

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/5/2



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** - 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. Two crystals C_1 and C_2 , made of pure silicon, are doped with arsenic and aluminium respectively.

(i) Identify the extrinsic semiconductors so formed.

(ii) Why is doping of intrinsic semiconductors necessary?

[2 marks]

Solution:

Concept:

- Doping means adding a small, controlled amount of suitable impurity to pure silicon to increase the concentration of mobile charge carriers.
- Silicon is tetravalent. A pentavalent impurity acts as a donor, whereas a trivalent impurity acts as an acceptor.

Step 1: (i) Identify the two semiconductors Arsenic has five valence electrons. Four form covalent bonds with neighbouring silicon atoms and the fifth is readily available for conduction. Thus, crystal C_1 becomes an n -type semiconductor, with electrons as majority carriers and holes as minority carriers. Aluminium has three valence electrons, so one of the four bonds lacks an electron and a hole is produced. Hence, C_2 becomes a p -type semiconductor, with holes as majority carriers and electrons as minority carriers.

Step 2: (ii) Explain why doping is necessary In intrinsic silicon, electrons and holes are generated thermally and their concentration is comparatively small at ordinary temperatures. Its conductivity is therefore low. Doping supplies many additional electrons or holes and increases the conductivity to a useful, controllable value for electronic devices. The crystal remains electrically neutral overall: the mobile carriers are balanced by fixed ionised impurity atoms.

Step 3: Conclusion C_1 is n -type and C_2 is p -type. Doping increases and controls the charge-carrier concentration, thereby increasing conductivity.

Quick Tip to Solve: Count impurity valence electrons: five gives a donor electron; three gives an acceptor hole in silicon.

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:

- A photodiode converts incident light into an electrical signal by producing electron-hole pairs near the depletion region of a p - n junction.
- The reverse-bias electric field separates these carriers and produces a photocurrent whose magnitude increases with incident light intensity.

Step 1: Explain the choice of reverse bias Without illumination, the reverse current is a small minority-carrier dark current. Incident photons of sufficient energy generate additional electron-hole pairs; the junction field sweeps electrons towards the n side and holes towards the p side. The resulting change in reverse current is appreciable relative to its small background and is readily detected. Reverse bias also widens the depletion region, favouring collection of the generated carriers.

Step 2: Compare with forward bias In forward bias, a large current flows due to injection of majority

carriers across the junction. The relatively small change produced by illumination is masked by this large background current, so light detection is less sensitive. Therefore, the fact that forward current is larger does not make forward bias preferable: a detector must distinguish the light-induced change clearly.

Step 3: State two uses Photodiodes are used (1) as light detectors in optical-fibre communication receivers, converting received optical signals into electrical signals, and (2) in automatic light-operated switches, such as switching street lights according to ambient illumination.

Step 4: Conclusion A photodiode is reverse biased because the light-induced change is easily measured against a small dark current. Two uses are optical communication receivers and automatic light-operated switches.

Quick Tip to Solve: Compare the illumination-induced change with the dark background, rather than comparing total forward and reverse currents.

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:

- An α particle has charge $+2e$ and mass approximately $4m_p$, whereas a hydrogen nucleus is a proton with charge $+e$ and mass m_p .
- Coulomb repulsion causes deflection, but the recoil of the target nucleus must be considered when its mass is smaller than that of the incident particle.

Step 1: Predict the scattering pattern Most α particles would pass through the thin hydrogen sheet with little deflection. The strong large-angle scattering and backward scattering characteristic of a gold foil would not be observed. Hydrogen has a much smaller nuclear charge than gold, so its Coulomb repulsion is weaker for comparable separations; consequently the deflections are generally smaller.

Step 2: Explain the role of the light nucleus A gold nucleus is much heavier than an α particle and behaves approximately as a fixed scattering centre. A proton is lighter than the α particle and recoils substantially, receiving energy and momentum from it. For illustration, in a head-on elastic encounter with a proton initially at rest, the outgoing α -particle velocity is $v'_\alpha = (m_\alpha - m_p)v / (m_\alpha + m_p) = 3v/5$, still in the forward direction. Thus even a head-on encounter does not reverse the incident α particle. In general, the maximum laboratory deflection for this mass ratio is $\sin^{-1}(m_p/m_\alpha) \approx 14.5^\circ$, consistent with absence of large-angle scattering.

Step 3: Conclusion The α particles would suffer only small forward deflections, with no backward scattering; the hydrogen nuclei would recoil because they are lighter than the incident α particles.

Quick Tip to Solve: Check both nuclear charge and target mass: a light proton recoils, so the fixed heavy-nucleus picture used for gold cannot be applied.

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 of energy $E = h\nu$, where h is Planck's constant and ν is the frequency of light.
- The work function ϕ is the minimum energy required to liberate an electron from the metal surface. The threshold frequency is $\nu_0 = \phi/h$.

Step 1: Compare the energy of one photon with the work function In the photoelectric effect, an electron absorbs the energy of a single photon. It can escape only when this energy is at least the work function:

$$h\nu \geq \phi \iff \nu \geq \nu_0.$$

For a frequency above threshold, Einstein's equation gives the maximum kinetic energy as $K_{\max} = h\nu - \phi$. Thus frequency decides whether an individual photon can supply the energy needed for emission.

Step 2: Explain what changing the intensity does At a fixed frequency, increasing intensity increases the number of photons incident per unit area per unit time, while leaving the energy $h\nu$ of each photon unchanged. If $\nu < \nu_0$, each photon has insufficient energy; increasing the number of such photons cannot cause photoelectric emission in the usual single-photon photoelectric effect. If $\nu > \nu_0$, greater intensity generally increases the number of emitted electrons and hence the photocurrent, without changing their maximum kinetic energy.

Step 3: Conclusion Photoelectron emission is determined by frequency because the photon energy must satisfy $h\nu \geq \phi$. Intensity controls the supply of photons and therefore the emission rate once the threshold condition is met.

Quick Tip to Solve: First compare $h\nu$ with the work function; only after this threshold check should you discuss intensity and photocurrent.

Section B (24 marks)

4. How will the interference pattern in Young's double-slit experiment be affected if:

- The screen is moved away from the plane of the slits.
 - The source slit is moved away from the plane of the slits.
 - The phase difference between the light waves emanating from the two slits S_1 and S_2 changes from 0 to π and remains constant.
- [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.
- A constant initial phase difference shifts the fringe pattern without changing fringe width. The observed phase difference includes both this initial phase and the phase due to the path difference.

Step 1: (i) Move the screen away from the double slits Moving the screen away increases D , while λ and d remain fixed. Hence

$$\beta' = \frac{\lambda D'}{d} > \frac{\lambda D}{d} = \beta \quad (D' > D).$$

The bright and dark fringes become more widely spaced: the pattern expands. Their spacing increases in direct proportion to the screen distance. With the same incident light, illumination on the more distant screen also decreases.

Step 2: (ii) Move the source slit away from the double slits The source slit illuminates S_1 and S_2 , which act as coherent sources. Moving the source slit farther away, while retaining its central alignment, does not change λ , D or d , nor the equal source-to-slit paths. Thus fringe width and fringe positions remain unchanged. However, less light reaches the double slits, so the fringes become less bright. Source-to-double-slit distance is not the D appearing in the fringe-width formula.

Step 3: (iii) Introduce a constant initial phase difference of π For equal slit intensities I_s , the intensity at a point whose geometrical path difference is δ is

$$I = 2I_s \left[1 + \cos \left(\frac{2\pi\delta}{\lambda} + \phi_0 \right) \right].$$

Changing ϕ_0 from 0 to π reverses the sign of the cosine term. Consequently, every former bright fringe becomes dark and every former dark fringe becomes bright. In particular, the central bright fringe becomes dark. The displacement magnitude is

$$\Delta y = \frac{\pi}{2\pi} \frac{\lambda D}{d} = \frac{\beta}{2}.$$

Since the added phase is constant, stable interference persists and the separation of consecutive bright fringes stays β .

Step 4: Conclusion (i) Fringe width increases as the screen moves away. (ii) Fringe width and positions remain unchanged, but brightness decreases. (iii) The pattern shifts by half a fringe width, interchanging bright and dark fringes, with no change in fringe width.

Quick Tip to Solve: Distinguish the source-to-slit distance from the slit-to-screen distance D ; a phase change of π always interchanges maxima and minima.

5. An alpha particle is accelerated through a potential difference of 100 V. Calculate:

- (i) The speed acquired by the alpha particle, and
- (ii) The de-Broglie wavelength associated with it.

(Take mass of alpha particle = 6.4×10^{-27} kg)

[3 marks]

Solution:

Concept:

- An alpha particle is a helium nucleus with charge $q = +2e = 3.2 \times 10^{-19}$ C. Its gain in kinetic energy through an accelerating potential difference V is qV .
- For non-relativistic motion, $K = \frac{1}{2}mv^2$ and momentum $p = mv$. The de Broglie wavelength is $\lambda = h/p$, where $h = 6.63 \times 10^{-34}$ J s.

Step 1: (i) Determine the kinetic energy gained Taking the initial kinetic energy as negligible, the electric field does work on the alpha particle. Using the given mass $m = 6.4 \times 10^{-27}$ kg and potential

difference $V = 100 \text{ V}$,

$$K = qV = (3.2 \times 10^{-19})(100) = 3.2 \times 10^{-17} \text{ J}.$$

The factor of two in the charge is essential: an alpha particle carries two elementary positive charges, so its energy gain is twice that of a singly charged particle at the same voltage.

Step 2: (i) Calculate the speed Equating the electrical energy gain to the kinetic energy gives

$$v = \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2(3.2 \times 10^{-17})}{6.4 \times 10^{-27}}} = \sqrt{1.0 \times 10^{10}} \text{ m s}^{-1}.$$

This speed is much smaller than the speed of light, so the non-relativistic expression used here is consistent.

Step 3: (ii) Calculate the associated wavelength First calculate the momentum using the speed obtained above:

$$p = mv = (6.4 \times 10^{-27})(1.0 \times 10^5) = 6.4 \times 10^{-22} \text{ kg m s}^{-1}.$$

Hence

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{6.4 \times 10^{-22}} \text{ m}.$$

Dividing the coefficients and subtracting the powers of ten gives the matter-wave wavelength.

Step 4: Conclusion (i) The speed acquired is $v = 1.0 \times 10^5 \text{ m s}^{-1}$. (ii) The associated de Broglie wavelength is $\lambda = 1.04 \times 10^{-12} \text{ m}$.

Quick Tip to Solve: Use the alpha particle charge $2e$, then compute $\lambda = h/\sqrt{2mqV}$ directly as a check on the two-stage calculation.

6(a). (i) Define SI unit of power of a lens.

(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.

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

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

[3 marks]

Solution:

Concept:

- The power of a lens is $P = 1/f$, where the focal length f is expressed in metres. Its SI unit is the dioptre, written D, equivalent to m^{-1} .
- For a thin lens in air, the lens maker's formula is $1/f = (\mu - 1)(1/R_1 - 1/R_2)$, where μ is the refractive index and the radii are signed using the Cartesian convention.
- The thin-lens formula is $1/f = 1/v - 1/u$, with distances measured from the optical centre. A positive focal length describes a converging lens.

Step 1: (i) Define the SI unit of lens power One dioptre is the power of a lens whose focal length has magnitude one metre. A converging lens of focal length $+1 \text{ m}$ has power $+1 \text{ D}$, while a diverging lens of focal length -1 m has power -1 D . Thus $1 \text{ D} = 1 \text{ m}^{-1}$; the focal length must be converted to metres before calculating the power.

Step 2: (ii.i) Apply the lens maker's formula Orient the convex surface towards the incident light.

Its radius is $R_1 = +25$ cm, while the plane surface has $R_2 = \infty$, so its reciprocal is zero. With glass refractive index $\mu = 1.5$,

$$\frac{1}{f} = (1.5 - 1) \left(\frac{1}{25} - 0 \right) = \frac{0.5}{25} \text{ cm}^{-1} = \frac{1}{50} \text{ cm}^{-1}.$$

Reversing the lens orientation gives the same focal length because the signed radii change together with their surface order. The positive result confirms that the glass plano convex lens in air is converging.

Step 3: (ii.ii) Locate and describe the image The object is in front of the lens, so $u = -50$ cm, while $f = +50$ cm. Substituting into the lens formula,

$$\frac{1}{50} = \frac{1}{v} - \frac{1}{-50} = \frac{1}{v} + \frac{1}{50}, \quad \frac{1}{v} = 0.$$

The object therefore lies at the first principal focus. Rays emerging from the lens are parallel and meet only at infinity on the other side. This is the limiting case of a real, inverted image with very large magnification; there is no finite image position at which a nearby screen can receive a sharp image.

Step 4: Conclusion (i) One dioptre is the power corresponding to a focal-length magnitude of 1 m. (ii.i) $f = +50$ cm. (ii.ii) The image is formed at infinity on the other side of the lens and is real, inverted and highly enlarged.

Quick Tip to Solve: For a plano convex lens in air, use $f = R/(\mu - 1)$; if the object distance equals this focal length, the emergent rays are parallel and the image is at infinity.

OR

6(b). 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:

- The distance of the second bright fringe from the central maximum pertaining to light of 600 nm.
- The least distance from the central maximum at which bright fringes due to both the wavelengths coincide.

[3 marks]

Solution:

Concept:

- For a slit of width a , the minima satisfy $a \sin \theta = m\lambda$. The secondary bright fringes lie approximately halfway between successive minima: $y_n \simeq (2n + 1)\lambda D/(2a)$, where $n = 1, 2, \dots$, D is the screen distance and the central maximum is excluded.
- Coincidence of secondary bright fringes requires the same screen displacement for both wavelengths. Their half-integral orders must therefore be included; the integral-order formula for Young's interference fringes does not apply to single-slit secondary maxima.

Step 1: (i) Locate the second secondary maximum Convert the data to SI units: $a = 0.6 \times 10^{-3}$ m, $D = 1.0$ m, and $\lambda_1 = 600 \times 10^{-9}$ m. The second bright fringe after the central maximum lies approximately between the second and third minima. Thus

$$y_2 \simeq \frac{5\lambda_1 D}{2a} = \frac{5(600 \times 10^{-9})(1.0)}{2(0.6 \times 10^{-3})} = 2.5 \times 10^{-3} \text{ m}.$$

This uses the standard school-level approximation for secondary maxima; unlike the minima, their exact locations are not half-integral orders.

Step 2: (ii) Test whether secondary bright fringes can coincide Let the secondary-fringe numbers for the two colours be positive integers n and k . Equal displacements would require

$$(2n + 1)600 = (2k + 1)480, \\ 5(2n + 1) = 4(2k + 1).$$

The left side is odd whereas the right side is even, so no such integers exist. Hence the usual single-slit bright-fringe approximation gives no nonzero coincident bright fringe for these wavelengths. Both central maxima coincide at $y = 0$. A displacement of 4 mm, obtained from $4\lambda_1 = 5\lambda_2$, instead coincides with the fourth and fifth minima respectively, and is a common dark fringe. It must not be presented as a common bright fringe. The wording of the printed part (ii) therefore has no positive-distance answer under the standard formula used in this question.

Step 3: Conclusion (i) The second bright fringe is approximately 2.5 mm from the central maximum. (ii) The central maxima coincide at 0; there is no nonzero common secondary bright fringe in the standard approximation. The common dark fringe is at 4 mm.

Quick Tip to Solve: For a single slit, check odd half-integral orders before claiming bright-fringe coincidence; integral orders locate dark fringes.

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

X-rays, microwaves, gamma rays, radio waves

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

[3 marks]

Solution:

Concept:

- All electromagnetic waves travel in vacuum at $c = 3.0 \times 10^8 \text{ m s}^{-1}$. Frequency ν and wavelength λ obey $c = \nu\lambda$, so shorter wavelength corresponds to higher frequency.
- Electromagnetic radiations are used according to their interaction with matter: radio waves carry information over long distances, while X-rays penetrate soft tissue and undergo diffraction by crystal lattices.

Step 1: (i) Arrange the four radiations Radio waves occupy the long-wavelength, low-frequency end of the electromagnetic spectrum. Microwaves have shorter wavelengths and higher frequencies than ordinary radio waves. X-rays have much shorter wavelengths than microwaves, and gamma rays occupy the highest-frequency end in the usual school-level ordering. Therefore the required ascending order is

$$\nu_{\text{radio}} < \nu_{\text{microwave}} < \nu_{\text{X-ray}} < \nu_{\text{gamma}}.$$

This is a frequency ordering: the corresponding wavelength order is reversed because the propagation speed in vacuum is the same for every category.

Step 2: (ii) State two uses each of radio waves and X-rays Choose radio waves and X-rays from the given list. Radio waves are used (1) in radio broadcasting to carry modulated audio signals from a transmitting station to receivers, and (2) in television broadcasting to carry picture and sound information wirelessly. X-rays are used (1) in medical radiography to reveal bone fractures, since

bones absorb X-rays more strongly than surrounding soft tissue, and (2) in crystal-structure analysis, where diffraction of X-rays by regularly spaced atomic planes reveals the arrangement and spacing of atoms. Thus each of the two selected radiations has two distinct applications, as requested.

Step 3: Conclusion (i) Radio waves, microwaves, X-rays, gamma rays. (ii) Radio waves: radio broadcasting and television broadcasting. X-rays: medical radiography and crystal-structure analysis.

Quick Tip to Solve: Read the direction of ordering first: ascending frequency means moving from long radio wavelengths toward short gamma wavelengths.

OR

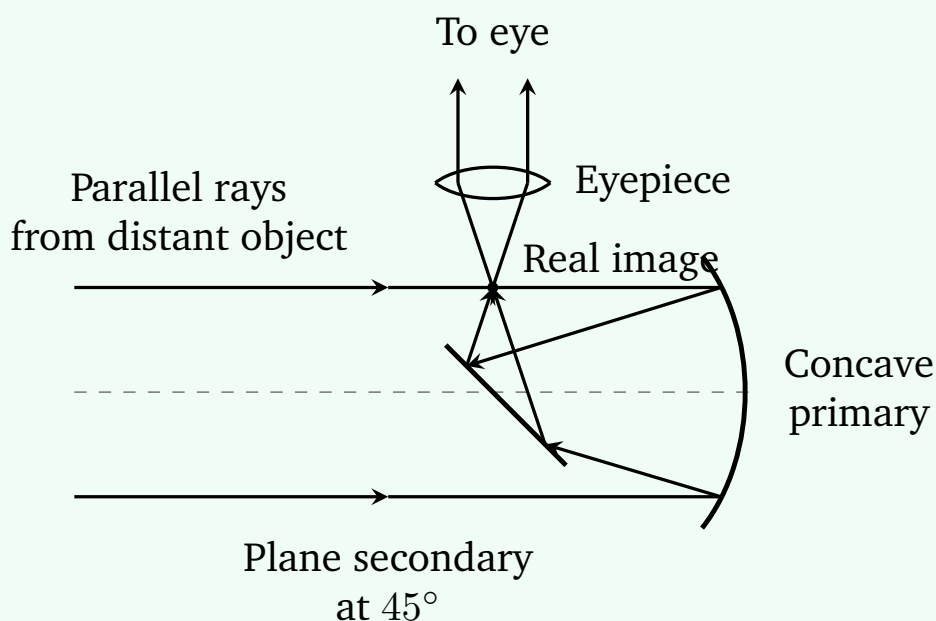
7(b). With the help of a ray diagram explain the working of a reflecting telescope. Mention two advantages of a reflecting telescope over a refracting telescope. [3 marks]

Solution:

Concept:

- A reflecting telescope uses a large concave, preferably parabolic, mirror as its objective. Parallel rays from a distant object are reflected towards its principal focus.
- A plane secondary mirror turns the converging beam towards an eyepiece. The eyepiece acts as a magnifier; for normal adjustment its focal plane contains the real image, giving a final virtual image at infinity.

Step 1: Explain the light path and image formation In the Newtonian arrangement shown, parallel rays from a distant star fall on the concave primary mirror. After reflection they converge towards the primary focus. A small plane mirror inclined at 45° to the principal axis intercepts these rays and turns them through 90° , towards the side of the telescope tube. The rays form a real image in the common focal plane of the primary optical system and the eyepiece. The eyepiece produces an enlarged virtual image for the observer. In normal adjustment, emergent rays are parallel and the eye views the final image at infinity. The angular magnification in magnitude is $M = f_o/f_e$, where f_o and f_e are the objective and eyepiece focal lengths.



Newtonian reflecting telescope, with the eyepiece adjusted for parallel emergent rays (schematic).

Step 2: State two advantages over a refracting telescope First, the reflecting objective has no chromatic aberration: reflection does not separate different wavelengths into different focal lengths, whereas refraction in a lens can do so. Second, a large-aperture primary mirror can be made and supported from behind more easily than a large objective lens. Its large aperture collects more light from faint objects and improves resolving power. Thus reflecting telescopes are particularly suitable for observing faint, distant astronomical objects.

Step 3: Conclusion A reflecting telescope forms a real image with a concave objective mirror and magnifies it with an eyepiece. Its two advantages are freedom from chromatic aberration and the practical availability of a large aperture for greater light collection and resolution.

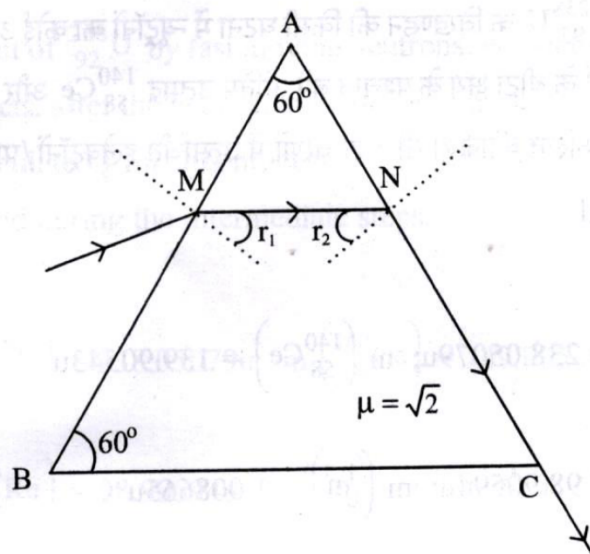
Quick Tip to Solve: Trace the beam in order: concave primary, inclined secondary, real image, then eyepiece; connect each advantage to the mirror objective.

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

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

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

[3 marks]



Solution:

Concept:

- Snell's law at the prism-to-air boundary is $\mu \sin r_2 = \sin e$, where r_2 is the internal incidence angle measured from the normal and e is the emergence angle in air.
- For a prism of apex angle A , $r_1 + r_2 = A$. At minimum deviation the path is symmetric: $r_1 = r_2 = A/2$ and $i = e$.
- The minimum deviation δ_m satisfies $\mu = \sin[(A + \delta_m)/2] / \sin(A/2)$.

Step 1: Find the incidence angle at face AC In the printed diagram the emergent ray runs along face AC. Hence it makes 90° with the normal at N, so $e = 90^\circ$. This is grazing emergence: the incidence angle inside the prism is the critical angle for the prism-air interface. Applying Snell's law with $\mu = \sqrt{2}$,

$$\sqrt{2} \sin r_2 = \sin 90^\circ = 1, \quad \sin r_2 = \frac{1}{\sqrt{2}}, \quad r_2 = 45^\circ.$$

The apex angle is $A = 60^\circ$, so this particular ray has $r_1 = 60^\circ - 45^\circ = 15^\circ$. Angles of incidence are measured from the normals, not from the prism faces. The sketch is schematic: the grazing emergent ray determines the required angle.

Step 2: Calculate the minimum deviation of the prism Minimum deviation is a separate symmetric arrangement of this same prism; the grazing ray shown need not have minimum deviation. For the symmetric path, $r_1 = r_2 = A/2 = 30^\circ$. Snell's law at entry gives

$$\sin i_m = \sqrt{2} \sin 30^\circ = \frac{1}{\sqrt{2}}, \quad i_m = 45^\circ.$$

The two outside angles are equal, so the deviation is

$$\delta_m = 2i_m - A = 2(45^\circ) - 60^\circ = 30^\circ.$$

Equivalently, substituting $\mu = \sqrt{2}$ and $A = 60^\circ$ into the minimum-deviation formula gives $\sin[(60^\circ + \delta_m)/2] = 1/\sqrt{2}$, yielding the same physical result.

Step 3: Conclusion (i) The internal incidence angle at face AC is $r_2 = 45^\circ$. (ii) The minimum deviation of the prism is $\delta_m = 30^\circ$.

Quick Tip to Solve: A ray emerging along a face has emergence angle 90° from its normal; calculate minimum deviation separately using the symmetric path.

9. (a) Use Bohr's postulate to prove that the radius of n^{th} orbit in a hydrogen atom is proportional to n^2 .

(b) How will the energy of a hydrogen atom change if n increases from 1 to ∞ ?

[3 marks]

Solution:

Concept:

- In hydrogen, electrostatic attraction supplies the centripetal force for an electron of mass m_e , speed v_n and orbital radius r_n .
- Bohr's angular-momentum postulate is $m_e v_n r_n = n\hbar = nh/(2\pi)$, where n is a positive integer and h is Planck's constant.
- The zero of energy is an electron at rest infinitely far from the proton; a bound hydrogen state has negative total energy.

Step 1: (a) Apply force balance and quantised angular momentum For a circular orbit, Coulomb's force gives

$$\frac{m_e v_n^2}{r_n} = \frac{e^2}{4\pi\epsilon_0 r_n^2}.$$

Here e is the magnitude of electron charge and ϵ_0 is the permittivity of free space. Bohr's postulate gives $v_n = n\hbar/(m_e r_n)$. Substitute this speed into the force equation:

$$\frac{n^2 \hbar^2}{m_e r_n^3} = \frac{e^2}{4\pi\epsilon_0 r_n^2}, \quad r_n = \frac{4\pi\epsilon_0 \hbar^2}{m_e e^2} n^2.$$

The coefficient contains only constants and equals the Bohr radius a_0 , so $r_n = a_0 n^2$.

Step 2: (b) Compare the ground state with the ionisation limit From force balance, the kinetic energy is $K = e^2/(8\pi\epsilon_0 r_n)$, whereas the potential energy is $U = -e^2/(4\pi\epsilon_0 r_n)$. Thus

$$E_n = K + U = -\frac{e^2}{8\pi\epsilon_0 r_n} = -\frac{13.6}{n^2} \text{ eV}.$$

Initially $E_1 = -13.6$ eV. As $n \rightarrow \infty$, the radius tends to infinity and $E_\infty \rightarrow 0$ from below. Therefore $\Delta E = E_\infty - E_1 = +13.6$ eV. This energy must be absorbed to remove the electron from the ground state; the negative sign of the initial energy denotes binding.

Step 3: Conclusion (a) $r_n = a_0 n^2$, hence $r_n \propto n^2$. (b) The energy increases from -13.6 eV to 0, an increase of 13.6 eV; the atom is ionised.

Quick Tip to Solve: At the ionisation limit use $E_\infty = 0$, and subtract the negative ground-state energy to obtain the positive energy absorbed.

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

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

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

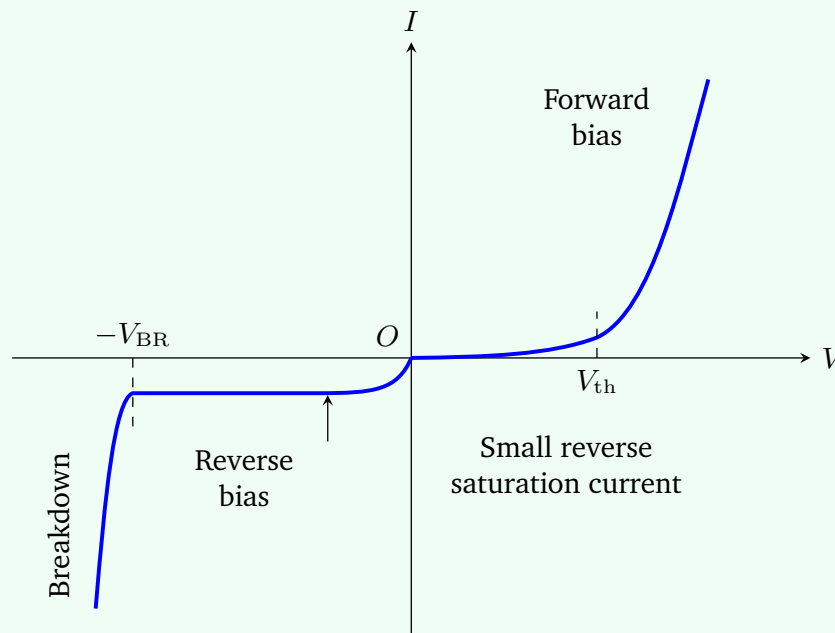
[3 marks]

Solution:

Concept:

- A p-n junction has a depletion region and potential barrier. Forward bias lowers this barrier, whereas reverse bias increases it.
- The diode's current-voltage characteristic is nonlinear: substantial forward current flows after the knee, but reverse current stays small until breakdown.

Step 1: (i) Sketch the current-voltage characteristic Plot applied voltage V horizontally and diode current I vertically. In forward bias, the current is initially small and then rises rapidly around the threshold or knee voltage V_{th} . In reverse bias, a small reverse saturation current flows, remaining approximately constant until the magnitude of reverse voltage reaches V_{BR} . Beyond this point the reverse current rises sharply. The schematic uses different scales for the small reverse current and the much larger forward current so that both behaviours remain visible.



Schematic V-I characteristic of a p-n junction diode (forward and reverse scales differ).

Step 2: (ii) Distinguish threshold voltage from breakdown voltage The threshold voltage is the forward voltage around which the diode begins to conduct appreciable current as the barrier is sufficiently reduced. Typical values are about 0.7 V for silicon and 0.3 V for germanium. It is a knee in a continuous curve, rather than a perfectly abrupt switch.

The breakdown voltage is the magnitude of reverse voltage at which the reverse current increases sharply because of Zener or avalanche breakdown. It depends on junction doping and construction. Thus the threshold describes the onset of strong conduction in forward bias, while breakdown describes a sharp increase of current in reverse bias. A series resistance is needed to limit current when operating in breakdown.

Step 3: (iii) State the property responsible for rectification A junction diode offers low resistance in forward bias and very high resistance in reverse bias below breakdown. This gives predominantly

unidirectional conduction. During one half-cycle of an applied alternating voltage the diode is forward biased and conducts; during the opposite half-cycle it is reverse biased and largely blocks current. Consequently the load current flows in one direction, producing a pulsating direct output suitable for rectification.

Step 4: Conclusion The characteristic has a forward knee at V_{th} and reverse breakdown at $V = -V_{BR}$. Threshold is a forward-bias quantity; breakdown is a reverse-bias quantity. The diode's unidirectional conduction makes it suitable for rectifying alternating voltages.

Quick Tip to Solve: Put the threshold on the positive-voltage branch and breakdown on the negative-voltage branch; rectification follows from the large difference between forward and reverse resistance.

11. 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 reaction is its Q -value: $Q = (m_{\text{initial}} - m_{\text{final}})c^2$. A positive mass decrease corresponds to released energy.
- Nucleon number is conserved. The incident neutron contributes to the initial mass even though no neutron is emitted. Use $1 \text{ u } c^2 = 931.5 \text{ MeV}$.
- Beta decay changes the nuclear charge but leaves the mass number unchanged. The problem instructs us to neglect the masses of the emitted electrons or positrons.

Step 1: Account for the incident neutron The final mass numbers add to $140 + 99 = 239$, whereas uranium has mass number 238. Thus one incident neutron is absorbed, giving $238 + 1 = 140 + 99$. No outgoing neutron term is included. The final charges add to $58 + 44 = 102$; their increase relative to uranium results from the intermediate beta decays. The supplied final product masses already refer to the products after these decays.

Step 2: Calculate the initial and final masses Using the supplied masses without premature rounding,

$$\begin{aligned} m_{\text{initial}} &= 238.05079 + 1.008665 \\ &= 239.059455 \text{ u}, \\ m_{\text{final}} &= 139.90543 + 98.90594 \\ &= 238.81137 \text{ u}. \end{aligned}$$

The initial mass is that of the uranium atom plus the incoming neutron; the final mass is the sum of the two stated product masses, following the prescribed neglect of emitted lepton masses.

Step 3: Convert the mass decrease into energy The mass decrease is

$$\Delta m = 239.059455 - 238.81137 = 0.248085 \text{ u}.$$

Hence

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

The positive sign indicates an exothermic fission process; the lost rest mass appears as energy of the products and radiation.

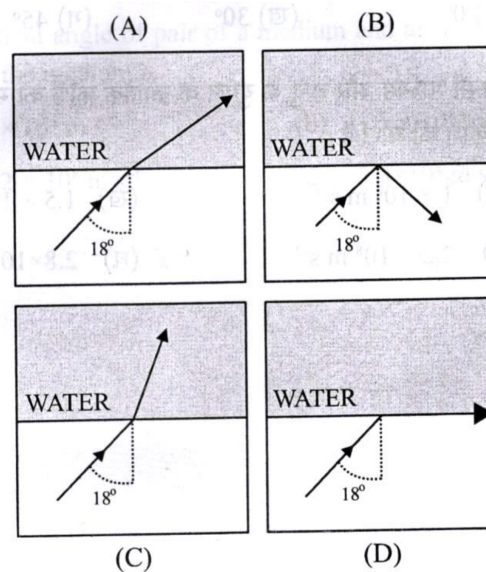
Step 4: Conclusion $Q \simeq 231.1 \text{ MeV}$, released in the fission process.

Quick Tip to Solve: Always count the absorbed neutron on the initial side before subtracting the final fragment masses.

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]



(A) Figure (A)

(B) Figure (B)

(C) Figure (C)

(D) Figure (D)

Correct Answer: (A) Figure (A)

Solution:

Concept:

- Denser-to-rarer refraction bends light away from the normal.
- Grazing emergence requires $i = C$; total internal reflection requires $i > C$.

Step 1: Compare the incidence and critical angles Here $i = 18^\circ < C = 20^\circ$, so a ray is transmitted into water. From Snell's law, $\sin r = \sin 18^\circ / \sin 20^\circ$, giving $r > i$: the ray bends away from the normal.

Step 2: Test the four paths Figure (A) correctly shows refraction away from the normal. Figure (B)

shows only a reflected ray, requiring incidence above the critical angle. Figure (C) incorrectly bends towards the normal. Figure (D) shows grazing emergence, which needs $i = 20^\circ$, not 18° .

Step 3: Conclusion The correct path is shown in figure (A). Hence, the correct option is (A).

Quick Tip to Solve: Compare incidence with the critical angle, then check bending relative to the normal.

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:

- For a water-air boundary, the critical angle satisfies $\sin C = 1/\mu$, taking the refractive index of air as unity.
- The emerging rays form a circular patch on the surface. Its limiting radius is $R = d \tan C$, where d is the source depth.

Step 1: Obtain the limiting radius Rays incident at angles below C emerge, while rays with larger incidence undergo total internal reflection. The limiting ray and the vertical depth form a right triangle, so

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

Step 2: Calculate and compare the areas The circular surface patch therefore has area

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

Option (A) is half this area and option (D) is twice it. Option (C) has an incorrect square-root dependence instead of the squared tangent factor required in an area calculation.

Step 3: Conclusion $A = \frac{\pi d^2}{\mu^2 - 1}$. Hence, the correct option is (B).

Quick Tip to Solve: Use the escape cone to get the radius first, and square that radius only when finding the surface area.

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 incidence from a medium of refractive index n into air, $\sin C = 1/n$.
- Since sine increases over 0° to 90° , a smaller refractive index gives a larger critical angle.

Step 1: Compare the refractive indices The usual refractive indices in visible light are approximately 1.33 for water, 1.52 for crown glass, about 1.6 for flint glass, and 2.42 for diamond. Water has the smallest refractive index among these media, so its reciprocal is the largest.

Step 2: Apply the inverse relation Using $C = \sin^{-1}(1/n)$, water has a critical angle about 49° . Crown glass and flint glass have smaller values, roughly 41° and 39° , while diamond has about 24° . Thus neither glass nor diamond can give the maximum critical angle among the listed choices.

Step 3: Conclusion The critical angle is maximum for water. Hence, the correct option is (C).

Quick Tip to Solve: For emergence into air, select the smallest refractive index to obtain the largest critical angle.

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:

- A critical angle exists for incidence from the optically denser medium into the rarer medium.
- At the critical angle the refracted angle is 90° ; Snell's law becomes $\sin C = n_{\text{rarer}}/n_{\text{denser}}$.

Step 1: Choose the direction and substitute Medium A has refractive index 2.0, and medium B has refractive index 1.0. The critical angle is consequently for a ray in A incident on the A-B boundary. Thus

$$2.0 \sin C = 1.0 \sin 90^\circ, \quad \sin C = \frac{1}{2}.$$

Step 2: Compare the printed angles The acute angle whose sine is $1/2$ is 30° . The other listed angles have sines 0, $1/\sqrt{2}$, and $\sqrt{3}/2$, respectively, and none satisfies the required refractive-index ratio. The reciprocal ratio would exceed unity and cannot define a critical angle.

Step 3: Conclusion $C = 30^\circ$. Hence, the correct option is (B).

Quick Tip to Solve: Put the rarer index above the denser index; the sine of a critical angle must lie between zero and one.

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:

- At the critical angle C , the refracted ray in air makes 90° with the normal. Snell's law gives $n \sin C = n_{\text{air}}$, where n is the refractive index of the medium and $n_{\text{air}} \simeq 1$.
- The speed of light in a medium is $v = c/n$, where $c = 3.0 \times 10^8 \text{ m s}^{-1}$ is its speed in vacuum.

Step 1: Determine the refractive index For the medium-air interface, $C = 30^\circ$. Hence

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

The refractive index is dimensionless. The critical-angle relation uses the sine, rather than the cosine or the angle measured in degrees itself.

Step 2: Calculate the speed and compare the options Substitute this refractive index into the speed relation:

$$v = \frac{3.0 \times 10^8}{2} = 1.5 \times 10^8 \text{ m s}^{-1}.$$

Option (A) would require $n = 3$, whereas (C) and (D) would require $n \simeq 1.36$ and $n \simeq 1.07$, respectively. None gives the required $n = 2$; the speed in option (B) does.

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

Quick Tip to Solve: For a medium-air interface, combine the two formulae directly: $v = c \sin C$. At 30° , the speed is exactly half of c .