Wave Basics

Study Design

Properties of mechanical waves

- **explain a wave as the transmission of energy through a medium without the net transfer of matter**
- **distinguish between transverse and longitudinal waves**
- **identify the amplitude, wavelength, period and frequency of waves**
- **calculate the wavelength, frequency, period and speed of travel of waves using:**

  $v = f\lambda = \frac{<}{t}$
- **explain qualitatively the Doppler effect**
- **explain polarisation of visible light and its relation to a transverse wave model**

Introduction

Most information about our surroundings comes to us in some form of waves. It is through wave motion that sounds come to our ears, light to our eyes, and electromagnetic signals to our radios and televisions. Through *wave motion*, energy can be transferred from a source to a receiver without the transfer of matter between the two points.

If a stone drops into a quiet pool of water, a disturbance is created where the stone enters the water. This disturbance spreads out to eventually reach all parts of the pool.

The stone entering the water sets into motion the particles of the water that it strikes. These particles set neighbouring particles into motion and so the disturbance is propagated (spread) through the liquid. However, no individual particle travels far from its initial position –The wave transports of energy without transporting matter. The motion of the wave through the medium is a result of the action of successive parts of the medium on each other. If the particles were completely independent of each other, no wave could pass through.

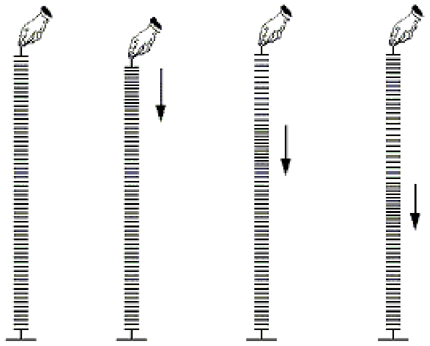
All forms of wave motion allow the transfer of energy without the net transfer of matter.

Categories of Waves

You will be familiar with several types of waves, water waves being the most obvious. You may be familiar with others such as pulses down a slinky, or the motion a string as illustrated in the diagram below. Other phenomenon, such as sound and light are waves. Waves can be grouped into two different categories, longitudinal and transverse waves.

Longitudinal Wave

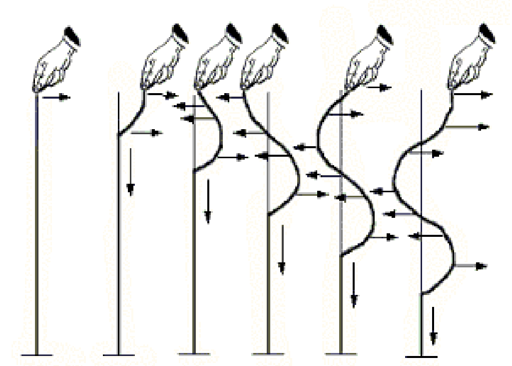
In a longitudinal wave, such as a pulse down a slinky as illustrated in the diagram below, the wave disturbance is in the same direction as the wave is travelling.



Examples: sound, pulses in slinkies.

Transverse Wave

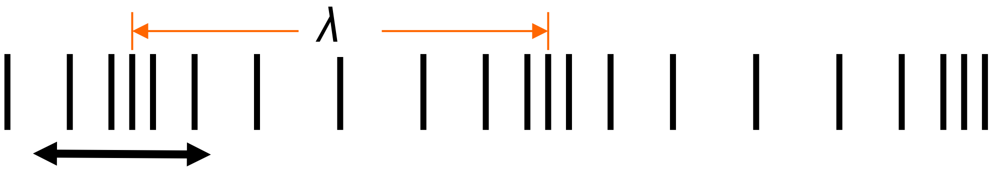
In a transverse wave, such as a pulse down a spring as illustrated in the diagram below, the wave disturbance is perpendicular to the direction as the wave is travelling.



Examples: Light, water waves.

Longitudinal waves

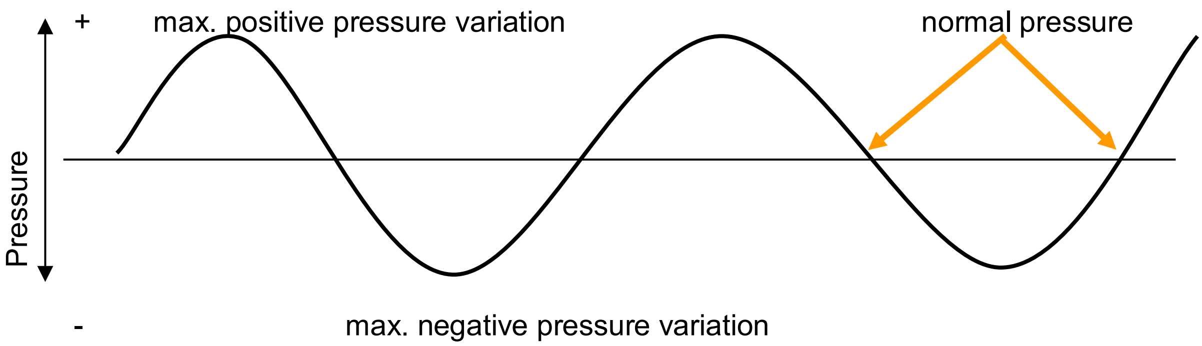
When the vibration of the waves is in the same direction as the line of travel, then the wave is longitudinal. In a longitudinal wave the motion is in the same direction as the motion of the wave, but the particles do not move forward, they vibrate around an equilibrium position.
The distance between any two identical points is called the wavelength λ.



The movement of particle is in this direction.

compression rarefaction

It is possible to represent this particle movement as a pressure variation

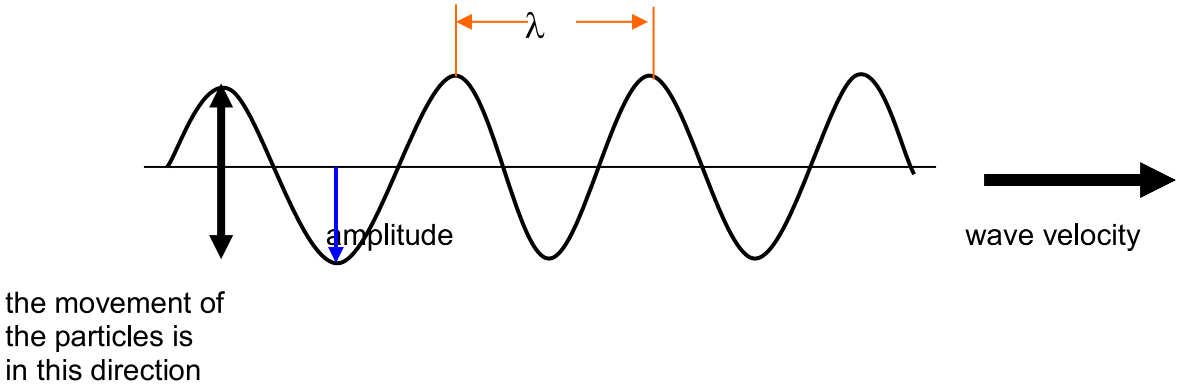


Lines close together represent high pressure regions, where there is less shading there is a lower pressure region. At the two positions of maximum pressure variation (compressions and rarefactions) the molecules at these points are in their rest position. The minimum pressure variation occurs when particles are the furthest from their rest positions. The air pressure is normal, (pressure variation is zero) midway between the compressions and rarefactions. When sound travels through air it is a series of compressions and rarefactions.

Transverse waves

When waves vibrate up and down in a direction perpendicular to the direction of motion of the wave, it is referred to as a transverse wave. e.g. water waves, where the motion of the water particles is at right angles (up and down) to the direction of the wave (forward).

A transverse wave is modelled below



Describing Waves

Waves can be characterised by key quantities: speed, frequency, period, amplitude and wavelength.

Frequency

Frequency is a measure of how rapidly the source of the wave is vibrating. The frequency (f) is defined as the number of vibrations per second. The units for frequency are Hertz, Hz, which are cycles per second.

Period (T)

The period is the length of time required for one full cycle of the wave to be complete. Frequency is the number of cycles per second, $\therefore\ f = \frac{1}{T}$, where T is the period, the time taken for 1 cycle.

Frequency is measured in Hertz or cycles per second.

Speed (v)

The speed of the wave is obviously how fast the wave is travelling. Sound waves propagate at about 330 m/s. The speed of light in a vacuum is 3×10^8 m/s. For a uniform medium, the speed is constant. The frequency, amplitude and wavelength of a wave do not change its speed.

Wave equation ($v = f\ \lambda$)

The wave equation links the velocity of the wave to the frequency and the wavelength.

$$\mathbf{v = f\ \lambda}$$

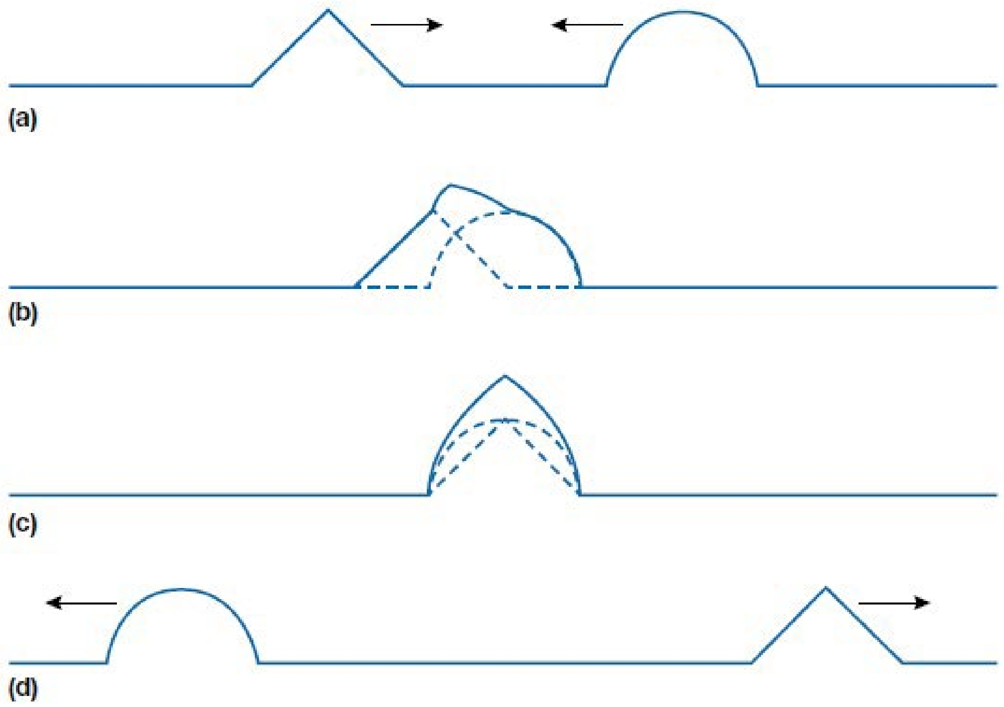
where v is the velocity in m/s, f is the frequency in Hz and λ is the wavelength in metres.

Amplitude

The amplitude of a wave is the distance from the rest position to the limit of a crest or trough; the total from crest to trough is **twice** the amplitude. The amplitude of the wave is an indication of the amount of energy that the wave is carrying.

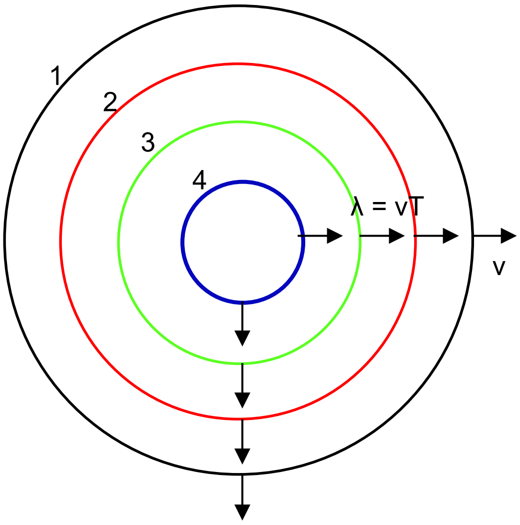
Superposition

The displacement of two waves combing with each other is calculated by the vector addition of the two components. The displacement of the combined pulse is the sum of the separate displacements.
The two pulses pass through each other without being altered. To find the total wave disturbance at any time, the individual displacements of each wave are added at each point.
When different sound waves pass through the same region of space, the individual waves add together to produce the resultant sound wave. This is called superposition.



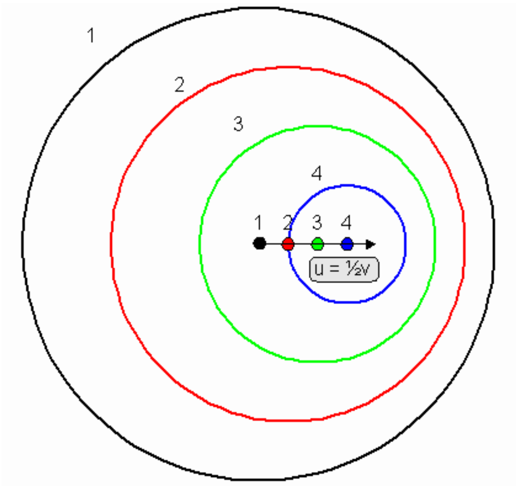
The Doppler Effect

If a wave source is stationary, then the waves will travel away from the source at the same speed in all directions. The wave fronts will be circular.



The Doppler effect is when the source of the sound wave is moving with respect to the observer.

As the source moves away from the observer there is an apparent increase in the wavelength and a decrease in the frequency.



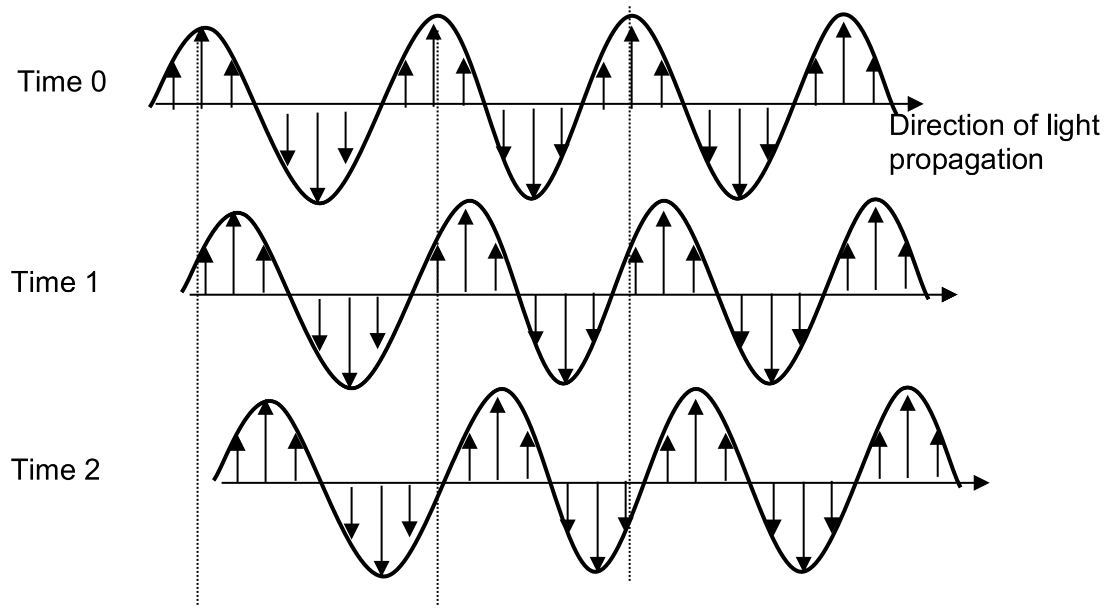
As the source moves towards the observer, there is an apparent shortening of the wavelength and hence an increase in the frequency.

Since the medium the wave is travelling in doesn't change, the speed of the wave remains constant. The wavefronts remain circular but the centre of the circle moves.

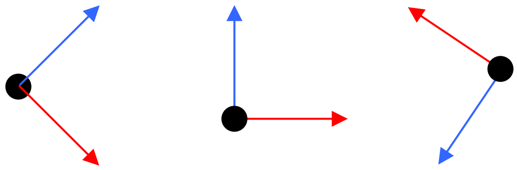
Using $v = f\lambda$, as the wavelength increases the frequency must decrease if v is constant.

Polarisation

Light is a transverse electromagnetic wave. The diagram below is a snapshot of an electromagnetic wave at three successive times. As the light propagates to the right, the electric field oscillates up and down as shown. There is a magnetic field oscillating into and out of the page, which is not shown.



The direction of oscillation of the electric field is called the polarization of the light. In a beam of light from most sources the light is unpolarised, which means that the electric fields of the light are oscillating in many different directions. Consider the diagram on the right. The light is travelling into the page. It is possible for the electric fields (blue arrows) and the magnetic fields (red arrows) to be oscillating in any direction, including the three shown. In unpolarised light, all of these directions are present at the same time.



Polaroid filters

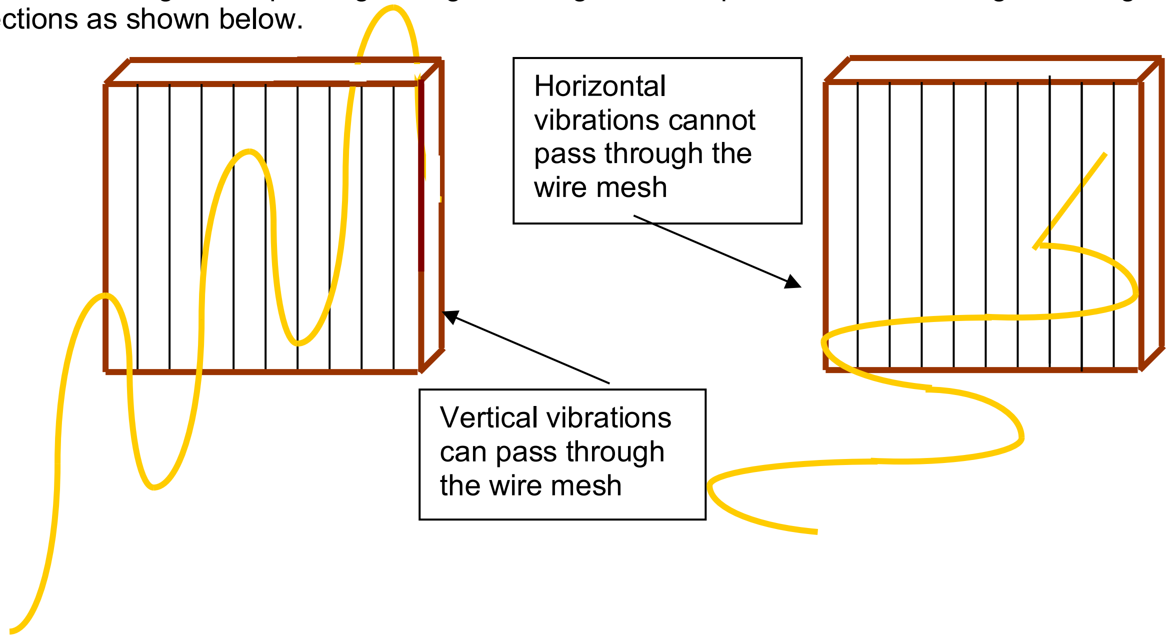
Polaroid filters select a particular polarisation state from an incident light wave. By convention the polarisation of a light wave is specified by the orientation of the electric field.
When we consider the intensity of the light before an after a polaroid filter, if the incident wave is unpolarised, then one half of the wave will emerge from the polaroid filter.
If the incident wave is unpolarised then the orientation of the polaroid filter doesn't matter.
If we place a second filter behind the first, with the same orientation, then the second filter has no effect.
If the second filter is oriented at right angles behind the first one, then no light emerges from the second filter.

Malus' Law

If the second filter is at an angle θ to the first one, then the intensity of the light that emerges from the combination of filters is $\frac{1}{2}\cos^2\theta$. This is called Malus' Law.

Polarising Light

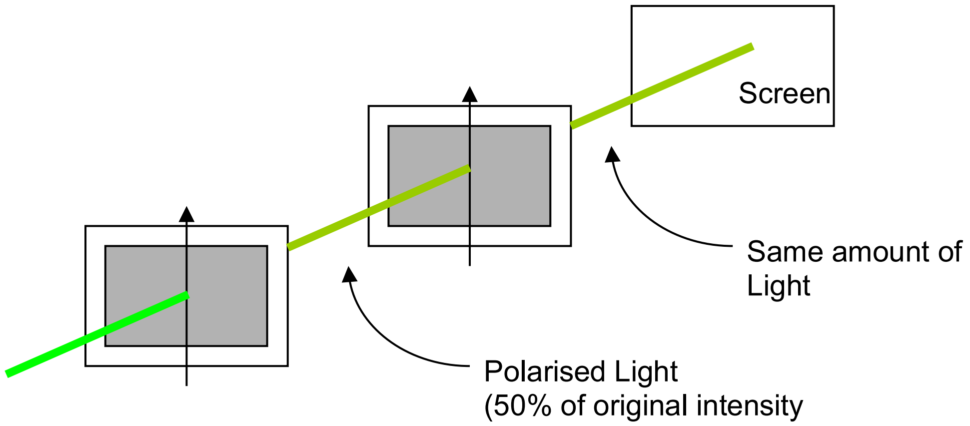
Consider a string that is passing through a wire grid. Wave passes are sent along the string in two directions as shown below.



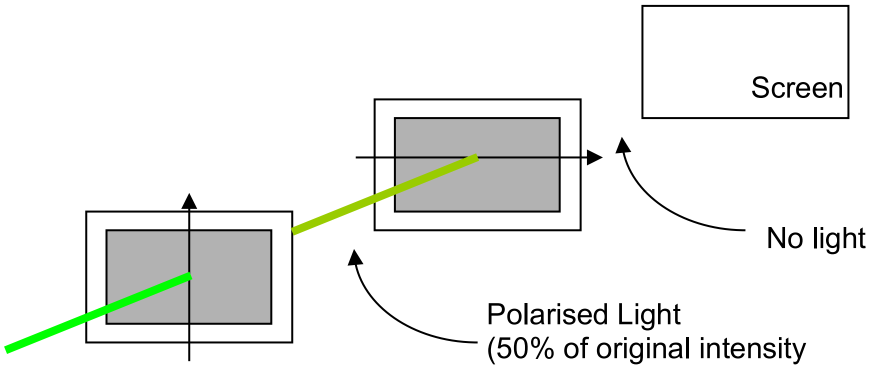
In a similar way, optical devices called polarisers only allow light with a specific polarisation to pass through them. This is commonly called plane polarisation.

Crossed Polarisers

If a second polariser is placed behind the first polariser, the amount of light getting through can be adjusted by rotating the second polariser. The arrow indicates the polarisation of light that gets through the polariser. If the directions of both polarisers are the same, then all of the light that gets through the first polariser will pass through the second polariser.



If the directions of both polarisers are at right angles to each other (called crossed polarisers), then no light will pass through.



For other angles, the amount of light getting through to the screen vary from almost all if the second polariser is nearly aligned, to next to nothing if the polarisers are almost crossed according to Malus' Law.

Sunglasses

When light reflects from a wet surface, it becomes partially horizontally polarised. Many sunglasses are designed to eliminate this glare. These sunglasses are polarised, so that they only allow light with a vertical polarisation to go through them. Light that is reflected from the water surface is not able to get through, and so the glare from the road is reduced.