Unit 3. Waves

Y12

Table of contents

1 Wave Basics

What is a wave? How many types of waves are there? Why are they useful?

→ **Wave:** transfer of energy without matter (by transmission of oscillations):

- Mechanical: oscillations of the medium.
- Electromagnetic: oscillations of fields (electrical or magnetic).

1.1 Analysis of a Wave

- Displacement x (m): distance to the equilibrium (average) position.
- Amplitude A (m): maximum displacement of a wave.
- Frequency f (Hertz Hz): number of cycles through a point per second.
- Wavelength λ (m): distance between 2 equal waypoints (eg 2 peaks). Figure 1
- Period T (s): time for 1 full oscillation or wavelength. Figure 2
- Phase θ (rad): stage of wave at a point (~ angle around a circle, we will see it…).

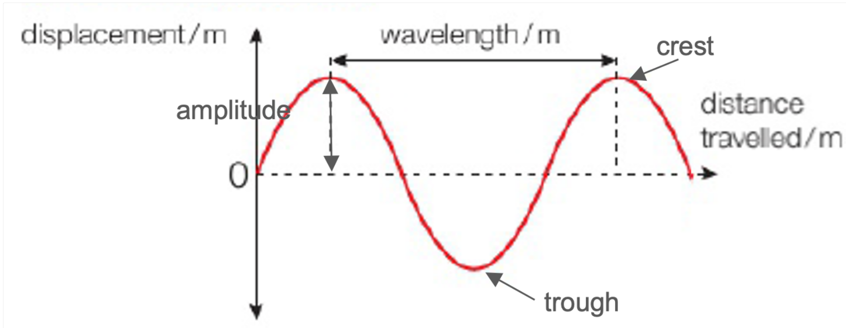

Figure 1: wave components 1

- Wave speed v (m/s): $v = \frac{d}{t}$ and also $v = f\lambda$ (Wave equation)
- Pulse-echo measurements (like bat and dolphin echolocation): emit a pulse of ultrasound (50-100kHz) and calculate $d = vt/2$ (rebound).

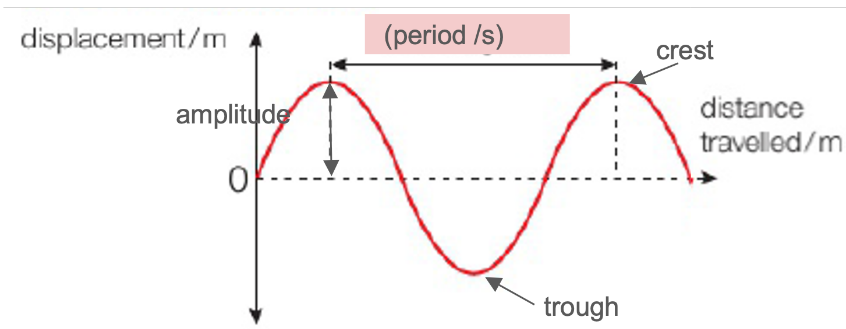

Figure 2: wave components 2

Checkpoint questions. (Extra: Read the experiment p.91, draw the wave diagram).

Answers

1. Graph from top to bottom: $0.2m$, $80m$, $5.5m$.
2. $1240m$ $(d = v \cdot t)$
3. $8.5 \cdot 10^{14}Hz$ $(f = c/\lambda$, wave equation)
4. As frequency is defined as waves per second, multipliying frequency by wavelenght is equivalent as dividing distance by time (velocity)
5. Student's own answers using $v = f \cdot \lambda$. Eg. estimated wavelenght is $5m$, estimated frequency is 1 wave every 3 seconds, so $f = 0.33Hz$. $v = f \cdot \lambda = 0.33 \times 5 = 1.7m\ s^{-1}$

2 Wave types

2.1 By oscillation plane

According to the oscillation plane, compared with wave displacement, we find transverse and longitudinal waves.

Do you know what transverse and longitudinal means?

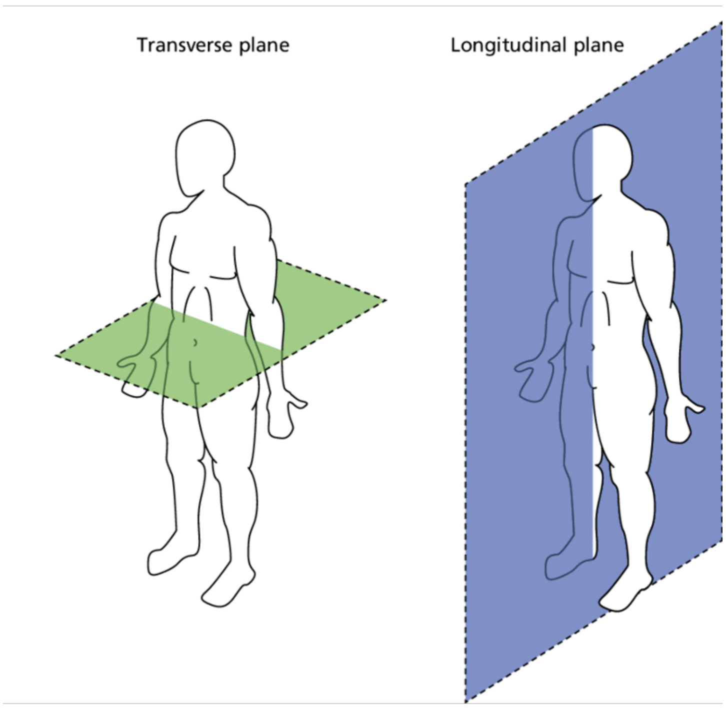

Figure 3: Transverse and longitudinal planes

→ Transverse wave: motion is perpendicular to displacement (up/down). Eg ropes, electromagnetic waves (light), earthquake S-waves.

→ Longitudinal wave: motion is parallel to displacement (front-back). Eg sound waves (compressions vs rarefactions), earthquake P-waves.

Both kinds of waves are represented in the same graphs.

- Compression: area at higher pressure (molecules closer together).
- Rarefaction: area at lower pressure (molecules further apart).

Watch this video

Minipractical: flick a string on top of the table and let it stop. Waves should remain visible. Measure the time for 10 "flicks" (oscillations) to calculate the frequency ($\frac{1}{T}$), and with a ruler the amplitude and wavelength. From this calculate the speed.

3 Wave Phase, Superposition

What is the phase in a wave? Why is it useful?

What is superposition? How can superposition apply to waves?

3.1 Phase

Phase (φ in radians) measures the wave position compared to a circular movement.

- Phase of 1 cycle (wavelength, λ) = 360° or $2\pi rad$.

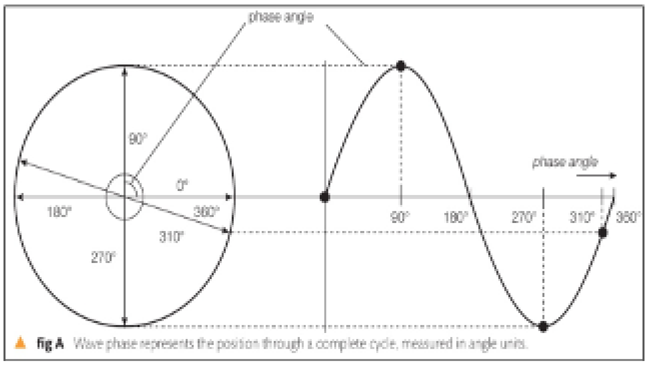

Figure 4: Phase compared to circular movement

- More than 1 cycle is expressed as the equivalent of the first cycle Eg: $450° = 360° + 90° \rightarrow 90°$; $2.5\pi\ rad = 2\pi\ rad + 0.5\pi\ rad \rightarrow 0.5\pi\ rad$.

  The phase between two point can be measured_ $\Delta\varphi_{twopoints} = 2\pi\frac{\Delta d(m)}{\lambda}$.

Watch this video.

3.2 Interference

- **Wavefront:** lines/surfaces with the wave at the same point Perpendicular to displacement of the wave.
- **Superposition:** if waves coincide in the same point, the amplitude of the different waves add. $Amplitude_T = A_i $. But displacement does not change.

→ In pulses, waves pass through each other. Figure 5

→ In continuous waves they do interfere (create a new wave, A_T). constructive ($A_T > A_i$) or destructive ($A_T < A_i$). It depends on the A_i and on the phase difference ($\Delta\theta$). Figure 6

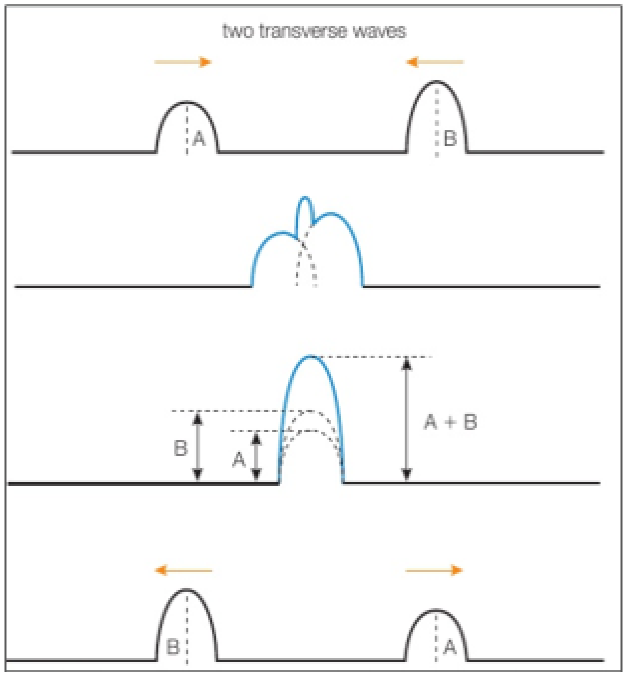

Figure 5: Waves add amplitude

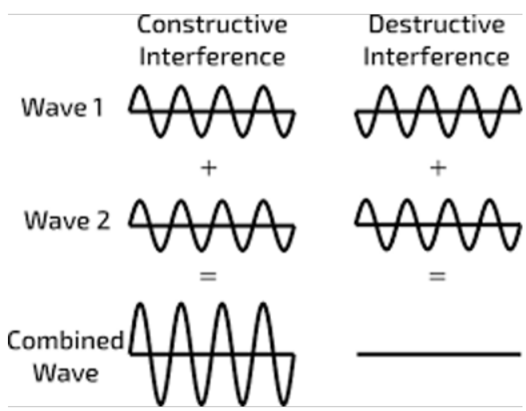

Figure 6: Constructive and destructive interference

! Important

NOT REQUIRED FOR UK: The general equation of a wave is

$$y(x,t) = A \cdot sin(2\pi \frac{x - vt}{\lambda}) = A \cdot sin(2\pi \frac{x}{\lambda} \mp \omega t + \varphi_0) = A \cdot cos(2\pi \frac{x}{\lambda} \mp \omega t + \varphi_0 - \frac{\pi}{2})$$

Also, $T = \frac{2\pi}{\omega} = \frac{1}{f}$ with $-$ = moving forward; $+$ = moving backward; $v = \frac{\omega\lambda}{2\pi}$.

4 Stationary waves

What are coherent waves?

Coherent waves: same frequency and "constant phase relationship" (=wavelength, so they stay in sync).

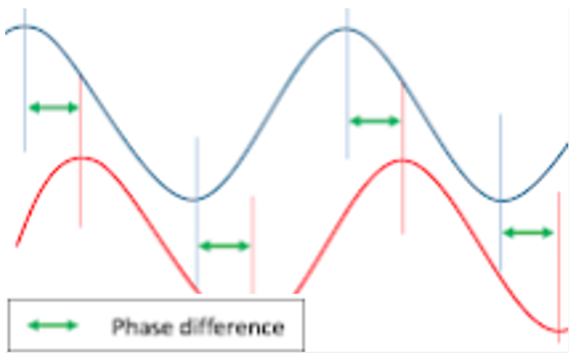

Figure 7: Constant phase shift

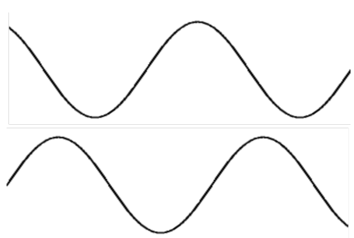

Figure 8: Constant phase in movement

Stationary ("standing") wave: superposition of opposite direction coherent waves. At points with opposite phase the interference results in no movement ("nodes"). Points with maximum amplitude are "antinodes". Total transfer of energy = 0 J (the net result is not a wave!).

Progressive waves do transfer energy. Watch here.

Harmonics: half-wavelengths that fit in a stretch of string L: "1st" or fundamental harmonic, $f_0 \rightarrow 0.5\lambda = L$

“2nd”: $\lambda = L$

“3rd”: $1.5\lambda = L$... etc.

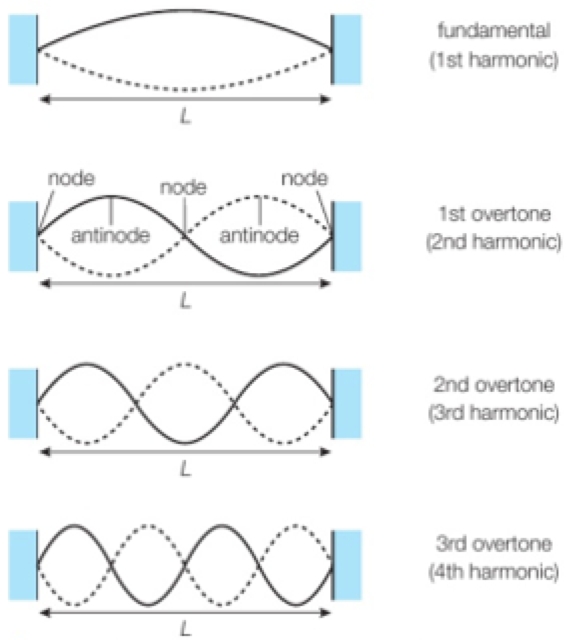

Figure 9: Harmonics