Waves

AS Level Physics 9702

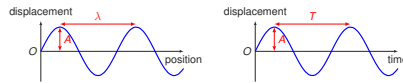
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By the end of this topic I can. . .

- describe waves using amplitude, wavelength, period, frequency and speed
- distinguish transverse and longitudinal, mechanical and electromagnetic waves
- use intensity, Malus's law and the Doppler effect

Wave terminology

- **amplitude** A: maximum displacement
- **wavelength** λ: distance between adjacent points in phase
- **period** T and **frequency** f



Wave speed

Wave speed

In one period the wave moves one wavelength.

$$f = \frac{1}{T}$$

$$v = \frac{\lambda}{T}$$

$$v = f\lambda$$

Example: amplitude

Example: amplitude

The amplitude is half the end-to-end distance: $A = \frac{1}{2}(21 - 18) = 1.5$ cm

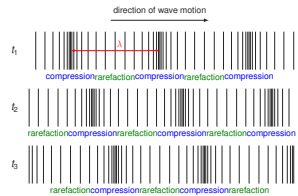
Example: period

Example: period

$$v = \frac{\lambda}{T} \quad \Rightarrow \quad T = \frac{\lambda}{v} = \frac{0.50}{4.0} = 0.125 \text{ s}$$

Transverse and longitudinal

- **transverse**: vibrations perpendicular to energy transfer
- **longitudinal**: vibrations parallel to energy transfer
- longitudinal: compressions and rarefactions



Example: sound wave

Example: sound wave

$$d = \frac{1}{2}\lambda = \frac{v}{2f} = \frac{330}{2 \times 550} \quad \Rightarrow \quad d = 0.30 \text{ m}$$

Sound waves

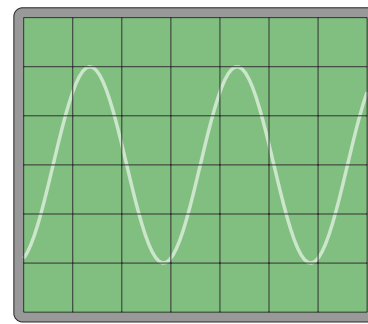
- longitudinal; needs a medium
- speed depends on the material
- pitch depends on frequency; loudness on amplitude
- oscilloscope: time-base and Y-gain

Example: oscilloscope trace

A sound wave is detected by a microphone and the trace is displayed on an oscilloscope as shown. If the time-base is set at 0.5 ms div^{-1} and the voltage gain is set at 2 V div^{-1}. What is the frequency and the amplitude of the signal?

Example: oscilloscope trace

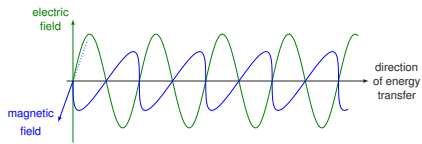
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period: $T = 3 \times 0.5\ \text{ms} = 1.5 \times 10^{-3}\ \text{s}$
frequency: $f = \frac{1}{T} = \frac{1}{1.5 \times 10^{-3}\ \text{s}} \approx 667\ \text{Hz}$
amplitude: $A = 2 \times 2\ \text{V} = 4.0\ \text{V}$

Electromagnetic waves

- can travel through a vacuum at $c = 3.00 \times 10^8$ m s^{-1}
- transverse: E and B perpendicular
- spectrum: radio, microwave, IR, visible, UV, X-ray, γ



Example: EM wavelength

Example: EM wavelength

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8}{25 \times 10^12} \quad \Rightarrow \quad \lambda = 1.2 \times 10^{-5}\ \text{m} \quad \text{(infra-red)}$$

Intensity

Intensity

Power per unit area.

- unit: W m^{-2}

$$I = \frac{P}{S}$$

$$I \propto A^2$$

$$I \propto \frac{1}{r^2}$$

Example: amplitude increase

Example: amplitude increase

$I \propto A^2 \quad \Rightarrow \quad \frac{I'}{I} = \left(\frac{A'}{A}\right)^2 = (1 + 50\%)^2 = 2.25 \quad \Rightarrow$ so intensity is increased by 125%

Example: two observers

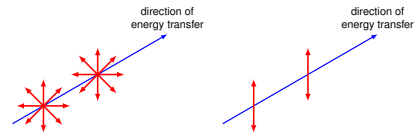
Example: two observers

$$I \propto \frac{1}{r^2} \quad \Rightarrow \quad \frac{I_A}{I_B} = \left(\frac{r_B}{r_A}\right)^2 = \left(\frac{1}{2}\right)^2 \quad \Rightarrow \quad \frac{I_A}{I_B} = \frac{1}{4}$$

$$I \propto A^2 \quad \Rightarrow \quad \frac{A_A}{A_B} = \sqrt{\frac{I_A}{I_B}} = \sqrt{\frac{1}{4}} \quad \Rightarrow \quad \frac{A_A}{A_B} = \frac{1}{2}$$

Polarisation

- vibrations in **one direction only**
- only transverse waves can be polarised
- polariser transmits component along its axis



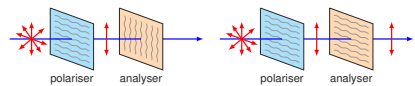
Malus's law

Malus's law

Intensity transmitted by an analyser at angle θ.

- $A = A_0 \cos\theta$
- series of filters: apply to each in turn

$$I = I_0 \cos^2\theta$$



Example: two filters

Example: two filters

through first filter: $A_1 = A\cos\theta_1 = A\cos 45^\circ \quad \Rightarrow \quad A_1 = \frac{1}{\sqrt{2}}A$ light is polarised in a direction at 60° to the vertical

through second filter: $A_2 = A_1\cos\theta_2 = \frac{1}{\sqrt{2}}A \times \cos(75^\circ - 45^\circ) \quad \Rightarrow \quad A_2 = \frac{\sqrt{6}}{4}A$

$I_2 = \left(\frac{\sqrt{6}}{4}\right)^2 I \quad \Rightarrow \quad I_2 = \frac{3}{8}I$

or, $I_2 = I\cos^2\theta_1\cos^2\theta_2 = I \times \cos^2 45^\circ \times \cos^2(75^\circ - 45^\circ) \quad \Rightarrow \quad I_2 = \frac{3}{8}I$

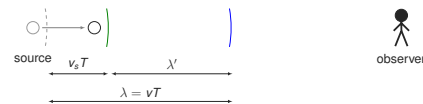
Doppler effect

Doppler effect

Relative motion of source and observer changes the **observed frequency**.

- towards: higher; away: lower
- use $-$ for approach, $+$ for recession

$$f' = f \frac{v}{v \mp v_s}$$



Example: police siren

Example: police siren

$$f' = f\frac{v}{v - v_s} = 500 \times \frac{340}{340 - 16} \quad \Rightarrow \quad f' \approx 525 \text{ Hz}$$

Example: red-shift

Example: red-shift

The original frequency of H_α: $f = \frac{c}{\lambda} = \frac{3.00\times10^8}{656\times10^{-9}} \approx 4.57 \times 10^{14}$ Hz
The observed wavelength is longer (redshift), this means the star is moving away, or receding.
To find speed of star, we can consider observed frequency: $f' = \frac{c}{\lambda'} = f\frac{c}{c+v_s}$

$$\frac{3.00 \times 10^8}{680 \times 10^{-9}} = 4.57 \times 10^{14} \times \frac{3.00 \times 10^8}{3.00 \times 10^8 + v_s} \quad \Rightarrow \quad v_s \approx 1.10 \times 10^7 \text{ m s}^{-1}$$

alternatively, we can consider observed wavelength: $\lambda' = \lambda + v_s T$, or: $\Delta\lambda = \lambda' - \lambda = \frac{v_s}{f}$

$$(680 - 656) \times 10^{-9} = \frac{v_s}{4.57 \times 10^{14}} \quad \Rightarrow \quad v_s \approx 1.10 \times 10^7 \text{ m s}^{-1}$$

Key equations

speed	$v = f\lambda$	Malus	$I = I_0 \cos^2\theta$
intensity	$I = \dfrac{P}{S}$	Doppler	$f' = f\,\dfrac{v}{v \mp v_s}$