bias; breakdown voltage marks the onset of rapid current increase in reverse bias.

Quick Tip to Solve: State the bias direction with each definition: forward for threshold, reverse for breakdown.

11(iii). Write the property of a junction diode which makes it suitable for rectification of ac voltages.

Solution:

Concept:

- Rectification converts an alternating voltage into a unidirectional, pulsating output by using a device with different conducting properties in the two directions.
- A junction diode offers low resistance in forward bias and very high resistance in reverse bias, provided the reverse voltage is below breakdown.

Step 1: Examine the conducting half-cycle When the polarity of the applied ac voltage forward-biases the junction diode, it conducts appreciable current through the load once the forward voltage is sufficient. The diode thus allows this polarity of the applied signal to produce load current.

Step 2: Examine the opposite half-cycle When the applied voltage reverses polarity, the junction becomes reverse-biased. Its high reverse resistance permits only a negligible leakage current below breakdown, so it effectively blocks current in the opposite direction. This unequal conduction in the two directions provides the basis of rectification.

Step 3: Conclusion A junction diode is suitable for rectification because of its unidirectional conducting property: low resistance in forward bias and very high resistance in reverse bias.

Quick Tip to Solve: Connect the property directly to rectification: the diode conducts forward current and blocks reverse current below breakdown.

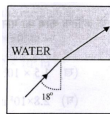
Section C (5 marks)

12. A ray of light travels from a denser to a rarer medium. After refraction, it bends away from the normal. When we keep increasing the angle of incidence, the angle of refraction also increases till the refracted ray grazes along the interface of two media. The angle of incidence for which it happens is called critical angle. If the angle of incidence is increased further the ray will not emerge and it will be reflected back in the denser medium. This phenomenon is called total internal reflection of light. [5 marks]

12(i). A ray of light travels from a medium into water at an angle of incidence of 18° . The refractive index of the medium is more than that of water and the critical angle for the interface between the two media is 20° . Which one of the following figures best represents the correct path of the ray of light? [1 mark]



Correct Answer: (A)



Solution:

Concept:

- When light travels from an optically denser medium to a rarer medium, the refracted ray bends away from the normal: its angle of refraction exceeds its angle of incidence.
- Total internal reflection requires incidence greater than the critical angle C ; at $i = C$ the refracted ray just grazes the interface.

Step 1: Compare incidence with the critical angle Here $i = 18^\circ$ and $C = 20^\circ$, so $i < C$. The ray therefore emerges into water; it is neither totally internally reflected nor refracted along the interface. By Snell's law, $\sin r = \sin 18^\circ / \sin 20^\circ$, giving $r \approx 64.6^\circ$.

Step 2: Identify the direction of bending Water has the lower refractive index, so the emerging ray makes a larger angle with the normal, as in diagram (A). Diagram (B) depicts internal reflection, (C) shows bending towards the normal, and (D) shows grazing emergence, which would require incidence of 20° .

Step 3: Conclusion The ray emerges into water, bending away from the normal. Hence, the correct option is (A).

Quick Tip to Solve: First compare i with C ; when $i < C$, select the transmitted ray bending away from the normal in the rarer medium.

12(ii). A point source of light is placed at the bottom of a tank filled with water, of refractive index μ , to a depth d . The area of the surface of water through which light from the source can emerge, is: [1 mark]

- (A) $\frac{\pi d^2}{2(\mu^2 - 1)}$
(B) $\frac{\pi d^2}{\mu^2 - 1}$
(C) $\frac{\pi d^2}{\sqrt{2}\sqrt{\mu^2 - 1}}$
(D) $\frac{2\pi d^2}{\mu^2 - 1}$

Correct Answer: (B) $\frac{\pi d^2}{\mu^2 - 1}$

Solution:

Concept:

- At a water-air boundary, the critical angle C satisfies $\sin C = 1/\mu$, where μ is the refractive index of water relative to air.
- The extreme emergent rays form a cone of half-angle C . Its intersection with the horizontal surface is a circle of radius $R = d \tan C$, where d is the source depth.

Step 1: Determine the limiting radius Rays striking the water surface with incidence less than C can emerge; those beyond this limit undergo total internal reflection. From the right triangle formed by the source, its vertical projection and a limiting point on the surface,

$$R = d \tan C, \quad \tan^2 C = \frac{\sin^2 C}{1 - \sin^2 C} = \frac{1}{\mu^2 - 1}.$$

Step 2: Calculate the circular area The complete circular patch has area $A = \pi R^2$. Thus $A = \pi d^2 \tan^2 C$. It is a disk, not a semicircle, so no factor of $1/2$ occurs as in (A); (D) doubles the disk area. Option (C) also fails because the area requires the square of $\tan C$.

Step 3: Conclusion

$$A = \frac{\pi d^2}{\mu^2 - 1}.$$

Hence, the correct option is (B).

Quick Tip to Solve: Use $R = d \tan C$, then square the radius; $\sin C = 1/\mu$ alone does not give the radius of the emergence patch.

12(iii). For which of the following media, with respect to air, the value of critical angle is maximum?

[1 mark]

- (A) Crown glass
- (B) Flint glass
- (C) Water
- (D) Diamond

Correct Answer: (C) Water

Solution:

Concept:

- For light passing from a medium of refractive index μ into air, the critical angle satisfies $\sin C = 1/\mu$.
- The sine function increases between 0° and 90° . Hence, a lower refractive index gives a larger critical angle.

Step 1: Compare the refractive indices The usual visible-light refractive indices are approximately 1.33 for water, 1.52 for crown glass, 1.62 for flint glass and 2.42 for diamond. Water has the smallest refractive index among the four media.

Step 2: Relate the ordering to critical angle Since $C = \sin^{-1}(1/\mu)$, water gives the largest argument of the inverse sine and therefore the largest critical angle, about 49° . Crown glass, flint glass and diamond have larger refractive indices, giving smaller critical angles of approximately 41° , 38° and 24° , respectively; these eliminate (A), (B) and (D).

Step 3: Conclusion Water has the maximum critical angle with respect to air. Hence, the correct option is (C).

Quick Tip to Solve: For the same rarer medium (air), reverse the refractive-index ordering to obtain the critical-angle ordering.

12(iv). The critical angle for a pair of two media A and B of refractive indices 2.0 and 1.0 respectively is:

[1 mark]

- (A) 0°
- (B) 30°
- (C) 45°
- (D) 60°

Correct Answer: (B) 30°

Solution:

Concept:

- The critical angle C is the incidence angle in the denser medium for which the refracted ray in the rarer medium makes 90° with the normal.
- Snell's law gives $n_A \sin C = n_B \sin 90^\circ$, so $\sin C = n_B/n_A$, where $n_A > n_B$.

Step 1: Identify the direction of incidence Medium A has refractive index 2.0, whereas medium B has refractive index 1.0. Thus the critical-angle condition applies to light travelling from A to B. The ratio in Snell's law must be the rarer index divided by the denser index.

Step 2: Substitute and compare the options At grazing refraction,

$$\sin C = \frac{1.0}{2.0} = \frac{1}{2}.$$

In the physical interval $0^\circ < C < 90^\circ$, the angle with sine $1/2$ is 30° . The sines of 0° , 45° and 60° are respectively 0, $1/\sqrt{2}$ and $\sqrt{3}/2$; hence options (A), (C) and (D) do not satisfy Snell's law for these media.

Step 3: Conclusion The critical angle is 30° . Hence, the correct option is (B).

Quick Tip to Solve: Put the smaller refractive index over the larger one; a ratio of $1/2$ immediately gives a critical angle of 30° .

12(v). The critical angle of pair of a medium and air is 30° . The speed of light in the medium is: [1 mark]

(A) $1 \times 10^8 \text{ m s}^{-1}$

(B) $1.5 \times 10^8 \text{ m s}^{-1}$

(C) $2.2 \times 10^8 \text{ m s}^{-1}$

(D) $2.8 \times 10^8 \text{ m s}^{-1}$

Correct Answer: (B) $1.5 \times 10^8 \text{ m s}^{-1}$

Solution:

Concept:

- For light going from a medium of refractive index n into air, $\sin C = 1/n$, taking the refractive index of air as unity.
- Refractive index relates speed v in the medium to vacuum speed c by $n = c/v$, with $c = 3 \times 10^8 \text{ m s}^{-1}$.

Step 1: Calculate the refractive index At the critical angle the refracted ray travels along the interface. With $C = 30^\circ$, Snell's law gives

$$n = \frac{1}{\sin 30^\circ} = \frac{1}{1/2} = 2.$$

The medium therefore slows light to one-half of its speed in vacuum.

Step 2: Find the speed and check the options Substitute the index into the speed relation:

$$v = \frac{c}{n} = \frac{3 \times 10^8}{2} = 1.5 \times 10^8 \text{ m s}^{-1}.$$

Options (A), (C) and (D) would give refractive indices 3, approximately 1.36 and approximately 1.07, respectively. None equals the required value 2, so none reproduces the stated critical angle.

Step 3: Conclusion The speed is $1.5 \times 10^8 \text{ m s}^{-1}$. Hence, the correct option is (B).

Quick Tip to Solve: For a medium-air boundary combine the two formulae directly: $v = c \sin C$. Here $\sin 30^\circ = 1/2$.