

CBSE Class 12 Physics Question Paper 2022 with Solution PDF-Set 55/3/1

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:** Q. Nos. **1** to **3** are of **2** marks each.
- (iv) **Section B:** Q. Nos. **4** to **11** are of **3** marks each.
- (v) **Section C:** Q. No. **12** is a case study based questions 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.

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

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

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

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

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

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

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

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

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

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

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

Section A (6 marks)

1. What is meant by doping of an intrinsic semiconductor? Name the two types of atoms used for doping of Ge/Si. [2 marks]

Solution:

Concept:

- An intrinsic semiconductor is pure silicon or germanium, with equal equilibrium concentrations of free electrons and holes.
- Doping introduces a small, controlled quantity of suitable impurity atoms into a pure semiconductor to increase its electrical conductivity.

Step 1: Define doping Doping is the deliberate addition of a very small, controlled amount of impurity to an intrinsic semiconductor such as Si or Ge. The impurity changes the concentration of mobile charge carriers, producing an extrinsic semiconductor with greater conductivity. The impurity is introduced in a sufficiently small proportion that the host crystal structure is substantially retained.

Step 2: Identify the two dopant types Si and Ge atoms are tetravalent. A pentavalent impurity, such as phosphorus, arsenic or antimony, supplies an extra electron after forming four covalent bonds; it is a donor and produces an n-type semiconductor. A trivalent impurity, such as boron, aluminium, gallium or indium, leaves one bond short of an electron, creating a hole; it is an acceptor and produces a p-type semiconductor.

Step 3: Conclusion Doping means adding a small, controlled amount of suitable impurity to pure Si or Ge. The two types used are pentavalent donor atoms and trivalent acceptor atoms.

Quick Tip to Solve: Compare the dopant's valence with four: five supplies an extra electron, whereas three leaves a hole.

2(a). (i) Distinguish between isotopes and isobars.

(ii) Two nuclei have different mass numbers A_1 and A_2 . Are these nuclei necessarily the isotopes of the same element? Explain. [2 marks]

Solution:

Concept:

- The atomic number Z is the number of protons and identifies the element. The mass number $A = Z + N$ is the total number of protons and neutrons, where N is the neutron number.
- Isotopes share the same Z but have different A ; isobars share the same A but have different Z .

Step 1: Distinguish isotopes from isobars (i) Isotopes are nuclei of the same element with equal atomic numbers but different mass numbers, and therefore different neutron numbers. For example, ${}^{12}_6\text{C}$ and ${}^{14}_6\text{C}$ are isotopes. Isobars are nuclei of different elements with equal mass numbers but different atomic numbers; for example, ${}^{14}_6\text{C}$ and ${}^{14}_7\text{N}$.

Step 2: Test whether different mass numbers suffice (ii) Knowing only that $A_1 \neq A_2$ does not establish that the two nuclei have the same proton number. They are isotopes only if the additional condition $Z_1 = Z_2$ holds. As a counterexample, ${}^{12}_6\text{C}$ and ${}^{16}_8\text{O}$ have different mass numbers but also different atomic numbers, so they belong to different elements.

Step 3: Conclusion Isotopes have the same Z and different A , whereas isobars have the same A and

different Z . No: different mass numbers alone do not necessarily make two nuclei isotopes; their atomic numbers must also be equal.

Quick Tip to Solve: Check the lower number Z first: isotope identification needs equal proton numbers as well as different mass numbers.

OR

2(b). (i) Name the factors on which photoelectric emission from a surface depends.

(ii) Define the term ‘threshold frequency’ for a photosensitive material.

[2 marks]

Solution:

Concept:

- In photoelectric emission, a surface electron absorbs a photon of energy $h\nu$. Emission requires this energy to be at least the work function ϕ of the material, where h is Planck’s constant and ν is the light frequency.
- The threshold frequency satisfies $h\nu_0 = \phi$. For incident light above threshold, increasing intensity increases the rate of photoelectron emission.

Step 1: State the factors controlling emission (i) Photoelectric emission depends on the nature of the photosensitive material, the frequency of the incident light and its intensity. The material’s work function and the incident frequency decide whether emission is possible. For $\nu < \nu_0$, no photoelectrons are emitted even if the intensity is increased. At a fixed frequency above threshold, greater intensity means more photons arrive per second and hence more photoelectrons are emitted per second. Frequency also determines the maximum kinetic energy through $K_{\max} = h\nu - \phi$.

Step 2: Define threshold frequency (ii) The threshold frequency ν_0 is the minimum frequency of incident radiation required to just cause photoelectric emission from a given photosensitive material. At threshold, the photon energy just equals the work function and the maximum kinetic energy is zero:

$$\nu_0 = \frac{\phi}{h}, \quad K_{\max} = 0.$$

Thus, the threshold is a characteristic of the material and is independent of incident intensity.

Step 3: Conclusion The relevant factors are the nature of the surface, incident-light frequency and incident-light intensity. Threshold frequency is the minimum frequency required for emission, $\nu_0 = \phi/h$.

Quick Tip to Solve: Separate onset from rate: frequency and work function set the onset, while intensity controls the emission rate above threshold.

3. Explain the formation of the barrier potential in a p-n junction.

[2 marks]

Solution:

Concept:

- In a p-n junction, holes are the majority carriers on the p side and electrons are the majority carriers on the n side. Their concentration gradients cause diffusion across the junction.
- Uncovered, immobile donor and acceptor ions form a space-charge region. Its electric field opposes

further majority-carrier diffusion and produces a built-in potential difference.

Step 1: Trace diffusion and recombination When the p and n regions are brought into contact, electrons diffuse from the n side to the p side, while holes diffuse from the p side to the n side. Near the junction, electrons and holes recombine. Consequently, this region becomes depleted of mobile charge carriers and is called the depletion region.

Step 2: Identify the barrier established by the fixed ions Electrons leaving the n side uncover positively charged donor ions; holes leaving the p side uncover negatively charged acceptor ions. These ions remain fixed in the crystal. The resulting electric field points from the n side to the p side and opposes further diffusion of the majority carriers. The associated potential difference across the depletion region is the barrier potential. As it develops, the field produces drift current opposite to diffusion current. At thermal equilibrium these currents balance, so the net current is zero although carrier motion continues.

Step 3: Conclusion The barrier potential is the built-in potential difference produced by the fixed space charges in the depletion region of a p-n junction. It opposes further diffusion of majority carriers across the junction.

Quick Tip to Solve: Remember the sequence: diffusion, recombination, fixed ions, then the opposing electric field and barrier potential. The field points from n to p.

Section B (24 marks)

4. State Bohr's postulate to explain stable orbits in a hydrogen atom. Prove that the speed with which the electron revolves in n^{th} orbit is proportional to $(1/n)$. [3 marks]

Solution:

Concept:

- Bohr postulated that electrons revolve in certain permitted stationary orbits without radiating energy. Each orbit therefore has a definite, constant energy.
- The angular momentum in a permitted orbit is quantised: $m_e v_n r_n = n\hbar = nh/(2\pi)$, where $n = 1, 2, 3, \dots$, m_e is the electron mass, v_n its speed and r_n the orbit radius.
- In hydrogen, the electrostatic attraction of the proton supplies the centripetal force: $m_e v_n^2 / r_n = k e^2 / r_n^2$, where $k = 1/(4\pi\epsilon_0)$ and e is the magnitude of the electron charge.

Step 1: State the postulate for stable orbits According to Bohr, an electron can revolve around the nucleus only in certain allowed stationary orbits. It does not emit radiation while remaining in any one of these orbits, so it does not continuously lose energy and spiral into the nucleus. The allowed orbits satisfy the angular-momentum condition

$$m_e v_n r_n = \frac{nh}{2\pi} = n\hbar.$$

Radiation is emitted or absorbed only when the electron changes from one stationary state to another, with the photon energy equal to the difference between their energies.

Step 2: Write the force equation for hydrogen The hydrogen nucleus has charge $+e$. Taking it as fixed, the attractive Coulomb force on the electron provides the required centripetal force for its

circular orbit:

$$\frac{ke^2}{r_n^2} = \frac{m_e v_n^2}{r_n}.$$

Multiplying by r_n^2 gives

$$m_e v_n^2 r_n = ke^2.$$

Step 3: Eliminate the radius using quantisation Divide the force relation by the angular-momentum relation. The common factors m_e , r_n and one power of v_n cancel:

$$\begin{aligned}\frac{m_e v_n^2 r_n}{m_e v_n r_n} &= \frac{ke^2}{n\hbar}, \\ v_n &= \frac{ke^2}{n\hbar} = \frac{e^2}{2\varepsilon_0 h} \frac{1}{n}.\end{aligned}$$

For the same hydrogen atom, e , ε_0 and h are constants; only the quantum number n changes between allowed orbits.

Step 4: Conclusion Bohr's stationary orbits are stable because an electron in an allowed orbit does not radiate energy. Its speed is $v_n = e^2/(2\varepsilon_0 h n)$, hence $v_n \propto 1/n$.

Quick Tip to Solve: Divide $m_e v_n^2 r_n = ke^2$ by $m_e v_n r_n = n\hbar$: this gives the speed directly without first deriving the orbit radius.

5. Briefly explain how emf is generated in a solar cell. Draw its I-V characteristics.

[3 marks]

Solution:

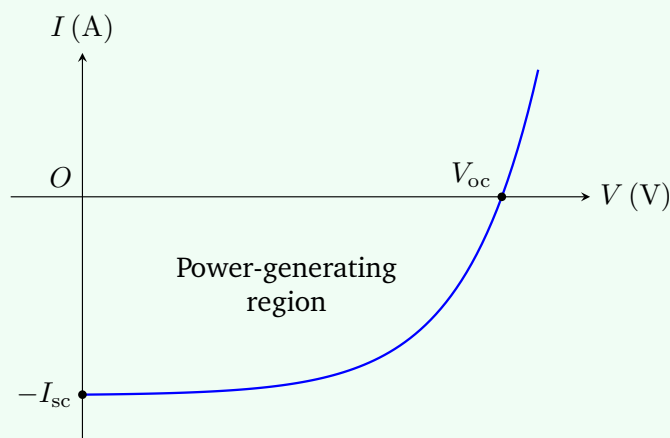
Concept:

- A solar cell is an illuminated p-n junction which converts light energy directly into electrical energy by the photovoltaic effect; it operates without an external bias.
- Photons with energy $h\nu \geq E_g$, where E_g is the semiconductor band gap, create electron-hole pairs. The built-in electric field in the depletion layer separates these carriers.
- With current I taken positive in the ordinary forward-diode direction, the illuminated characteristic is shifted downward by the photocurrent. The power-generating portion lies in the fourth quadrant.

Step 1: Generate and separate the charge carriers Light incident on the junction produces electron-hole pairs in and near the depletion region. The junction's built-in electric field points from the n side towards the p side. It drives electrons towards the n side and holes towards the p side before they can recombine.

Step 2: Explain the development of emf The separated electrons accumulate on the n side and holes on the p side. Consequently, the p terminal becomes positive relative to the n terminal and a photovoltage develops across the junction. At open circuit, the photovoltage makes the forward junction current balance the light-generated current, so the net terminal current is zero. Connecting a load allows conventional current to flow from the p terminal through the load to the n terminal; continued illumination supplies the energy.

Step 3: Identify the characteristic intercepts The sketch uses terminal voltage $V = V_p - V_n$ and the forward-diode current sign convention. At $V = 0$, the current is $-I_{sc}$, where I_{sc} is the magnitude of the short-circuit current. At $I = 0$, the voltage is the open-circuit voltage V_{oc} . Between these intercepts, $V > 0$ and $I < 0$, so the cell delivers electrical power to a load.



Solar-cell I-V characteristic at fixed illumination (forward-diode current convention).

Step 4: Conclusion The solar-cell emf arises from light-generated electron-hole pairs separated by the junction field, making the p side positive and the n side negative. Its illuminated I-V curve has intercepts $-I_{sc}$ and V_{oc} ; the fourth-quadrant portion represents power generation.

Quick Tip to Solve: State the current sign convention before drawing: using forward-diode current puts the solar cell's power-generating curve below the voltage axis.

6. A narrow beam of protons, each having 4.1 MeV energy is approaching a sheet of lead ($Z = 82$). Calculate:

- the speed of a proton in the beam, and
- the distance of its closest approach.

[3 marks]

Solution:

Concept:

- For a nonrelativistic proton of mass m_p , kinetic energy and speed are related by $K = \frac{1}{2}m_p v^2$. Convert MeV to joules before finding v .
- In a head-on encounter with a heavy lead nucleus, the proton is momentarily at rest at the distance of closest approach. Conservation of energy gives $K = kZe^2/r_{\min}$, taking the initial potential energy to be negligible. Here $k = 1/(4\pi\epsilon_0)$, $Z = 82$, and the proton charge is $+e$.

Step 1: Convert the incident kinetic energy Use $e = 1.6 \times 10^{-19}$ C and $m_p = 1.673 \times 10^{-27}$ kg. Since one electron volt is 1.6×10^{-19} J, the energy of each proton is

$$K = 4.1 \times 10^6 \times 1.6 \times 10^{-19} = 6.56 \times 10^{-13} \text{ J.}$$

Step 2: Calculate the speed of the proton Rearranging the kinetic-energy relation gives

$$\begin{aligned} v &= \sqrt{\frac{2K}{m_p}} = \sqrt{\frac{2(6.56 \times 10^{-13})}{1.673 \times 10^{-27}}} \\ &= \sqrt{7.84 \times 10^{14}} \simeq 2.80 \times 10^7 \text{ m s}^{-1}. \end{aligned}$$

This speed is about $0.093c$, so the nonrelativistic expression is appropriate for this calculation.

Step 3: Apply energy conservation at closest approach The lead nucleus has charge $+82e$, whereas the

incident particle is a proton of charge $+e$. For the minimum head-on distance, electrostatic repulsion converts the incident kinetic energy completely into electric potential energy. Treating the much heavier nucleus as stationary,

$$K = \frac{k(82e)e}{r_{\min}}, \quad r_{\min} = \frac{k 82e^2}{K}.$$

With $k = 9 \times 10^9 \text{ N m}^2\text{C}^{-2}$,

$$\begin{aligned} r_{\min} &= \frac{(9 \times 10^9)(82)(1.6 \times 10^{-19})^2}{6.56 \times 10^{-13}} \\ &= 2.88 \times 10^{-14} \text{ m}. \end{aligned}$$

The distance is measured between the proton and the centre of the lead nucleus. A non-head-on trajectory does not reach this minimum separation at the same incident energy.

Step 4: Conclusion (i) The proton speed is $v \simeq 2.8 \times 10^7 \text{ m s}^{-1}$. (ii) The head-on distance of closest approach is $r_{\min} \simeq 2.9 \times 10^{-14} \text{ m}$, or about 29 fm.

Quick Tip to Solve: Use Ze^2 for a proton incident on lead; the extra factor of two used for an alpha particle does not apply here.

7. In a diffraction pattern due to a single slit, how will the angular width of central maximum change, if

- (i) Orange light is used in place of green light,
- (ii) the screen is moved closer to the slit,
- (iii) the slit width is decreased?

Justify your answer in each case.

[3 marks]

Solution:

Concept:

- For a single slit of width a , the first minima on the two sides of the central maximum satisfy $a \sin \theta = \lambda$, where λ is the wavelength and θ is measured from the central axis.
- The angular width is $\Delta\theta = 2\theta \simeq 2\lambda/a$ for small diffraction angles. The corresponding linear width on a screen at distance D is $W \simeq 2D\lambda/a$.

Step 1: Compare the wavelengths of orange and green light Orange light has a longer wavelength than green light. Keeping the slit width fixed, the first-minimum relation gives a larger value of θ for orange light. Hence the central maximum becomes angularly wider:

$$\frac{\Delta\theta_{\text{orange}}}{\Delta\theta_{\text{green}}} \simeq \frac{\lambda_{\text{orange}}}{\lambda_{\text{green}}} > 1.$$

Step 2: Distinguish angular width from screen width Moving the screen closer decreases D , but neither a nor λ changes. The directions of the two first minima therefore remain the same and the angular width is unchanged. The linear width W on the screen does decrease. Indeed, $W/D \simeq 2\lambda/a$ remains constant; a smaller physical pattern need not mean a smaller angular width.

Step 3: Reduce the slit width in the diffraction relation For the same wavelength, reducing a increases λ/a . Thus the first minima move farther from the axis and the angular width increases. In the usual

small-angle regime,

$$\Delta\theta \propto \frac{1}{a}.$$

For example, halving the slit width approximately doubles the angular width, provided the diffraction angles remain small.

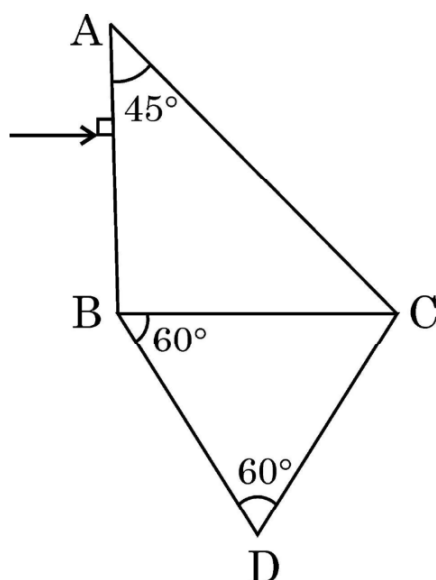
Step 4: Conclusion The angular width (i) increases with orange light, (ii) remains unchanged when the screen is moved closer, and (iii) increases when the slit is narrowed.

Quick Tip to Solve: Write $\Delta\theta \simeq 2\lambda/a$ first: screen distance affects linear width, but does not occur in angular width.

8(a). Write two necessary conditions for total internal reflection.

(b) Two prisms ABC and DBC are arranged as shown in figure.

The critical angles for the two prisms with respect to air are 41.1° and 45° respectively. Trace the path of the ray through the combination. [3 marks]



Solution:

Concept:

- Total internal reflection requires light to travel from an optically denser medium towards a rarer medium, with the angle of incidence greater than the critical angle for that pair of media.
- Angles of incidence are measured from the normal. A ray incident normally is undeviated; in reflection the angle of reflection equals the angle of incidence.

Step 1: State both conditions for total internal reflection The incident ray must be in the medium of greater refractive index and be directed towards a medium of smaller refractive index. Its incidence angle must also satisfy $i > i_c$. At $i = i_c$, the refracted ray travels along the boundary, so the strict inequality is necessary for total internal reflection.

Step 2: Trace the ray through prism ABC The horizontal ray enters face AB along its normal and continues straight to AC. Since the angle at A is 45° , its incidence angle at AC is 45° . Here

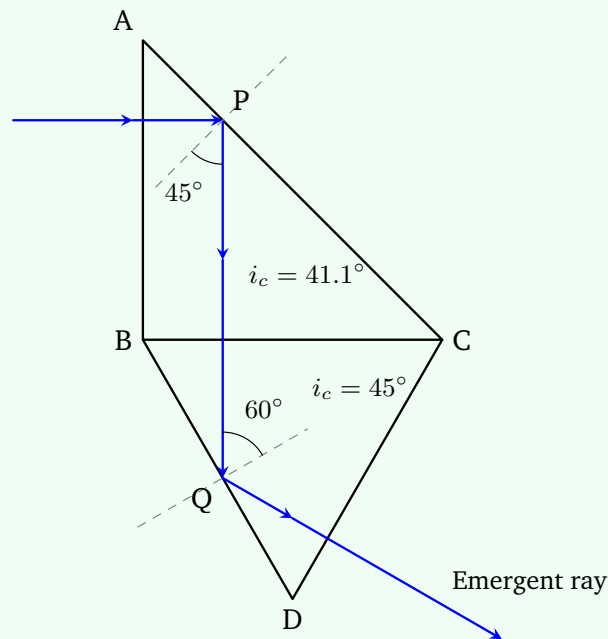
$$45^\circ > 41.1^\circ,$$

so it undergoes total internal reflection at AC. The reflected ray travels vertically downwards. It reaches BC normally and enters the second prism without changing direction, although its speed changes between the materials.

Step 3: Trace the ray through prism DBC The lower prism is equilateral: its angles at B and D are both 60° . The downward ray meets BD, whose normal makes 60° with that ray. Therefore the incidence angle is 60° , greater than the second prism's critical angle:

$$60^\circ > 45^\circ.$$

The ray is totally internally reflected at BD and travels downwards to the right. This reflected direction is perpendicular to DC, so it emerges from DC into air without deviation. In the diagram, P and Q mark the two reflecting points; the dashed lines are normals.



Ray path through the two prisms (dashed normals at P and Q).

Step 4: Conclusion The necessary conditions are denser-to-rarer incidence and $i > i_c$. The ray enters AB normally, reflects totally at AC and BD, crosses BC normally, and emerges normally through DC, directed downwards to the right.

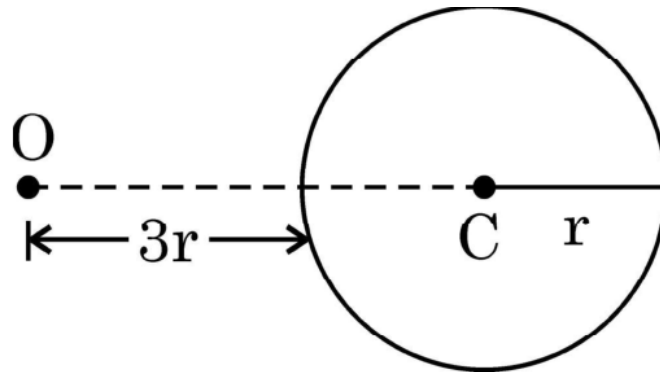
Quick Tip to Solve: Draw a normal at each struck face before comparing angles: the two TIR incidence angles are 45° at AC and 60° at BD.

8(b). (a) An object is placed in front of a converging lens. Obtain the conditions under which the magnification produced by the lens is (i) negative and (ii) positive.

(b) A point object is placed at O in front of a glass sphere as shown in figure.

Show the formation of image by the sphere.

[3 marks]



Solution:

Concept:

- For a thin lens, $1/f = 1/v - 1/u$ and the transverse magnification is $m = v/u$. With light travelling to the right, a real object has $u < 0$ and a converging lens has $f > 0$.
- For refraction at a spherical surface, $n_2/v - n_1/u = (n_2 - n_1)/R$. Distances are measured from the pole of the particular surface; R is positive when its centre lies to the right.

Step 1: Obtain the conditions on lens magnification in part (a) Write $u = -a$, where $a > 0$ is the object distance. The lens formula gives

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{a}, \quad v = \frac{af}{a-f}, \quad m = -\frac{f}{a-f}.$$

(i) If $a > f$, then $v > 0$ and $m < 0$: the object is beyond the principal focus and the real image is inverted. (ii) If $0 < a < f$, then $v < 0$ and $m > 0$: the object lies between the focus and optical centre, and the image is virtual, erect and enlarged. At $a = f$, the emergent rays are parallel and there is no image at a finite distance.

Step 2: Refract the rays at the first surface of the sphere Let P_1, P_2 be the front and rear poles of the sphere of radius r , with $P_1P_2 = 2r$. The printed separation is $OP_1 = 3r$, not $OC = 3r$. Denote the glass refractive index relative to air by μ ; the question does not specify its numerical value. For the first surface, $u_1 = -3r$, $R_1 = +r$, $n_1 = 1$, and $n_2 = \mu$. Thus

$$\frac{\mu}{v_1} - \frac{1}{-3r} = \frac{\mu - 1}{r} \Rightarrow v_1 = \frac{3\mu r}{3\mu - 4}.$$

The first surface bends a paraxial ray toward its normal. Its continuation inside glass is directed toward the intermediate image I_1 for ordinary glass.

Step 3: Refract again at the rear surface in part (b) The intermediate image acts as the object for the rear surface. Its distance must be measured from P_2 :

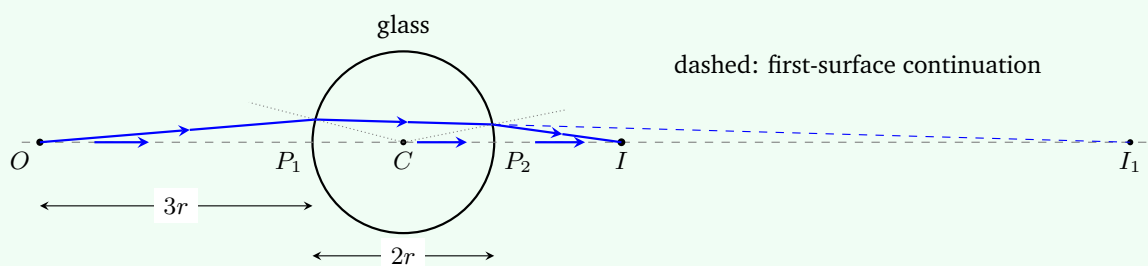
$$u_2 = v_1 - 2r = \frac{(8 - 3\mu)r}{3\mu - 4}, \quad R_2 = -r.$$

At the glass-to-air surface,

$$\frac{1}{v_2} - \frac{\mu}{u_2} = \frac{1 - \mu}{-r},$$

$$\frac{1}{v_2} = \frac{\mu - 1}{r} + \frac{\mu(3\mu - 4)}{(8 - 3\mu)r} = \frac{7\mu - 8}{(8 - 3\mu)r}.$$

The off-axis ray bends away from the rear-surface normal and meets the undeviated axial ray at I , as shown. This is a real image for ordinary glass. The drawing is schematic and uses the common illustrative value $\mu = 3/2$; that value is not supplied by the printed question. For this value, $v_1 = 9r$, $u_2 = 7r$, and $v_2 = 7r/5$.



Successive refractions through the glass sphere (schematic; illustrative $\mu = 3/2$, paraxial rays).

Step 4: Conclusion (a) Magnification is negative for an object beyond the focus and positive for an object between the focus and the converging lens. (b) Successive refractions form the image I at $P_2I = (8 - 3\mu)r/(7\mu - 8)$ in the paraxial approximation; for the illustrative assumption $\mu = 3/2$, the image is real and lies $7r/5$ beyond the rear surface.

Quick Tip to Solve: For the sphere, use $u_1 = -3r$, then shift the origin by its diameter: $u_2 = v_1 - 2r$. Reverse the sign of the radius at the rear surface.

9. An electron is accelerated from rest through a potential difference of 100 V. Find:

- the wavelength associated with
- the momentum of and
- the velocity required by, the electron.

[3 marks]

Solution:

Concept:

- An electron accelerated from rest gains kinetic energy $K = eV$, where e is the magnitude of its charge and V is the accelerating potential difference.
- For non-relativistic motion, $K = p^2/(2m_e) = m_e v^2/2$; the de Broglie wavelength is $\lambda = h/p$, where p is momentum and h is Planck's constant.

Step 1: Convert the electrical energy into kinetic energy The potential difference is $V = 100$ V. Using $e = 1.6 \times 10^{-19}$ C, the electron's gain in kinetic energy is

$$K = eV = (1.6 \times 10^{-19})(100) = 1.6 \times 10^{-17} \text{ J}.$$

The initial kinetic energy is zero. The negative charge determines the direction of acceleration, whereas the energy gain uses the positive magnitude eV .

Step 2: Calculate the associated wavelength for part (i) Combining the de Broglie relation with $p = \sqrt{2m_e eV}$, and using $m_e = 9.1 \times 10^{-31}$ kg and $h = 6.63 \times 10^{-34}$ J s, gives

$$\begin{aligned}\lambda &= \frac{h}{\sqrt{2m_e eV}} \\ &= \frac{6.63 \times 10^{-34}}{\sqrt{2(9.1 \times 10^{-31})(1.6 \times 10^{-17})}} \\ &= 1.23 \times 10^{-10} \text{ m.}\end{aligned}$$

This is the wavelength associated with the moving electron, not a wavelength of emitted radiation.

Step 3: Determine the momentum for part (ii) The momentum magnitude follows from the same kinetic energy:

$$p = \sqrt{2m_e K} = \sqrt{2.912 \times 10^{-47}} = 5.40 \times 10^{-24} \text{ kg m s}^{-1}.$$

As a check, the product $p\lambda$ equals Planck's constant within rounding.

Step 4: Determine the acquired velocity for part (iii) Divide the momentum by the electron mass:

$$v = \frac{p}{m_e} = \frac{5.396 \times 10^{-24}}{9.1 \times 10^{-31}} = 5.93 \times 10^6 \text{ m s}^{-1}.$$

The speed is about $0.020c$, so the non-relativistic expressions used above are appropriate. The electron moves toward higher electric potential, opposite to the electric field; no spatial direction is specified in the question.

Step 5: Conclusion (i) $\lambda = 1.23 \times 10^{-10}$ m; (ii) $p = 5.40 \times 10^{-24}$ kg m s⁻¹; (iii) the acquired speed is $v = 5.93 \times 10^6$ m s⁻¹, toward higher potential.

Quick Tip to Solve: Find $p = \sqrt{2m_e eV}$ once; then obtain both $\lambda = h/p$ and $v = p/m_e$. Keep the 100 eV energy distinct from its value in joules.

10. In a Young's double slit experiment using light of wavelength 600 nm, the slit separation is 0.8 mm and the screen is kept 1.6 m from the plane of the slits. Calculate:

(i) the fringe width

(ii) the distance of (a) third minimum and (b) fifth maximum, from the central maximum. [3 marks]

Solution:

Concept:

- In Young's double-slit experiment, the fringe width is $\beta = \lambda D/d$, where λ is the wavelength, D the slit-to-screen distance and d the slit separation. The usual small-angle approximation applies because $D \gg d$.
- Bright fringes satisfy path difference $n\lambda$, so their distances from the central maximum are $y_n = n\beta$. The central maximum has order $n = 0$.
- The n th dark fringe has path difference $(n - \frac{1}{2})\lambda$ and distance $y_n = (n - \frac{1}{2})\beta$, with the first minimum corresponding to $n = 1$.

Step 1: Convert the given quantities to SI units Use one consistent system of units before substituting:

$$\lambda = 600 \times 10^{-9} \text{ m}, \quad d = 0.8 \times 10^{-3} \text{ m}, \quad D = 1.6 \text{ m}.$$

The screen is much farther from the slits than their separation, as required by the standard fringe-position formula.

Step 2: Calculate the fringe width for part (i) Consecutive bright fringes, or consecutive dark fringes, are separated by

$$\beta = \frac{\lambda D}{d} = \frac{600 \times 10^{-9} \times 1.6}{0.8 \times 10^{-3}} \text{ m} = 1.2 \times 10^{-3} \text{ m} = 1.2 \text{ mm}.$$

Step 3: Locate the third minimum for part (ii)(a) The first, second and third minima occur at $\beta/2$, $3\beta/2$ and $5\beta/2$, respectively. Thus, for $n = 3$,

$$y_{3,\text{dark}} = \left(3 - \frac{1}{2}\right) \beta = \frac{5}{2} \times 1.2 \text{ mm} = 3.0 \text{ mm}.$$

Counting the first dark fringe at half a fringe width avoids an off-by-one error.

Step 4: Locate the fifth maximum for part (ii)(b) Count the central maximum as the zeroth-order bright fringe. The fifth maximum away from it therefore corresponds to $n = 5$:

$$y_{5,\text{bright}} = 5\beta = 5 \times 1.2 \text{ mm} = 6.0 \text{ mm}.$$

Both the bright and dark fringe systems are symmetric about the centre; the requested distances are positive magnitudes on either side.

Step 5: Conclusion (i) The fringe width is 1.2 mm. (ii) From the central maximum, (a) the third minimum is 3.0 mm away and (b) the fifth maximum is 6.0 mm away, on either side.

Quick Tip to Solve: Calculate β once; multiply it by $n - \frac{1}{2}$ for the n th minimum and by n for the n th maximum, counting the central maximum as zero.

11(a). Electromagnetic waves of wavelengths λ_1 , λ_2 and λ_3 are used in radar systems, in water purifiers and in remote switches of TV, respectively.

(i) Identify the electromagnetic waves, and

(ii) Write one source of each of them.

[3 marks]

Solution:

Concept:

- Different regions of the electromagnetic spectrum have characteristic interactions with matter. A wave's application therefore helps identify the region of the spectrum to which it belongs.
- Microwaves can be sent as narrow beams and reflected by objects for radar detection. Ultraviolet radiation has germicidal action, while infrared radiation is used to carry control signals over short distances.

Step 1: Identify the radar waves and their source For λ_1 , the electromagnetic waves are **microwaves**. Their short wavelengths allow a suitably sized antenna to produce a directional beam. Radar receives the reflected beam from a target and uses it to locate the object. One source is a **magnetron**, an electronic device that generates microwave radiation.

Step 2: Identify the water-purifier waves and their source For λ_2 , the waves are **ultraviolet rays**. Their germicidal action inactivates microorganisms in water, which is why they are used in water purifiers for disinfection. One source is a **mercury-vapour discharge lamp**, which emits ultraviolet

radiation. The relevant application is disinfection, rather than removal of dissolved salts.

Step 3: Identify the television-remote waves and their source For λ_3 , the waves are **infrared rays**. The remote transmits a coded sequence of infrared pulses, which the receiver in the television detects and converts into the requested control action. One source is an **infrared light-emitting diode (LED)**, the practical emitter used in a TV remote.

Step 4: Conclusion λ_1 : microwaves, produced by a magnetron; λ_2 : ultraviolet rays, produced by a mercury-vapour discharge lamp; λ_3 : infrared rays, produced by an infrared LED.

Quick Tip to Solve: Match each application with its action: reflected directional beams mean microwaves, germicidal action means ultraviolet, and coded TV-remote pulses mean infrared.

OR

11(b). (i) State two conditions for two light sources to be coherent.

(ii) Give two points of difference between an interference pattern due to a double-slit and a diffraction pattern due to a single slit. [3 marks]

Solution:

Concept:

- Coherent sources emit waves of the same frequency and maintain a constant phase difference. These conditions keep the positions of constructive and destructive interference fixed.
- For ideal identical narrow double slits, the fringe width is $\beta = \lambda D/d$, where d is slit separation and D is the screen distance. For a single slit of width a , minima satisfy $a \sin \theta = n\lambda$.

Step 1: State the two coherence conditions (i) The two sources must have the same frequency, or equivalently the same wavelength in the same medium. (ii) Their phase difference must remain constant with time; it need not be zero. If the phase difference fluctuates randomly, the bright and dark positions move rapidly and a stable interference pattern is lost. Equal amplitudes improve contrast but are not a defining condition for coherence.

Step 2: Compare the widths of the bright bands In ideal double-slit interference, successive bright fringes have equal width $\lambda D/d$; the central bright fringe has the same width as the others. In single-slit diffraction, the central bright maximum is approximately twice as wide as each secondary bright band: its width is $2\lambda D/a$, while the spacing between successive minima on either side is approximately $\lambda D/a$. These widths use the usual small-angle, distant-screen approximation.

Step 3: Compare the intensities of the maxima With equally illuminated identical narrow slits, the ideal double-slit interference maxima have the same intensity. In single-slit diffraction, the central maximum is the brightest and successive secondary maxima become progressively weaker away from the centre. A real double-slit pattern can also have a diffraction envelope; the standard comparison refers to its ideal interference fringes.

Step 4: Conclusion Coherence requires equal frequencies and a constant phase difference. The two pattern differences are uniform bright-fringe widths and equal ideal maxima for double-slit

interference, compared with a twice-wide central maximum and diminishing secondary intensities for single-slit diffraction.

Quick Tip to Solve: Compare width and brightness separately: diffraction has a wider, brighter centre; ideal double-slit interference repeats uniformly.

Section C (5 marks)

CASE STUDY

12. A compound microscope consists of two converging lenses. One of them, of smaller aperture and smaller focal length is called objective and the other of slightly larger aperture and slightly larger focal length is called eye-piece. Both the lenses are fitted in a tube with an arrangement to vary the distance between them. A tiny object is placed in front of the objective at a distance slightly greater than its focal length. The objective produces the image of the object which acts as an object for the eye-piece. The eye piece, in turn produces the final magnified image. [5 marks]

12(I). In a compound microscope the images formed by the objective and the eye-piece are respectively [1 mark]

- (A) virtual, real
- (B) real, virtual
- (C) virtual, virtual
- (D) real, real

Correct Answer: (B) real, virtual

Solution:

Concept:

- A converging lens forms a real image when the object is beyond its principal focus. The microscope objective forms a magnified intermediate image.
- The eyepiece acts as a simple magnifier; its object is at or within its focal plane, giving the final virtual image.

Step 1: Identify the objective image The tiny object is placed just beyond the focal point of the objective. Its refracted rays actually meet on the other side of that lens, so the intermediate image is real, inverted and enlarged. Options (A) and (C), which call this image virtual, are therefore incorrect.

Step 2: Identify the eyepiece image This intermediate image serves as the eyepiece's object. The eyepiece is adjusted so that it acts as a magnifying glass, producing a virtual enlarged image for the eye, either at the near point or at infinity in normal adjustment. Option (D) incorrectly describes the final image as real.

Step 3: Conclusion The objective and eyepiece form real and virtual images, respectively. Hence, the correct option is (B).

Quick Tip to Solve: Follow the image in two stages: the objective projects a real image, and the eyepiece magnifies that image virtually.

12(II). The magnification due to a compound microscope does not depend upon

[1 mark]

- (A) the aperture of the objective and the eye-piece
- (B) the focal length of the objective and the eye-piece
- (C) the length of the tube
- (D) the colour of the light used

Correct Answer: (A) the aperture of the objective and the eye-piece

Solution:

Concept:

- For normal adjustment, the approximate magnifying power is $M \simeq (L/f_o)(D/f_e)$, where L is the effective tube length, f_o, f_e are the objective and eyepiece focal lengths, and D is the least distance of distinct vision.
- Aperture controls light collection and resolving power, while geometrical magnification depends on focal lengths and the image arrangement.

Step 1: Inspect the magnification formula The formula contains the tube length and both focal lengths, so options (B) and (C) describe quantities on which magnification depends. Neither lens aperture appears: changing the clear aperture at fixed focal lengths and image positions does not change the geometrical image scale.

Step 2: Check the colour alternative Colour can affect magnification indirectly. The refractive index of a lens material varies with wavelength, so its focal length also varies with the colour of the incident light. Thus option (D) is not the independent quantity sought here. Aperture affects brightness and the ability to distinguish fine detail, which must not be confused with magnifying power.

Step 3: Conclusion The magnification does not depend upon the aperture of the objective and the eyepiece. Hence, the correct option is (A).

Quick Tip to Solve: Write $M \simeq LD/(f_o f_e)$: aperture is absent, but colour can alter the focal lengths through dispersion.

12(III). Which of the following is not correct in the context of a compound microscope?

[1 mark]

- (A) Both the lenses are of short focal lengths.
- (B) The magnifying power increases by decreasing the focal lengths of the two lenses.
- (C) The distance between the two lenses is more than $(f_o + f_e)$.
- (D) The microscope can be used as a telescope by interchanging the two lenses.

Correct Answer: (D) The microscope can be used as a telescope by interchanging the two lenses.

Solution:

Concept:

- A compound microscope uses short focal lengths to obtain large magnification: approximately $M = (L/f_o)(D/f_e)$ in normal adjustment, with effective tube length L and near-point distance D .
- An astronomical telescope needs an objective of long focal length and large aperture to collect light from distant objects, together with a short-focal-length eyepiece.

Step 1: Check the microscope statements Both microscope lenses have short focal lengths, so (A) is correct. The magnifying power increases as either focal length decreases, other parameters fixed, so (B) is correct. In the usual microscope arrangement, the objective forms an intermediate image well beyond its focus. For normal adjustment the lens separation is $v_o + f_e > f_o + f_e$, where v_o is the objective image distance; thus (C) describes the standard arrangement.

Step 2: Test whether swapping the lenses is sufficient Interchanging the microscope lenses does not provide the long-focal-length, large-aperture objective required for an astronomical telescope. Both lenses remain short-focal-length lenses designed for observing a nearby tiny object. A telescope also requires a different arrangement for a distant object. Consequently (D) is the incorrect statement sought by the question.

Step 3: Conclusion A compound microscope cannot be converted into the required telescope merely by interchanging its two lenses. Hence, the correct option is (D).

Quick Tip to Solve: For this negative question, check the instrument design: microscope objectives have short focal lengths, whereas telescope objectives need long focal lengths.

12(IV). A compound microscope consists of an objective of 10X and an eye-piece of 20X. The magnification due to the microscope would be [1 mark]

- (A) 2
- (B) 10
- (C) 30
- (D) 200

Correct Answer: (D) 200

Solution:

Concept:

- A compound microscope magnifies in two successive stages: first the objective, then the eyepiece.
- Its magnifying power in magnitude is $M = |m_o|M_e$, where $|m_o|$ is the objective's linear magnification and M_e is the eyepiece's angular magnification.

Step 1: Read the two magnification factors The objective is rated $10\times$, so it forms an intermediate image ten times the object's linear size. The eyepiece is rated $20\times$ and magnifies this intermediate image for the eye. These are successive multiplicative factors, not focal lengths to be inserted in a ratio.

Step 2: Multiply the successive magnifications Apply the compound-microscope relation:

$$M = 10 \times 20 = 200.$$

Dividing the ratings gives the distractor 2; retaining only the objective gives 10; adding the ratings gives 30. None represents two successive magnification stages. The requested magnification is a dimensionless magnitude; image inversion does not change this positive rating.

Step 3: Conclusion The microscope provides a magnification of $200\times$. Hence, the correct option is (D).

Quick Tip to Solve: Multiply the magnification ratings printed on a microscope's objective and eyepiece; do not add or divide them.

12(V). The focal lengths of objective and eye-piece of a compound microscope are 1.2 cm and 3.0 cm respectively. The object is placed at a distance of 1.25 cm from the objective. If the final image is formed at infinity, the magnifying power of the microscope would be [1 mark]

- (A) 100
- (B) 150
- (C) 200
- (D) 250

Correct Answer: (C) 200

Solution:

Concept:

- For the objective, the lens formula is $1/f_o = 1/v_o - 1/u_o$, where f_o , u_o and v_o are its focal length, object distance and image distance in the Cartesian sign convention.
- When the final image is at infinity, the magnifying power in magnitude is $M = |v_o/u_o|(D/f_e)$, where f_e is the eyepiece focal length and $D = 25$ cm is the standard least distance of distinct vision.

Step 1: Find the objective image distance The object is on the incident side of the converging objective, so $u_o = -1.25$ cm and $f_o = +1.2$ cm. Hence,

$$\frac{1}{v_o} = \frac{1}{f_o} + \frac{1}{u_o} = \frac{1}{1.2} - \frac{1}{1.25} = \frac{1}{30} \text{ cm}^{-1}.$$

Thus $v_o = 30$ cm, and the objective magnification is $m_o = v_o/u_o = -24$. The negative sign indicates an inverted intermediate image.

Step 2: Combine the objective and eyepiece magnifications For relaxed viewing, the eyepiece forms the final image at infinity and has angular magnification $D/f_e = 25/3$. Therefore,

$$M = |m_o| \frac{D}{f_e} = 24 \times \frac{25}{3} = 200.$$

The values 100, 150 and 250 in (A), (B) and (D) do not equal this product. Using $1 + D/f_e$ would be inappropriate because that expression applies to a final image at the near point.

Step 3: Conclusion The magnifying power is 200, with the final image inverted relative to the object. Hence, the correct option is (C).

Quick Tip to Solve: With the object distance given, first calculate the exact objective magnification using the lens formula; for a final image at infinity, multiply its magnitude by $25/f_e$ with f_e in centimetres.