Waves

This resource can be used in support of the following curricula (assessed from 2015):
AQA: Physics A2 and A level – Unit 3 **OCR:** Physics A2 and A level – Unit 4
Edexcel: Physics A2 and A level – Topic 5

For Students:
Revision Notes

Be sure to familiarise yourself with the different classes of waves and the language used to describe them. You may be asked to label or draw a graphical representation of a wave.

Wavelength, λ, is defined as the distance between adjacent peaks or troughs and is measured in metres (m)

Frequency, f, has the unit hertz (Hz), and is the number of waves passing a given point every second

Period, T, is the time taken for one complete oscillation and it is measured in seconds (s). Frequency is the reciprocal of period (f = 1/T)

Amplitude, A, is the maximum displacement of a particle from its equilibrium position. In other words it is the height of the wave from the zero point, measured in metres (m).
It is NOT the height from crest to trough

Wave velocity, v, is the speed of propagation of the wave in metres per second (ms^{-1}). In air, sound waves propagate at 340 ms^{-1}. The speed of light in a vacuum, c, is a constant and is 3×10^8 ms^{-1}

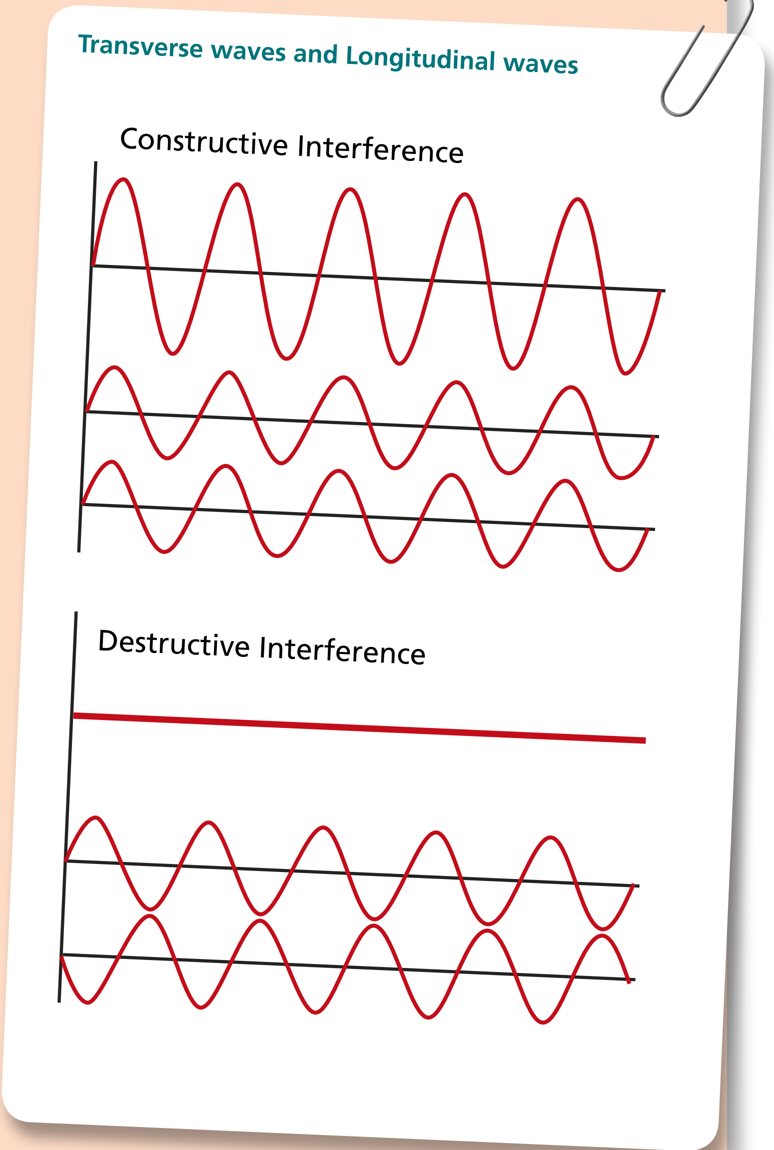
The frequency, speed, and wavelength of any wave can be linked by the **wave equation**:

$$v = \lambda f$$

where v is the speed of the wave in ms^{-1}, f is the frequency in Hz, λ is the wavelength in m. Because f = 1/T, this is also equivalent to v = λ/T (or speed = distance / time)

A **transverse** wave is one in which the displacement is at 90° to the direction of travel. All electromagnetic waves are transverse and can travel in a vacuum.

In **longitudinal** waves, the displacement is parallel to the direction of travel of the wave. There are regions of high pressure (compression), and regions of low pressure (rarefaction). They must travel through a medium (e.g. air).

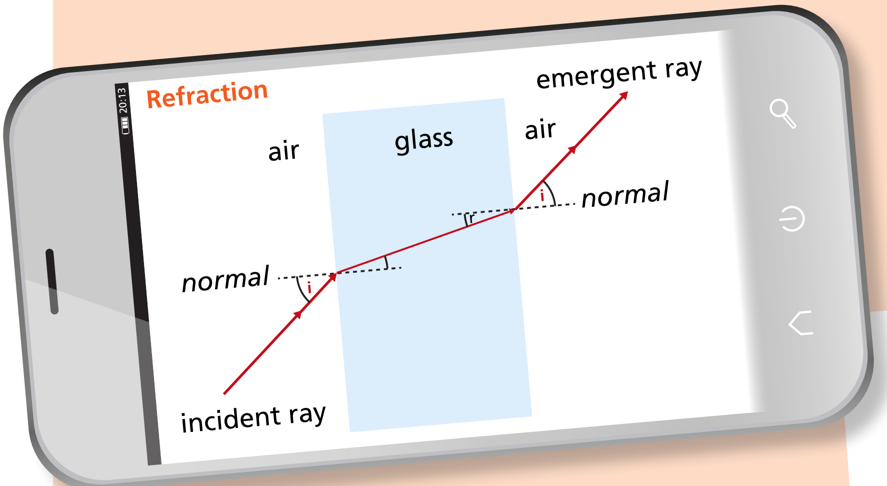


Refraction

Waves (light) will always take the fastest route from point A to point B – a straight line. If this path takes the light through different materials, it may be forced to deflect from its original path, by a process called refraction. Refraction only happens if light enters a material at an angle to the normal.

The less dense a material is, the faster light travels. In more dense materials, its speed is reduced. The refractive index (n) is the ratio of the speed of light in a vacuum (c) to the speed of light in the medium (v).

The refractive index can be used to determine the angle at which the light bends. We do this using an equation called **Snell's law**. When light hits the boundary between two transparent media, some will reflect back into the first medium, the rest will refract into the second media. Remember that light can either refract towards the normal (when slowing down while crossing the boundary) or away from the normal (when speeding up while crossing the boundary).



Here, Snell's Law says

$$n_{air} \sin \theta_i = n_{glass} \sin \theta_r$$

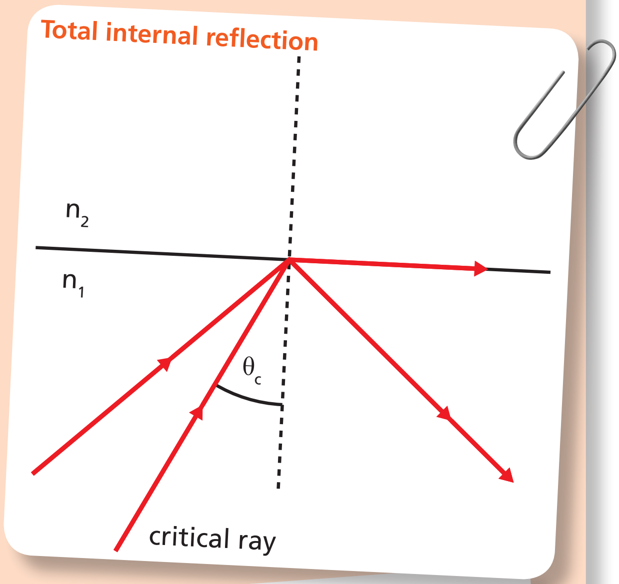
A useful thing to remember is that the refractive index of air (n air) is very close to 1. Water has a higher refractive index than air (because it is more dense), and glass a higher refractive index again (n_{glass}).

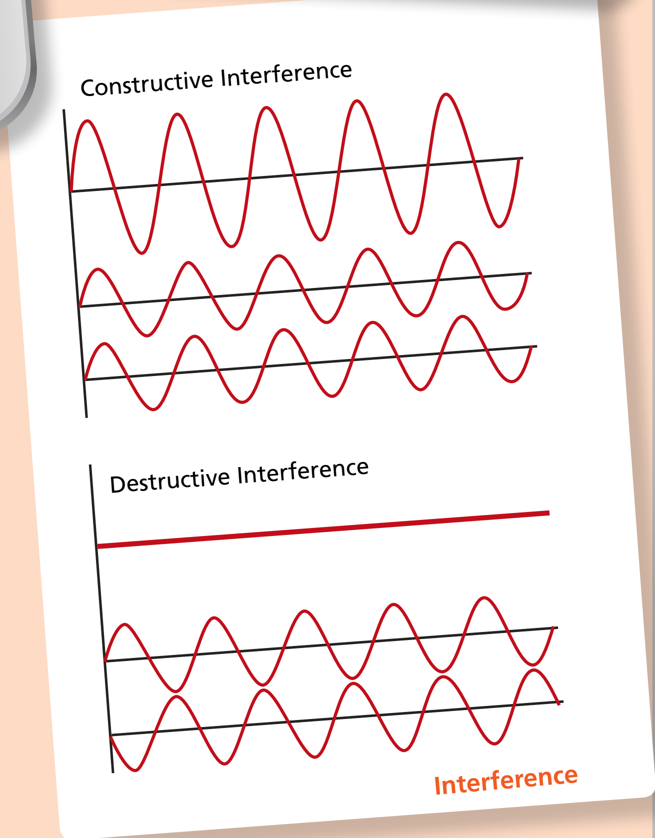
There is one particularly interesting type of refraction - when light travels from a medium of higher to lower index. The light ray can actually bend so much that it never goes beyond the boundary between the two media. This case of refraction is called **total internal reflection**.

The critical angle (θ_{crit}) is the first angle for which the incident ray does not leave the first region. Any incident angle greater than the **critical angle** will consequently be reflected from the boundary instead of being refracted. If $n_2 < n_1$,

$$\sin \theta_{crit} = n_2 / n_1$$

The light that travels inside optical fibre hits the surface with an angle of incidence greater than the critical angle, so that all light is reflected toward the inside of the fibre. By repeating this process thousands of times, light can be transmitted over long distances, allowing us to communicate at light-speed across the world.



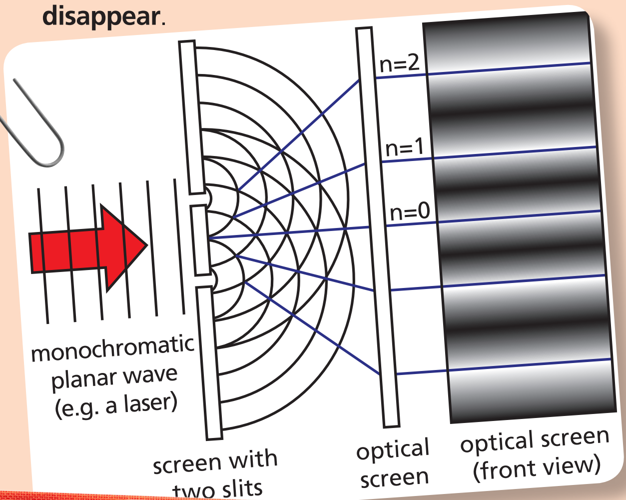


Diffraction and Interference

Interference and diffraction are often confused.

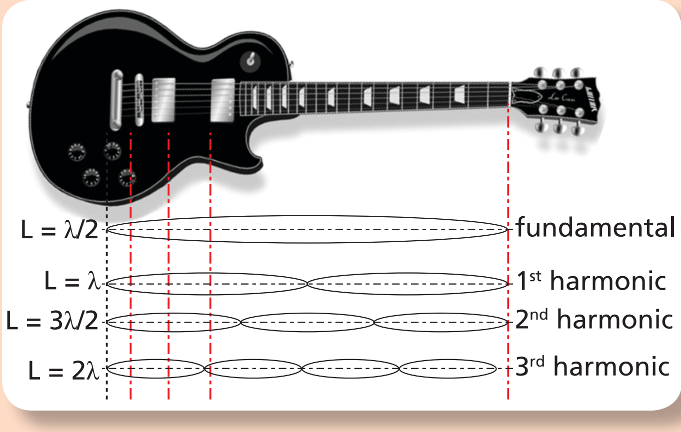
Diffraction refers to the apparent bending of waves around small obstacles and the spreading out of waves past small openings. When two separate waves originating from the same source spread out (diffract) and coincide, they **interfere** and form a pattern – we see:

- Regions of **constructive** interference where crests meet crests and troughs meet troughs. The resultant amplitude is larger than the amplitude of each individual wave. If the waves are of visible light, the resultant region will look four times as intense.
- Where the waves are in **antiphase**, they cancel each other out. If the waves are of visible light, the light will **disappear**.



Young's double-slit experiment shows us that coherent light (such as a laser) undergoes interference. This is evidence that light can behave as a wave.

The formation **of stationary (or standing) waves** is a special case of interference. Stationary waves occur on a guitar string when it is plucked, with nodes (locations of minimum amplitude) at the two ends and an antinode (location of maximum amplitude) in the middle.

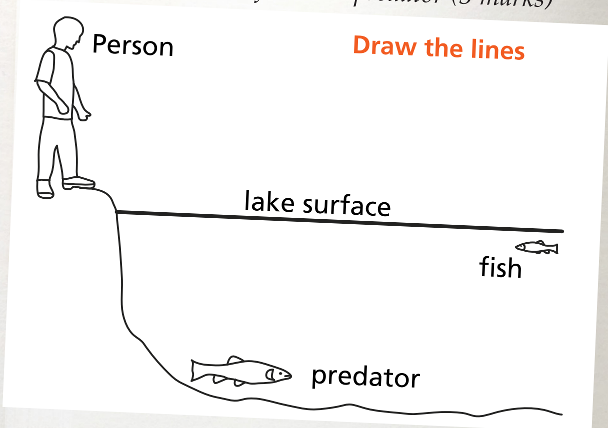


The lowest possible frequency standing wave that can fit on a guitar string will be the fundamental frequency (1st harmonic). It is the longest wavelength for that string. The wavelength, λ = 2 x L.

If we increase the frequency and decrease the wavelength, the next wave that will fit will be the 2nd harmonic, and so on.

Exam Questions

Q1: Looking upward when the surface of the lake is smooth, the fish can see people on the bank and predators near the bottom of the lake. On the diagram draw one ray of light reaching the fish (i) from the person's head, and (ii) from the predator (3 marks)



Calculate the critical angle for light passing from water to air. The refractive index for light travelling from air into water is 1.33. (2 marks)

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Q2: This figure below represents a stationary wave formed on a steel string fixed at P and Q when it is plucked at its centre. (a) Explain why a stationary wave is formed on the string (3 marks)

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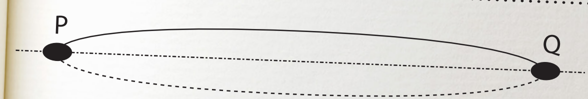

(b) The stationary wave has a frequency of 150 Hz. The string PQ has a length of 1.2m. Calculate the wave speed (ms-1) of the waves forming the stationary wave (2 marks)

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Did you know?
Because seismometers pick up vibrations through the earth, they can be used to detect sound and movement. The seismometers at AWE's Blacknest facility picked up sounds waves moving through the ground from a local music festival. It was even possible to tell the genre of music being played!

For Teachers: Experiment!

The Speed of Waves in Water

In this experiment, you will determine the speed of a wave as it crosses a shallow tray of water, and consider the uncertainties in your measurements

Equipment: Selection of baking trays (or similar), Water, Stop clock, Rulers (30 cm and 1 m)

Method

1. Fill the tray with water to a depth of about 1cm
2. Measure the actual depth in a number of places and also the length of the tray. Record your readings
3. Prepare a table to collect your data. It should include columns for **distance travelled** and **time taken**, and include columns for repeat readings
4. You should also consider your measurement uncertainty
5. Briefly raise one end of the tray about 1cm and allow to drop so that a ripple is sent across the surface of the water and is reflected backwards and forwards by the ends of the tray
6. Time how long the wave takes to cross the tray once, then how long the wave takes to cross the tray and then return to its starting position (travelling double the distance)
7. Because the waves will bounce off each end of the tray, keep counting the crossings until the wave is too faint to see, up to a maximum of eight crossings
8. Plot a graph of distance travelled by the wave against time and include analysis of the measurement error at each point
9. Use this data to determine the average speed on the wave (v). Calculate v with the smallest uncertainty
10. Repeat this experiment by varying the depth of the water (d) - what difference does that make to the measured average speed?
11. Use your results from #10 to determine the relationship between wave speed (v) and water depth (d)

Things for students to consider

- *What was the independent variable in your investigation?*
- *What was the dependent variable in your investigation?*
- *What was the precision of this piece of equipment?*
- *Use your graph to comment on the reliability of your results*
- *How could you increase the reliability of your results?*
- *How could you increase the precision of your results?*

Learn more!

- Free wave property animations: https://www.tes.co.uk/teaching-resource/wave-property-animations-11029063
- The Virtual Physical Laboratory software, which contains over 250 interactive experiments for use by teachers and by pupils: http://www.npl.co.uk/educate-explore/virtual-physical-laboratory/