Waves

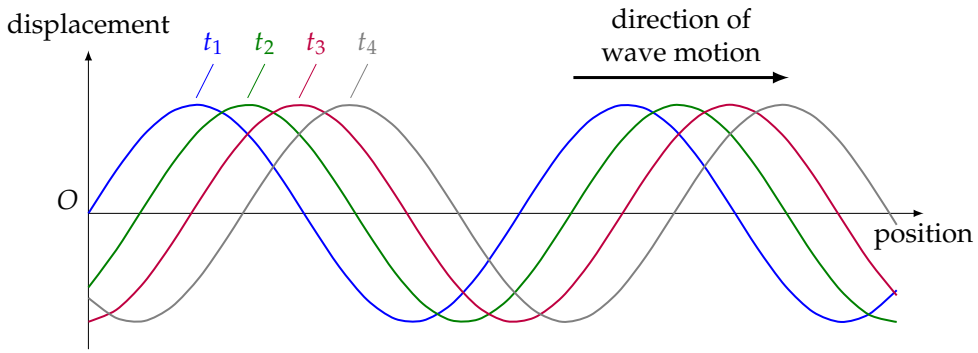
Name _____ Date _____

By the end of this topic I can…

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

Describing waves

A wave transfers _____ from place to place without transferring _____.



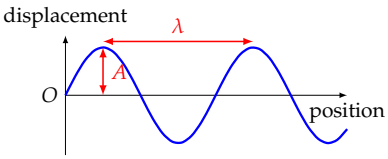
• **displacement**: distance of a point from its _____

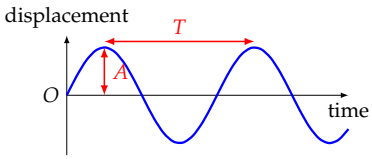
• **amplitude** A: the _____

• **wavelength** λ: the distance between _____ vibrating in phase (e.g. crest to crest)

• **period** T: the time for _____ of a point;
frequency f: the number of oscillations per unit time

$[f] =$ _____ $= \text{s}^{-1}$





In one period the wave moves forward one wavelength, so the **wave speed** is

Example 9.1 When a wave travels on a water surface, the maximum depth of water is 21 cm and the minimum depth is 18 cm. What is the amplitude of the wave?

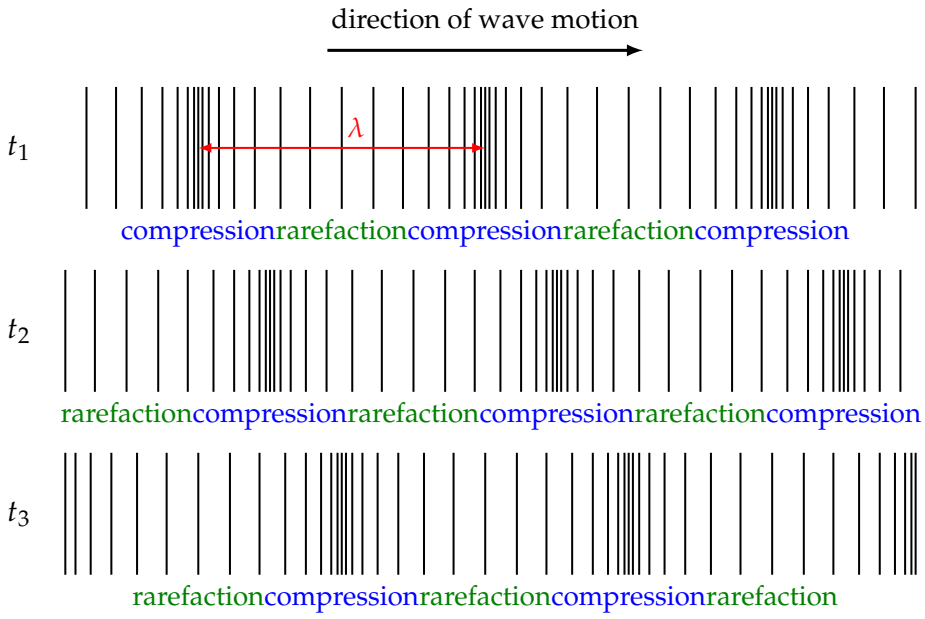
Example 9.2 A wave travelling at 4.0 m s^{-1} has a wavelength of 50 cm, what is its period?

Types of wave

Transverse and longitudinal

A **transverse** wave has vibrations _____ to the direction of energy transfer.
A **longitudinal** wave has vibrations _____ to the direction of energy transfer.

- transverse examples: _____, waves on a string, water surface waves
- longitudinal examples: _____, waves on a slinky; they have _____ and _____



Example 9.3 What is the distance between a compression and a rarefaction for a sound wave of frequency 550 Hz? (Speed of sound in air is about 330 m s^{-1}.)

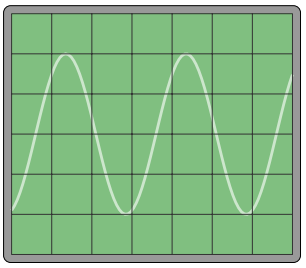
Sound waves

• sound is a _____ wave and needs a _____: it cannot travel through a vacuum

• the speed depends on the _____ (air $\approx$ 340 m s^{-1}, water $\approx$ 1500 m s^{-1}, steel $\approx$ 5000 m s^{-1}), not on frequency

• _____ depends on frequency; _____ depends on amplitude

• an **oscilloscope** displays voltage (y) against time (x); the _____ sets the time per division and the _____ the volts per division



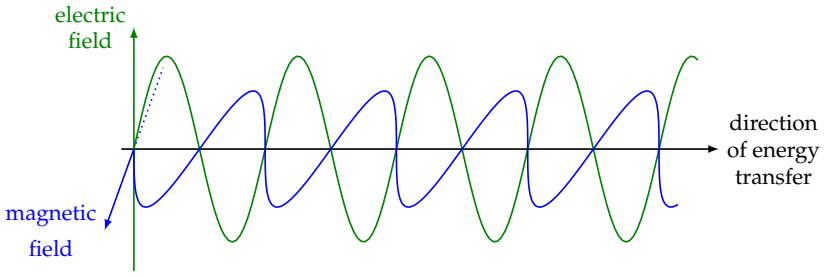
Example 9.4 A sound wave is detected by a microphone and the trace is displayed on an oscilloscope as shown. If the time-base is set at 0.5 ms div^{-1} and the voltage gain is set at 2 V div^{-1}. What is the frequency and the amplitude of the signal?

Electromagnetic waves

• **mechanical waves** need a _____; **electromagnetic waves** can travel through a _____

• EM waves are _____: oscillating _____ at right angles to each other and to the direction of travel

• all EM waves travel at c = _____ in a vacuum



Region	Wavelength / m	Frequency / Hz
radio waves	$10^{-1} \sim 10^{6}$	$10^{2} \sim 10^{9}$
microwaves	$10^{-3} \sim 10^{-1}$	$10^{9} \sim 10^{11}$
infra-red	$7 \times 10^{-7} \sim 10^{-3}$	$10^{11} \sim 10^{14}$
visible light	$4 \times 10^{-7} \sim 7 \times 10^{-7}$	$10^{14} \sim 10^{15}$
ultraviolet	$10^{-9} \sim 4 \times 10^{-7}$	$10^{15} \sim 10^{17}$
X-rays	$10^{-13} \sim 10^{-9}$	$10^{17} \sim 10^{19}$
γ-rays	$10^{-16} \sim 10^{-11}$	$10^{19} \sim 10^{24}$

- order of increasing wavelength:

_____

Example 9.5 A beam of electromagnetic radiation is known to have a frequency of 25 THz in vacuum. What is its wavelength?

Intensity

Intensity is the _____:

$[I] =$ _____

- intensity is proportional to the _____:

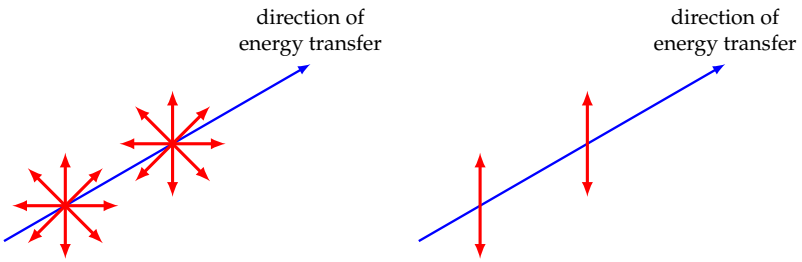
- from a point source the energy spreads over $4\pi r^2$, so (inverse square law)

Example 9.6 If the amplitude of an incoming wave is increased by 50%, what is the increase in the wave intensity?

Example 9.7 Two observers A and B are at a distance r_A and r_B from a point source where $r_A = 2r_B$. (a) Find the ratio of their intensities $\frac{I_A}{I_B}$. (b) Find the ratio of their amplitudes $\frac{A_A}{B_B}$.

Polarisation

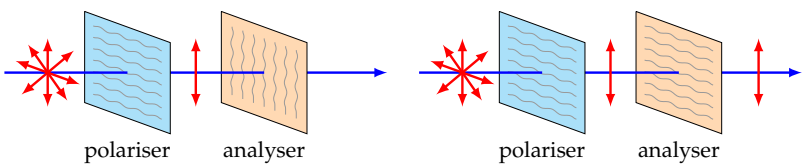
A wave is **plane-polarised** if its vibrations are in _____, perpendicular to the direction of energy transfer.



- only _____ waves can be polarised; sound cannot
- a **polariser** transmits only the component of vibration _____; unpolarised light emerges plane-polarised

Malus's law: plane-polarised light of intensity I_0 meeting an analyser at angle θ to its axis transmits

- amplitude transmitted: $A = A_0 \cos\theta$; for several filters apply the law _____, using the new plane of polarisation each time

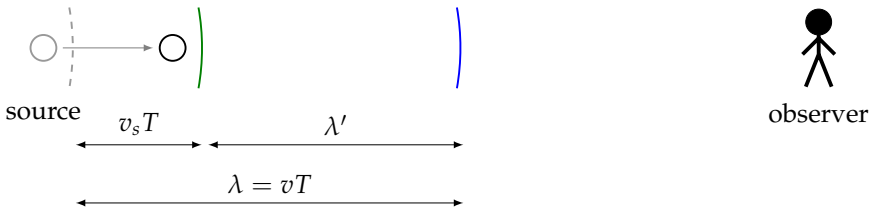


Example 9.8 A beam of light polarised in the vertical direction has an amplitude A and intensity I. It passes through a polarising filter whose axis of polarisation is at 45° to the vertical. (a) What is the amplitude and the direction of polarisation of the emerging beam? (b) If the emerging beam then enters another filter whose axis of polarisation is at 75° to the vertical, what is the amplitude and intensity of the emerging beam?

Doppler effect

The **Doppler effect** is the change in _____ caused by relative motion between a wave source and an observer.

- source moving _____ the observer: wavelength shorter, frequency _____; moving _____: lower



In one period the source moves $v_s T$, so $\lambda' = \lambda \mp v_s T$ ($-$ for approach), which gives (source moving, observer at rest)

- use $-$ when the source moves _____ the observer and $+$ when it moves _____
- uses: _____, blood-flow imaging, _____ of stars

Example 9.9 A police car moving towards you at 16 m s^{-1} sirens at 500 Hz. Given that the speed of sound in air is 340 m s^{-1}, at what frequency do you hear the siren?

Example 9.10 A star emits an H_α line of wavelength 656 nm. (a) What is the frequency of this H_α line? (b) An observer on earth detects a wavelength of 680 nm, what can we say about motion of the star? (c) Find the relative speed of the star with respect to the earth.

Practice questions

Question 9.1 A bottle floating on water bobs up and down over a total distance of 20 cm twice each second. Find its amplitude and frequency.

Question 9.2 A horn produces a note of frequency 512 Hz. Sound travels at 330 m s^{-1} in air. Find the wavelength.

Question 9.3 On an oscilloscope with the time-base at 5.0 ms div^{-1}, 3 complete waveforms are seen over 5 divisions. Find (a) the period, (b) the frequency.

Question 9.4 An electromagnetic wave has a period of 1.0 ps. Find (a) its wavelength, (b) the number of wavelengths in 1.0 m.

Question 9.5 A sound wave has amplitude A_0 and intensity I_0. The amplitude increases to $3A_0$. Find the new intensity.

Question 9.6 Radiation of intensity 500 W m^{-2} arrives normally on a solar panel of effective area 4.0 m^2. How much energy arrives in one hour? What if the amplitude is doubled?

Question 9.7 Horizontally polarised light of intensity I_0 passes through a filter with its plane of polarisation at 30° to the horizontal. Find the transmitted intensity.

Question 9.8 Vertically polarised light of intensity I_0 meets a filter B with a horizontal axis. (a) Find the emergent intensity. (b) A filter C at 45° to the vertical is inserted before B. Find the new emergent intensity.

Question 9.9 A car's horn sounds at 500 Hz but a roadside observer hears 450 Hz. Find the speed and direction of the car (speed of sound 340 m s^{-1}).

Question 9.10 An ambulance travelling at 25 m s^{-1} passes close to a stationary observer. Its signal has frequency 1500 Hz. What is the overall change in the frequency heard (speed of sound 340 m s^{-1})?