

IB Physics – Theme C: Wave Behaviour

IB Physics SL/HL (2023 syllabus) · Total marks: 68 · Answers on the last page

Covers C.1 simple harmonic motion, C.2 wave model, C.3 wave phenomena (refraction, diffraction, interference, polarisation), C.4 standing waves and resonance and C.5 Doppler effect. Take $g = 9.81 \text{ m s}^{-2}$, speed of sound 340 m s^{-1} and $c = 3.00 \times 10^8 \text{ m s}^{-1}$. Calculator allowed; allow about 75 minutes. Questions marked HL use HL-only content.

Section A – Skills (Short questions.)

1. A 0.25 kg mass hangs from a spring of spring constant 40 N m^{-1} and oscillates vertically with amplitude 5.0 cm .
 - (a) Show that the period of oscillation is about 0.50 s .
 - (b) Calculate the maximum speed of the mass.
 - (c) Calculate the maximum acceleration of the mass. [6]
2. A simple pendulum has length 0.80 m .
 - (a) Calculate its period on Earth.
 - (b) State two conditions required for the motion to be simple harmonic. [4]
3. A sound wave of frequency 250 Hz travels through air at 340 m s^{-1} .
 - (a) Calculate its wavelength.
 - (b) State the difference between a transverse and a longitudinal wave, giving sound as an example of one of them. [4]
4. A ray of light in air is incident on a glass block (refractive index 1.50) at an angle of incidence of 40° .
 - (a) Calculate the angle of refraction.
 - (b) Calculate the critical angle for the glass-air boundary.
 - (c) Calculate the speed of light in the glass. [6]
5. Unpolarised light of intensity I_0 passes through a polariser and then an analyser whose transmission axis is at 60° to that of the polariser.
 - (a) State the intensity of light leaving the polariser.
 - (b) Calculate the intensity of light leaving the analyser in terms of I_0 . [3]

Section B – Exam style

6. Laser light of wavelength 633 nm illuminates two narrow slits separated by 0.25 mm . A screen is placed 2.0 m from the slits.
 - (a) Explain how bright fringes are formed on the screen.
 - (b) Calculate the separation of adjacent bright fringes.
 - (c) State and explain what happens to the fringe separation if the slit separation is increased. [7]
7. A diffraction grating has 600 lines per mm . Light of wavelength 500 nm is incident normally on the grating.
 - (a) Calculate the angle of the second-order maximum.
 - (b) Determine the highest order maximum that can be observed. [5]
8. A pipe of length 0.60 m is closed at one end and open at the other. The speed of sound is 340 m s^{-1} .

- (a) Describe the positions of the displacement nodes and antinodes for the fundamental (first harmonic).
- (b) Calculate the frequency of the first harmonic.
- (c) Calculate the frequency of the next harmonic that can be produced.
- (d) Explain why a standing wave is formed in the pipe. [8]

9. A police siren emits sound at 500 Hz. The car moves at 30 m s^{-1} towards a stationary observer.
- (a) Calculate the frequency heard by the observer as the car approaches.
 - (b) Calculate the frequency heard as the car moves away.
 - (c) The observer instead runs at 20 m s^{-1} towards a stationary siren. Calculate the frequency heard. [6]

Section C – Extended

10. (HL) A particle performs SHM with amplitude 5.0 cm and angular frequency 12.6 rad s^{-1} . At $t = 0$ it is at the equilibrium position moving in the positive direction.
- (a) Write an equation for the displacement x as a function of time.
 - (b) Calculate the speed of the particle when its displacement is 3.0 cm.
 - (c) The mass of the particle is 0.25 kg. Calculate the total energy of the oscillation.
 - (d) Sketch, by description, how the kinetic energy varies with displacement. [8]
11. The hydrogen-alpha line has a wavelength of 656.3 nm in the laboratory. In the spectrum of a distant galaxy the same line is observed at 656.4 nm.
- (a) State whether the galaxy is moving towards or away from Earth.
 - (b) Estimate the speed of the galaxy relative to Earth.
 - (c) State one assumption made in your calculation. [5]
12. Light of wavelength 600 nm passes through a single slit of width 0.10 mm.
- (a) Calculate the angular width of the central maximum.
 - (b) Describe the effect on the diffraction pattern of using blue light instead.
 - (c) The slit is now replaced by two slits. Explain why the intensity of the double-slit fringes is modulated by the single-slit pattern. [6]

Answers

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

- $T = 2\pi\sqrt{\frac{0.25}{40}} = 0.497 \approx 0.50 \text{ s}$
 - $\omega = 12.6 \text{ rad s}^{-1}$; $v_{\max} = \omega A = 0.63 \text{ m s}^{-1}$
 - $a_{\max} = \omega^2 A = 8.0 \text{ m s}^{-2}$
- $T = 2\pi\sqrt{\frac{0.80}{9.81}} = 1.79 \text{ s}$
 - Acceleration proportional to displacement from equilibrium and directed towards it; small amplitude (small angle); negligible friction/air resistance
- $\lambda = \frac{340}{250} = 1.36 \text{ m}$
 - Transverse: oscillations perpendicular to direction of energy transfer; longitudinal (sound): oscillations parallel to direction of energy transfer
- $\sin r = \frac{\sin 40^\circ}{1.50} \Rightarrow r = 25.4^\circ$
 - $\sin c = \frac{1}{1.50} \Rightarrow c = 41.8^\circ$
 - $v = \frac{3.00 \times 10^8}{1.50} = 2.00 \times 10^8 \text{ m s}^{-1}$
- $\frac{I_0}{2}$
 - $I = \frac{I_0}{2} \cos^2 60^\circ = 0.125 I_0$
- Light from the two slits overlaps (coherent sources); where path difference is a whole number of wavelengths the waves arrive in phase and interfere constructively, giving a bright fringe
 - $s = \frac{\lambda D}{d} = \frac{633 \times 10^{-9} \times 2.0}{0.25 \times 10^{-3}} = 5.1 \times 10^{-3} \text{ m}$
 - Fringe separation decreases since $s \propto \frac{1}{d}$
- $d = 1.67 \times 10^{-6} \text{ m}$; $\sin \theta = \frac{2 \times 500 \times 10^{-9}}{1.67 \times 10^{-6}} \Rightarrow \theta = 36.9^\circ$
 - $n_{\max} = \frac{d}{\lambda} = 3.33$, so the third order is the highest
- Node at the closed end, antinode at the open end; pipe length is $\frac{\lambda}{4}$
 - $\lambda = 2.4 \text{ m}$; $f_1 = \frac{340}{2.4} = 142 \text{ Hz}$
 - Only odd harmonics: $f_3 = 3f_1 = 425 \text{ Hz}$
 - The wave reflects at the closed end and superposes with the incident wave; at resonant frequencies the two waves of equal frequency and amplitude travelling in opposite directions produce fixed nodes and antinodes
- $f' = 500 \times \frac{340}{340-30} = 548 \text{ Hz}$
 - $f' = 500 \times \frac{340}{340+30} = 459 \text{ Hz}$
 - $f' = 500 \times \frac{340+20}{340} = 529 \text{ Hz}$
- $x = 0.050 \sin(12.6t)$ (metres)
 - $v = \omega \sqrt{A^2 - x^2} = 12.6 \sqrt{0.05^2 - 0.03^2} = 0.51 \text{ m s}^{-1}$
 - $E = \frac{1}{2} m \omega^2 A^2 = 0.050 \text{ J}$
 - Inverted parabola: maximum (0.050 J) at $x = 0$, zero at $x = \pm A$
- Away (redshift, wavelength increased)
 - $v = c \frac{\Delta \lambda}{\lambda} = 3.00 \times 10^8 \times \frac{0.10}{656.3} = 4.6 \times 10^4 \text{ m s}^{-1}$
 - $v \ll c$ (non-relativistic approximation)
- $\theta = \frac{\lambda}{b} = 6.0 \times 10^{-3} \text{ rad}$, so angular width $= 1.2 \times 10^{-2} \text{ rad}$ (0.69°)
 - Shorter wavelength: central maximum narrower, minima closer together

(c) Each slit diffracts independently, so the interference fringes have intensities limited by the single-slit envelope; fringes near single-slit minima are missing

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