Wave Basics

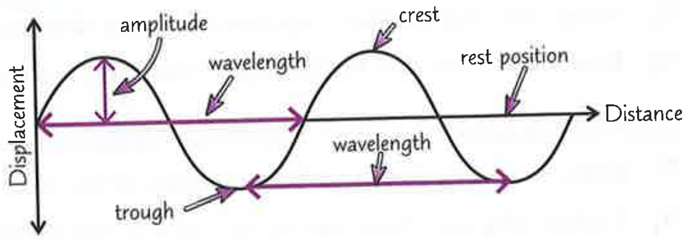
Waves transfer energy from one place to another without transferring any matter (stuff). Clever so and so's.

Waves Transfer Energy and Information in the Direction they are Travelling

When waves travel through a medium, the particles of the medium vibrate and transfer energy and information between each other. BUT overall, the particles stay in the same place.

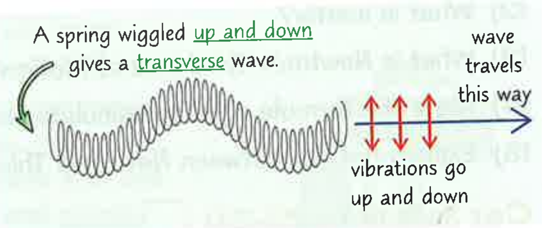
For example, if you drop a twig into a calm pool of water, ripples form on, and move across, the water's surface. The ripples don't carry the water (or the twig) away with them though. Similarly, if you strum a guitar string and create a sound wave, the sound wave travels to your ear (so you can hear it) but it doesn't carry the air away from the guitar — if it did, it would create a vacuum.

1) The amplitude of a wave is the displacement from the rest position to a crest or trough.
2) The wavelength is the length of a full cycle of the wave (e.g. from crest to crest, or from compression to compression — see below).
3) Frequency is the number of complete cycles of the wave passing a certain point per second. Frequency is measured in hertz (Hz). 1 Hz is 1 wave per second.
4) The period of a wave is the number of seconds it takes for one full cycle. Period = 1 ÷ frequency.



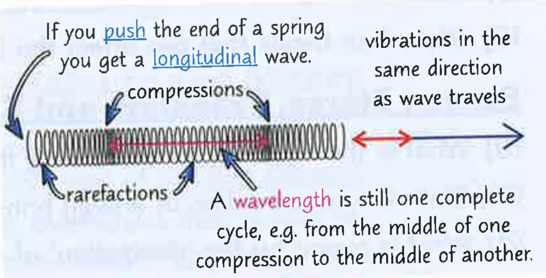
Transverse Waves Have Sideways Vibrations

In transverse waves, the vibrations are perpendicular (at 90°) to the direction the wave travels. Most waves are transverse, including:
1) All electromagnetic waves, e.g. light (p.43).
2) S-waves (see p.37).
3) Ripples and waves in water (see p.33).



Longitudinal Waves Have Parallel Vibrations

1) In longitudinal waves, the vibrations are parallel to the direction the wave travels.
2) Examples are sound waves (p.35) and P-waves (p.37).
3) Longitudinal waves squash up and stretch out the arrangement of particles in the medium they pass through, making compressions (high pressure, lots of particles) and rarefactions (low pressure, fewer particles).



Wave Speed = Frequency × Wavelength

Wave speed is no different to any other speed — it tells you how quickly a wave moves through space. There are two ways to calculate wave speed:

$$v = \frac{x}{t}$$

Wave speed (m/s), Distance (m), Time (s)

This is called the wave equation.

$$v = f\lambda$$

Wave speed (m/s), Wavelength (m), Frequency (Hz)

What about Mexican waves...

You won't get far unless you understand these wave basics. Try a question to test your knowledge.

Q1 A wave has a speed of 0.15 m/s and a wavelength of 7.5 cm. Calculate its frequency. [3 marks]

Measuring Waves

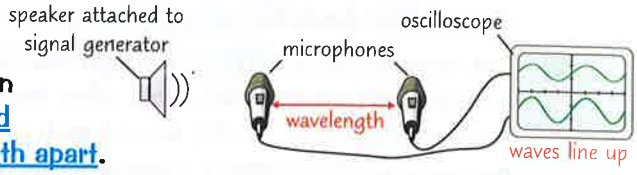
PRACTICAL

The speeds, frequencies and wavelengths of waves can vary by huge amounts. So you have to use suitable equipment to measure waves in different materials, to make sure you get accurate and precise results.

Use an Oscilloscope to Measure the Speed of Sound

By attaching a signal generator to a speaker you can generate sounds with a specific frequency. You can use two microphones and an oscilloscope to find the wavelength of the sound waves generated.

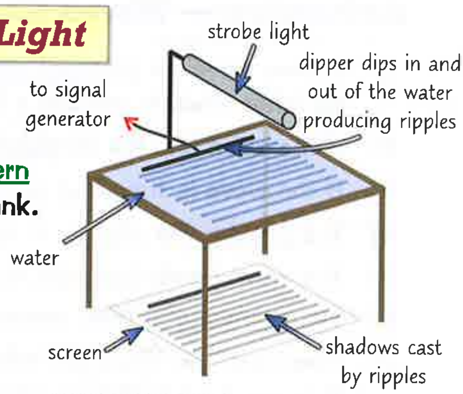
1) Set up the oscilloscope so the detected waves at each microphone are shown as separate waves.
2) Start with both microphones next to the speaker, then slowly move one away until the two waves are aligned on the display, but have moved exactly one wavelength apart.



3) Measure the distance between the microphones to find one wavelength (λ).
4) You can then use the formula $v = f\lambda$ (p.32) to find the speed (v) of the sound waves passing through the air — the frequency (f) is whatever you set the signal generator to in the first place.

Measure the Speed of Water Ripples Using a Strobe Light

1) Using a signal generator attached to the dipper of a ripple tank you can create water waves at a set frequency.
2) Dim the lights and turn on the strobe light — you'll see a wave pattern made by the shadows of the wave crests on the screen below the tank.
3) Alter the frequency of the strobe light until the wave pattern on the screen appears to 'freeze' and stop moving. This happens when the frequency of the waves and the strobe light are equal — the waves appear not to move because they are being lit at the same point in their cycle each time.
4) The distance between each shadow line is equal to one wavelength. Measure the distance between lines that are 10 wavelengths apart, then find the average wavelength.
5) Use $v = f\lambda$ to calculate the speed of the waves.

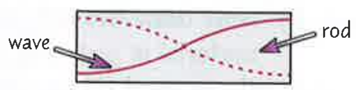


You can find the frequency by using a regular light, so you can see the waves moving. Count how many waves pass a mark on the screen in a given time, then divide this by the time in seconds to find the frequency.

Use Peak Frequency to find the Speed of Waves in Solids

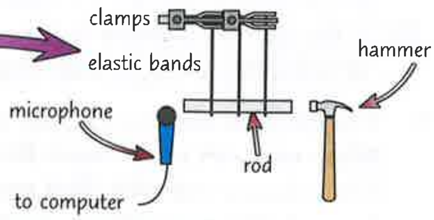
You can find the speed of waves in a solid by measuring the frequency of the sound waves produced when you hit the object, e.g. a rod, with a hammer. Hitting the rod causes waves to be produced along the rod. These waves make the rod vibrate and produce sound waves in the air around the rod (this is how a percussion triangle works). These sound waves have the same frequencies as the waves in the rod.

Lots of waves at lots of different frequencies are created in the rod when it is hit. The peak (loudest) frequency is created by this wave in the rod:



rod length = half a wavelength

1) Measure and record the length of a metal rod, e.g. a brass rod.
2) Set up the apparatus shown in the diagram, making sure to secure the rod at its centre.
3) Tap the rod with the hammer. Write down the peak frequency displayed by the computer.
4) Repeat this three times to get an average peak frequency.
5) Calculate the speed of the wave using $v = f\lambda$, where λ is equal to twice the length of the rod.



My wave speed depends on how tired my arm is...

The sound and water waves experiments are really common, so make sure they're firmly stuck in your head.

Q1 Describe an experiment to measure the wavelength of a water wave. [4 marks]

Reflection

If you're anything like me, you'll have spent hours gazing into a mirror in wonder. Here's why...

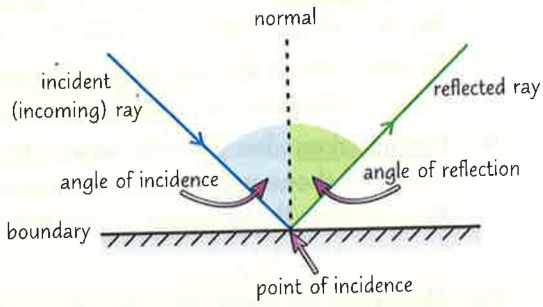
You Can Draw a Simple Ray Diagram for Reflection

1) The law of reflection is true for all reflected waves:

Angle of incidence = Angle of reflection

2) The angle of incidence is the angle between the incoming wave and the normal.
3) The angle of reflection is the angle between the reflected wave and the normal.
4) The normal is an imaginary line that's perpendicular (at right angles) to the surface at the point of incidence (the point where the wave hits the boundary).
5) The normal is usually shown as a dotted line.

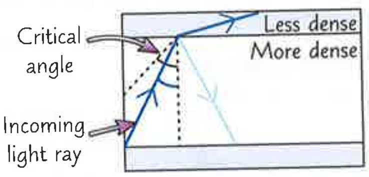
A ray is a line showing the path a wave travels in. Rays are always drawn as straight lines.



Total Internal Reflection Depends on the Critical Angle

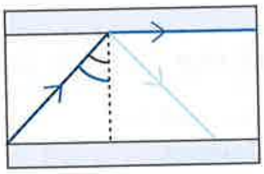
1) A wave hitting a surface can experience total internal reflection (it is reflected back into the material).
2) This can only happen when the wave travels through a dense material like glass or water towards a less dense substance like air, and the angle of incidence, i, is larger than a certain angle, called the critical angle. Every boundary has its own, different critical angle.

If i is less than the critical angle



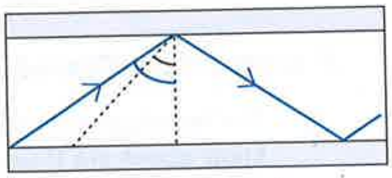
Most of the light is refracted into the outer layer, but some of it is internally reflected.

If i is equal to the critical angle



The ray would go along the surface (with quite a bit of internal reflection as well).

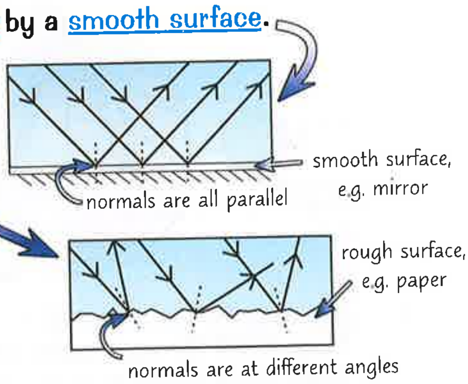
If i is larger than the critical angle



No light comes out. It's all internally reflected, i.e. total internal reflection.

Reflection can be Specular or Diffuse

1) Waves are reflected by different boundaries in different ways.
2) Specular reflection is when waves are reflected in a single direction by a smooth surface.
3) This means you get a clear reflection, e.g. when light is reflected by a mirror.
4) Diffuse reflection occurs when waves are reflected by a rough surface (e.g. paper) and the waves are reflected in all directions.
5) This happens because the normal is different for each incident ray, so each ray has a different angle of incidence. The rule angle of incidence = angle of reflection still applies.
6) When light is reflected by something rough, the surface looks matt, and you don't get a clear reflection.



My reflection is absolutely spectacular...

Remember, the angle of incidence is always equal to the angle of reflection of a wave.

Q1 Name the type of reflection that occurs when waves are reflected by a smooth mirror. [1 mark]

Q2 A light ray is incident on a mirror at an angle of 30°. Draw a ray diagram to show its reflection. [3 marks]

Investigating Refraction

PRACTICAL

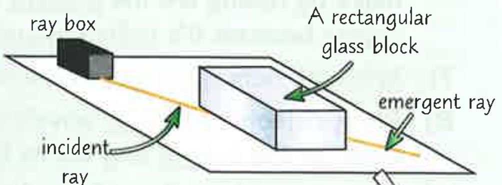
Hurrah — it's time to whip out your ray box and get some refraction going on. This is just one practical that covers how electromagnetic waves behave — there's another one over on page 44.

You Need to Do This Experiment in a Dim Room

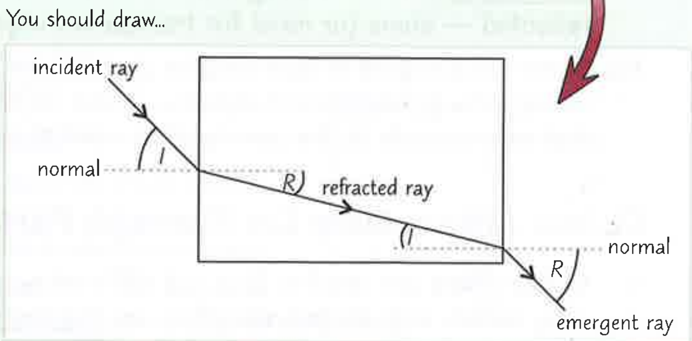
1) This experiment uses a ray of light, so it's best to do it in a dim room so you can clearly see the ray.
2) The ray of light must be thin, so you can easily see the middle of the ray when tracing it and measuring angles from it.
3) To do this, you can use a ray box — an enclosed box that contains a light bulb. A thin slit is cut into one of the sides — allowing a thin ray of light out of the box that you can use for your experiment.

You Can Use a Glass Block to Investigate Refraction

Light is refracted at the boundary between air and glass. You can investigate this by looking at how much light is refracted when it passes through a glass block.



1) Place a rectangular glass block on a piece of paper and trace around it. Use a ray box to shine a ray of light at the middle of one side of the block.
2) Trace the incident ray and the emergent ray on the other side of the block. Remove the block and, with a straight line, join up the incident ray and the emergent ray to show the path of the refracted ray through the block.
3) Draw the normal at the point where the light ray entered the block. Use a protractor to measure the angle between the incident ray and the normal (the angle of incidence, *I*) and the angle between the refracted ray and the normal (the angle of refraction, *R*).
4) Do the same for the point where the ray emerges from the block.
5) Repeat this three times, keeping the angle of incidence as the ray enters the block the same.
6) Calculate an average for each of the angles.



Head over to page 34 for a reminder about refraction.

- You should see that the ray of light bends towards the normal as it enters the block (so the angle of refraction is less than the angle of incidence). This is because air has one of the lowest optical densities that there is (p.34) so the light ray will almost always slow down when it enters the block.
- You should then see the ray of light bends away from the normal as it leaves the block. This is because the light ray speeds up as it leaves the block and travels through the air.
- It's important to remember that all electromagnetic waves can be refracted — this experiment uses visible light so that you can actually see the ray being refracted as it travels through the block.

Bonus tip: glass also slows down pesky bugs.

Lights, camera, refraction...

This experiment isn't the trickiest, but you still have to be able to describe how to do it and what it shows.

Q1 a) Describe an experiment you could do to measure how much light is refracted when it enters a glass block. [3 marks]

b) Explain why a thin beam of light should be used. [1 mark]