

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/5/1



Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)

Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

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

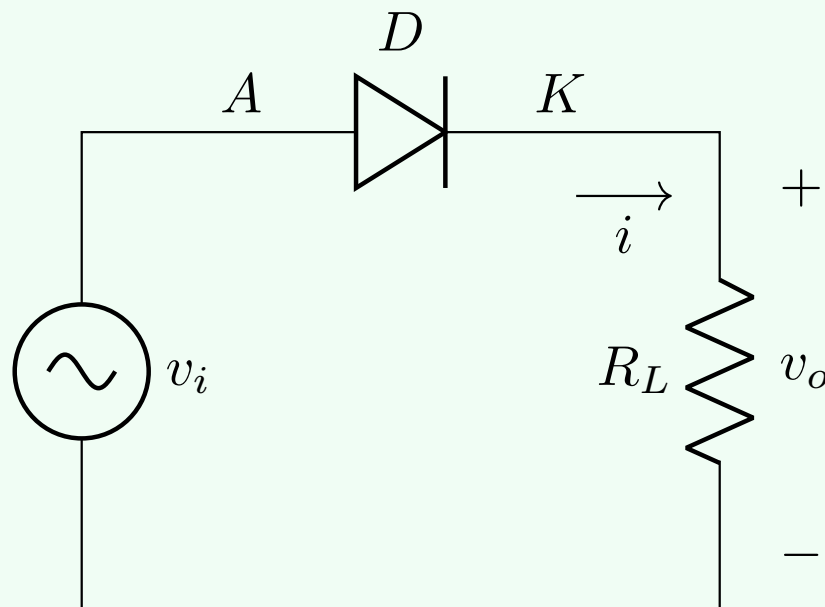
1. With the help of a circuit diagram, explain briefly how a p-n junction diode works as a half-wave rectifier. [2 marks]

Solution:

Concept:

- A p-n junction diode conducts appreciably when forward biased and blocks current when reverse biased, neglecting its very small reverse leakage current.
- Rectification converts an alternating input into a unidirectional output. The load voltage is $v_o = iR_L$, where i is the load current and R_L the load resistance.

Step 1: Connect the diode and load Connect a diode D in series with the load resistance R_L across an alternating source, as shown. The anode A is connected to the upper source terminal; the cathode K faces the load. Take the output across R_L , with its upper terminal positive. This orientation selects the positive half-cycles of the input.



Half-wave rectifier: AC source, series diode and load output

Step 2: Examine the two half-cycles During a positive half-cycle, the upper source terminal is positive relative to the lower terminal. The diode is forward biased, so current flows through D and R_L ; the load receives the positive half of the input, apart from the diode's forward voltage drop. During a negative half-cycle, the diode is reverse biased and practically no load current flows, so $v_o \simeq 0$. For an ideal diode and input $v_i = V_m \sin \omega t$,

$$v_o = \begin{cases} V_m \sin \omega t, & \sin \omega t \geq 0, \\ 0, & \sin \omega t < 0. \end{cases}$$

Step 3: Conclusion Only one half of each AC cycle appears across the load. The output is therefore a unidirectional, pulsating DC voltage: the diode acts as a half-wave rectifier.

Quick Tip to Solve: Mark the anode and cathode first: the half-cycle that makes the anode positive is passed to the load; the other is blocked.

2(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 α -particle and a nucleus. The repulsive force is proportional to the nuclear charge.
- Scattering also depends on the target mass. An α -particle has mass approximately $4m_p$, while a hydrogen nucleus is a proton of mass m_p ; the lighter target recoils substantially.

Step 1: Compare the electrostatic interaction A hydrogen nucleus has charge $+e$, whereas a gold nucleus has charge $+79e$. At the same separation the repulsion on an α -particle is much weaker for hydrogen. Most incident particles would therefore pass through the thin sheet with little or no deflection, and the characteristic large-angle scattering from gold would disappear.

Step 2: Account for the light target's recoil The hydrogen nucleus is much lighter than the incident α -particle, so it is set into motion and carries away momentum and energy. It cannot turn the heavier projectile backwards as an almost stationary gold nucleus can. For example, in a head-on elastic encounter with a proton initially at rest, conservation of momentum and kinetic energy gives the outgoing projectile velocity

$$v'_\alpha = \frac{4m_p - m_p}{4m_p + m_p} v_\alpha = \frac{3}{5} v_\alpha > 0.$$

Thus even the head-on α -particle continues forward with reduced speed. Non-head-on encounters give only small forward deflections, together with recoiling hydrogen nuclei.

Step 3: Conclusion With a thin solid hydrogen sheet, the α -particles mainly continue in the forward direction with small deflections; large-angle and backward scattering are absent. This is due to hydrogen's smaller nuclear charge and, especially, its nucleus being lighter than the incident particle.

Quick Tip to Solve: Compare both nuclear charge and mass: a lighter proton recoils, so the fixed-heavy-nucleus picture used for gold cannot explain hydrogen scattering.

OR

2(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 photon of frequency ν carries energy $E = h\nu$, where h is Planck's constant.

- The work function ϕ is the minimum energy needed to liberate an electron from the metal. Its threshold frequency is $\nu_0 = \phi/h$.

Step 1: Compare photon energy with the work function In the photoelectric effect, an electron absorbs the energy of one incident photon. Einstein's photoelectric equation is

$$K_{\max} = h\nu - \phi.$$

Emission therefore requires $h\nu \geq \phi$, or $\nu \geq \nu_0$. If $\nu < \nu_0$, the energy of each photon is insufficient to release an electron, so photoelectric emission does not occur even when the light is intense.

Step 2: Explain the role of intensity At a fixed frequency, increasing the intensity increases the number of photons incident per second, without changing the energy $h\nu$ of an individual photon. Once the frequency is above threshold, more photons can liberate more electrons per second, increasing the photoelectric current. Increasing intensity alone does not overcome the work function when the frequency is below threshold, and does not increase the maximum kinetic energy at a fixed frequency.

Step 3: Conclusion The frequency determines whether each photon has enough energy to liberate an electron. Thus emission occurs only at or above the threshold frequency; intensity controls the number of emitted photoelectrons once this energy condition is satisfied.

Quick Tip to Solve: Check $h\nu \geq \phi$ first: intensity changes photon count, while frequency changes energy per photon.

3. 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 is a light-sensitive p-n junction. Incident photons of sufficient energy create electron-hole pairs, especially in its depletion region.
- In reverse bias, the junction field separates these carriers and produces a photocurrent. The photocurrent increases with the incident light intensity.

Step 1: Explain why reverse bias gives sensitive detection In darkness, the reverse current is very small and is due mainly to minority carriers. When light falls on the junction, it generates additional electron-hole pairs. The reverse-bias electric field sweeps electrons towards the n-side and holes towards the p-side, producing an increase in reverse current. This light-induced change is large relative to the small dark current and is therefore readily detected.

Step 2: Compare with forward bias and give uses In forward bias, the large current is dominated by majority-carrier injection. The extra current caused by illumination is a small fraction of this large background current, so changes in light intensity are harder to measure. Reverse bias is therefore preferred for light sensing even though its total current is much smaller. Two uses are: (i) detecting optical signals in optical-fibre communication receivers, and (ii) detecting light in automatic switching

systems, such as automatic street-light controls.

Step 3: Conclusion A photodiode is operated in reverse bias because illumination produces an easily measurable change relative to the small dark current. It is used in optical-fibre receivers and in automatic light-controlled switches.

Quick Tip to Solve: Compare the change in current with the dark-current background; a larger total current does not necessarily give better light sensitivity.

Section B (24 marks)

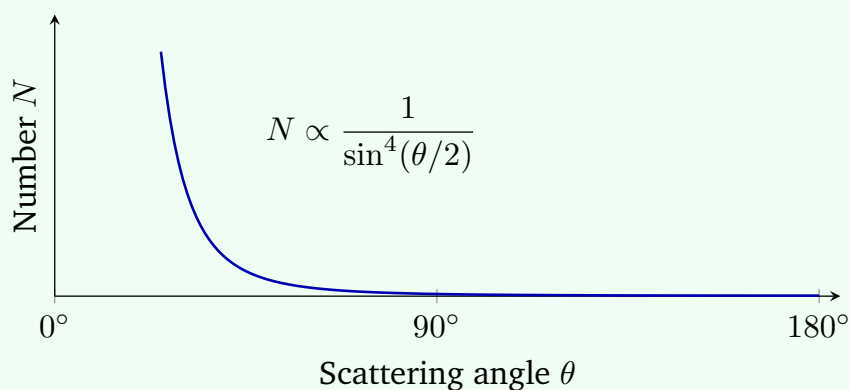
4. Draw a graph showing the variation of number of particles scattered (N) with the scattering angle θ in Geiger-Marsden experiment. Why only a small fraction of the particles are scattered at $\theta > 90^\circ$? Mention two limitations of Rutherford nuclear model of an atom. [3 marks]

Solution:

Concept:

- In Rutherford scattering, the positively charged α -particles are deflected by electrostatic repulsion from the small, positively charged nucleus.
- For the same incident beam and equal detector solid angles, the number N scattered through angle θ varies as $N \propto 1/\sin^4(\theta/2)$. Here θ is measured from the original beam direction.
- An electron moving in a circular orbit is accelerated. Classical electromagnetic theory predicts that an accelerated charge radiates energy.

Step 1: Sketch the angular distribution Plot scattering angle θ on the horizontal axis and the number of scattered particles N on the vertical axis. The curve is very high at small angles, falls steeply as the angle increases, and becomes very small at large angles. Thus most particles undergo little or no deflection, while very few are scattered backwards. The sketch shows the qualitative trend; the ideal Rutherford expression is singular at $\theta = 0$, so no finite intercept at the origin is implied.



Qualitative Rutherford scattering distribution; the forward singularity is omitted.

Step 2: Explain the rarity of backward scattering Deflection through $\theta > 90^\circ$ requires a very close encounter with the nucleus, corresponding to a small impact parameter. Only then is the repulsive

Coulomb force strong enough to turn the particle backwards. The nuclear size is extremely small compared with the atomic size, and most of the atom is empty space. Therefore only a small fraction of the incident particles approach the nucleus closely enough for such large-angle scattering.

Step 3: State two limitations of the nuclear model **Atomic stability:** The orbiting electron has centripetal acceleration and should radiate energy continuously. Its energy would decrease, its orbit would shrink, and it would spiral into the nucleus. Rutherford's model therefore cannot explain why atoms are stable.

Discrete line spectra: The model gives no rule for permitted electron energies or stationary orbits. Classically, a continuously losing electron would emit over a continuous range of frequencies. It cannot explain the discrete spectral lines characteristic of an atom.

Step 4: Conclusion The N -versus- θ graph falls steeply with increasing angle. Rare close encounters with the tiny nucleus produce scattering beyond 90° . Rutherford's model fails to explain atomic stability and discrete atomic line spectra.

Quick Tip to Solve: Link a large scattering angle to a small impact parameter, then recall the two failures: an orbiting charge radiates, and classical orbits do not select discrete energies.

5. (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.

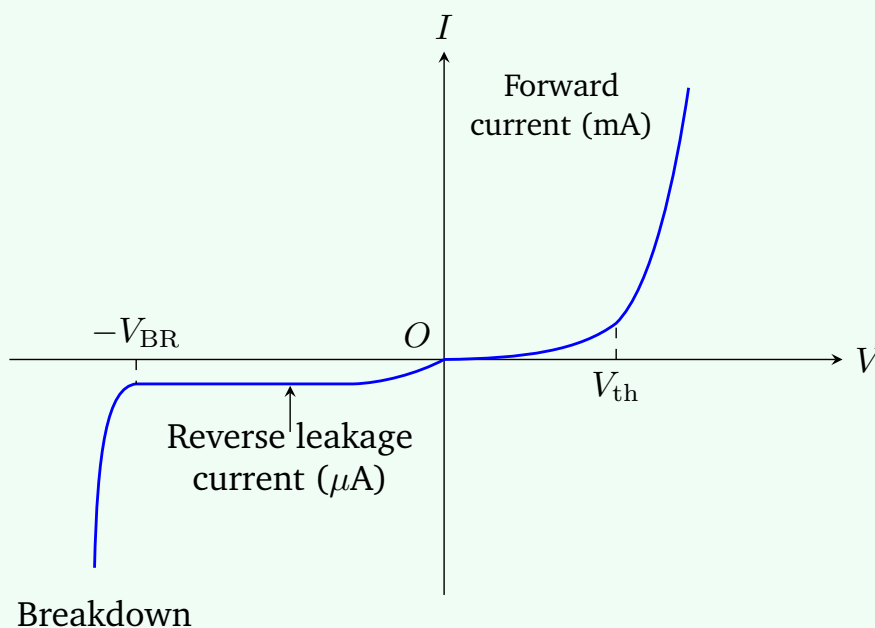
[3 marks]

Solution:

Concept:

- The V-I characteristic relates the current I through a p-n junction diode to the applied voltage V . Forward bias reduces the junction barrier; reverse bias increases it.
- A diode has a low effective resistance in forward conduction and a very high resistance in reverse bias below breakdown. This directional conduction is the basis of rectification.

Step 1: (i) Draw and interpret the characteristic Take forward voltage and forward current as positive. Initially the forward current is small; beyond the knee, or threshold voltage V_{th} , it rises rapidly with a small increase in voltage. Under reverse bias, a small reverse saturation current flows and remains nearly constant until the reverse voltage reaches the breakdown magnitude V_{BR} . At breakdown, the magnitude of reverse current increases sharply. The graph is schematic: the forward current is normally shown on a milliampere scale and the reverse leakage current on a microampere scale, so their sizes are not directly comparable.



Schematic diode V-I characteristic; forward and reverse current scales differ.

Step 2: (ii) Distinguish the two voltages Threshold voltage is the forward-bias voltage near the knee beyond which the diode current becomes appreciable and rises rapidly. Its typical value is about 0.7 V for silicon and 0.3 V for germanium; it is not a sharp boundary below which current is exactly zero. Breakdown voltage is the magnitude of the reverse-bias voltage at which reverse current increases abruptly because of Zener or avalanche breakdown. Thus threshold concerns forward conduction, whereas breakdown concerns a large reverse current; breakdown is shown at $V = -V_{BR}$ on the voltage axis.

Step 3: (iii) Identify the rectifying property The diode conducts readily when forward biased but blocks current almost completely when reverse biased below breakdown. When an alternating voltage reverses polarity, the diode therefore permits appreciable current during the forward-bias half-cycle and suppresses it during the reverse-bias half-cycle. The load current becomes unidirectional, which is the required rectification of ac voltage.

Step 4: Conclusion The characteristic has a forward knee and a reverse breakdown region. Threshold voltage refers to appreciable forward conduction, while breakdown voltage refers to the sharp rise of reverse current. The diode's unidirectional conduction makes it suitable for rectification.

Quick Tip to Solve: Sketch both bias regions: label the positive forward knee and the negative breakdown voltage separately, then connect rectification to low forward and high reverse resistance.

6. 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 defect gives a positive Q -value and an exoergic reaction.
- Nucleon number is conserved, including the incoming neutron. Use the conversion $1 \text{ u } c^2 = 931.5 \text{ MeV}$, where u is the unified atomic mass unit.
- Beta decay changes the proton number but leaves the mass number unchanged. As instructed, masses of the electrons or positrons emitted during the intermediate steps are neglected.

Step 1: Identify the initial and final masses The incoming fast neutron must be included in the initial mass. The initial nucleon number is $238 + 1 = 239$, and the final products have $140 + 99 = 239$. This agrees with the statement that no neutrons are emitted. The final proton numbers sum to $58 + 44 = 102$, whereas the initial nuclear charge is 92; the intervening beta-minus decays account for this increase, with ten beta electrons in the net charge balance. Their masses are neglected as directed, so the specified final-product masses enter the calculation directly.

$$\begin{aligned} m_{\text{initial}} &= m(^{238}_{92}\text{U}) + m(^1_0\text{n}) \\ &= 238.05079 + 1.008665 \\ &= 239.059455 \text{ u}, \\ m_{\text{final}} &= m(^{140}_{58}\text{Ce}) + m(^{99}_{44}\text{Ru}) \\ &= 139.90543 + 98.90594 \\ &= 238.81137 \text{ u}. \end{aligned}$$

Step 2: Calculate the mass defect and convert to energy Subtract the final mass from the initial mass, retaining the printed precision during the arithmetic:

$$\begin{aligned} \Delta m &= 239.059455 - 238.81137 \\ &= 0.248085 \text{ u}, \\ Q &= \Delta m c^2 \\ &= 0.248085 \times 931.5 \text{ MeV} \\ &= 231.0911775 \text{ MeV}. \end{aligned}$$

The initial mass exceeds the final mass, so the decrease in rest energy becomes released energy. Including the incident neutron is essential: omitting it would give the wrong sign and magnitude for the mass defect.

Step 3: Conclusion

$$Q \simeq +231.1 \text{ MeV}$$

Approximately 231 MeV is released in the stated process under the prescribed neglect of emitted electron/positron masses.

Quick Tip to Solve: Check mass-number conservation first: $238 + 1 = 140 + 99$. This immediately reminds you to include the incoming neutron in the initial mass before multiplying the mass defect by 931.5.

7. How can you differentiate whether a pattern is produced by a single slit or double slits? Derive the expression for the angular position of (i) bright and (ii) dark fringes produced in a single slit diffraction. [3 marks]

Solution:

Concept:

- In single-slit diffraction, secondary wavelets from different points across a slit of width a interfere. The path difference between its extreme edges at angle θ is $a \sin \theta$.
- For monochromatic light of wavelength λ , the intensity is $I = I_0(\sin \beta / \beta)^2$, where $\beta = \pi a \sin \theta / \lambda$. The central maximum is at $\theta = 0$.

Step 1: Distinguish the two patterns A single slit produces a very intense, broad central bright band. Its width between the first minima is twice the approximate width of each secondary bright band, and the secondary maxima become rapidly weaker away from the centre. In ideal double-slit interference with equally illuminated narrow slits, successive bright and dark fringes are equally spaced, bright fringes have equal widths and approximately equal intensities, and the central bright fringe is not twice as wide. Finite-width double slits also have a diffraction envelope, but the closely spaced interference fringes within that envelope distinguish them from the single-slit pattern.

Step 2: Derive the angular positions of dark fringes Divide the slit into two equal halves. The path difference between corresponding points in the halves is $(a/2) \sin \theta$. When this equals $\lambda/2$, the contributions cancel pairwise, producing the first minimum: $a \sin \theta = \lambda$. For the next minimum, divide the slit into four equal strips and cancel adjacent strips in pairs. More generally, division into $2n$ equal strips gives a path difference $\lambda/2$ between paired points when

$$a \sin \theta_n = n\lambda, \quad n = \pm 1, \pm 2, \dots$$

Thus $\theta_n = \sin^{-1}(n\lambda/a)$, or $\theta_n \simeq n\lambda/a$ for small angles. Only orders satisfying $|n\lambda/a| \leq 1$ can occur.

Step 3: Derive the angular positions of bright fringes At $\theta = 0$, all wavelets reach in phase and form the central maximum. For nonzero β , differentiate the intensity to locate secondary maxima:

$$\frac{dI}{d\beta} = 2I_0 \frac{\sin \beta}{\beta} \frac{\beta \cos \beta - \sin \beta}{\beta^2} = 0.$$

Excluding the zeros $\sin \beta = 0$, which give dark fringes, secondary maxima satisfy $\tan \beta = \beta$. This

is the exact condition. For the usual board-level approximate positions, a bright fringe is taken nearly midway between successive minima. The n th secondary maximum on either side is therefore approximately at

$$a \sin \theta \simeq \pm \left(n + \frac{1}{2} \right) \lambda, \quad n = 1, 2, \dots,$$

giving $\theta \simeq \pm(2n + 1)\lambda/(2a)$ at small angles. The midpoint expression is an approximation, especially for the first secondary maximum.

Step 4: Conclusion The broad, dominant central maximum identifies single-slit diffraction. Dark fringes obey $a \sin \theta = n\lambda$; the central bright fringe is at $\theta = 0$, and secondary bright fringes obey $\tan \beta = \beta$, with approximate positions $a \sin \theta \simeq \pm(n + 1/2)\lambda$, $n \geq 1$.

Quick Tip to Solve: Check the central band first: twice the width and much brighter side bands' contrast indicate single-slit diffraction. Keep secondary-maximum midpoint positions explicitly approximate.

8(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 $P = 1/f$, with focal length f expressed in metres. Its SI unit is the dioptre, denoted 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 of glass and R_1, R_2 are the signed radii of its surfaces.
- With the Cartesian sign convention and incident light travelling left to right, the lens formula is $1/f = 1/v - 1/u$, and magnification is $m = v/u$.

Step 1: (i) Define the SI unit of lens power One dioptre is the power of a lens whose focal length has magnitude 1 m. Thus $1 \text{ D} = 1 \text{ m}^{-1}$. A converging lens with focal length +1 m has power +1 D; a diverging lens with focal length -1 m has power -1 D.

Step 2: (ii.i) Calculate the focal length Take the convex surface first, so its centre of curvature lies to the right: $R_1 = +25 \text{ cm}$. The plane surface has $R_2 = \infty$, and hence contributes zero curvature.

Substituting $\mu = 1.5$ in the lens-maker's formula gives

$$\begin{aligned}\frac{1}{f} &= (1.5 - 1) \left(\frac{1}{25} - 0 \right) \text{ cm}^{-1} \\ &= \frac{1}{50} \text{ cm}^{-1}, \\ f &= +50 \text{ cm} = +0.50 \text{ m}.\end{aligned}$$

The positive focal length confirms that this plano-convex glass lens is converging in air.

Step 3: (ii.ii) Determine the image position and nature The object is in front of the lens, so $u = -50 \text{ cm}$, while $f = +50 \text{ cm}$. The object therefore lies at the principal focus. Applying the lens formula,

$$\begin{aligned}\frac{1}{50} &= \frac{1}{v} - \frac{1}{-50}, \\ \frac{1}{v} &= \frac{1}{50} - \frac{1}{50} = 0.\end{aligned}$$

The emerging rays are parallel and the image is at infinity on the other side of the lens. In the usual limiting description of image formation by a converging lens, the image is real, inverted and highly enlarged. At exactly the focus, there is no finite image distance or finite magnification; no finite screen position gives a sharp image.

Step 4: Conclusion (i) The SI unit is the diopetre: $1 \text{ D} = 1 \text{ m}^{-1}$. (ii.i) The focal length is $+50 \text{ cm}$. (ii.ii) The image is at infinity; conventionally it is described as real, inverted and highly enlarged, with parallel emergent rays.

Quick Tip to Solve: For a plano-convex lens in air, use $f = R/(\mu - 1)$. Compare the object distance with this focal length before calculating the image distance.

OR

8(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:

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

[3 marks]

Solution:

Concept:

- For a single slit of width a , the central maximum is at $y = 0$. Minima obey $a \sin \theta = n\lambda$, whereas secondary bright fringes lie approximately midway between successive minima.
- With the small-angle approximation, the n th secondary bright fringe is at $y_n \simeq (n + \frac{1}{2})\lambda D/a$, where $n = 1, 2, \dots$, D is the slit-screen distance and λ is the wavelength. This is the usual school-level approximation for secondary maxima.

Step 1: (i) Locate the second secondary bright fringe Convert the given quantities to SI units: $a = 0.6 \times 10^{-3} \text{ m}$, $D = 1.0 \text{ m}$ and $\lambda_1 = 600 \times 10^{-9} \text{ m}$. The central maximum is counted separately, so

the second bright fringe outside it corresponds to $n = 2$. Hence

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

There is a corresponding fringe on each side of the central maximum; its distance is 2.5 mm.

Step 2: (ii) Check whether secondary bright fringes can coincide For secondary bright fringes of orders n and m to coincide, their distances must be equal. Using $\lambda_2 = 480 \text{ nm}$, this requires

$$\begin{aligned}(2n + 1)600 &= (2m + 1)480, \\ 5(2n + 1) &= 4(2m + 1).\end{aligned}$$

The left-hand side is odd, while the right-hand side is even. Thus no positive integer orders satisfy the coincidence condition for secondary bright fringes in this approximation. Both wavelengths do have their central bright maximum at $y = 0$. Consequently, if central maxima are included, the least distance is zero; if the question intends a nonzero coincidence of secondary bright fringes, no such distance exists in the standard approximation. Do not use $n\lambda_1 = m\lambda_2$ to answer the printed bright-fringe question: that condition applies to single-slit minima. In particular, $n = 4$, $m = 5$ gives $y = 4.0 \text{ mm}$, where both patterns are dark, not bright.

Step 3: Conclusion (i) The second secondary bright fringe is approximately 2.5 mm from the centre. (ii) The common central maximum is at 0; there is no nonzero coincidence of secondary bright fringes under the standard approximate formula. The printed wording must not be silently changed to dark fringes.

Quick Tip to Solve: For single-slit diffraction, use integer multiples for dark fringes and half-integer multiples for approximate secondary bright fringes; check parity before searching for coincident orders.

9. (a) Calculate the energy and momentum of a photon in a monochromatic beam of wavelength 331.5 nm.

(b) How fast should a hydrogen atom travel in order to have the same momentum as that of the photon in part (a)? [3 marks]

Solution:

Concept:

- A photon of wavelength λ has energy $E = h\nu = hc/\lambda$ and momentum $p = E/c = h/\lambda$, where h is Planck's constant and c is the speed of light.
- A slowly moving hydrogen atom has mechanical momentum $p_H = m_H v$. Equal momentum requires $m_H v = h/\lambda$; the atom's speed need not equal the photon's speed.

Step 1: (a) Calculate the photon energy Write the wavelength in metres:

$$\lambda = 331.5 \text{ nm} = 3.315 \times 10^{-7} \text{ m}.$$

Taking $h = 6.63 \times 10^{-34} \text{ J s}$ and $c = 3.00 \times 10^8 \text{ m s}^{-1}$,

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34})(3.00 \times 10^8)}{3.315 \times 10^{-7}} = 6.00 \times 10^{-19} \text{ J}.$$

This is about 3.75 eV, using $1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$.

Step 2: (a) Calculate the photon momentum Although a photon has zero rest mass, it carries momentum. The appropriate relation is $p = h/\lambda$, not a massive-particle expression with a rest mass:

$$p = \frac{6.63 \times 10^{-34}}{3.315 \times 10^{-7}} = 2.00 \times 10^{-27} \text{ kg m s}^{-1}.$$

As a consistency check, $pc = (2.00 \times 10^{-27})(3.00 \times 10^8) = 6.00 \times 10^{-19} \text{ J}$, agreeing with the energy found above.

Step 3: (b) Equate the atom's momentum to the photon's momentum Use the hydrogen atom mass $m_H \simeq 1.67 \times 10^{-27} \text{ kg}$, approximately the proton mass because the electron contributes very little. Then

$$v = \frac{p}{m_H} = \frac{2.00 \times 10^{-27}}{1.67 \times 10^{-27}} \simeq 1.20 \text{ m s}^{-1}.$$

This speed is much smaller than c , so the nonrelativistic relation $p_H = m_H v$ used for the atom is justified. Matching the momentum magnitudes does not imply matching energies, since a photon and an atom obey different energy-momentum relations.

Step 4: Conclusion (a) Photon energy: $6.00 \times 10^{-19} \text{ J}$.

Photon momentum: $2.00 \times 10^{-27} \text{ kg m s}^{-1}$.

(b) Hydrogen atom speed: 1.20 m s^{-1} approximately.

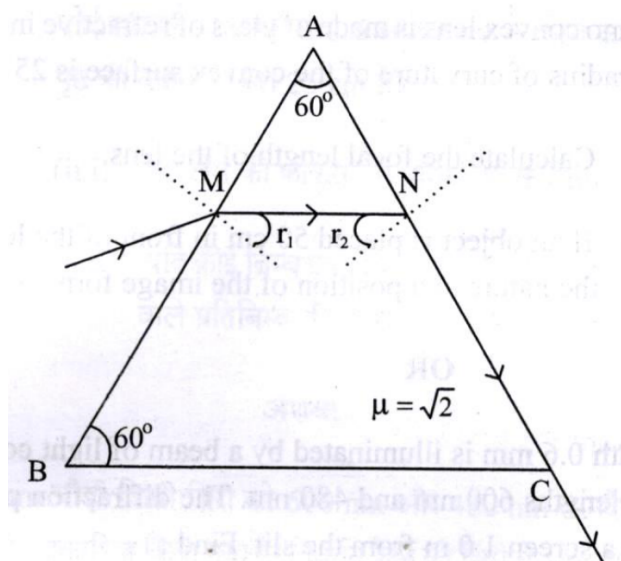
Quick Tip to Solve: Compute photon momentum directly as h/λ , then divide by the hydrogen atom mass; do not use the electron mass for a hydrogen atom.

10. 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 a prism-air boundary is $\mu \sin r_2 = \sin e$, where r_2 is the internal angle of incidence measured from the normal and e is the angle of emergence in air.
- For a prism of apex angle A , its refractive index and minimum deviation δ_m obey $\mu = \frac{\sin[(A + \delta_m)/2]}{\sin(A/2)}$. At minimum deviation the path is symmetric: $i = e$ and $r_1 = r_2 = A/2$.

Step 1: (i) Identify the angle of emergence at face AC The official diagram shows the emerging ray travelling along face AC. Hence it makes a right angle with the normal to that face: $e = 90^\circ$. This is grazing emergence, so the internal incidence angle at AC equals the critical angle for the prism-air boundary. Angles in Snell's law must be measured from the normal, not from the surface.

Step 2: (i) Apply Snell's law at AC Taking the refractive index of air as unity and using $\mu = \sqrt{2}$,

$$\begin{aligned}\sqrt{2} \sin r_2 &= \sin 90^\circ = 1, \\ \sin r_2 &= \frac{1}{\sqrt{2}}, \\ r_2 &= 45^\circ.\end{aligned}$$

The sketch is schematic; the grazing emerging ray fixes the relevant angle through refraction.

Step 3: (ii) Use the minimum-deviation relation The printed apex angle is $A = 60^\circ$. Minimum deviation refers to the symmetric path through the prism, rather than the grazing path in part (i). Thus

$$\begin{aligned}\sin\left(\frac{60^\circ + \delta_m}{2}\right) &= \mu \sin \frac{A}{2} \\ &= \sqrt{2} \sin 30^\circ = \frac{1}{\sqrt{2}}.\end{aligned}$$

For the physical minimum-deviation path, $(60^\circ + \delta_m)/2 = 45^\circ$. Therefore $\delta_m = 2(45^\circ) - 60^\circ = 30^\circ$. Equivalently, at this symmetric setting $r_1 = r_2 = 30^\circ$, $i = e = 45^\circ$, and $\delta_m = i + e - A$.

Step 4: Conclusion (i) The angle of incidence at face AC is $r_2 = 45^\circ$. (ii) The angle of minimum deviation is $\delta_m = 30^\circ$.

Quick Tip to Solve: A ray emerging along a prism face has $e = 90^\circ$; first use the critical-angle condition, then calculate minimum deviation for the separate symmetric path.

- 11(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 with speed c in vacuum, and their frequency ν and wavelength λ satisfy $c = \nu\lambda$. Thus increasing frequency corresponds to decreasing wavelength.
- Electromagnetic radiation is used according to its interaction with matter: microwaves can heat food and carry communication signals, while X-rays penetrate soft tissue and reveal internal structure.

Step 1: (i) Arrange the four radiations by frequency The standard electromagnetic spectrum in increasing frequency is radio waves, microwaves, infrared, visible light, ultraviolet, X-rays and gamma rays. Selecting only the four radiations listed in the question gives

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

Radio waves occupy the low-frequency end of the listed groups; microwaves have higher frequency than ordinary radio waves. X-rays and gamma rays lie at the high-frequency end. The required order is therefore radio waves, microwaves, X-rays, gamma rays, with wavelengths decreasing along this sequence.

Step 2: (ii) Give two uses of microwaves Microwaves are used in microwave ovens to heat and cook food: their energy is absorbed by water-containing food and converted into thermal energy. They are also used in satellite communication to transmit television, telephone and data signals between ground stations and satellites. Suitable microwave bands pass through the atmosphere and can be directed into narrow beams using antennas.

Step 3: (ii) Give two uses of X-rays X-rays are used in medical radiography to detect bone fractures because bone and soft tissue absorb X-rays differently, producing image contrast. They are also used in X-ray diffraction to study crystal structures: diffraction patterns from regularly spaced atomic planes allow the arrangement and spacing of atoms to be determined. These are two distinct uses of the second chosen radiation.

Step 4: Conclusion (i) Ascending frequency: radio waves < microwaves < X-rays < gamma rays.
(ii) Microwaves: cooking food and satellite communication. X-rays: detecting bone fractures and studying crystal structures.

Quick Tip to Solve: Recall the full spectrum from radio to gamma, remove the unlisted bands, and give two distinct applications for each of two chosen radiations.

OR

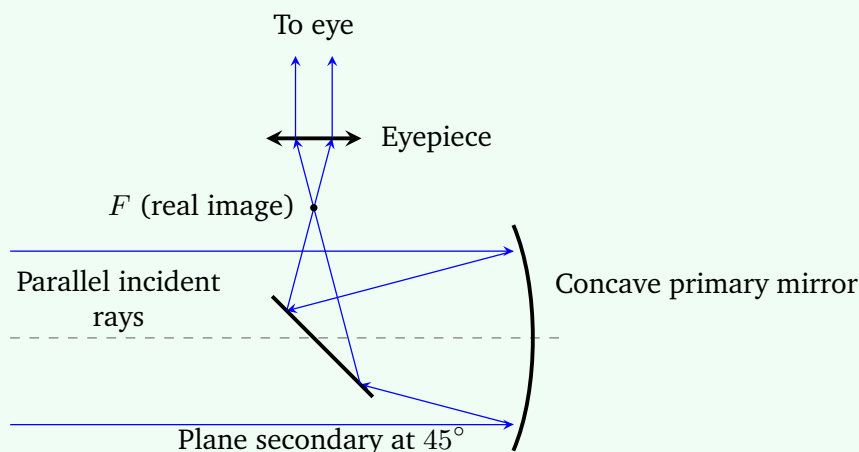
11(b). With the help of a ray diagram explain the working of a reflecting telescope. Mention two advantages of a reflecting telescope over a refracting telescope. [3 marks]

Solution:

Concept:

- A concave reflecting objective collects nearly parallel rays from a distant object and forms a real, inverted image near its principal focus.
- A small plane secondary mirror redirects the converging beam to an eyepiece. The eyepiece magnifies the real image; in normal adjustment this image lies in its focal plane and the final image is at infinity.

Step 1: Collect and focus the light In the Newtonian arrangement shown, light from a distant astronomical object enters the telescope and falls on a large concave primary mirror. The mirror reflects the rays towards its focus and forms a real, inverted image of the object. A small plane mirror, inclined at 45° to the primary axis, intercepts the converging beam before that focus and sends it towards the side of the telescope. The folded focus is labelled F .



Newtonian reflecting telescope in normal adjustment (schematic, not to scale)

Step 2: Magnify the image with the eyepiece The eyepiece is placed so that the real image at the folded focus lies in its first focal plane. It acts as a magnifier, producing the final enlarged, virtual image at infinity for relaxed viewing. The magnitude of angular magnification in normal adjustment 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.

Step 3: State two advantages over a refracting telescope First, the reflecting objective is free from chromatic aberration: reflection does not separate colours according to wavelength as a refracting objective lens does. Second, a mirror can be supported from its back and made with a much larger aperture than a large objective lens. A larger aperture collects more light from faint objects and improves resolving power.

Step 4: Conclusion The concave primary and eyepiece give a magnified image. A reflecting objective avoids chromatic aberration and allows a large aperture for greater light-gathering and resolving power.

Quick Tip to Solve: Draw the incoming parallel rays, concave primary, inclined secondary and eyepiece; place the folded real image in the eyepiece focal plane.

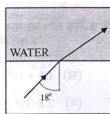
Section C (5 marks)

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:

- Total internal reflection occurs for travel from a denser to a rarer medium only when the incidence angle i exceeds the critical angle C .
- Below the critical angle, the transmitted ray bends away from the normal: $n_m \sin i = n_w \sin r$, where $n_m > n_w$.

Step 1: Compare the incidence and critical angles Here $i = 18^\circ$ and $C = 20^\circ$, so $i < C$. The ray therefore emerges into water; it neither undergoes total internal reflection as in (B) nor grazes the surface as in (D). Grazing refraction requires $i = C$.

Step 2: Choose the direction of bending The starting medium is optically denser than water, so the refracted angle is greater than the incidence angle. The outgoing ray must bend away from the normal, as shown in (A). Diagram (C) bends towards the normal and therefore depicts the wrong direction of refraction. For confirmation, $n_w/n_m = \sin 20^\circ$, giving $\sin r = \sin 18^\circ / \sin 20^\circ$, so $r \approx 64.6^\circ$, measured from the normal.

Step 3: Conclusion The ray refracts into water and bends away from the normal. Hence the correct option is (A), the first figure.

Quick Tip to Solve: First compare incidence with the critical angle; only then check whether the transmitted ray bends towards or away from 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:

- At a water-air interface, the critical angle obeys $\sin C = 1/\mu$, with air's refractive index taken as unity.
- The escaping rays form a cone inside water. Its intersection with the horizontal surface is a circle of radius $R = d \tan C$, where d is the source depth.

Step 1: Find the radius of the emergent patch Draw the limiting ray from the source to the surface, making the critical angle C with the vertical normal. The right triangle gives $R/d = \tan C$. Rays reaching points outside this circle have incidence greater than C and undergo total internal reflection.

Step 2: Calculate the circular area Using $\sin C = 1/\mu$, we get $\cos C = \sqrt{\mu^2 - 1}/\mu$ and $\tan C = 1/\sqrt{\mu^2 - 1}$. Thus

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

The extra factors of one-half and two in (A) and (D) are unsupported. Option (C) retains square roots instead of squaring the radius factor and introduces an extra $\sqrt{2}$.

Step 3: Conclusion The area through which light emerges is $A = \pi d^2/(\mu^2 - 1)$. Hence the correct option is (B).

Quick Tip to Solve: Find the escape-circle radius with depth times tangent of the critical angle, then square that radius before multiplying by pi.

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 a medium of refractive index $\mu > 1$ adjoining air, $\sin C = 1/\mu$, where C is the critical angle.
- Since sine increases between 0° and 90° , a smaller refractive index gives a larger critical angle.

Step 1: Compare the refractive indices Water has refractive index about 1.33, smaller than crown glass (about 1.52), flint glass (about 1.62) and diamond (about 2.42). These approximate values are sufficient to establish that water has the largest value of $1/\mu$.

Step 2: Apply the critical-angle relation Therefore $C = \sin^{-1}(1/\mu)$ is largest for water, about 48.8° . Crown glass gives about 41° , flint glass about 38° , and diamond about 24.4° . Hence (A), (B) and (D) cannot be the maximum. The comparison concerns the critical angle for each medium with respect to air, with light incident from the medium towards air.

Step 3: Conclusion Water has the maximum critical angle among these media. Hence the correct option is (C).

Quick Tip to Solve: For interfaces with the same rarer medium, choose the smallest denser-medium 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:

- The critical angle C is the angle of incidence in the denser medium at which the refracted ray travels along the interface, so the angle of refraction is 90° .
- Snell's law is $n_A \sin i = n_B \sin r$, where n_A and n_B are the refractive indices. For incidence from denser A into rarer B, $\sin C = n_B/n_A$.

Step 1: Substitute the two refractive indices Medium A has $n_A = 2.0$, while medium B has $n_B = 1.0$. Critical incidence must occur from A to B. At the limiting refracted angle,

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

Step 2: Check the angles in the options The physically relevant incidence angle lies between 0° and 90° . In this range, $\sin 30^\circ = 1/2$. Option (A), 0° , has sine zero; option (C), 45° , has sine $1/\sqrt{2}$; and option (D), 60° , has sine $\sqrt{3}/2$. These three values do not satisfy the limiting refraction condition.

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

Quick Tip to Solve: Put the rarer-medium index above the denser-medium index: a ratio of one-half 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 incident from a medium of refractive index n into air of refractive index approximately one, the critical angle C obeys $n \sin C = 1$.
- The refractive index is $n = c/v$, where $c = 3.0 \times 10^8 \text{ m s}^{-1}$ is the speed of light in vacuum and v is its speed in the medium.

Step 1: Find the refractive index from the critical angle At critical incidence the refracted ray makes 90° with the normal. Applying Snell's law with $C = 30^\circ$,

$$n \sin 30^\circ = 1 \sin 90^\circ, \quad n = \frac{1}{\sin 30^\circ} = 2.$$

Thus the medium has twice the refractive index of air.

Step 2: Calculate the speed and test the choices Substitute this index into the speed relation:

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

The speeds in options (A), (C) and (D) would give indices 3, approximately 1.36 and approximately 1.07, respectively. None gives $\sin C = 1/2$, so none matches the printed critical angle. Option (B) alone gives $n = 2$.

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 formulae directly as $v = c \sin C$; at 30° , the speed is half of c .