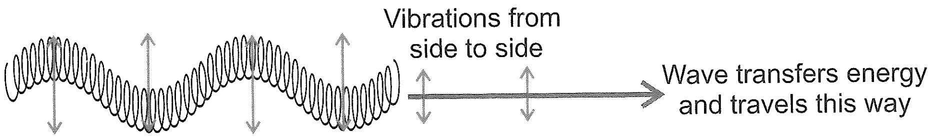
Waves

Waves Transfer *Energy* Without Transferring *Matter*

1) Waves are **oscillations** that transfer energy — like water waves or electromagnetic waves.
2) Waves carry **energy** from one place to another **without** transferring **matter**.

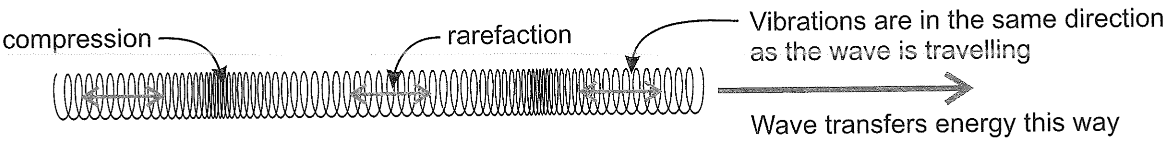
Transverse Waves Vibrate at *90°* to the Direction of Travel

Transverse waves have **vibrations** at **90°** to the direction of **energy transfer** and **travel**.
E.g. **electromagnetic** waves (like light) or shaking a Slinky® spring from side to side.



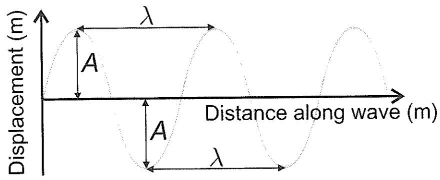
Longitudinal Waves Vibrate *Along* the Direction of Travel

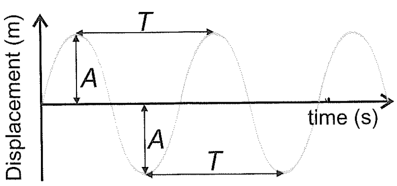
Longitudinal waves vibrate in the **same direction** as the direction of **energy transfer** and **travel**.
They are made of alternate **compressions** and **rarefactions** of the medium.
E.g. sound waves or pushing on the end of a Slinky® spring.



You Can Show Wave Motion on a *Graph*

A **displacement-distance** graph shows **how far** each part of the wave is **displaced** from its **equilibrium position** for different distances along the wave.





You can also consider **just one point** on a wave and plot how its **displacement** changes with **time**. This is a **displacement-time** graph.

Displacement = how far a point on the wave has moved from its equilibrium position
Amplitude (*A*) = the largest possible displacement from the equilibrium position
Wavelength (λ) = the length of one wave cycle, from crest to crest or trough to trough
Period (*T*) = the time taken for a whole cycle (vibration) to complete, or to pass a given point

Transverse waves are terrible singers — they always skip the chorus...

1) Sketch a graph of displacement against distance for five full wavelengths of a wave with amplitude 0.01 metres and wavelength 0.02 metres.
2) Sketch a graph of displacement against time for three complete oscillations of one part of a wave of amplitude 0.05 metres and time period 0.8 seconds.

Frequency and the Wave Equation

Frequency is the Number of *Oscillations per Second*

If a wave has a **time period** of 0.2 seconds, it takes 0.2 seconds for a point on the wave to complete **one full oscillation**. So in one second the point will complete **5 full oscillations**.

The number of oscillations that one point on a wave completes every second is called the **frequency** of the wave. It has the symbol ***f*** and is measured in **hertz** (Hz).

So a wave with a time period of 0.2 seconds has a **frequency** of 5 hertz.

The equation for frequency is:

$$\text{Frequency} = \frac{1}{\text{time period}} \quad \text{or} \quad f = \frac{1}{T}$$

> **EXAMPLE:** A wave has a frequency of 350 Hz. What is the period of oscillation of one point on that wave?
>
> $T = \frac{1}{f} = \frac{1}{350} = 0.002857... =$ **0.0029 s (to 2 s.f.)**

The *Wave Equation* Relates *Speed, Frequency* and *Wavelength*

For a wave of **frequency *f*** (in hertz), **wavelength λ** (in metres) and **wave speed *v*** (in metres per second) the wave equation is:

$$\textbf{speed = frequency × wavelength} \quad \text{or} \quad v = f \times \lambda$$

> **EXAMPLE:** Sound is a longitudinal wave. If a sound with a frequency of 250 Hz has a wavelength of 1.32 metres in air, what is the speed of sound in air?
>
> $v = f \times \lambda = 250 \times 1.32 =$ **330 ms^{-1}**

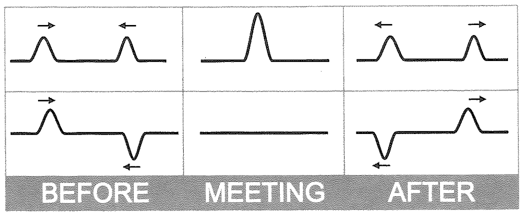
> **EXAMPLE:** All electromagnetic waves travel at 3.0×10^8 ms^{-1} in a vacuum. If a radio wave has a wavelength of 1.5 km in a vacuum, what is its frequency?
>
> $v = f \times \lambda$, so $f = \frac{v}{\lambda} = \frac{3.0 \times 10^8}{1.5 \times 10^3} =$ **200 000 Hz** (or 200 kHz)

Wave equation: lift arm + oscillate hand = pleasant non-vocal greeting...

1) A radio wave has a frequency of 6.25×10^5 Hz.
   What is the time period of the radio wave?
2) A sound wave has a time period of 0.0012 s. Find the frequency of the sound.
3) A wave along a spring has a frequency of 3.5 Hz and a wavelength of 1.4 m.
   What is the speed of the wave?
4) A wave has time period 7.1 s and is moving at speed 180 ms^{-1}.
   a) What is the frequency of the wave?
   b) What is the wavelength of the wave?

Superposition of Waves

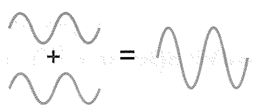
Superposition Happens When Two Waves Meet



1) If two waves meet (e.g. waves on a rope travelling in opposite directions), their displacements will briefly **combine**.
2) They become **one single wave**, with a **displacement** equal to the displacement of each individual wave **added together**.
3) This is called **superposition**.
4) If two **crests** meet, the **heights** of the waves are **added together** and the crest height **increases**. This is called **constructive interference** because the **amplitude** of the superposed waves is **larger** than the amplitude of the individual waves.
5) If the **crest** of one wave meets the **trough** of another wave, you **subtract** the trough **depth** from the crest **height**. So if the crest height is **the same** as the trough depth they'll **cancel out**. This is called **destructive interference** because the **amplitude** of the superposed waves is **smaller** than that of the individual waves.
6) After combining, the waves then carry on **as they were** before.

If Waves are *In Phase* they *Interfere Constructively*

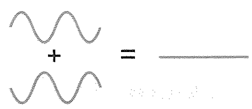
1) Two waves travelling in the **same direction** are **in phase** with each other when the **peaks** of one wave **exactly line up** with the **peaks** of the **other**, and the **troughs** of one wave **exactly line up** with the **troughs** of the **other**.
2) If these waves are **superposed**, they **interfere constructively**. The **combined amplitude** of the final wave is equal to the **sum** of the individual waves.



In phase, constructive interference

If Waves are *Out of Phase* they *Interfere Destructively*

1) Two waves are **exactly out of phase** if the **peaks** of one wave line up with the **troughs** of the other (and vice versa).
2) If these waves are **superposed**, they **interfere destructively**. If the individual waves had the same amplitude originally, they will **cancel each other out**.



Out of phase, destructive interference

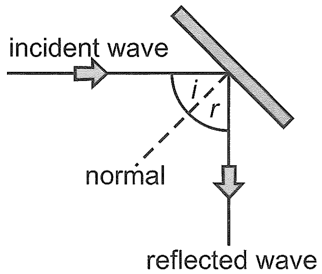
Constructive interference — getting woken up early by noisy builders...

1) What is meant by:
   a) superposition?
   b) constructive interference?
   c) destructive interference?
2) A wave with an amplitude of 0.67 mm is superposed with an identical wave with the same amplitude. The waves are in phase. What is the amplitude of the superposed wave?
3) Two waves, both of amplitude 19.1 m, are exactly out of phase. What is the amplitude of the single wave formed when they superpose?
4) A wave with an amplitude of 35 cm is in phase with a 41 cm amplitude wave. The waves meet and constructive interference occurs. What is the amplitude of the combined wave?

Reflection and Diffraction

Waves can be Reflected

1) When a wave hits a **boundary** between one medium and another, some (or nearly all) of the wave is **reflected back.**

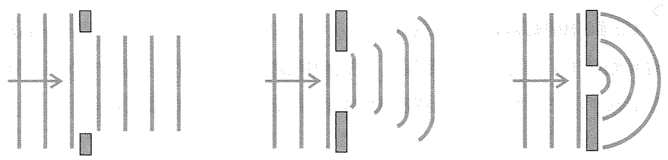


2) The angle of the **incident** (incoming) wave is called the **angle of incidence**, and the angle of the **reflected** wave is called the **angle of reflection.**
3) The angles of incidence and reflection are both **measured from the normal** — an imaginary line running **perpendicular** to the **boundary**.
4) The **law of reflection** says that:

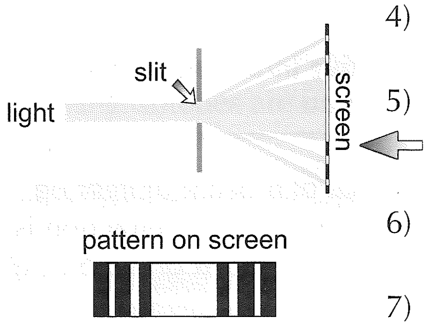
angle of incidence (*i*) = angle of reflection (*r*)

Diffraction — Waves Spreading Out

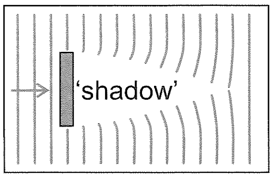
1) Waves **spread out** ('**diffract**') at the edges when they pass through a **gap** or **pass an object**.
2) The **amount** of diffraction depends on the **size** of the gap relative to the **wavelength** of the wave. The **narrower the gap**, or the **longer the wavelength**, the more the wave spreads out.



3) A **narrow gap** is one about the same size as the **wavelength** of the wave. So whether a gap counts as narrow or not depends on the wave.



4) If light is shone at a **narrow slit** about the **same width** as the **wavelength** of the light, the light **diffracts**.
5) The diffracted light forms a **diffraction pattern** of **bright** and **dark fringes**. This pattern is caused by **constructive** and **destructive interference** of light waves (see p.34).
6) You get diffraction around the edges of **obstacles** too.
7) The **shadow** is where the wave is **blocked**. The **wider** the obstacle compared to the **wavelength**, the **less diffraction** it causes, so the **longer** the shadow.



Mind the gap between the train and the platform — you might diffract...

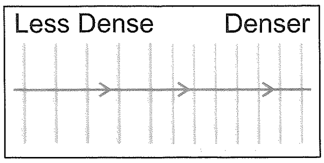
1) What is the law of reflection?
2) Sketch a diagram of a light wave being reflected at an angle by a mirror. Label the incident and reflected waves, the normal, the angle of incidence and the angle of reflection.
3) A water wave travels through a gap about as wide as its wavelength. The gap is made slightly larger. How will the amount of diffraction change?
4) What happens when light is shone at a slit about the same size as its wavelength?

Refraction

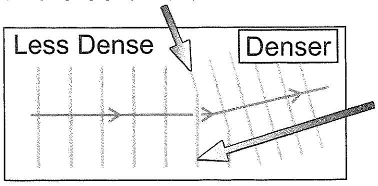
*Waves can be **Refracted***

1) Reflection isn't all that happens when a wave meets a boundary. Usually, some of it is **refracted** too — it passes through the boundary and **changes direction**.
2) Waves travel at **different speeds** in **different media**.
   E.g. — electromagnetic waves, like light, usually travel slower in denser media.

If a wave hits a boundary 'face on', it **slows down** without changing direction.



But if the wave hits at an angle, this bit **slows down first**...



...while this bit carries on at the same speed until it meets the boundary. The wave **changes direction**.

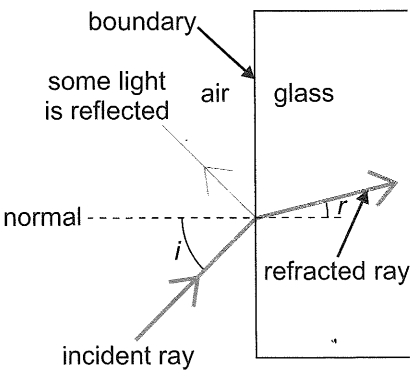
When an electromagnetic wave enters a **denser** medium, it bends **towards** the normal. When one enters a **less dense** medium, it bends **away** from the normal.

*The **Refractive Index** is a **Ratio of Speeds***

The **refractive index** of a medium, *n*, is the **ratio** of the speed of light in a **vacuum** to the speed of light in **that medium**. **Every** transparent material has a refractive index and different materials have **different refractive indices**.

*You can **Calculate** the Refractive Index using **Snell's Law***

When an **incident ray** travelling in **air** meets a boundary with **another material**, the **angle of refraction** of the ray, *r*, depends on the **refractive index** of the material and the **angle of incidence**, *i*.



This is called **Snell's Law**. **refractive index (*n*)** = $\frac{\sin i}{\sin r}$

> **EXAMPLE:** The angle of incidence of a beam of light on a glass block is 65°. The angle of refraction is 35°. What is the refractive index of the block?
>
> $n = \frac{\sin i}{\sin r} = \frac{\sin 65}{\sin 35} = 1.580... = \mathbf{1.6}$

You can **rearrange** Snell's Law to find an angle of refraction or incidence, e.g. $r = \sin^{-1}(\frac{\sin i}{n})$.

This page has a high refractive index — it's really slowed me down...

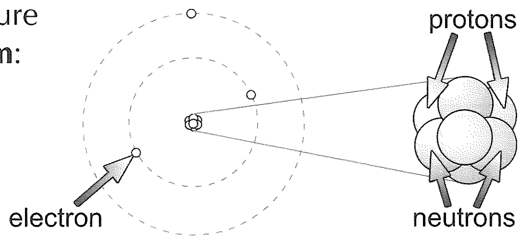
1) A wave hits a boundary between two media head on. Describe what happens to the wave.
2) A wave hits a boundary between two media at an angle. Describe what happens to the wave.
3) A light wave travelling in air hits a transparent material at an angle of 72° to the normal to the boundary. The angle of refraction is 39°. What is the refractive index of the material?
4) A light wave hits the surface of the water in a pond at 23° to the normal. The refractive index of the pond water is 1.3. What is the angle of refraction?

Atomic Structure

*Atoms are **Made Up** of **Three** Types of **Particle***

1) According to the **nuclear model**, the atom is made up of electrons, protons and neutrons.
2) The **nucleus** is at the **centre** of the atom. It contains **protons** (which have a **positive** charge) and **neutrons** (which have **no charge**), giving the nucleus an **overall positive charge**. Protons and neutrons are both known as **nucleons**.
3) The nucleus is **tiny** but it makes up **most** of the **mass** of the atom. The rest of the atom is mostly **empty space**, containing only the negative **electrons** which orbit **around** the nucleus.

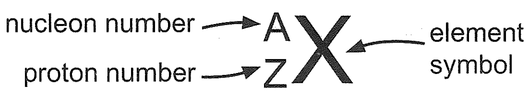
Here's the structure of a **lithium atom**:



	relative mass	relative charge
proton	1	+1
neutron	1	0
electron	0.0005	–1

Atomic Structure** can be **Represented** Using **Nuclide Notation

1) The **proton number** (or atomic number), **Z**, is the number of **protons** in an atom.
2) The **nucleon number** (or mass number), **A**, is the total number of **protons** and **neutrons**.
3) An element can be **described** by its **proton** and **nucleon numbers**:



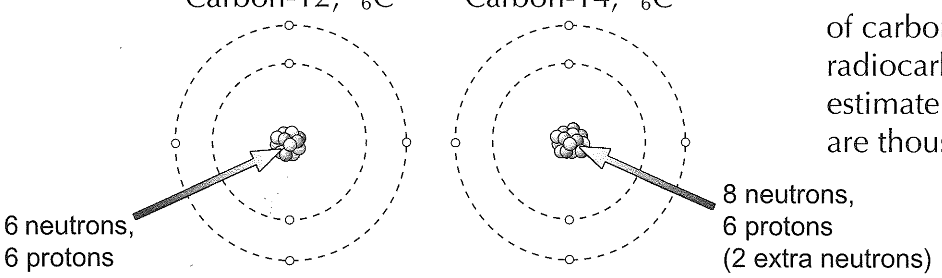
For example, lithium has 4 neutrons and 3 protons, so its symbol is $^{7}_{3}\mathrm{Li}$.

Isotopes** are **Different Forms** of the **Same Element

1) Isotopes are atoms with the **same number** of **protons** but a **different number** of **neutrons**.
2) This means they have the **same proton number**, but **different nucleon numbers**.
3) Many isotopes are **unstable** and give off **radiation** (see next page).

EXAMPLE: Carbon-12 and carbon-14 are two isotopes of carbon.

Carbon-12, $^{12}_{6}\mathrm{C}$ Carbon-14, $^{14}_{6}\mathrm{C}$



The radioactive decay of carbon-14 is used in radiocarbon dating to estimate the age of things that are thousands of years old.

Radiocarbon dating — what physicists do on Valentine's Day...

1) How many protons and neutrons are there in each of the following nuclei?
   a) $^{241}_{95}\mathrm{Am}$ b) $^{239}_{94}\mathrm{Pu}$ c) $^{90}_{38}\mathrm{Sr}$ d) $^{60}_{27}\mathrm{Co}$ e) $^{226}_{88}\mathrm{Ra}$
2) What is an isotope of an element?