

A-Level Physics – Waves and Quantum

A-Level · Total marks: 64 · Answers on the last page

Covers wave properties, refraction and total internal reflection, superposition and stationary waves, two-source interference and diffraction gratings, the photoelectric effect, energy levels and wave-particle duality. Use $h = 6.63 \times 10^{-34} \text{ J s}$, $c = 3.00 \times 10^8 \text{ m s}^{-1}$, $e = 1.60 \times 10^{-19} \text{ C}$, $m_e = 9.11 \times 10^{-31} \text{ kg}$. Calculator allowed; allow about 75 minutes.

Section A – Skills (Give answers to 3 significant figures.)

1. A tuning fork of frequency 512 Hz produces sound waves that travel at 340 m s^{-1} in air.
 - (a) Calculate the wavelength of the sound.
 - (b) State the difference between a longitudinal and a transverse wave. [3]
2. A ray of light in air strikes a glass block of refractive index 1.52 at an angle of incidence of 35° .
 - (a) Calculate the angle of refraction.
 - (b) Calculate the speed of light in the glass.
 - (c) Calculate the critical angle for the glass-air boundary. [5]
3. Calculate the energy of a photon of blue light of wavelength 450 nm, giving your answer in joules and in electronvolts. [3]
4.
 - (a) Calculate the de Broglie wavelength of an electron moving at $5.0 \times 10^6 \text{ m s}^{-1}$.
 - (b) Explain why the diffraction of electrons by a crystal provides evidence for wave-particle duality. [4]
5. A string of length 0.75 m is fixed at both ends and vibrates in its second harmonic. The speed of waves on the string is 180 m s^{-1} .
 - (a) State the wavelength of the wave on the string.
 - (b) Calculate the frequency of the second harmonic.
 - (c) State the frequency of the fundamental. [4]

Section B – Exam-style (Structured questions with explanation.)

6. Monochromatic light of wavelength 630 nm is incident on two slits separated by 0.25 mm. A screen is 2.4 m from the slits.
 - (a) Calculate the fringe spacing.
 - (b) Explain why the light must be coherent to produce a stable pattern.
 - (c) Describe how the pattern changes if the slit separation is doubled. [6]
7. A diffraction grating with 500 lines per mm is illuminated normally by sodium light of wavelength 589 nm.
 - (a) Show that the slit spacing is $2.0 \times 10^{-6} \text{ m}$.
 - (b) Calculate the angle of the first-order maximum.
 - (c) Determine the highest order maximum that can be observed and calculate its angle. [6]
8. Two loudspeakers connected to the same signal generator emit sound of frequency 850 Hz in phase. The speed of sound is 340 m s^{-1} . A microphone is placed 3.0 m from one speaker and 3.6 m from the other.
 - (a) Calculate the wavelength of the sound.

- (b) Determine the path difference in wavelengths and state what the microphone detects.
(c) State the phase difference between the two waves at the microphone. [5]
9. A metal surface has work function 2.3 eV. It is illuminated with ultraviolet light of wavelength 350 nm.
(a) Calculate the energy of an incident photon in eV.
(b) Calculate the maximum kinetic energy of the emitted photoelectrons in joules.
(c) Calculate the threshold frequency of the metal.
(d) Explain why increasing the intensity of the light does not change the maximum kinetic energy. [8]
10. An electron in a hydrogen atom falls from the $n = 2$ level (-3.4 eV) to the ground state (-13.6 eV).
(a) Calculate the energy of the emitted photon in joules.
(b) Calculate the wavelength of the photon and state the region of the electromagnetic spectrum it belongs to.
(c) Explain why the emission spectrum of hydrogen consists of discrete lines. [6]

Section C – Challenge (Extended problems.)

11. Electrons are accelerated from rest through a potential difference of 2.0 kV in an electron diffraction tube.
(a) Show that the speed of the electrons is about $2.7 \times 10^7 \text{ m s}^{-1}$.
(b) Calculate the de Broglie wavelength of the electrons.
(c) Explain how the diffraction rings would change if the accelerating voltage were increased. [7]
12. An optical fibre has a core of refractive index 1.50 and cladding of refractive index 1.45.
(a) Calculate the critical angle at the core-cladding boundary.
(b) Explain the purpose of the cladding.
(c) In a photoelectric experiment, the stopping potential V_s is measured for several frequencies f and a graph of V_s against f is plotted. State what the gradient and the f -intercept of the graph represent. [7]

Answers

Check your working against these. If an answer does not match, try the question again before looking for the method.

- $\lambda = \frac{340}{512} = 0.664 \text{ m}$
 - Longitudinal: oscillations parallel to the direction of energy transfer; transverse: perpendicular
- $\sin r = \frac{\sin 35^\circ}{1.52}, r = 22.2^\circ$
 - $\frac{3.00 \times 10^8}{1.52} = 1.97 \times 10^8 \text{ m s}^{-1}$
 - $\sin C = \frac{1}{1.52}, C = 41.1^\circ$
- $E = \frac{hc}{\lambda} = 4.42 \times 10^{-19} \text{ J} = 2.76 \text{ eV}$
- $\lambda = \frac{h}{mv} = 1.46 \times 10^{-10} \text{ m}$
 - Diffraction is a wave property; electron wavelength is comparable to atomic spacing, so a diffraction pattern forms, showing particles exhibit wave behaviour
- 0.75 m
 - $f = \frac{180}{0.75} = 240 \text{ Hz}$
 - 120 Hz
- $w = \frac{\lambda D}{s} = \frac{630 \times 10^{-9} \times 2.4}{0.25 \times 10^{-3}} = 6.05 \times 10^{-3} \text{ m (6.0 mm)}$
 - Constant phase difference is required so that the positions of constructive and destructive interference do not change with time
 - Fringe spacing halves to about 3.0 mm
- $d = \frac{1 \times 10^{-3}}{500} = 2.0 \times 10^{-6} \text{ m}$
 - $\sin \theta = \frac{589 \times 10^{-9}}{2.0 \times 10^{-6}}, \theta = 17.1^\circ$
 - $n_{\max} < \frac{d}{\lambda} = 3.40$, so $n = 3$ at $\theta = 62.1^\circ$
- 0.40 m
 - 0.6 m = 1.5λ ; destructive interference, minimum intensity
 - 180° (π rad)
- $\frac{hc}{\lambda} = 5.68 \times 10^{-19} \text{ J} = 3.55 \text{ eV}$
 - $3.55 - 2.3 = 1.25 \text{ eV} = 2.0 \times 10^{-19} \text{ J}$
 - $f_0 = \frac{\phi}{h} = \frac{2.3 \times 1.60 \times 10^{-19}}{6.63 \times 10^{-34}} = 5.55 \times 10^{14} \text{ Hz}$
 - One photon interacts with one electron; intensity changes the number of photons per second, not the energy of each photon
- $10.2 \text{ eV} = 1.63 \times 10^{-18} \text{ J}$
 - $\lambda = \frac{hc}{E} = 1.22 \times 10^{-7} \text{ m (122 nm)}$, ultraviolet
 - Electrons occupy discrete energy levels; photons are emitted only with energies equal to the differences between levels

11. (a) $\frac{1}{2}mv^2 = eV$, $v = \sqrt{\frac{2 \times 1.60 \times 10^{-19} \times 2000}{9.11 \times 10^{-31}}} = 2.65 \times 10^7 \text{ m s}^{-1}$
(b) $\lambda = \frac{h}{mv} = 2.74 \times 10^{-11} \text{ m}$
(c) Higher speed gives shorter wavelength, so less diffraction: rings become smaller (closer to the centre)
12. (a) $\sin C = \frac{1.45}{1.50}$, $C = 75.2^\circ$
(b) Protects the core, prevents light leaking between adjacent fibres, and gives a well-defined critical angle to keep light within the core (reduces modal dispersion)
(c) Gradient $= \frac{h}{e}$; f -intercept is the threshold frequency f_0 (and V_s -intercept is $-\phi/e$)

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