Wave Basics

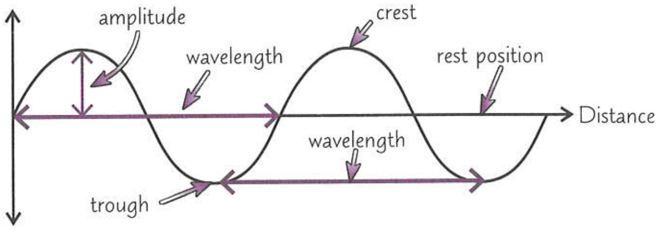
Waves transfer energy from one place to another without transferring any matter (stuff). Clever so and so's.

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.

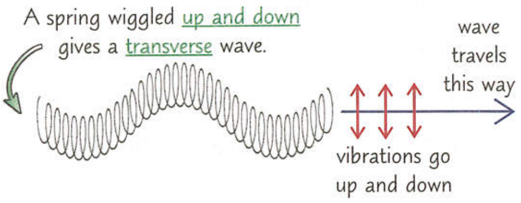
1) The amplitude of a wave is the displacement from the rest position to a crest or trough.
2) The wavelength is the length of a full cycle of the wave (e.g. from crest to crest, or from compression to compression — see below).
3) Frequency is the number of complete cycles of the wave passing a certain 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.

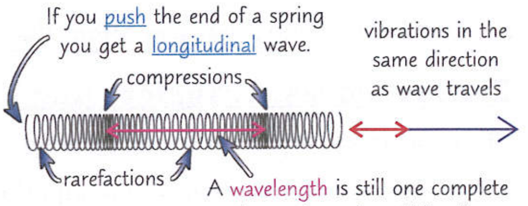
Transverse Waves Have Sideways Vibrations

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).



A wavelength is still one complete cycle, e.g. from the middle of one compression to the middle of another.

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:

Wave speed (m/s)

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

Distance (m)

Time (s)

This is called the wave equation.

Wave speed (m/s)

$$v = f\lambda$$

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

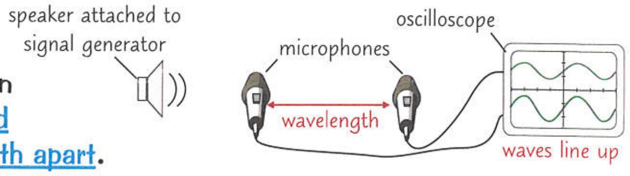
PRACTICAL

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.

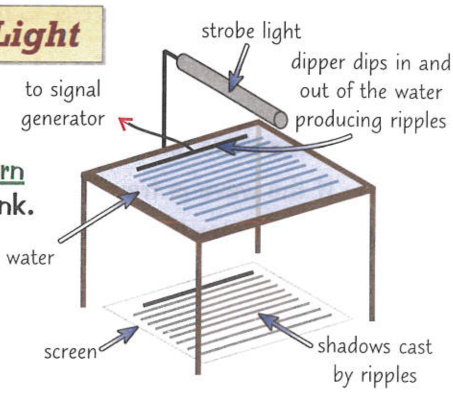
1) Set up the oscilloscope so the detected waves at each microphone are shown as separate waves.
2) Start with both microphones next to the speaker, then slowly move one away until the two waves are aligned on the display, but have moved exactly one wavelength apart.



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.

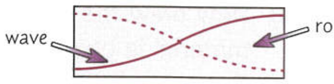


You can find the frequency by using a regular light, so you can see the waves moving. Count how many waves pass a mark on the screen in a given time, then divide this by the time in seconds to find the frequency.

Use Peak Frequency to find the Speed of Waves in Solids

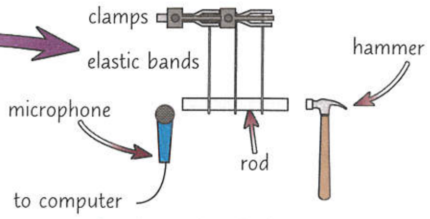
You can find the speed of waves in a solid by measuring the frequency of the sound waves produced when you hit the object, e.g. a rod, with a hammer. Hitting the rod causes waves to be produced along the rod. These waves make the rod vibrate and produce sound waves in the air around the rod (this is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

Wave Behaviour at Boundaries

When waves cross a boundary, they can be absorbed, transmitted, reflected, refracted... Read on for more.

Waves Are Absorbed, Transmitted and Reflected at Boundaries

When a wave meets a boundary between two materials (a material interface), three things can happen:

1) The wave is ABSORBED by the second material — the wave transfers energy to the material's energy stores. Often, the energy is transferred to a thermal energy store, which leads to heating (this is how a microwave works, see page 46).
2) The wave is TRANSMITTED through the second material — the wave carries on travelling through the new material. This often leads to refraction (see below). This can be used in communications (p.46) as well as in the lenses of glasses and cameras (p.41).
3) The wave is REFLECTED — this is where the incoming ray is neither absorbed or transmitted, but instead is 'sent back' away from the second material (see p.38). This is how echoes are created.

What actually happens depends on the wavelength of the wave and the properties of the materials involved.

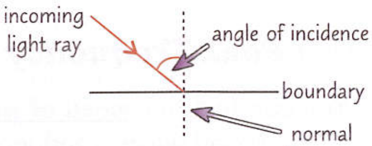
Refraction — Waves Changing Direction at a Boundary

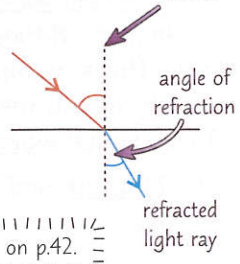
You might see refraction of light talked about in terms of 'optical density'.

1) Waves travel at different speeds in materials with different densities. So when a wave crosses a boundary between materials it changes speed.
2) If the wave hits the boundary at an angle, this change of speed causes a change in direction — refraction.
3) If the wave is travelling along the normal it will change speed, but it's NOT refracted.
4) The greater the change in speed, the more a wave bends (changes direction).
5) The wave bends towards the normal if it slows down, and away from the normal if it speeds up.
6) Electromagnetic (EM) waves (see p.43) like light usually travel more slowly in denser materials.
7) How much an EM wave refracts can be affected by its wavelength — shorter wavelengths bend more. This can lead to the wavelengths spreading out (dispersion), e.g. white light becoming a spectrum.
8) The frequency of a wave stays the same when it crosses a boundary. As $v = f\lambda$, this means that the change in speed is caused by a change in wavelength — the wavelength decreases if the wave slows down, and increases if it speeds up.

A ray diagram shows the path that a wave travels. You can draw one for a refracted light ray:

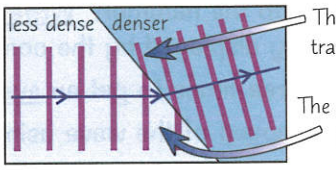
1) First, start by drawing the boundary between your two materials and the normal (a line that is at 90° to the boundary).
2) Draw an incident ray that meets the normal at the boundary.
3) The angle between the ray and the normal is the angle of incidence. (If you're given this angle, make sure to draw it carefully using a protractor.)
4) Now draw the refracted ray on the other side of the boundary. If the second material is optically denser than the first, the refracted ray bends towards the normal (like on the right). The angle between the refracted ray and the normal (the angle of refraction) is smaller than the angle of incidence.
5) If the second material is less optically dense, the angle of refraction is larger than the angle of incidence.





There are more ray diagrams on p.42.

9) You can also show refraction using wave front diagrams. When one part of the wave front crosses a boundary into a denser material, that part travels slower than the rest of the wavefront, so the wave bends.



This part of the wave front travels slower than the rest.

The space between wave fronts shows the wavelength.

Red light bends the least — it should try yoga...

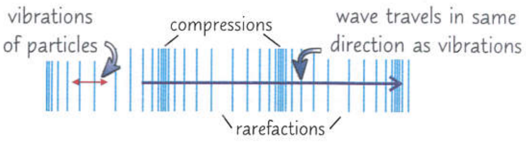
Refraction has loads of uses (e.g. in glasses, cameras and telescopes) so make sure you really understand it.

Q1 A light ray enters air from water at 50° to the normal. How does it bend relative to the normal? [1 mark]

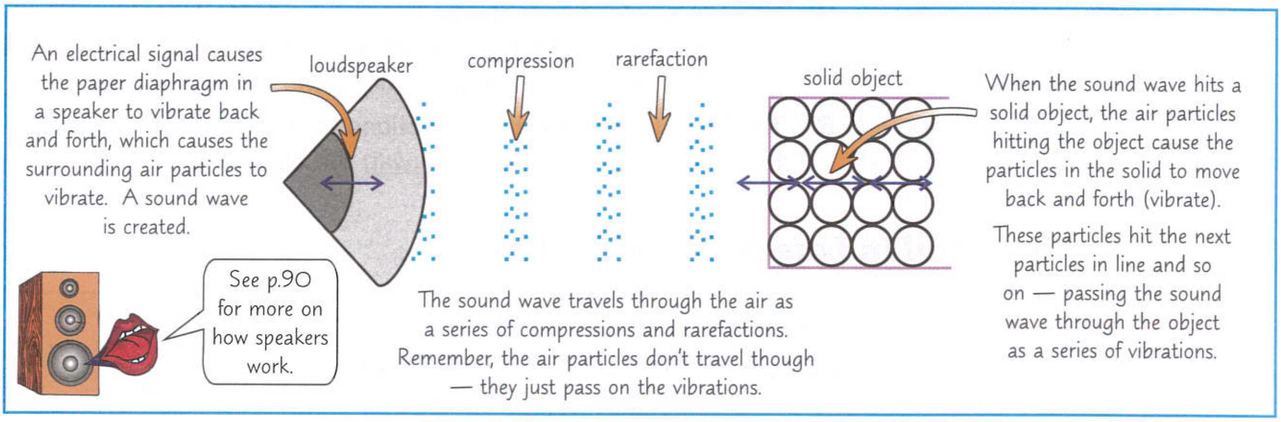
Sound

Time to learn all about the properties of sound waves and how they cause us to hear things. Don't panic though — you won't be quizzed on each individual part of the ear, just make sure you have a general idea.

Sound Travels as a Wave



1) Sound waves are caused by vibrating objects.
2) These vibrations are passed through the surrounding medium as a series of compressions and rarefactions. Sound waves are a type of longitudinal wave (see page 32).
3) When a sound wave travels through a solid it does so by causing particles in the solid to vibrate.
4) However, not all frequencies of sound can be transferred through an object. An object's **SIZE**, **SHAPE** and **STRUCTURE** determines which frequencies it can transmit.



An electrical signal causes the paper diaphragm in a speaker to vibrate back and forth, which causes the surrounding air particles to vibrate. A sound wave is created.

See p.90 for more on how speakers work.

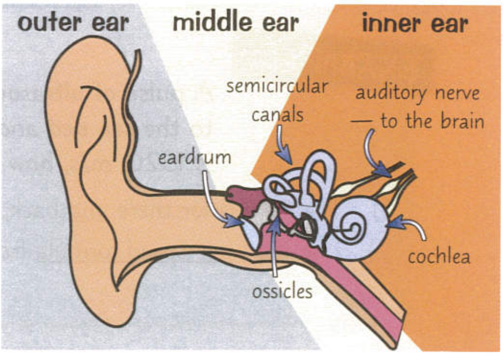
The sound wave travels through the air as a series of compressions and rarefactions. Remember, the air particles don't travel though — they just pass on the vibrations.

When the sound wave hits a solid object, the air particles hitting the object cause the particles in the solid to move back and forth (vibrate).

These particles hit the next particles in line and so on — passing the sound wave through the object as a series of vibrations.

5) Sound travels at different speeds in different media — sound waves generally travel faster in liquids than they do in gases, and faster in solids than they do in liquids.
6) Like all waves, the frequency of sound doesn't change when it passes from one medium into another. But because $v = f\lambda$ the wavelength does — it gets longer when the wave speeds up, and shorter when it slows down.
7) So sound waves can refract as they enter different media. (However, since sound waves are always spreading out so much, the change in direction is hard to spot under normal circumstances.)
8) Sound waves will be reflected by hard, flat surfaces. Echoes are just reflected sound waves.
9) Sound can't travel in space because it's mostly a vacuum (there are no particles to move or vibrate).

You Hear Sound When Your Eardrum Vibrates



1) Sound waves that reach your eardrum cause it to vibrate.
2) These vibrations are passed on to tiny bones in your ear called ossicles, through the semicircular canals and to the cochlea.
3) The cochlea turns these vibrations into electrical signals which get sent to your brain.
4) The brain interprets the signals as sounds of different pitches and volumes, depending on their frequency and intensity. A higher frequency sound wave has a higher pitch.
5) Human hearing is limited by the size and shape of our eardrum, and the structure of all the parts within the ear that vibrate to transmit the sound wave.

Sorry, listening to music doesn't count as revision...

Make sure you know that sound waves make solids vibrate and that your vibrating eardrum lets you hear them.

Q1 Briefly describe how you hear a sound wave. [3 marks]

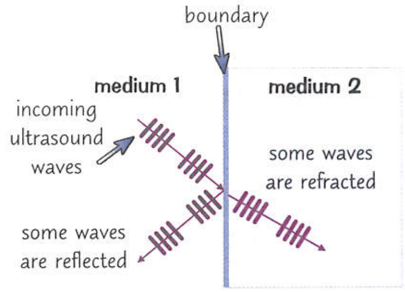
Ultrasound

Can you hear that? If not, 'that' could be ultrasound — a handy wave used for seeing hidden objects.

Ultrasound is Sound with Frequencies Higher Than 20 000 Hz

Electrical devices can be made that produce electrical oscillations of any frequency. These can easily be converted into mechanical vibrations to produce sound waves above 20 000 Hz (i.e. above the range of human hearing). This is called ultrasound and it pops up all over the place.

Ultrasound Waves Get Partially Reflected at Boundaries

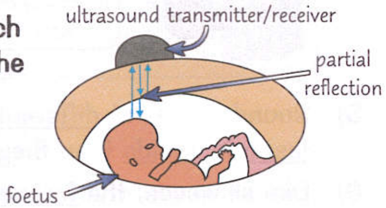


1) When a wave passes from one medium into another, some of the wave is reflected off the boundary between the two media, and some is transmitted (and refracted). This is partial reflection.
2) What this means is that you can point a pulse (short burst) of ultrasound at an object, and wherever there are boundaries between one substance and another, some of the ultrasound gets reflected back.
3) The time it takes for the reflections to reach a detector can be used to measure how far away the boundary is.

Ultrasound is Useful in Lots of Different Ways

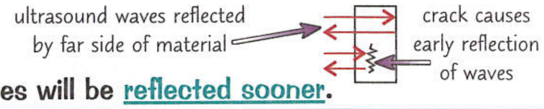
Medical imaging, e.g. pre-natal scanning of a foetus

1) Ultrasound waves can pass through the body, but whenever they reach a boundary between two different media (like fluid in the womb and the skin of the foetus) some of the wave is reflected back and detected.
2) The exact timing and distribution of these echoes are processed by a computer to produce a video image of the foetus.
3) So far as we know, ultrasound imaging like this is completely safe.



Industrial imaging, e.g. finding flaws in materials

1) Ultrasound can also be used to find flaws in objects such as pipes, or materials such as wood or metal.
2) Ultrasound waves entering a material will usually be reflected by the far side of the material.
3) If there is a flaw such as a crack inside the object, the waves will be reflected sooner.

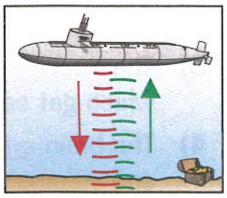


Ultrasound is also used in echo sounding, which is a type of sonar used by boats and submarines to find out the distance to the seabed or to locate objects in deep water.

EXAMPLE:

A pulse of ultrasound takes 4.5 seconds to travel from a submarine to the sea bed and back again. If the speed of sound in seawater is 1520 m/s, how far away is the submarine from the seabed?

1) The 4.5 s is for there and back, so halve the time. $4.5 \div 2 = 2.25$ s
2) Use the wave speed formula from p.32. $x = vt = 1520 \times 2.25$
$= 3420$ m



Partially reflected — completely revised...

Ultrasound waves are really useful, so make sure you can describe how looking at the time taken for them to be reflected can let you see the structure of things you would otherwise be unable to — like the inside of a metal.

Q1 Calculate how long it takes for an ultrasound pulse to return to a submarine from the seabed, if the speed of sound in seawater is 1520 m/s and the submarine is 2500 m above the seabed. [3 marks]

Infrasound and Seismic Waves

Studying the paths of certain types of wave through structures can give you clues to some of the properties of the structure that you can't see by eye. You've already seen this with ultrasound, time for some more.

Infrasound is Sound with Frequencies Lower Than 20 Hz

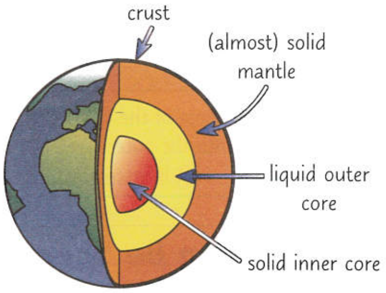
1) Infrasound waves are sound waves so low in frequency that we can't hear them — they're under 20 Hz.
2) Some animals communicate using infrasound — for example elephants and whales. By detecting infrasound, scientists are able to track these animals for conservation purposes.
3) Natural events like erupting volcanoes, avalanches and earthquakes also produce infrasound in the local area. Scientists can monitor infrasound to try to predict events, e.g. if a volcano will shortly erupt.
4) Earthquakes also produce waves that travel through the different layers of the Earth. Some of these waves have frequencies less than 20 Hz — i.e. they're infrasound waves. We can use these waves to explore the structure of the Earth (see below).

Earthquakes and Explosions Cause Seismic Waves

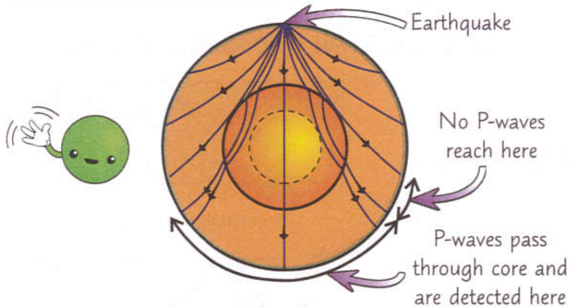
1) When there's an earthquake somewhere, it produces seismic waves at a range of frequencies which travel out through the Earth. We detect these waves all over the surface of the planet using seismometers.
2) Seismologists work out the time it takes for the waves to reach each seismometer. They also note which parts of the Earth don't receive the waves at all.
3) When seismic waves reach a boundary between different layers of material (which all have different properties, like density) inside the Earth, some waves will be absorbed and some will be refracted.
4) Most of the time, if the waves are refracted, they change speed gradually, resulting in a curved path. But when the properties change suddenly, the wave speed changes abruptly, and the path has a kink.

P-waves Can Travel Through the Earth's Core, S-waves Can't

1) The main two seismic waves you need to know about are P-waves and S-waves.
2) By observing how seismic waves are absorbed and refracted, scientists have been able to work out where the properties of the Earth change dramatically. Our current understanding of the internal structure of the Earth and the size of the Earth's core is based on these observations.

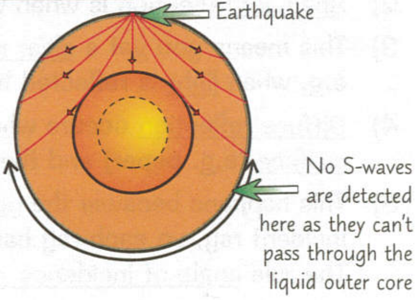


P-waves inside the Earth



P-waves are longitudinal.
They travel through solids and liquids.
They travel faster than S-waves.

S-waves inside the Earth



S-waves are transverse and only travel through solids. They're slower than P-waves.

I'll take an Earth with a gooey filling and a crispy crust to go...

Wow, who knew earthquakes could be so educational as well as destructive...

Q1 S-waves produced at the Earth's North Pole would not be detected at the South Pole. Suggest one conclusion you can make about the Earth's core from the observation. Explain your answer. [2 marks]

Reflection

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

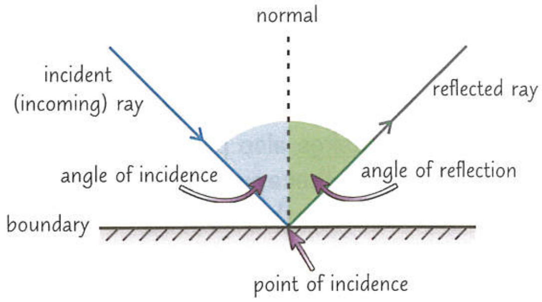
You Can Draw a Simple Ray Diagram for Reflection

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

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

   Angle of incidence = Angle of reflection

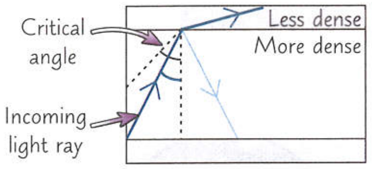
2) The angle of incidence is the angle between the incoming wave and the normal.
3) The angle of reflection is the angle between the reflected wave and the normal.
4) The normal is an imaginary line that's perpendicular (at right angles) to the surface at the point of incidence (the point where the wave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



Total Internal Reflection Depends on the Critical Angle

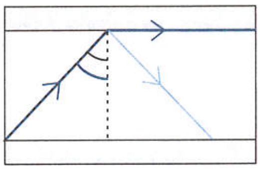
1) A wave hitting a surface can experience total internal reflection (it is reflected back into the material).
2) This can only happen when the wave travels through a dense material like glass or water towards a less dense substance like air.
3) This happens when the angle of incidence, *i*, is larger than the critical angle for that particular material — every material has its own, different critical angle.

If *i* is less than the critical angle



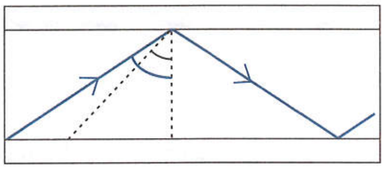
Most of the light is refracted into the outer layer, but some of it is internally reflected.

If *i* is equal to the critical angle



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

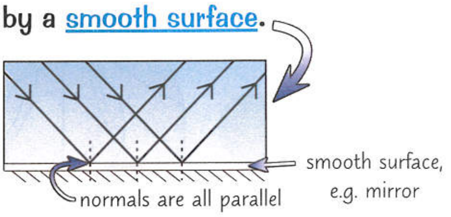
If *i* is larger than the critical angle

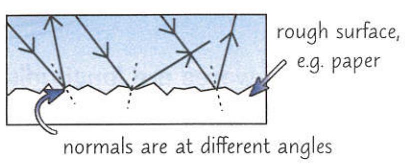


No light comes out. It's all internally reflected, i.e. total internal reflection.

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.

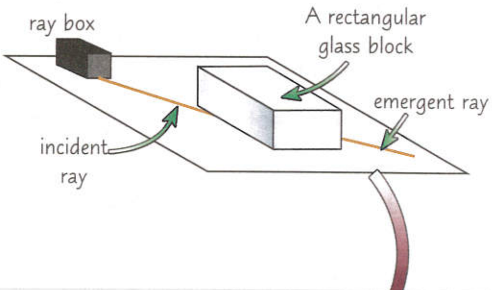
You Need to Do This Experiment in a Dim Room

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.

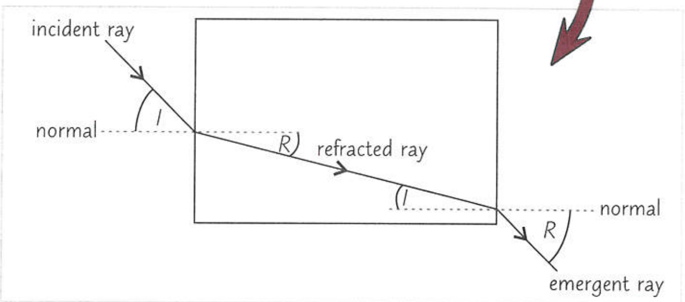
You Can Use a Glass Block to Investigate Refraction

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.



You should draw...



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.

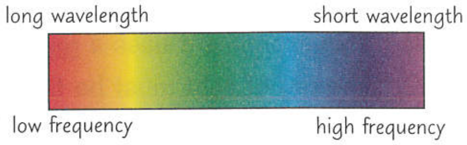
Q1 a) Describe an experiment you could do to measure how much light is refracted when it enters a glass block. [3 marks]

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

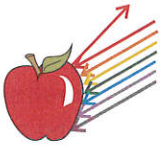
Visible Light and Colour

The colour something appears to be is all about what wavelengths of light we're seeing when we look at it.

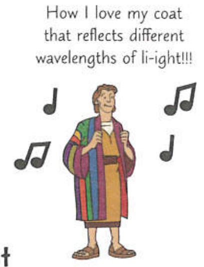
Colour and Transparency Depend on Absorbed Wavelengths



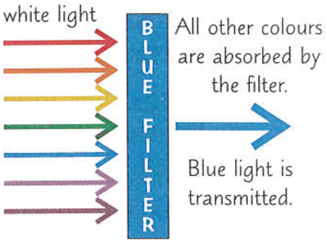
1) Colour is about differences in absorption, transmission and reflection of different wavelengths by different materials.
2) White light is a mixture of all the different colours of light, which all have different wavelengths.
3) Different objects absorb, transmit and reflect different wavelengths of light in different ways.
4) Opaque objects are objects that do not transmit light. When visible light waves hit them, they absorb some wavelengths of light and reflect others.
5) The colour of an opaque object depends on which wavelengths of light are reflected. E.g. a red apple appears to be red because the wavelengths corresponding to the red part of the visible spectrum are reflected.



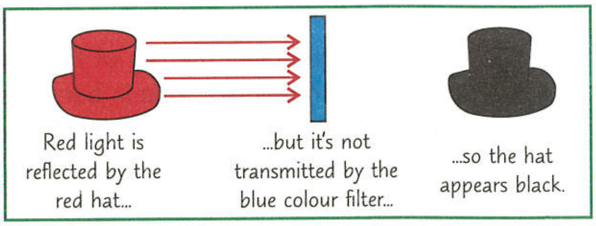
6) Colours can also mix together to make other colours. The only colours you can't make by mixing are the primary colours: pure red, green and blue. So a banana may look yellow because it's reflecting yellow light OR because it's reflecting both red and green light.
7) White objects reflect all of the wavelengths of visible light equally.
8) Black objects absorb all wavelengths of visible light. Your eyes see black as the lack of any visible light (i.e. the lack of any colour).
9) Transparent (see-through) and translucent (partially see-through) objects transmit light, i.e. not all light that hits the surface of the object is absorbed or reflected — some (or most for transparent objects) can pass through.
10) Some wavelengths of light may be absorbed or reflected by translucent and (to a lesser extent) transparent objects. These objects will appear to be the colour of light that corresponds to the wavelengths most strongly transmitted by the object.



Colour Filters Only Let Through Particular Wavelengths



1) Colour filters are used to filter out different wavelengths of light, so that only certain colours (wavelengths) are transmitted — the rest are absorbed.
2) A primary colour filter only transmits that colour, e.g. if white light is shone at a blue colour filter, only blue light will be let through. The rest of the light will be absorbed.
3) If you look at a blue object through a blue colour filter, it would still look blue. Blue light is reflected from the object's surface and is transmitted by the filter.
4) However, if the object was e.g. red (or any colour not made from blue light), the object would appear black when viewed through a blue filter. All of the light reflected by the object will be absorbed by the filter.
5) Filters that aren't for primary colours let through both the wavelengths of light corresponding to that colour and the wavelengths of the primary colours that can be added together to make that colour. E.g. cyan can be made from blue and green light mixed together. So a cyan colour filter will let through the wavelengths of light that correspond to cyan, blue and green.



Have you seen my white shirt? It's red and yellow and green and...

Hopefully you now know enough about absorption and reflection that you're feeling pretty confident. Once you've got them down, this page is pretty easy — red objects reflect red light and red filters let red light through. Simple.

Q1 a) Explain why a cucumber looks green. [2 marks]
b) State the colour a cucumber would look if you looked at it through a red filter. [1 mark]

Lenses

Lenses bring light rays to a focus or spread them out. Which is pretty darn useful, I can tell you.

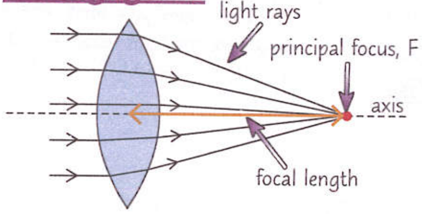
Different Lenses Produce Different Kinds of Image

Lenses form images by refracting light (p.34) and changing its direction. There are two main types of lens — converging and diverging. They have different shapes and have opposite effects on light rays.

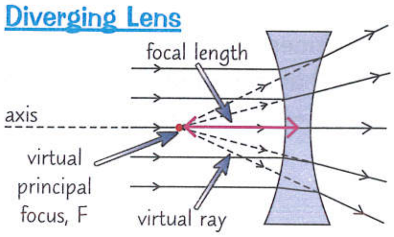
1) A converging lens bulges outwards in the middle. It causes parallel rays of light to be brought together (converge) at the principal focus. They're sometimes called convex lenses.
2) A diverging (or concave) lens caves inwards. It causes parallel rays of light to spread out (diverge).
3) The axis of a lens is a line passing through the middle of the lens.
4) The principal focus of a converging lens is where rays hitting the lens parallel to the axis all meet.
5) The principal focus of a diverging lens is the point where rays hitting the lens parallel to the axis appear to all come from — you can trace them back until they all appear to meet up at a point behind the lens.
6) There is a principal focus on each side of the lens. The distance from the centre of the lens to the principal focus (F) is called the focal length.

When a ray enters any lens, it bends towards the normal. When it leaves, it bends away from the normal (p.34).

Converging Lens



Diverging Lens

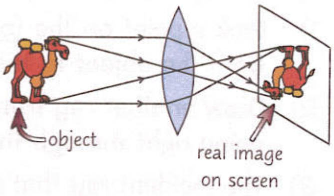


To describe an image, say if it's bigger or smaller than the object, if it's upright or inverted and if it's real or virtual.

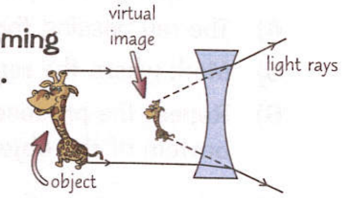
Images are formed at points where all the light rays from a certain point on an object appear to come together.

There are two types of images that can be formed by lenses:

1) A **REAL image** is formed when the light rays actually come together to form the image. The image can be captured on a screen, because the light rays actually meet at the place where the image seems to be. E.g. the image formed on the eye's retina.



2) A **VIRTUAL image** is when the light rays from the object appear to be coming from a completely different place to where they're actually coming from. The light rays don't actually come together at the point where the image seems to be, so it cannot be captured on a screen. E.g. magnifying glasses create virtual images.



The Power of a Lens Increases with its Curvature

1) Focal length is related to the power of the lens. The more powerful the lens, the more strongly it converges rays of light, so the shorter the focal length.
2) For a converging lens, the power is positive. For a diverging lens, the power is negative.
3) The curvature of a lens affects its power. To make a more powerful lens from a certain material like glass, you just have to make it with more strongly curved surfaces.
4) Some materials are better at focusing light than others. This means powerful lenses can be made thinner by changing the material they're made from (using a material that's better at focusing light means you don't need to make the lens as curved to get the same focal length).

He's magnificent, that pug...

Make sure you know the differences between real and virtual images — they can be pretty tough.

Q1 What is the principal focus of: a) a converging lens b) a diverging lens? [2 marks]

Q2 Sketch parallel rays of light being focused by a converging lens. [2 marks]

Lenses and Ray Diagrams

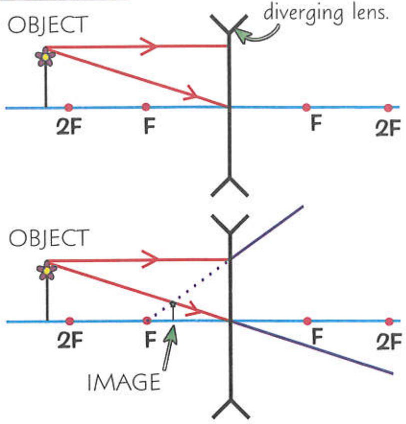
You need to be able to draw ray diagrams for converging and diverging lenses too.

Draw a Ray Diagram for an Image Through a Diverging Lens

1) Pick a point on the top of the object. Draw a ray going from the object to the lens parallel to the axis of the lens.
2) Draw another ray from the top of the object going right through the middle of the lens.
3) The incident ray that's parallel to the axis is refracted so it appears to have come from the principal focus (F). Draw a ray from the principal focus. Make it dotted before it reaches the lens (as it's virtual here).
4) The ray passing through the middle of the lens doesn't bend.
5) Mark where this ray meets the virtual ray. That's the top of the image.
6) Repeat the process for a point on the bottom of the object. When the bottom of the object is on the axis, the bottom of the image is also on the axis.

A diverging lens always produces a virtual image. The image is the right way up, smaller than the object and on the same side of the lens as the object — no matter where the object is.

This represents a diverging lens.

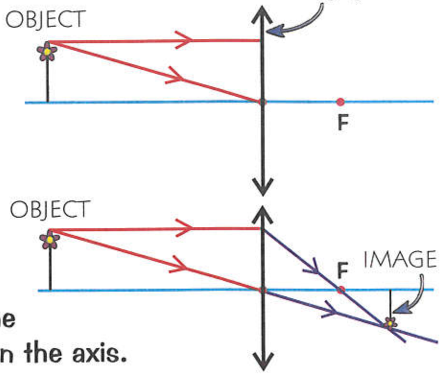


If you get a lens that looks like this in your exam, you don't need to show how the light refracts inside it.

Draw a Ray Diagram for an Image Through a Converging Lens

1) Pick a point on the top of the object. Draw a ray going from the object to the lens parallel to the axis of the lens.
2) Draw another ray from the top of the object going right through the middle of the lens.
3) The incident ray that's parallel to the axis is refracted through the principal focus (F). Draw a refracted ray passing through F.
4) The ray passing through the middle of the lens doesn't bend.
5) Mark where the rays meet. That's the top of the image.
6) Repeat the process for a point on the bottom of the object. When the bottom of the object is on the axis, the bottom of the image is also on the axis.

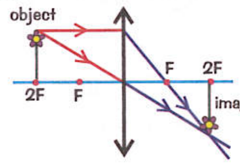
This is another way of drawing a converging lens.



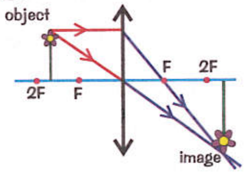
The distance from the lens to the object affects the size and position of the image:

1) An object 2F (two focal lengths) from the lens produces a real, inverted (upside down) image the same size as the object and at 2F on the other side of the lens.
2) An object between F and 2F will make a real, inverted image bigger than the object and beyond 2F.
3) An object nearer than F will make a virtual image the right way up, bigger than the object and on the same side of the lens.

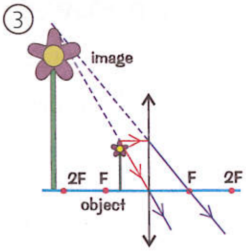
①



②



③



Warning — too much revision can cause a loss of focus...

Congratulations, you've reached the end of lenses. Why not celebrate with some practice questions?

Q1 What kind of image does a diverging lens produce? [1 mark]

Q2 Draw a ray diagram for an object at a distance of 0.5F in front of a converging lens. [3 marks]

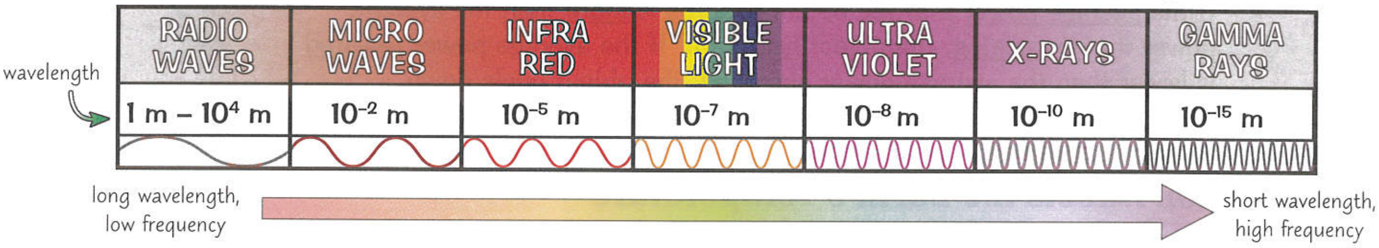
Electromagnetic Waves

You've learned a lot about light so far, but light's just one small part of the EM spectrum...

There's a Continuous Spectrum of EM Waves

1) Electromagnetic (EM) waves are transverse waves (p.32).
2) They all travel at the same speed through a vacuum (space). But they travel at different speeds in different materials (which can lead to refraction and dispersion, p.34).
3) EM waves vary in wavelength from around 10^{-15} m to more than 10^{4} m.
4) We group them based on their wavelength and frequency — there are seven basic types, but the different groups merge to form a continuous spectrum.
5) EM waves are generated by a variety of changes in atoms and their nuclei, giving a large range of frequencies. E.g. changes in the nucleus of an atom create gamma rays (p.51) and visible light is often produced by changes in an electron's energy level (p.50). This also explains why atoms can absorb a range of frequencies — each one causes a different change.
6) Our eyes can only detect a small part of this spectrum — visible light. Different colours of light have different wavelengths — from longest to shortest: red, orange, yellow, green, blue, indigo, violet.

Electromagnetic waves aren't vibrations of particles, they're vibrations of electric (p.84) and magnetic (p.85) fields. This means they can travel through a vacuum.



7) All EM waves transfer energy from a source to an absorber. For example, when you warm yourself by an electric heater, infrared waves transfer energy from the thermal energy store of the heater (the source) to your thermal energy store (the absorber).
8) The higher the frequency of the EM wave, the more energy it transfers (and so the more dangerous it is for humans — see below).

Different EM Waves Have Different Properties

As you saw on p.34, when EM waves meet a boundary they can be absorbed, transmitted, refracted or reflected. What happens depends on the materials at the boundary and the wavelength of the EM wave — e.g. some materials absorb some wavelengths of light but reflect others. This is what causes things to be a certain colour (p.40).

EM waves are sometimes called EM radiation.

Differences in how EM waves are transmitted, reflected and absorbed have implications for human health:

1) Radio waves are transmitted through the body without being absorbed.
2) Some wavelengths of microwaves can be absorbed, causing heating of cells, which may be dangerous.
3) Infrared (IR) and visible light are mostly reflected or absorbed by the skin, causing some heating too. IR can cause burns if the skin gets too hot.
4) Ultraviolet (UV) is also absorbed by the skin. But it has a higher frequency, so it is potentially more dangerous. It's a type of ionising radiation (p.50) and when absorbed it can cause damage to cells on the surface of your skin, which could lead to skin cancer. It can also damage your eyes and cause a variety of eye conditions or even blindness.
5) X-rays and gamma rays are also ionising, so they can cause mutations and damage cells too (which can lead to cancer). But they have even higher frequencies, so transfer even more energy, causing even more damage. They can also pass through the skin and be absorbed by deeper tissues.

Most of the UV radiation produced by the Sun is absorbed by the Earth's atmosphere.

Learn about the EM spectrum and wave goodbye to exam woe...

Here's a handy mnemonic for the order of EM waves: 'Rock Music Is Very Useful for eXperiments with Goats'.

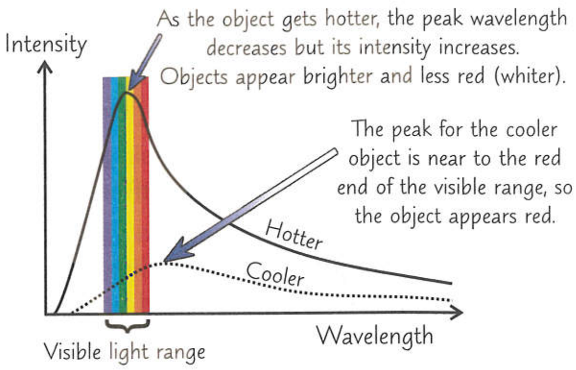
Q1 Explain why gamma rays are more dangerous to humans than visible light. [2 marks]

Emitting and Absorbing EM Radiation

You, me, the cat, we all emit radiation. And it's vital to keeping us at a fairly constant temperature.

Every Object Absorbs and Emits EM Radiation

1) ALL objects are continually emitting (radiating) and absorbing EM radiation over a range of wavelengths.
2) The distribution and intensity of these wavelengths ONLY depends on the object's temperature. Intensity is the power per unit area (power is energy transferred per second, p.66).
3) As the temperature of an object increases, the intensity of every emitted wavelength increases.
4) However, the intensity increases more rapidly for shorter wavelengths than longer wavelengths. This causes the peak wavelength (the wavelength with the highest intensity) to decrease.



As the object gets hotter, the peak wavelength decreases but its intensity increases. Objects appear brighter and less red (whiter).

The peak for the cooler object is near to the red end of the visible range, so the object appears red.

5) The rate at which an object absorbs and radiates EM radiation also affects its temperature:
   - If the average power that the object absorbs is more than the average power that it radiates, the object heats up. If the average power radiated is larger than the average power absorbed, the object cools down.
   - An object at a constant temperature radiates and absorbs the same average power.

Radiation Affects the Earth's Temperature

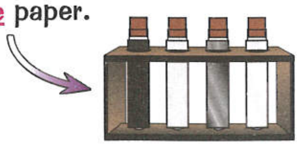
1) The overall temperature of the Earth depends on the amount of radiation it reflects, absorbs and emits.
2) During the day, lots of radiation (including light) is transferred to the Earth from the Sun.
3) Some of this is reflected, but most of it is absorbed. The radiation is reflected and absorbed by the Earth's ATMOSPHERE, CLOUDS and SURFACE. This causes an increase in local temperature.
4) At night, radiation is emitted by the atmosphere, clouds and the Earth's surface. This causes a decrease in the local temperature.
5) Overall, the temperature of the Earth stays fairly constant.
6) Changes to the atmosphere can cause a change to the Earth's overall temperature. If the atmosphere starts to absorb more radiation without emitting the same amount, the overall temperature will rise until absorption and emission are equal again (global warming).

Black Surfaces are Better Emitters than White Ones

PRACTICAL

You can investigate how well different surfaces emit radiation with this simple experiment:

1) Wrap four identical test tubes with material, e.g. paper. The material covering each test tube should be the same, but each one should have a different surface or be a different colour, e.g. black and white paper, glossy and matte paper.
2) Boil water in a kettle and fill each test tube with the same volume of water.
3) Use a thermometer to measure the temperature of the water in the test tubes every minute. Seal the test tubes with bungs between measurements.



The temperature of the water will decrease quicker for the test tubes surrounded by surfaces that are good emitters of radiation. You should find that matte (or dull) surfaces are better emitters than shiny ones and that black surfaces emit radiation better than white ones.

Feelin' hot hot hot...

Get that link between radiation and temperature firmly stuck in your head. Then have a go at this question:

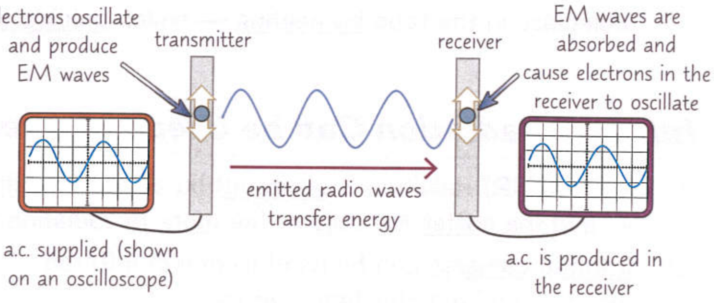
Q1 Explain what is happening in terms of radiation and temperature when a bowl of ice cream is left on a counter in a warm room. [2 marks]

EM Waves for Communication

Different EM waves have different properties, which make them useful to us in different ways.

Radio Waves are Made by Oscillating Charges

1) EM waves are made up of oscillating electric and magnetic fields.
2) Alternating currents (a.c.) (p.79) are made up of oscillating charges. As the charges oscillate, they produce oscillating electric and magnetic fields, i.e. electromagnetic waves.
3) The frequency of the waves produced will be equal to the frequency of the alternating current.
4) You can produce radio waves using an alternating current in an electrical circuit. The object in which charges (electrons) oscillate to create the radio waves is called a transmitter.
5) When transmitted radio waves reach a receiver, the radio waves are absorbed.
6) The energy carried by the waves is transferred to the electrons in the material of the receiver.
7) This energy causes the electrons to oscillate and, if the receiver is part of a complete electrical circuit, it generates an alternating current.
8) This current has the same frequency as the radio wave that generated it.

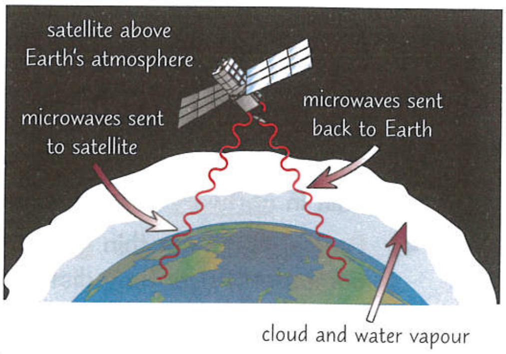


Radio Waves are Used Mainly for Communication and Broadcasting

1) Long-wave radio (wavelengths of 1 – 10 km) can be received halfway round the world from where they started, because long wavelengths bend around the curved surface of the Earth. This makes it possible for radio signals to be received even if the receiver isn't in line of the sight of the transmitter.
2) Short-wave radio signals (wavelengths of about 10 m – 100 m) can, like long-wave, be received at long distances from the transmitter. That's because they are reflected by the Earth's atmosphere.
3) Bluetooth® uses short-wave radio waves to send data over short distances between devices without wires (e.g. wireless headsets so you can use your phone while driving a car).
4) The radio waves used for TV and FM radio transmissions have very short wavelengths. To get reception, you must be in direct sight of the transmitter — the signal doesn't bend or travel far through buildings.

Microwaves and Radio Waves are Used by Satellites

1) Communication to and from satellites (including satellite TV signals and satellite phones) uses EM waves which can pass easily through the Earth's watery atmosphere.
2) These waves are usually microwaves, but can sometimes be relatively high frequency radio waves.
3) For satellite TV, the signal from a transmitter is transmitted into space and picked up by the satellite receiver dish orbiting thousands of kilometres above the Earth.
4) The satellite transmits the signal back to Earth in a different direction, where it's received by a satellite dish on the ground.



Size matters — and my wave's longer than yours...

Producing radio waves — who knew it was so tricky? It's worth it though — they're just so darn useful.

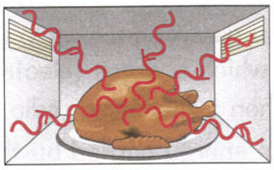
Q1 Explain why signals between satellites are usually transmitted as microwaves. [1 mark]

Microwaves and Infrared

Haven't had enough uses of EM waves? Good, because here are just a few more uses of those incredibly handy waves — complete with the all-important reasons for why they have been used. Get learning.

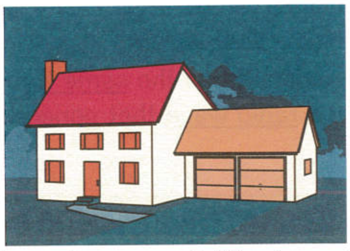
Microwave Ovens Use a Different Wavelength from Satellites

1) In communications, the microwaves used need to pass through the Earth's watery atmosphere.
2) In microwave ovens, the microwaves need to be absorbed by water molecules in food — so they use a different wavelength to those used in satellite communications.
3) The microwaves penetrate up to a few centimetres into the food before being absorbed and transferring the energy they are carrying to the water molecules in the food, causing the water to heat up.
4) The water molecules then transfer this energy to the rest of the molecules in the food by heating — which quickly cooks the food.



Infrared Radiation Can be Used to Increase or Monitor Temperature

1) Infrared (IR) radiation is given out by all hot objects — and the hotter the object, the more IR radiation it gives out.
2) Infrared cameras can be used to detect infrared radiation and monitor temperature.
3) The camera detects the IR radiation and turns it into an electrical signal, which is displayed on a screen as a picture. This is called thermal imaging.
4) Thermal imaging is used by police to see suspects that are trying to escape or hide in the dark.
5) Infrared sensors can be used in security systems. If infrared radiation is detected, an alarm sounds or a security light turns on.
6) Absorbing IR radiation causes objects to get hotter. Food can be cooked using IR radiation — the temperature of the food increases when it absorbs IR radiation, e.g. from a toaster's heating element.
7) Electric heaters heat a room in the same way. Electric heaters contain a long piece of wire that heats up when a current flows through it. This wire then emits lots of infrared radiation (and a little visible light — the wire glows). The emitted IR radiation is absorbed by objects and the air in the room — energy is transferred by the IR waves to the thermal energy stores of the objects, causing their temperature to increase.



Different colours represent different amounts of IR radiation being detected. Here, the redder the colour, the more infrared radiation is being detected.

Infrared Can Also Transfer Information

1) Infrared radiation can also be used to transfer information.
2) For example, it can be used to send files between mobile phones or laptops. The distances must be fairly small and the receiver must be in the line of sight of the emitter.
3) This is also how TV remote controls work. In fact, some mobile phones now have built in software which means that you can use your phone as a TV remote.
4) Optical fibres are thin glass or plastic fibres that can carry data (e.g. from telephones or computers) over long distances as pulses of infrared radiation. They usually use a single wavelength to prevent dispersion (p.34), which can otherwise cause some information to be lost.
5) They use total internal reflection (p.38) to send lots of data over long distances.

Revision time — adjust depending on brain wattage...

The next time you're feeling hungry and zap some food in the microwave, think of it as doing revision.

Q1 Give three uses of infrared radiation. [3 marks]

More Uses of EM Waves

And we're still not finished with uses of waves — is there no end to their talents...

Photography Uses Visible Light

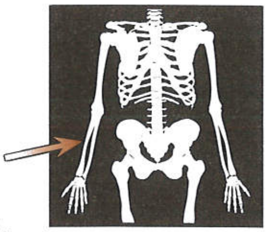
1) Visible light is the light that we can see. So it's only natural that we use it for illuminating things so that we can see them.
2) Photographic film reacts to light to form an image. This is how traditional cameras create photographs.
3) Digital cameras contain image sensors, which detect visible light and generate an electrical signal. This signal is then converted into an image that can be stored digitally or printed.

Ultraviolet is Used in Fluorescent Lamps

1) Fluorescence is a property of certain chemicals, where ultraviolet (UV) radiation is absorbed and then visible light is emitted. That's why fluorescent colours look so bright — they actually emit light.
2) Fluorescent lights use UV to emit visible light. They're energy-efficient (p.26) so they're good to use when light is needed for long periods (like in your classroom).
3) Security pens can be used to mark property (e.g. laptops). Under UV light the ink will glow, but it's invisible otherwise, helping to identify stolen property.
4) Bank notes and passports use a similar technique to detect forgeries — genuine notes and passports have special markings that only show up under UV light.
5) Ultraviolet radiation is sometimes used to sterilise water. It kills bacteria in the water, making it safe to drink. (Gamma rays are used in a similar way, see below.)

X-rays Let Us See Inside Things

1) X-rays can be used to view the internal structure of objects and materials, including our bodies.
2) They affect photographic film in the same way as light, meaning you can take X-ray photographs. But X-ray images are usually formed electronically these days.
3) Radiographers in hospitals take X-ray images to help doctors diagnose broken bones — X-rays are transmitted by flesh but are absorbed by denser material like bones or metal.
4) To produce an X-ray image, X-ray radiation is directed through the object or body onto a detector plate. The brighter bits of the image are where fewer X-rays get through, producing a negative image (the plate starts off all white).



5) X-rays are also used in airport security scanners to detect hidden objects that can't be detected with metal detectors.

Gamma Rays are Used for Sterilising Things

1) Gamma rays are used to sterilise medical instruments — they kill microbes (e.g. bacteria).
2) Food can be sterilised in the same way — again killing microbes. This keeps the food fresh for longer, without having to freeze it, cook it or preserve it some other way, and it's perfectly safe to eat.
3) Some medical imaging techniques such as tracers (p.55) use gamma rays to detect cancer.
4) Gamma radiation is also used in cancer treatments (p.56) — radiation is targeted at cancer cells to kill them. Doctors have to be careful to minimise the damage to healthy cells when treating cancer like this.

Don't lie to an X-ray — they can see right through you...

I hate to say it, but go back to page 45 and re-read all of the uses for electromagnetic waves to really learn them.

Q1 State two uses of ultraviolet radiation. [2 marks]

Q2 Suggest one advantage of sterilising food with gamma rays. [1 mark]

Revision Questions for Section 2

Wave goodbye to Section 2 — you've finally reached the end. Now see how much you've learnt.

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Wave Properties (p.32-34) ☐

1) What is the amplitude, wavelength, frequency and period of a wave? ☐
2) Describe the difference between transverse and longitudinal waves and give an example of each kind. ☐
3) Describe experiments you could do to measure the speed of sound and the speed of ripples in water. ☐
4) Explain refraction and draw a ray diagram for a light ray entering a less optically dense material. ☐

Sound and Exploring Structures with Waves (p.35-37) ☐

5) What affects an object's ability to transmit given frequencies of sound? ☐
6) What is the frequency of ultrasound? ☐
7) Explain how ultrasound is used in industrial imaging and echo sounding. ☐
8) What is the frequency of infrasound? ☐
9) Describe how S-waves and P-waves can be used to explore the structure of the Earth's core. ☐

Reflection and Refraction (p.38-39) ☐

10) True or false? The angle of incidence always equals the angle of reflection for reflected waves. ☐
11) Draw a ray diagram for a light ray being reflected, where the angle of incidence is 25°. ☐
12) What conditions are needed for total internal reflection to occur? ☐
13) Define specular and diffuse reflection. ☐
14) Explain why you need to conduct experiments to investigate refraction in a dim room. ☐

Visible Light and Colour (p.40) ☐

15) True or false? Opaque objects transmit light. ☐
16) Explain what happens to white light that hits a white object. ☐
17) Describe how colour filters work. ☐

Lenses (p.41-42) ☐

18) Explain the terms 'real image' and 'virtual image'. ☐
19) Explain how a lens' curvature affects its power. ☐
20) Draw the ray diagram symbols for a converging lens and a diverging lens. ☐
21) True or false? Diverging lenses always produce real images. ☐

Uses and Dangers of Electromagnetic Waves (p.43-47) ☐

22) True or false? All electromagnetic waves are transverse. ☐
23) Give one potential danger of: a) ultraviolet radiation b) X-rays and gamma rays. ☐
24) Describe the average power absorption and radiation for an object at a constant temperature. ☐
25) Explain how absorption, reflection and emission of radiation affects the Earth's temperature. ☐
26) Describe an experiment you could do to investigate how different materials radiate energy. ☐
27) What kind of current is used to generate radio waves in an antenna? ☐
28) What type of radiation is used in thermal imaging cameras? ☐
29) Give two uses of gamma rays. ☐