CAIE Physics A-level

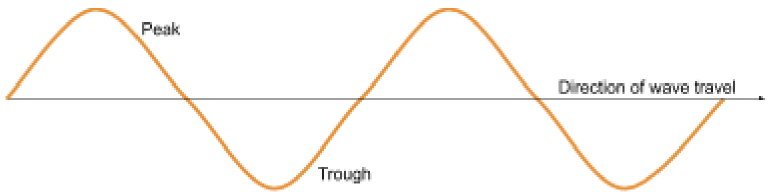
Topic 7: Waves

Notes

7 - Waves

7.1 - Progressive Waves

Wave motion can be demonstrated using the vibration of a rope:



As you can see, the wave is made up of consecutive peaks and troughs, which repeat continuously.

You need to be aware of the following **key terms**:

Displacement	The distance of a particle away from the equilibrium position.
Amplitude	A wave's maximum displacement from the equilibrium position.
Frequency (f)	The number of complete oscillations passing through a point per second.
Wavelength (λ)	The length of one whole oscillation (e.g. the distance between successive peaks/troughs).
Speed (v)	The distance travelled by the wave per unit time.
Phase difference	How much a wave lags behind another, (units are radians, degrees or fractions of a cycle). This value is used to compare the stages that two waves are in.
Period (T)	The time taken for one full oscillation.

The **speed (v)** of a wave is equal to the wave's frequency multiplied by its wavelength.

$$v = f\lambda$$

The above equation can be derived using the definitions of speed, frequency and wavelength as shown below:

1. Consider a wave travelling at a speed v, with a wavelength of λ m.

$$speed = \frac{distance}{time}$$

$$v = \frac{distance\ travelled\ by\ wave}{time}$$

2. A wave travels a distance equal to its wavelength during one time period, therefore:

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

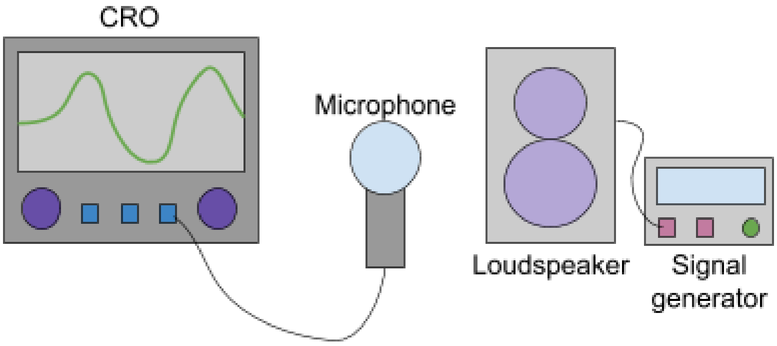
3. As f = 1/T, substitute frequency into the above equation.

$$v = f\lambda$$

A **progressive wave** is a type of wave that transfers energy without transferring material.

You can measure the **frequency** and **amplitude** of a sound using a **cathode-ray oscilloscope (CRO)**. Connect a microphone to the CRO input and play the sound using a signal generator attached to a speaker.

To find the **frequency**:



1. The CRO will display the sound wave's **displacement-time** graph. In order to change the scale on the x-axis so that the waveforms fill as much of the screen as possible, adjust the time-base settings on the oscilloscope.
2. Measure the number of full waves that appear on the screen and the number of divisions they appear on. Multiply the number of divisions by the time-base to find the time taken, so that you can calculate the period of the wave (time taken for one full oscillation).
3. Finally, use the formula $f = \frac{1}{T}$ to calculate frequency.

To find the **amplitude**:

1. The y-axis of the CRO will show the displacement of the wave. The voltage/divisions setting will give the scale of the y axis. Each division will correspond to a stated voltage. Ensure the wave fills as much vertical space on the screen as possible by changing the voltage/div.
2. Measure the number of divisions the wave spans vertically and multiply this by the voltage/division to obtain the amplitude in terms of voltage.

Intensity is the power (energy transferred per unit time) per unit area, and can be calculated using the equation below:

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

Where P is the power and A is the area.

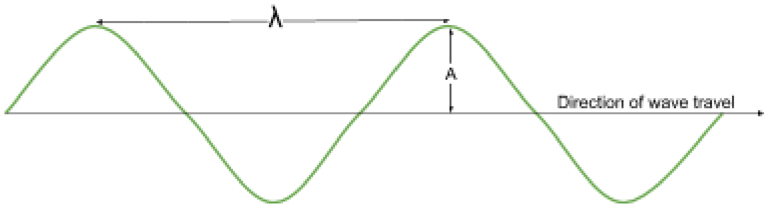
The **intensity of a wave** is **directly proportional to its amplitude squared**, as shown below:

$$Intensity \propto (amplitude)^2$$

7.2 - Transverse and longitudinal waves

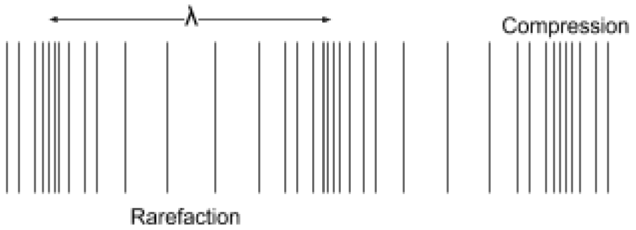
Transverse waves - the oscillations of particles (or fields) isat right angles to the direction of energy transfer

- All electromagnetic (EM) waves are **transverse** and travel at 3 x 10^8 ms^{-1} in a vacuum.
- Transverse waves can be demonstrated by shaking a slinky vertically or through the waves seen on a string, when it's attached to a signal generator.



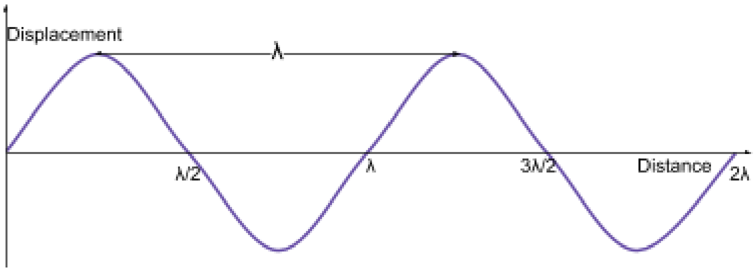
Longitudinal waves - the oscillations of particles are parallel to the direction of energy transfer

- These are made up of compressions and rarefactions and can't travel in a vacuum.
- Sound is an example of a longitudinal wave, and they can be demonstrated by pushing a slinky horizontally.

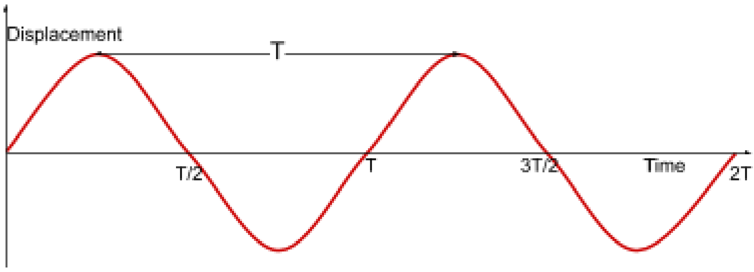


There are two types of graphs which can be used to represent waves:

➔ **Displacement-distance graphs -** these show how the displacement of a particle varies with the distance of wave travel and can be used to measure wavelength.
For a transverse wave, the displacement distance graph will look very similar to the actual wave, whereas for a longitudinal wave the graph will look very different from the wave.

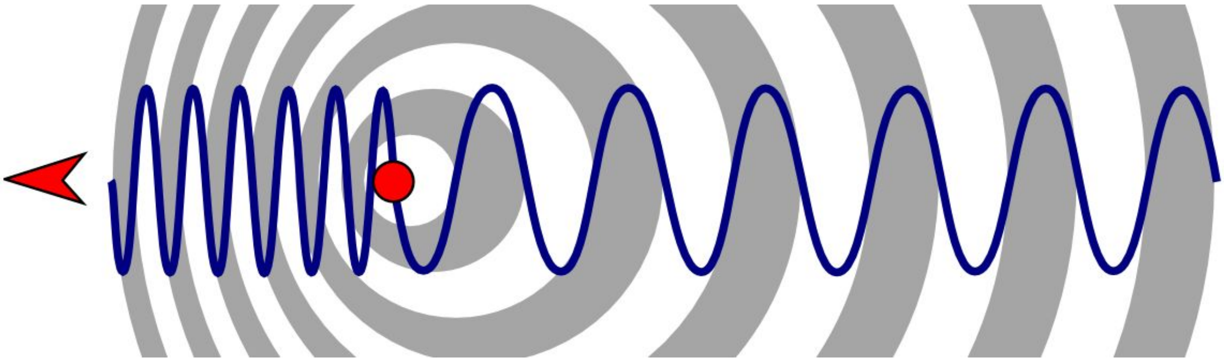


➔ **Displacement-time graphs -** these show how the displacement of a particle varies with time and can be used to measure the period of a wave.



7.3 - Doppler Effect for Sound Waves

The **Doppler effect** is the **compression or spreading out of waves** that are emitted or reflected by a **moving source**. As the source is moving, the wavelengths in front of it are compressed and the wavelengths behind it are spread out as shown in the diagram below, this leads to a **change in observed frequency**. An example of the doppler effect can be heard in the sound of a car moving past you.



You can calculate the **observed frequency (f_o)** of a moving source of sound when it moves relative to a stationary observer using the equation below:

$$f_o = \frac{f_s v}{(v \pm v_s)}$$

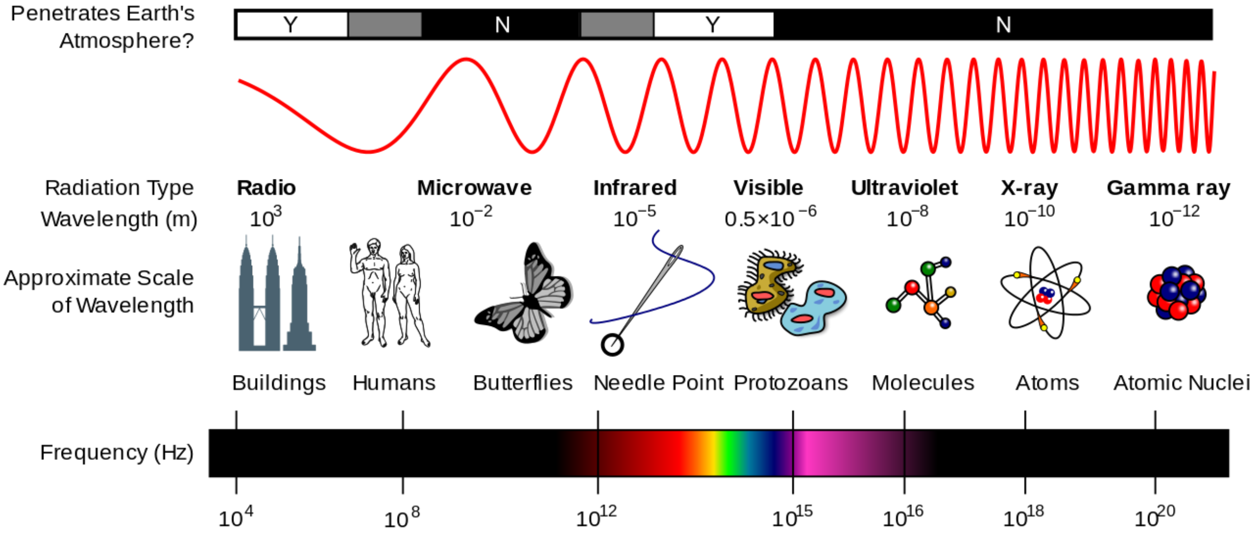
Where $\mathbf{f_s}$ is the frequency given out by the moving source, **v** is the speed of sound, and $\mathbf{v_s}$ is the constant speed of the source.

The sign on the bottom of the equation depends on whether the source is moving towards or away from the observer:

- **v_s is added** when the source is moving **away** from the observer
- **v_s is subtracted** when the source is moving **towards** from the observer.

7.4 - Electromagnetic Spectrum

The electromagnetic spectrum contains all electromagnetic (EM) waves; these are classified into principal categories by their wavelengths. The diagram below shows the principal categories and their associated wavelengths.



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You should be aware of the orders of magnitude (the power of ten) of the above principal categories, as shown in the table below:

EM radiation	Order of magnitude of wavelength (m)
Radio	10^3
Microwave	10^{-2}
Infrared	10^{-5}
Visible	10^{-7}
Ultraviolet	10^{-8}
X-ray	10^{-10}
Gamma ray	10^{-12}

Wavelengths in the range 400-700nm are visible to the human eye.

All EM waves travel at the same speed in free space, which is **3×10^8 ms^{-1}**, the speed of light in free space (c).

7.5 - Polarisation

A **polarised wave oscillates in only one plane** (e.g only up and down if vertically polarised), **only transverse waves can be polarised.** Polarisation provides **evidence for the nature of transverse waves** because polarisation can only occur if a wave's oscillations are perpendicular to its direction of travel (as they are in transverse waves).

The intensity of a wave is affected by polarisation. As the process of passing through a polarising filter excludes waves of certain orientations, the intensity of the wave after filtering is always less than or equal to its intensity before.

The resulting intensity is described by **Malus' Law**, $I = I_0 cos^2$. An electromagnetic wave with an initial intensity I_0 passes through a filter with a polarisation angle θ and has a subsequent intensity I .