

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

Question Paper with Solutions

Conducted by the Central Board of Secondary Education (CBSE)



Time Allowed: 2 hours

Maximum Marks: 35

General Instructions

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

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

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

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

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

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

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

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

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

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

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

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

Section A (6 marks)

1(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:

- Atomic number Z is the number of protons and identifies the element. Mass number $A = Z + N$ counts protons and neutrons, where N is the neutron number.
- Isotopes have equal Z and unequal A ; isobars have equal A and unequal Z .

Step 1: (i) Distinguish the two classes Isotopes are nuclei of the same element, having the same atomic number but different mass numbers; they differ in neutron number. For example, ${}^{12}_6\text{C}$ and ${}^{14}_6\text{C}$ are isotopes. Isobars are nuclei of different elements with the same mass number but different atomic numbers, for example ${}^{14}_6\text{C}$ and ${}^{14}_7\text{N}$.

Step 2: (ii) Check whether unequal mass numbers are sufficient Knowing only $A_1 \neq A_2$ does not establish that the proton numbers are equal. The nuclei could belong to different elements; for instance, ${}^{12}_6\text{C}$ and ${}^{16}_8\text{O}$ have unequal mass numbers and unequal atomic numbers. To identify isotopes, the additional condition $Z_1 = Z_2$ must be verified.

Step 3: Conclusion Isotopes have the same Z but different A ; isobars have the same A but different Z . Two nuclei with different mass numbers are not necessarily isotopes of the same element.

Quick Tip to Solve: Compare atomic numbers first: equal proton numbers identify the same element; only then compare mass numbers to identify isotopes.

OR

1(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:

- Photoelectric emission is the liberation of electrons from a material surface by incident radiation of sufficiently high frequency.
- A photon supplies energy $h\nu$. The work function ϕ is the minimum energy needed to free an electron, so the threshold condition is $h\nu_0 = \phi$.

Step 1: (i) Identify the factors controlling emission Photoelectric emission depends on the nature of the photosensitive material (its work function), the frequency of the incident radiation, and its intensity. Emission is possible only when the incident frequency reaches the material's threshold frequency. Above threshold, increasing intensity increases the number of incident photons per unit time and hence the number of emitted electrons per unit time. Increasing frequency increases the maximum kinetic energy, according to $K_{\max} = h\nu - \phi$; intensity alone cannot cause emission below threshold.

Step 2: (ii) Define threshold frequency The threshold frequency ν_0 is the minimum frequency of

incident radiation that can just cause photoelectric emission from a given photosensitive material. At threshold, the most energetic emitted electrons have zero kinetic energy, giving $\nu_0 = \phi/h$. Below this frequency, a single photon has insufficient energy to overcome the work function, regardless of the light intensity in the usual photoelectric experiment.

Step 3: Conclusion The factors are the material's nature, incident frequency, and incident intensity. Threshold frequency is the minimum frequency required to initiate photoelectric emission from that material.

Quick Tip to Solve: Separate the roles: frequency decides whether emission occurs and the maximum energy; intensity above threshold controls the number emitted.

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

[2 marks]

Solution:

Concept:

- A p-n junction joins a p-type region, with holes as majority carriers, to an n-type region, with electrons as majority carriers.
- Diffusion carries majority carriers down their concentration gradients; the electric field of exposed fixed ions drives an opposing drift current.

Step 1: Diffusion and formation of the depletion layer On forming the junction, electrons diffuse from the n-side to the p-side, while holes diffuse from the p-side to the n-side because of the concentration differences. They recombine near the junction. The n-side near the junction is left with immobile positively charged donor ions, while the p-side is left with immobile negatively charged acceptor ions. This region becomes depleted of mobile majority carriers and is called the depletion layer.

Step 2: Development of the opposing potential barrier The fixed space charges produce an electric field directed from the positive n-side to the negative p-side. This field opposes further majority-carrier diffusion: it pushes electrons towards the n-side and holes towards the p-side. The associated potential difference across the depletion layer is the barrier potential. As the layer develops, the opposing drift current increases until it balances the diffusion current. In an unbiased junction at thermal equilibrium, the net current is zero, although these two opposing carrier flows persist.

Step 3: Conclusion The barrier potential forms when diffusion and recombination expose fixed donor and acceptor ions near the junction. Their electric field opposes further diffusion and establishes equilibrium across the depletion layer.

Quick Tip to Solve: Remember the exposed charges: n-side positive, p-side negative; their field points from n to p and opposes majority-carrier diffusion.

3. Name the extrinsic semiconductors formed when a pure germanium is doped with (i) a trivalent and (ii) pentavalent impurity. Draw the energy band diagrams of extrinsic semiconductors so formed.

[2 marks]

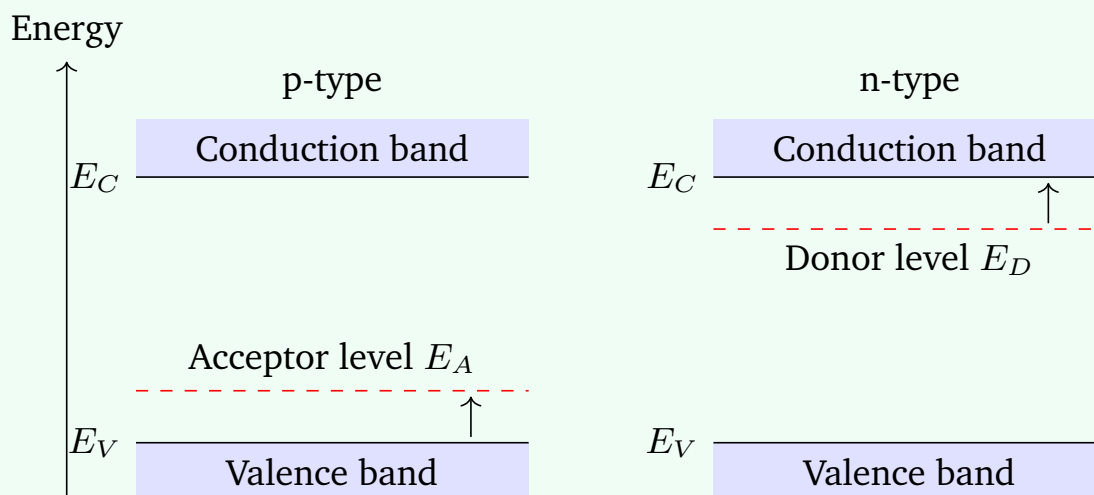
Solution:

Concept:

- Impurity energy levels lie within the forbidden energy gap between the conduction-band edge E_C and valence-band edge E_V .
- Trivalent impurities accept electrons and produce holes; pentavalent impurities donate electrons to the conduction band.

Step 1: Trivalent doping Germanium has four valence electrons. A trivalent impurity provides only three electrons for covalent bonding, leaving one bond deficient in an electron. This deficiency is a hole. The semiconductor formed is p -type, with holes as majority carriers and electrons as minority carriers. The acceptor level E_A lies just above the valence band. A valence electron can acquire the small energy needed to enter this level, leaving a mobile hole in the valence band.

Step 2: Pentavalent doping A pentavalent impurity forms four covalent bonds and has one extra, weakly bound electron. The semiconductor formed is n -type, with electrons as majority carriers and holes as minority carriers. The donor level E_D lies just below the conduction band. A small thermal energy raises the extra electron into the conduction band, where it contributes to conduction. Both impurity levels are inside the forbidden gap, as shown in the schematic diagrams.



Energy bands of p -type and n -type germanium (not to scale)

Step 3: Conclusion (i) Trivalent doping gives p -type germanium with an acceptor level just above E_V . (ii) Pentavalent doping gives n -type germanium with a donor level just below E_C .

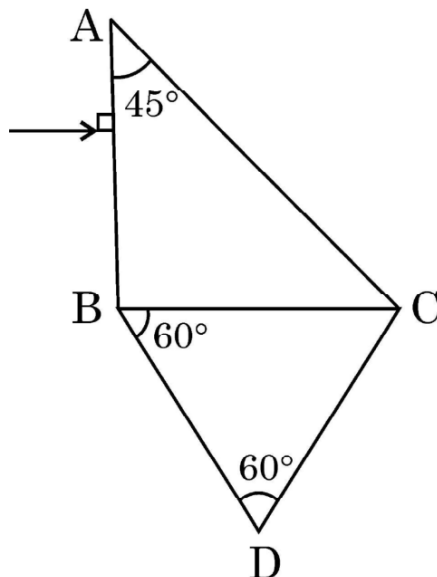
Quick Tip to Solve: Draw the acceptor level close to the valence band and the donor level close to the conduction band, always inside the forbidden gap.

Section B (24 marks)

4(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:

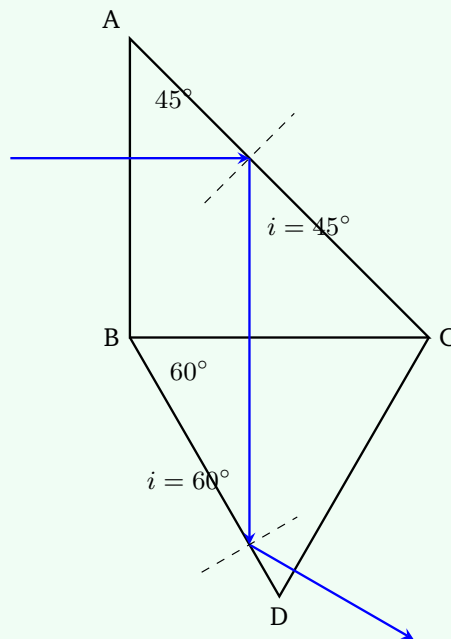
Concept:

- Total internal reflection requires propagation from an optically denser medium towards a rarer medium, with incidence angle greater than the critical angle for those media.
- Angles of incidence and reflection are measured from the normal; the law of reflection is $r = i$. At normal incidence a transmitted ray is undeviated.

Step 1: State the two necessary conditions (a) The ray must travel from an optically denser medium towards an optically rarer medium. Its angle of incidence in the denser medium must exceed the critical angle for that interface, $i > i_c$. At $i = i_c$, the refracted ray grazes the interface; total internal reflection requires a strictly larger angle.

Step 2: Follow the ray through prism ABC (b) The incident horizontal ray enters face AB normally and therefore continues straight. Since $\angle A = 45^\circ$ and $AB \perp BC$, face AC is inclined at 45° to the horizontal. The incidence angle on AC is thus 45° . This exceeds the first prism's critical angle 41.1° , so the ray undergoes total internal reflection and travels vertically downwards. It crosses the common horizontal face BC normally, entering prism DBC without a change in direction.

Step 3: Follow the ray through prism DBC The lower prism has angles of 60° , so its sloping face BD makes 60° with BC . The vertically downward ray makes 30° with BD , and therefore 60° with its normal. Since $60^\circ > 45^\circ$, it undergoes total internal reflection at BD . The reflected ray travels downwards and to the right, perpendicular to face DC . Hence its incidence angle at DC is zero, and it emerges into air undeviated. The path is shown below; dashed lines indicate normals at the reflecting faces.



Ray path through the two prisms

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

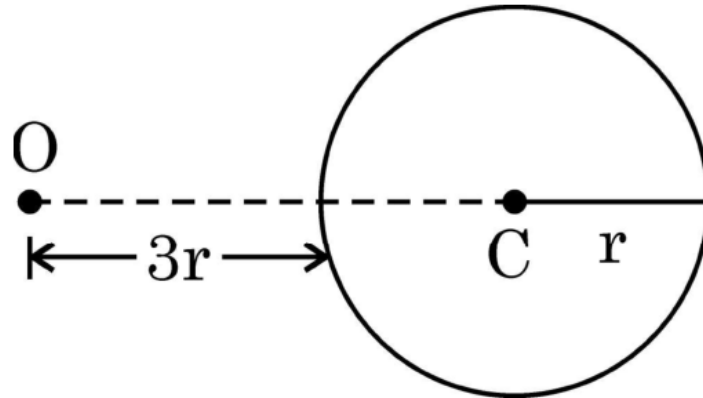
Quick Tip to Solve: First draw the normal at each sloping face: the downward ray meets BD at an incidence angle of 60 degrees, not the 30-degree angle it makes with the face.

4(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 converging lens, $1/f = 1/v - 1/u$ and the signed transverse magnification is $m = v/u$; $f > 0$ and a real object on the left has $u < 0$.
- Refraction at a spherical surface follows $n_2/v - n_1/u = (n_2 - n_1)/R$. Distances are measured from each surface pole, positive to the right for light travelling from left to right.

Step 1: (a) Conditions for negative and positive magnification Let the real object's distance be $d > 0$, so $u = -d$. The lens equation gives

$$v = \frac{fd}{d-f}, \quad m = \frac{v}{u} = -\frac{f}{d-f}.$$

(i) If $d > f$, the object lies beyond the principal focus: $v > 0$ and $m < 0$. The image is real and inverted, so its signed height is opposite to the object's height. (ii) If $0 < d < f$, the object lies between the optical centre and the principal focus: $v < 0$ and $m > 0$. The image is virtual, erect and enlarged, on the object's side of the lens. When $d = f$, the emergent rays are parallel and the image is at infinity; finite magnification is undefined.

Step 2: (b) Refraction at the first surface of the glass sphere Let P_1 and P_2 be the left and right poles; $P_1P_2 = 2r$. The figure gives $OP_1 = 3r$. Write the glass refractive index as n , since the printed question does not specify it, and take air's index as 1. For the first surface, $u_1 = -3r$, $R_1 = +r$, giving

$$\frac{n}{v_1} + \frac{1}{3r} = \frac{n-1}{r}, \quad v_1 = \frac{3nr}{3n-4}.$$

For the usual school-level glass value $n = 3/2$, $v_1 = 9r$: rays refracted at the first surface would converge at I_1 , nine radii to its right, if the glass continued beyond the second surface.

Step 3: Refraction at the second surface and image formation The rays meet the second surface before reaching I_1 , so I_1 is its virtual object. Thus

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

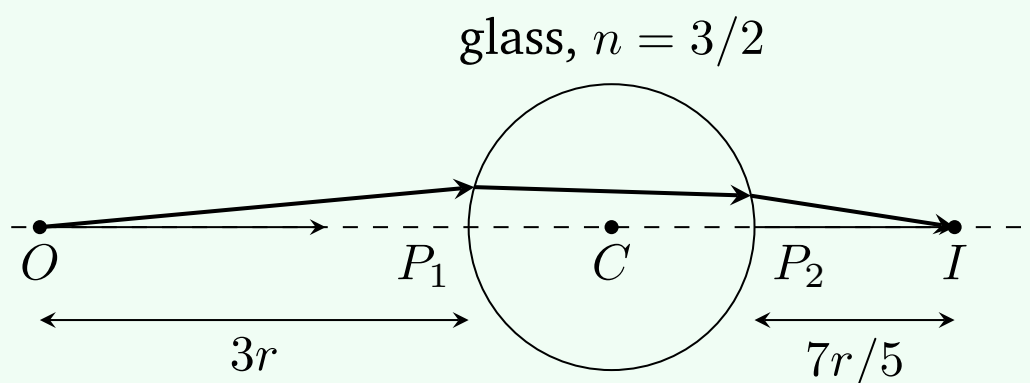
Applying glass-to-air refraction,

$$\frac{1}{v_2} - \frac{n}{u_2} = \frac{1-n}{-r}, \quad v_2 = \frac{(8-3n)r}{7n-8}.$$

With $n = 3/2$, $u_2 = 7r$ and

$$\frac{1}{v_2} = \frac{3}{14r} + \frac{1}{2r} = \frac{5}{7r}, \quad v_2 = \frac{7r}{5}.$$

The positive image distance shows that emergent paraxial rays converge to a real image on the axis to the right of the sphere. The axial ray through C travels normally at both surfaces and is undeviated; a neighbouring ray bends towards the normal on entry and away from it on exit, meeting the axial ray at I . The figure below schematically shows this formation; the surface formula fixes the accurate paraxial image position.



Schematic paraxial ray path for glass of index $3/2$; the image is $7r/5$ beyond P_2 .

Step 4: Conclusion (a) Magnification is negative for a real object beyond the focus and positive for an object between the lens and the focus. (b) The image distance from the right surface is $v_2 = (8-3n)r/(7n-8)$; for $n = 3/2$, the sphere forms a real image $7r/5$ beyond its right surface.

Quick Tip to Solve: At the second spherical surface, reset the origin to its pole: subtract the sphere's diameter from the first image distance and use a negative radius.

5. The work function of a metal is 2.31 eV. Photoelectric emission occurs when light of frequency 6.4×10^{14} Hz is incident on the metal surface. Calculate:

- (i) the energy of the incident radiation,
- (ii) the maximum kinetic energy of the emitted electron and
- (iii) the stopping potential of the surface.

[3 marks]

Solution:

Concept:

- The energy per incident photon is $E = h\nu$, where h is Planck's constant and ν is frequency.
- Einstein's photoelectric equation gives $K_{\max} = h\nu - \phi$, where ϕ is the work function. The stopping potential satisfies $eV_s = K_{\max}$.

Step 1: (i) Calculate the incident photon energy Using $h = 6.626 \times 10^{-34}$ J s and $e = 1.602 \times 10^{-19}$ C,

$$E = (6.626 \times 10^{-34})(6.4 \times 10^{14}) = 4.24064 \times 10^{-19} \text{ J}.$$

Converting joules to electron volts,

$$E = \frac{4.24064 \times 10^{-19}}{1.602 \times 10^{-19}} \text{ eV} = 2.647 \text{ eV}.$$

This is the energy of each photon; the total energy of an entire light beam would require its photon count.

Step 2: (ii) Calculate the maximum kinetic energy The photon energy exceeds the work function 2.31 eV, so photoelectric emission is possible. Subtract the energy needed to remove the electron from the surface:

$$K_{\max} = 2.647 - 2.31 = 0.337 \text{ eV}.$$

In SI units, the same subtraction gives

$$K_{\max} = 4.24064 \times 10^{-19} - (2.31)(1.602 \times 10^{-19}) = 5.4002 \times 10^{-20} \text{ J}.$$

This is the largest kinetic energy: electrons that lose energy while reaching the surface emerge with smaller kinetic energies.

Step 3: (iii) Find the stopping potential A retarding potential stops even the fastest electrons when the electrical work eV_s equals their kinetic energy. Hence,

$$V_s = \frac{5.4002 \times 10^{-20}}{1.602 \times 10^{-19}} \text{ V} = 0.337 \text{ V}.$$

The stated value is the magnitude of the stopping potential; the collector is negative relative to the emitting surface, and the photocurrent becomes zero.

Step 4: Conclusion (i) $E \simeq 4.24 \times 10^{-19} \text{ J} = 2.65 \text{ eV}$; (ii) $K_{\max} \simeq 5.40 \times 10^{-20} \text{ J} = 0.337 \text{ eV}$; (iii) $V_s \simeq 0.337 \text{ V}$.

Quick Tip to Solve: Subtract the work function in eV from the photon energy in eV; the answer has the same numerical value as the stopping potential in volts.

6. A beam of light consisting of two wavelengths 600 nm and 500 nm is used in a Young's double slit experiment. The slit separation is 1.0 mm and the screen is kept 0.60 m away from the plane of the slits. Calculate:

- (i) the distance of the second bright fringe from the central maximum for wavelength 500 nm, and
(ii) the least distance from the central maximum where the bright fringes due to both the wavelengths coincide.

[3 marks]

Solution:

Concept:

- Constructive interference occurs when the path difference is $n\lambda$, where $n = 0, 1, 2, \dots$ is the bright-fringe order and λ is the wavelength.
- For screen distance D and slit separation d , the position of the n th bright fringe is $y_n = n\lambda D/d$. The fringe width is $\beta = \lambda D/d$.
- Bright fringes of two wavelengths coincide when their integer orders obey $n_1\lambda_1 = n_2\lambda_2$.

Step 1: Convert the given quantities The slit separation is $d = 1.0 \times 10^{-3} \text{ m}$, the screen distance is

$D = 0.60$ m, and the wavelengths are 600×10^{-9} m and 500×10^{-9} m. All substitutions below use SI units.

Step 2: (i) Second bright fringe for 500 nm The central maximum is order zero, so the second bright fringe has $n = 2$. Thus

$$y_2 = \frac{2\lambda D}{d} = \frac{2(500 \times 10^{-9})(0.60)}{1.0 \times 10^{-3}} = 6.0 \times 10^{-4} \text{ m.}$$

The two symmetric positions lie on either side of the centre; the requested distance is their positive distance from the centre.

Step 3: (ii) First coincidence away from the centre Let n_1 correspond to 600 nm and n_2 to 500 nm. Equal screen positions require

$$n_1(600) = n_2(500), \quad 6n_1 = 5n_2.$$

Since 5 and 6 are coprime, the smallest positive orders are $n_1 = 5$ and $n_2 = 6$. Hence

$$y = \frac{5(600 \times 10^{-9})(0.60)}{1.0 \times 10^{-3}} = 1.8 \times 10^{-3} \text{ m.}$$

Substituting order six for 500 nm gives the same result. Both central maxima also coincide at zero; the least distance requested is conventionally the first nonzero coincidence away from this common central maximum.

Step 4: Conclusion (i) 0.60 mm . (ii) The least nonzero coincidence distance is 1.8 mm , involving the fifth bright fringe of 600 nm and sixth bright fringe of 500 nm.

Quick Tip to Solve: Reduce 600:500 to 6:5, then reverse the ratio to obtain the smallest coincident orders 5:6.

7(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:

- Electromagnetic waves have different wavelength ranges and hence different interactions with matter. Their applications can be used to identify the corresponding spectral region.
- Microwaves are useful for radar, ultraviolet radiation has a germicidal action, and infrared radiation is used to transmit coded signals to television receivers.
- A source must actually emit the identified radiation; a detector or the device receiving the signal is not a source.

Step 1: Identify the waves used in radar and give a source The radiation of wavelength λ_1 is **microwave radiation**. Radar transmits a directed microwave beam and detects its reflection from a target. The return time provides distance information, and short wavelengths permit directional beams using practical antennas. One source of microwaves is a **klystron oscillator**; a magnetron is another suitable microwave source. Thus the radar application identifies the wave category without

requiring a numerical value of λ_1 .

Step 2: Identify the waves used in water purifiers and give a source The radiation of wavelength λ_2 is **ultraviolet radiation**. Its germicidal action damages the genetic material of microorganisms, helping disinfect water. One source is a **mercury-vapour lamp**, which emits ultraviolet radiation. The purification application here refers to disinfection by radiation; it should not be confused with infrared heating or with a filter removing dissolved impurities.

Step 3: Identify the waves used in television remote switches and give a source The radiation of wavelength λ_3 is **infrared radiation**. A television remote sends pulses of infrared light carrying a coded command to the receiver. One source is an **infrared light-emitting diode (IR LED)**, as used in the remote control itself. Hot bodies also emit infrared radiation, but the IR LED gives a specific source directly related to this application. The waves carry the control signal; their role is not to produce visible illumination.

Step 4: Conclusion λ_1 : microwaves, source: klystron oscillator. λ_2 : ultraviolet waves, source: mercury-vapour lamp. λ_3 : infrared waves, source: infrared LED.

Quick Tip to Solve: Link each function to its spectrum: radar reflection means microwaves, germ killing means ultraviolet, and TV remote pulses mean infrared.

OR

7(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 have the same frequency and a constant phase difference. This phase difference need not be zero.
- Interference involves waves from two coherent slits; single-slit diffraction involves secondary wavelets from different portions of one slit.

Step 1: (i) Conditions for coherence The sources must emit light of the same frequency, and hence the same wavelength in a given medium. Their phase difference must remain constant with time. These conditions ensure a stable interference pattern, since constructive and destructive superposition then occur at fixed positions. Equal frequency alone is insufficient: two independent sources can have a randomly changing relative phase, causing the observed interference fringes to average out.

Step 2: (ii) Difference in fringe widths For ideal narrow double slits, interference bright fringes have equal widths and are equally spaced, with fringe width $\beta = \lambda D/d$. Here λ is the wavelength, D is the screen distance and d is slit separation. In single-slit diffraction, the central bright maximum is twice as wide as each secondary maximum in the usual school-level description. For slit width a , the central width is $2\lambda D/a$, while the regions between successive minima on either side have width $\lambda D/a$, using the small-angle approximation.

Step 3: (ii) Difference in intensities With equal-amplitude coherent waves from ideal narrow slits, all double-slit interference bright fringes have the same maximum intensity. In single-slit diffraction, the central maximum is the brightest, and the secondary maxima become progressively weaker farther

from the centre. The comparison assumes the ideal interference pattern; in an actual double-slit experiment, finite slit widths can also introduce a diffraction envelope that modulates the interference maxima.

Step 4: Conclusion Coherence requires equal frequency and constant phase difference. The two differences are equal-width interference fringes versus a broad diffraction central maximum, and equal ideal interference maxima versus decreasing diffraction secondary maxima.

Quick Tip to Solve: Compare width and brightness separately; a constant phase difference need not be zero.

8. 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 diffraction minima satisfy $a \sin \theta = \lambda$, where λ is the wavelength and θ is measured from the central direction.
- The angular width of the central maximum is $\Delta\theta = 2 \sin^{-1}(\lambda/a) \simeq 2\lambda/a$ for small diffraction angles. It depends on wavelength and slit width, not on screen distance.

Step 1: Identify the boundaries of the central maximum The central bright maximum lies between the first dark minima on its two sides, at angles $+\theta$ and $-\theta$. Thus its total angular width is 2θ , not θ . For the usual small-angle single-slit arrangement,

$$\Delta\theta \simeq \frac{2\lambda}{a}.$$

Holding one quantity fixed makes the effect of changing the other immediately apparent.

Step 2: (i) Replace green light by orange light Orange light has a longer wavelength than green light. At fixed slit width, $\Delta\theta$ increases with λ , so the angular width increases. Quantitatively, in the small-angle approximation,

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

The first minima therefore move farther from the central direction.

Step 3: (ii) Move the screen closer The angular width remains unchanged, since the directions of the first minima are set by $a \sin \theta = \lambda$ and do not depend on screen distance D . The linear width on the screen does decrease: $W \simeq 2D\lambda/a$. Hence a smaller observed width in centimetres does not imply a smaller angular spread in this diffraction arrangement.

Step 4: (iii) Decrease the slit width At fixed wavelength, the angular width is inversely proportional to a in the small-angle approximation. Decreasing the slit width therefore increases the angular width. Equivalently, $\sin \theta = \lambda/a$ increases, so the first minima move farther away from the centre. A narrower slit produces a wider diffraction spread.

Step 5: Conclusion The angular width (i) increases with orange light, (ii) remains unchanged when

the screen is moved closer, and (iii) increases when the slit width decreases.

Quick Tip to Solve: Use $\Delta\theta \simeq 2\lambda/a$ for angular width; include D only when calculating linear width on the screen.

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

[3 marks]

Solution:

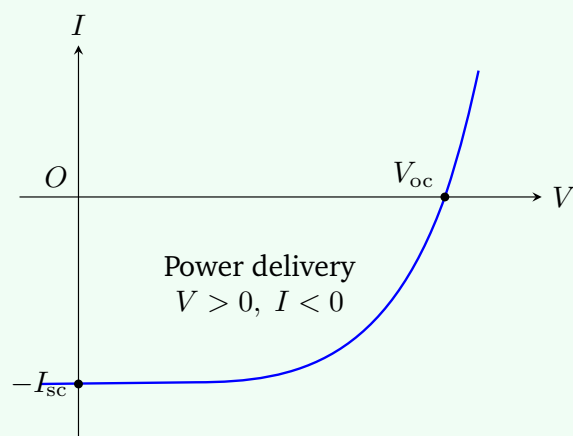
Concept:

- A solar cell is a large-area p-n junction that converts incident light energy into electrical energy by the photovoltaic effect, without an external bias.
- Photons with energy $h\nu \geq E_g$, where E_g is the semiconductor band gap, can generate electron-hole pairs. The junction's built-in electric field separates these carriers.

Step 1: Generate and separate charge carriers Light is allowed to fall on the junction through its thin exposed surface. Absorption of suitable photons produces electron-hole pairs in and near the depletion region. The electric field in the depletion region points from the ionised donors on the n side towards the ionised acceptors on the p side. It drives electrons towards the n region and holes towards the p region before they can recombine.

Step 2: Explain the emf and current delivery The separated carriers accumulate on opposite sides: the p side becomes positive relative to the n side. This produces a potential difference across the terminals, called the photovoltage or emf. With the terminals open, no external current flows and the potential difference reaches the open-circuit voltage V_{oc} . When an external load is connected, conventional current flows through the load from the p terminal to the n terminal, so the cell supplies electrical energy.

Step 3: Draw and interpret the illuminated I-V characteristic In the usual diode sign convention the light-generated current shifts the diode curve downwards. 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 V_{oc} . The operating portion between these intercepts lies in the fourth quadrant: $V > 0$ and $I < 0$, which means the solar cell delivers power to a load.



Illuminated solar-cell I-V characteristic; current is positive in the conventional diode direction.

Step 4: Conclusion The junction electric field separates light-generated electron-hole pairs, making the p terminal positive and the n terminal negative and hence generating an emf. The illuminated I-V curve has intercepts $(0, -I_{sc})$ and $(V_{oc}, 0)$ in the diode current convention.

Quick Tip to Solve: State the current sign convention before sketching: the generating portion lies in the fourth quadrant when diode current is taken as positive.

10. (a) James Chadwick, in 1932, studied the emission of neutral radiations when Beryllium nuclei were bombarded with alpha particles. He concluded that emitted radiations were neutrons and not photons. Explain.

(b) Two nuclei may have the same radius, even though they contain different number of protons and neutrons. Explain. [3 marks]

Solution:

Concept:

- In a collision, both energy and momentum are conserved. The recoil of a target nucleus therefore gives information about the mass and nature of the incident radiation.
- The nuclear radius obeys $R = R_0 A^{1/3}$, where $R_0 \approx 1.2 \times 10^{-15} \text{ m}$, $A = Z + N$ is the mass number, Z is the proton number and N is the neutron number.

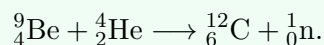
Step 1: Part (a): identify the experimental evidence Bombarding beryllium with alpha particles produced highly penetrating, electrically neutral radiation. When this radiation struck a hydrogen-rich substance such as paraffin wax, it knocked out energetic protons. Neutrality by itself did not distinguish neutrons from photons, because photons are also uncharged. The decisive observation was the large energy and momentum transferred to the recoil nuclei.

Step 2: Part (a): explain why the photon interpretation failed If the emitted radiation consisted of photons, conservation of energy and momentum in photon-proton collisions would require photons of implausibly high energy to account for the observed fast recoil protons, far beyond the available

reaction energy. Furthermore, recoil results for different target nuclei could not be consistently explained by that photon interpretation. They were explained by collisions with neutral particles having mass approximately equal to the proton mass. In a head-on elastic collision, the maximum fraction of projectile kinetic energy transferred to a stationary target is

$$\frac{K_{\text{recoil,max}}}{K_{\text{incident}}} = \frac{4mM}{(m+M)^2},$$

where m and M are the projectile and target masses. For a neutron incident on a proton, $m \approx M$, so nearly all its kinetic energy can be transferred. Chadwick therefore identified the radiation as neutrons. The reaction is



Step 3: Part (b): relate the radius to total nucleon number Nuclear size depends approximately on the total number of nucleons, rather than on the proton and neutron numbers separately. Thus two nuclei with different Z and N but equal $A = Z + N$ have the same radius according to $R = R_0 A^{1/3}$; such nuclei are isobars. For example, ${}_6^{14}\text{C}$ has 6 protons and 8 neutrons, whereas ${}_7^{14}\text{N}$ has 7 protons and 7 neutrons. Both have $A = 14$, so their radii are approximately $R_0 14^{1/3}$. The statement of equal radius is understood within this standard nuclear-radius approximation.

Step 4: Conclusion (a) The energetic recoil protons were consistent with collisions involving neutral particles of approximately proton mass, but not with photons of the available energy; these particles were neutrons. (b) Equal total nucleon number gives equal approximate radius even when the individual proton and neutron numbers differ.

Quick Tip to Solve: Do not use neutrality alone to rule out photons; use recoil energy and momentum. For equal nuclear radii, compare the sums $Z + N$.

11. (a) The energy of hydrogen atom in an orbit is -1.51 eV. What are kinetic and potential energies of the electron in this orbit?

(b) The electron in a hydrogen atom is typically found at a distance of about 5.3×10^{-11} m from the nucleus which has a diameter of about 1.0×10^{-15} m. Assuming the hydrogen atom to be a sphere of radius 5.3×10^{-11} m, what fraction of its volume is occupied by the nucleus? [3 marks]

Solution:

Concept:

- For an electron bound by the Coulomb force, kinetic energy K and potential energy U satisfy $U = -2K$. Total energy is $E = K + U = -K$.
- The volume of a sphere of radius r is $V = \frac{4}{3}\pi r^3$. Thus the fraction of atomic volume occupied by the nucleus equals the cube of the ratio of their radii.

Step 1: Relate the kinetic and potential energies The electrostatic force supplies the centripetal force for the electron. Therefore $mv^2/r = ke^2/r^2$, so $K = mv^2/2 = ke^2/(2r)$, whereas $U = -ke^2/r$. It follows that $U = -2K$ and $E = K + U = -K$. Using the given total energy,

$$K = -E = -(-1.51) = 1.51 \text{ eV}, \quad U = 2E = 2(-1.51) = -3.02 \text{ eV}.$$

The positive kinetic energy and negative potential energy are consistent with a bound electron. Their sum recovers the stated total energy: $1.51 - 3.02 = -1.51$ eV.

Step 2: Convert the nuclear diameter to radius The atomic radius is $R = 5.3 \times 10^{-11}$ m. The nucleus has diameter 1.0×10^{-15} m, hence its radius is

$$r_n = \frac{1.0 \times 10^{-15}}{2} = 5.0 \times 10^{-16} \text{ m.}$$

Both radii must be used in the same unit before comparing volumes.

Step 3: Calculate the occupied volume fraction The common factor $4\pi/3$ cancels between the spherical volumes:

$$\begin{aligned} \frac{V_n}{V_a} &= \frac{(4\pi/3)r_n^3}{(4\pi/3)R^3} = \left(\frac{r_n}{R}\right)^3 \\ &= \left(\frac{5.0 \times 10^{-16}}{5.3 \times 10^{-11}}\right)^3 \\ &= (9.434 \times 10^{-6})^3 \simeq 8.4 \times 10^{-16}. \end{aligned}$$

This is a dimensionless fraction, not a percentage. It shows that the nucleus occupies an extremely small portion of the assumed atomic sphere.

Step 4: Conclusion (a) The kinetic and potential energies are 1.51 eV and -3.02 eV, respectively. (b) The fraction occupied by the nucleus is approximately 8.4×10^{-16} .

Quick Tip to Solve: Use $K = -E$ and $U = 2E$; halve the nuclear diameter before cubing the radius ratio.

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 objective forms a real image when its object is outside its focal length.
- The eye-piece acts as a magnifier; its intermediate object is at or within its focal plane, producing a virtual final image.

Step 1: Identify the objective image The object is placed slightly beyond the focal point of the

objective. The emerging rays converge on the other side, producing a real, inverted and enlarged intermediate image. Thus options (A) and (C), which call this image virtual, are excluded.

Step 2: Identify the final image The intermediate image is the object for the eye-piece. For viewing, it lies within the eye-piece focal length, or at the focal plane in normal adjustment. The final image is virtual, at a finite distance or at infinity. Options (A) and (D), which describe a real final image, do not represent the microscope arrangement.

Step 3: Conclusion The objective and eye-piece form real and virtual images, respectively. The correct option is (B).

Quick Tip to Solve: Follow the two stages: the objective projects a real image; the eye-piece magnifies it for viewing.

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 $M = \frac{L}{f_o} \frac{D}{f_e}$, where L is tube length, D is the least distance of distinct vision and f_o, f_e are focal lengths.
- Lens aperture controls light collection and resolving ability; it does not enter the geometrical magnification formula.

Step 1: Inspect the magnification formula The objective contributes approximately L/f_o , and the eye-piece contributes D/f_e for a final image at infinity. At the near point the eye-piece factor becomes $1 + D/f_e$. In either adjustment, focal lengths and tube length affect magnification, so (B) and (C) are excluded.

Step 2: Distinguish aperture from colour effects Changing aperture primarily changes brightness and resolution, so (A) is the required independence. Colour can change the refractive index of lens material and therefore its focal length through dispersion; consequently it can affect magnification indirectly. This distinguishes (D) from the geometrical independence of aperture.

Step 3: Conclusion Magnification does not depend on the aperture of the objective and eye-piece. The correct option is (A).

Quick Tip to Solve: Check which quantity is absent from the magnification formula; aperture affects resolution instead.

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 two short-focal-length converging lenses to magnify a nearby tiny object.
- Its approximate magnifying power is $M = (L/f_o)(D/f_e)$; an astronomical telescope instead needs an objective with a long focal length relative to its eye-piece.

Step 1: Check the first three statements Both microscope lenses have short focal lengths, so (A) is correct. The magnifying power increases when either focal length decreases at fixed tube length, making (B) correct. The objective forms a real intermediate image beyond its focal plane, and the eye-piece is placed beyond that image; in normal adjustment their separation exceeds $f_o + f_e$, consistent with (C).

Step 2: Test the interchange claim Simply interchanging two short-focal-length microscope lenses does not provide the long-focal-length, large-aperture objective required for useful telescope operation. The microscope geometry is designed for a nearby object, while a telescope views distant objects. Thus interchange alone does not convert this microscope into the telescope described by school optics.

Step 3: Conclusion The incorrect statement is that a microscope can be used as a telescope by interchanging its two lenses. The correct option is (D).

Quick Tip to Solve: Remember the objective contrast: microscopes use a short focal length; telescopes use a long one.

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:

- The total magnification of a compound microscope is the product of the objective magnification and the eye-piece magnifying power.
- Each stage enlarges the image supplied to it, so successive magnification factors multiply rather than add.

Step 1: Identify the two factors The objective gives a magnification factor of 10, and the eye-piece

gives a factor of 20. The image already enlarged by the objective is viewed through the eye-piece, which supplies the second enlargement.

Step 2: Calculate and compare all options The total factor is

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

Option (A), 2, is a ratio of the factors, which is inappropriate for successive stages. Option (B), 10, omits the eye-piece contribution. Option (C), 30, adds the factors instead of multiplying them. Only (D) gives the product.

Step 3: Conclusion The microscope magnification is 200 times. The correct option is (D).

Quick Tip to Solve: For successive optical magnifiers, multiply the stated X factors: 10×20 , not their sum.

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:

- The objective obeys the thin-lens formula $1/f_o = 1/v_o - 1/u_o$, where f_o is its focal length and u_o, v_o are Cartesian object and image distances.
- For a final image at infinity, the eyepiece has angular magnification $m_e = D/f_e$, where $D = 25$ cm is the least distance of distinct vision. The microscope's magnifying power is $M = |v_o/u_o|D/f_e$.

Step 1: Calculate the objective magnification The object is on the incident side, so $u_o = -1.25$ cm, while $f_o = +1.2$ cm. Thus

$$\frac{1}{v_o} = \frac{1}{1.2} - \frac{1}{1.25} = \frac{1}{30} \text{ cm}^{-1}, \quad v_o = 30 \text{ cm}.$$

The objective forms a real, inverted intermediate image, with linear magnification $m_o = v_o/u_o = 30/(-1.25) = -24$. Its magnitude is therefore 24.

Step 2: Combine the objective and eyepiece magnifications Since the final image is at infinity, the intermediate image lies at the eyepiece's first focal plane. Its angular magnification is $m_e = 25/3$, giving

$$M = 24 \times \frac{25}{3} = 200.$$

Using $1 + D/f_e$ would apply to a final image at the near point and contradict the stated condition. Options (A), (B) and (D), namely 100, 150, 250, do not equal the product obtained from the given distances and the infinity-image formula.

Step 3: Conclusion The magnifying power is 200. Hence, the correct option is (C). The negative

signed magnification indicates that the final image is inverted relative to the object.

Quick Tip to Solve: With an object just beyond the objective focus, calculate its exact image distance first; then multiply the objective magnification by $25/f_e$ for a final image at infinity.