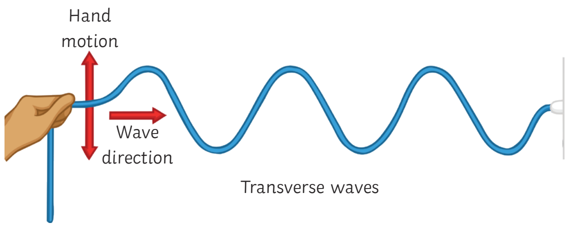
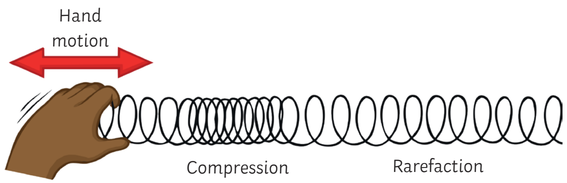
Transverse and Longitudinal Waves

Waves can be either **transverse** or **longitudinal**.

In a transverse wave, the vibrations are at a right angle (**perpendicular**) to the direction of the energy transfer. The wave has **peaks** (or crests) and **troughs**. Examples include **water waves** and **light waves**.

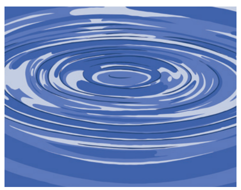


In a longitudinal wave, the vibrations are in the same direction (**parallel**) as the energy transfer. The wave has areas of **compression** and **rarefaction**. Examples of this type of wave are **sound waves**.

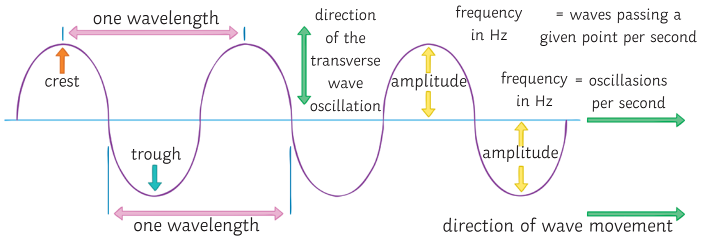


When a wave travels, energy is transferred but the matter itself does not move. Particles of water or air vibrate and transfer energy but do not move with the wave.

This can be shown by placing a cork in a tank of water and generating ripples across the surface. The cork will bob up and down on the **oscillations** of the wave but will not travel across the tank.



Properties of Waves



The **frequency** of a wave is the number of waves which pass a given point every second.

time period (s) = 1 ÷ frequency (Hz)

t = 1 ÷ f

The **wave speed** is how quickly the energy is transferred through a medium (how quickly the wave travels).

wave speed (m/s) = frequency (Hz) × wavelength (m)

v = f × λ

The speed of **sound waves** travelling through air can be measured by a simple method. One person stands a measured distance from a large flat wall, e.g. 100m. The person then claps and another person measures the time taken to hear the echo. The speed of the sound can then be calculated using the equation

speed = distance × time.

Remember the distance will be double because the wave has travelled to the wall and back again. It is important to take several measurements and calculate the average to reduce the likelihood of human error.

Sound Waves in Different Medium

How quickly sound waves can travel through a medium is determined by the **density** of the medium (material).

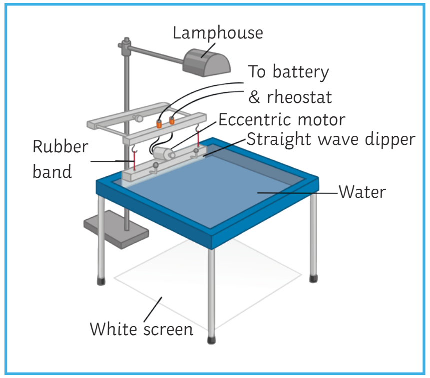
Sound waves will travel faster through a solid than a liquid as the spaces between the particles are smaller. This means that the **vibrations** and **energy** can be passed along the particles more quickly. In a gas, the transmission of sound is even slower as the space between the particles is greater.

The speed of sound in air is 330m/s.

Required Practical Investigation 8

Aim: make observations and identify the suitability of apparatus to measure the frequency, wavelength and speed of waves in a ripple tank and waves in a solid, and take appropriate measurements.

The **ripple tank apparatus** shown is the most commonly used for this investigation. It is likely you will work in groups or observe the investigation as a demonstration by your teacher.



Method (assuming the apparatus is already set-up):

Turn on the power and observe the waves. Make any necessary adjustments to the equipment so that the waves are clear to observe (alter the voltage supplying the motor). **N.B. The lowest frequency setting on the motor will ensure that the waves measurements can be made more easily.**

To measure the **wavelength**, use the metre ruler and make an estimate quickly. You may want to use a **stroboscope** and freeze the wave patterns to make measurements.

Record 10 wavelengths and calculate the **average** value.

Required Practical Investigation 8 (continued)

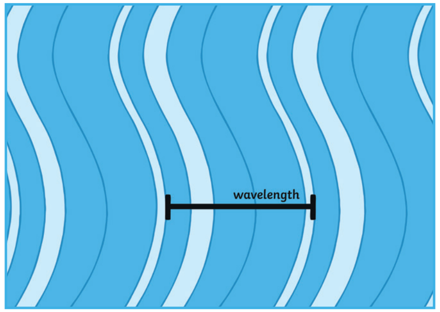
To measure the wave **frequency**, mark a given point onto the white paper and **count** the number of waves which pass the point within **10 seconds**. Divide your answer by 10 to find the number of **waves per second**.

Record 10 frequencies and calculate the **average** value.

To calculate the wave speed, use this formula:

speed = frequency × wavelength

Remember: the wavelength is the distance between one peak (or crest) of a wave and the next peak.



Required Practical Investigation 9

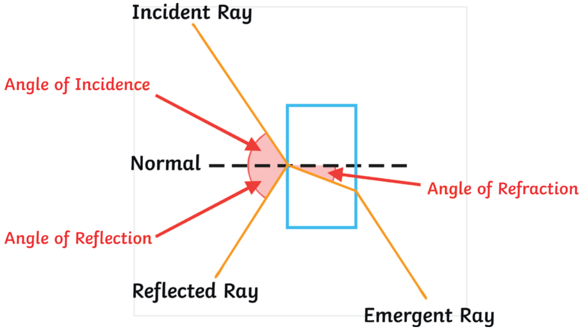
Aim: investigate the reflection of light by different types of surface and the refraction of light by different substances.

Method:

1. In a darkened room, set up the ray box on a flat surface and insert the filter to produce a single ray of light.
2. Place a glass block in the centre of a piece of plain A3 paper.
3. Draw a line around the glass block.
4. Draw a line at 90°C to the glass block and label the line normal, as shown in the diagram.
5. Position the ray box so the ray of light hits the glass at an angle.
6. Using a pencil, draw the incidence, reflected and emergent rays as shown in the diagram.
7. Remove the glass block and draw the refracted ray going through the block.
8. Using a protractor, measure the angles of incidence, reflection and refraction. Record your results.
9. Repeat the experiment by placing a clear acrylic block on the A3 paper in the same position as the glass block.
10. The incident ray must follow the same line as before. Draw the reflected and refracted rays and measure using a protractor.
11. Collect four sets of results from other members of the class.

The law of reflection states:

angle of incidence = angle of reflection



Risk assessment:

The ray box will become hot during use and may cause minor burns. To prevent this, you should not touch the lamp and ensure you allow time for the ray box to cool after use.

You will be working in a semi-dark environment which means there is a higher risk of trips or falls. You should ensure your working space is clear of bags and coats, and that stools are tucked under desks before you start your investigation.

Required Practical Investigation 10

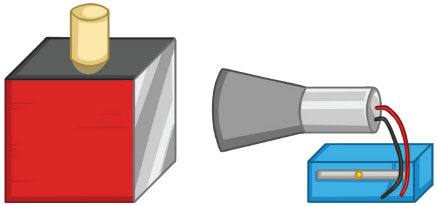
Aim: investigate how the amount of infrared radiation absorbed or radiated by a surface depends on the nature of that surface.

In this investigation, you are finding out which type of surface emits the most **infrared** radiation:

- **dark and matt**
- **dark and shiny**
- **light and matt**
- **light and shiny**

Method:

1. Place the **Leslie cube** on a heatproof mat.
2. Once the kettle has boiled, fill the Leslie cube with hot water.
3. Ensuring that the **thermometer** or the **infrared detector** is an **equal distance** from each of the surfaces (in turn) on the Leslie cube, measure the amount of infrared radiation emitted.
4. Repeat the experiment twice more to collect three results for each surface.

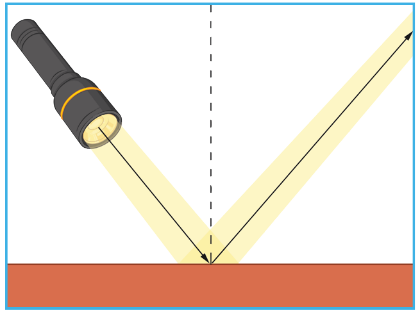


Reflection of Waves

When a **wave** comes into contact with a **surface** or a **boundary** between two media (different materials), it can be **reflected** or it can be **absorbed**.

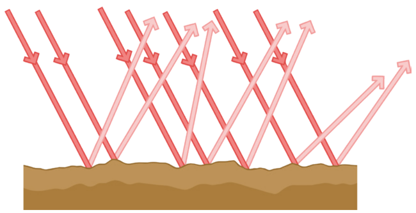
What happens depends on the properties of the surface the wave hits.

Specular reflection occurs when a wave is reflected in a **single direction** from a perfectly **smooth surface**.

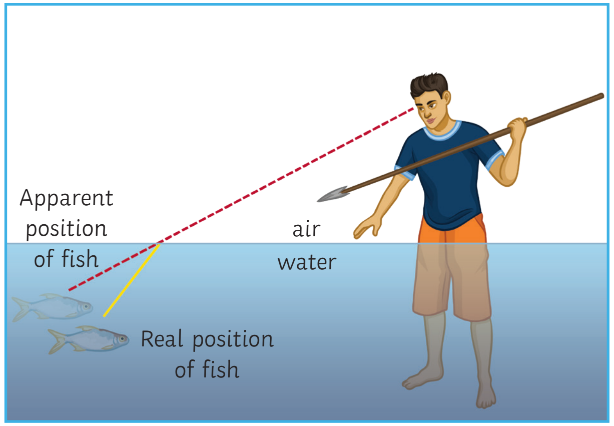


angle of incidence = angle of reflection (i = r)

Diffuse reflection occurs when a wave is reflected in **many directions** and happens at a rough or **uneven surface**.



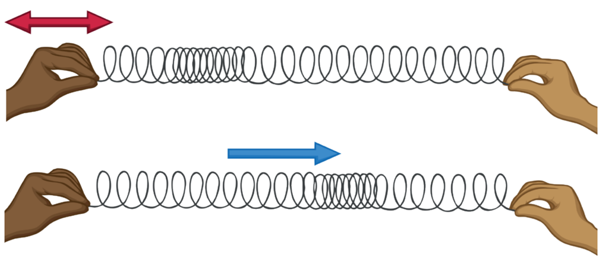
Refraction occurs when a wave **changes direction**, usually at the boundary or two different materials. The **density** of the material affects the **speed** at which the wave can travel through it. When a wave passes from a more dense material to a less dense material, it speeds up and so will bend.



Imagine a car travelling across a muddy river at an angle. As it approaches the bank of the river, one of the wheels will be on the dry bank while the other is still in the mud. The wheel on the dry bank will move faster than the one still in the mud and it will change direction.

Sound Waves (Higher tier only)

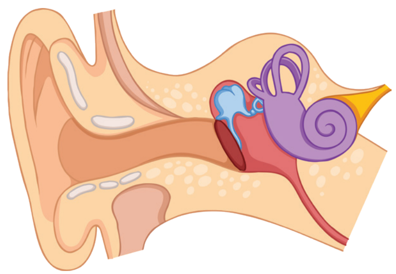
When an object vibrates, it can cause a **sound wave**. Remember, a sound wave is a **longitudinal** wave:



A sound wave can travel through a solid material. This is because the space between the particles is so small (almost non-existent) and the vibrations are transmitted more quickly than in liquids or gases.

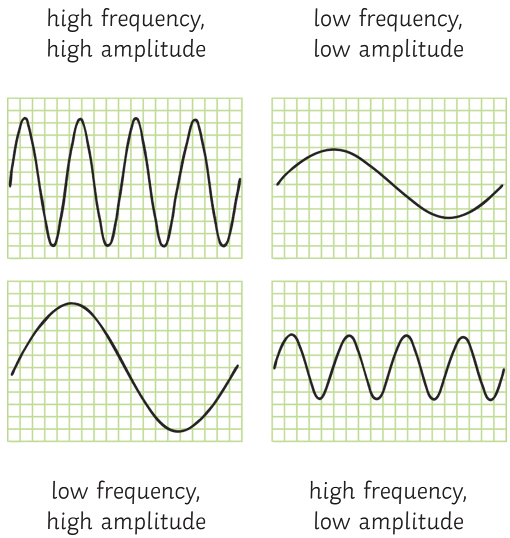
The speed of sound in air is about 330m/s. As the majority of space is a **vacuum** (no particles), sound waves do not travel in space.

Sound waves within the range of **20Hz to 20kHz** can usually be detected by the **human ear**.



Vibrations are passed along air particles down the ear canal and to the ear drum. The ear drum vibrates and transmits this to the small ear bones and then along the cochlea. The cochlea carries the vibrations to the auditory nerve which carries the sound wave as an electrical impulse to the brain.

Characteristics of a sound wave can be identified from an **oscilloscope** trace of the sound wave. The trace shows oscillations and wavelength of the sound wave. A **shorter wavelength** results in a **high-pitched** (high frequency) sound. A **greater height** of oscillations indicates a **higher amplitude** (volume) of the sound wave.



Waves for Detection and Exploration (Higher tier only)

Waves can be used to detect objects underwater, in the earth and even inside the human body.

Sonar systems used to explore **deep seas** use **high-frequency sound waves**. A sound wave is sent out from the device through the water and the **time taken** for the pulse to **reflect** from the surface is measured. The time taken with the speed of **sound in water** is used to find the **distance** of the object.

The equation used is:

distance (m) = speed (of sound) (m/s) × time (s)

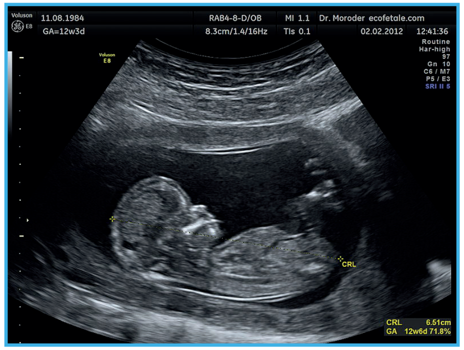
Volcanoes, earthquakes and explosions cause **seismic** waves to travel through the earth. There are two different types of seismic waves: **S-waves** and **P-waves**.

- P-waves are longitudinal waves which travel relatively quickly through solids and liquids.
- S-waves are transverse waves and they travel slower and only in solids.

Seismic waves can **change direction** when they are **reflected** or **refracted** at the boundary of different media (solid, liquid or gas). The **epicentre** of an earthquake can be found by calculating the difference in time taken for S- and P-waves to reach a certain point. Since the waves can change direction, at least three points are used to **triangulate** the data and pinpoint the source (where they all intercept).

The study of seismic waves has given scientists new **evidence** about the structure of the earth in parts which are not visible for direct observations.

Ultrasound waves are sound waves which have a **higher frequency** than the range which is detectable by the human ear. When the waves reach a boundary between different media, they are **partially reflected** and a detector is used to measure the time taken and calculate the distance. Ultrasound is used for **medical** and **industrial imaging**.



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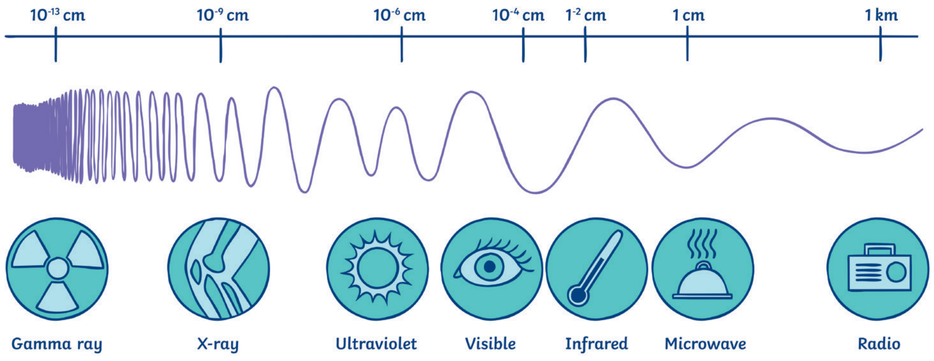
The Electromagnetic Spectrum

Electromagnetic waves transfer energy from a source to an **absorber** as **transverse** waves. The different waves are grouped depending on their **frequency** and form a continuous spectrum known as the **electromagnetic spectrum**. Each of the frequencies of waves travel at the same **velocity** and can pass through a **vacuum** as well as **air**.



Frequency	Wave	Use	Other Information
Low ↑	radio waves	Communication via television and radio, and satellite communications.	Easily transmitted through air and can be reflected to change their direction. Harmless if absorbed by the human body. Are reflected back off the atmosphere and cannot pass through into space.
	microwaves	Communications including satellite communications and cooking food.	When the molecules absorb microwaves, their internal energy increases. This can be harmful when internal body cells become heated by over exposure to microwaves. Can pass through the atmosphere and into space.
	infrared	Short-range communications (remote controls), electrical heaters, cooking food, optical fibres, security systems and thermal imaging cameras.	It can cause burns to skin.
	visible light	Used for lighting, photography and fibre optics.	Frequency range that is detectable by the human eye.
	ultraviolet	Sterilising water and killing bacteria. Detecting forged bank notes.	Causes skin tanning and can lead to burns or skin cancer.
	X-rays	Medical imaging and airport security scanners.	Very little energy is absorbed by body tissues. Instead, it is transmitted through the body. These waves can lead to gene mutation and cancer.
↓ High	gamma rays	Sterilising medical equipment or food and treatment for some cancers.	

You can remember the order of the electromagnetic spectrum easily with the phrase:

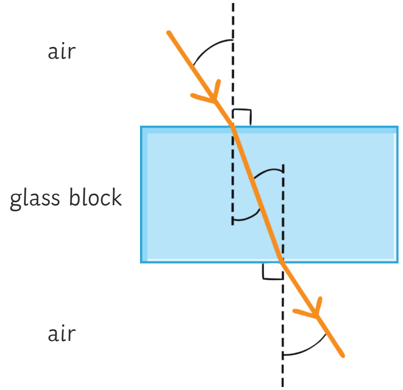
Roman men invented very unusual X-ray guns.

Properties of Electromagnetic Waves

You should be able to complete or construct a **ray diagram** to show how a wave is **refracted** at the boundary of a different medium.

As the wave moves **to** a more dense medium (e.g. from gas to solid), it slows down and bends so that the angle from the normal becomes smaller. The angle of incidence is larger than the angle of refraction.

As the wave moves **from** a more dense medium (e.g. from solid to gas), it speeds up and bends so that the angle from the normal becomes larger. The angle of refraction is larger than the angle of incidence.



The angle at which a wave enters the glass block is equal to the angle that it leaves the glass block (when entering and leaving the same medium); however, if a wave crosses a boundary between two mediums at an angle of 90˚C, then it will not change direction but instead carry on in a straight line.

Gamma rays occur as the result of changes to the nuclei of atoms and atoms themselves. It is a form of radiation and the waves can be generated and absorbed across a wide range of frequencies.

UV, X-rays and **gamma** are all types of **radiation** and can be **harmful** to human health; they cause damage to human body tissues. The severity of the damage caused depends on the dose of radiation a tissue or cell is exposed to. **Radiographers** and dentists who routinely carry out X-ray examinations wear a device to monitor the amount of exposure and ensure they are within a **safe limit**.

X-rays and gamma rays are **ionising** and can cause **mutations** to genes which may result in **cancer**.

UV waves can cause the skin to burn and age prematurely. UV exposure also increases the risk of developing **skin cancer**.

Radio Waves (Higher tier only)

Oscillations in **electrical circuits** can produce **radio waves** which when absorbed by a conductor, produce an **alternating current**.

The alternating current has the same **frequency** as the radio wave and so information can be coded for transmission. This is how **television** and **radio** are broadcast.

Temperature of the Earth (Higher tier only)

The temperature of the earth depends on:

- The rate at which **light** radiation and **infrared** radiation are **absorbed** by the **earth's surface** and **atmosphere**.
- The rate at which **light** radiation and **infrared** radiation are **emitted** by the **earth's surface** and **atmosphere**.

Light and infrared radiation absorbed by the earth cause the **internal energy** of the planet to **increase** and in turn, the surface of the earth **increases in temperature**.

Energy from the surface of the earth can be transferred to the atmosphere by **conduction** and **convection**.

The **infrared** radiation **emitted** from the earth's surface will either travel through the atmosphere and back into **space** or it will be **absorbed** (and **reflected**) by the **greenhouse gases** in the earth's atmosphere.

Visible Light

The colours of the **visible spectrum** can be remembered with the rhyme Richard Of York Gave Battle In Vain (red – orange – yellow – green – blue – indigo – violet).

These are all the **wavelengths** which are visible and detectable by the **human eye**. Each colour has a narrow range of wavelength and frequency within the spectrum.

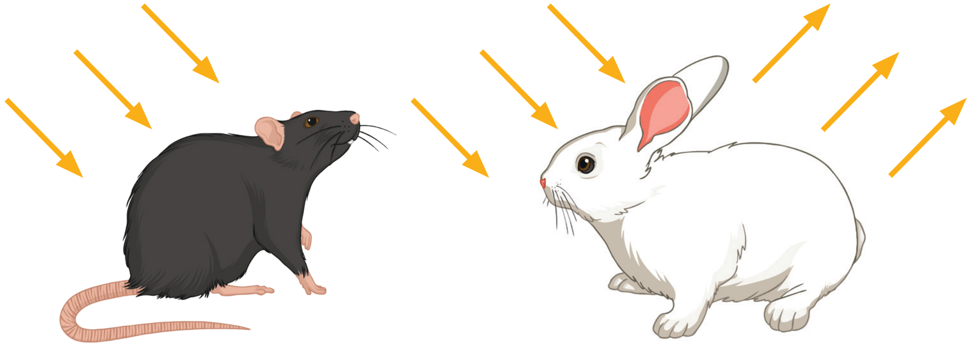
White light is the combination (full spectrum) of wavelengths in the visible light region of the electromagnetic spectrum.

A **colour filter** absorbs some wavelengths and only transmits certain wavelength(s). This means that a filter will absorb some colours and transmit others.

For example, a red filter absorbs all other colours in the spectrum except red, which it transmits.

An object which is **transparent** (see-through) or **translucent** (partially see-through) can transmit light.

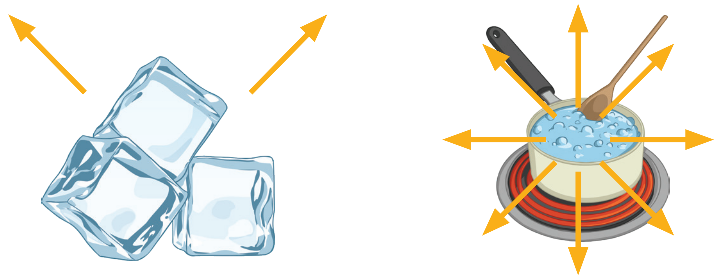
Opaque objects reflect and absorb light. The wavelengths which are reflected or absorbed determine the colour which the object is perceived.



For example, an object which absorbs all wavelengths will appear black. An object which reflects all wavelengths will appear white. An object which reflects only green colour wavelengths and absorbs the others will appear green.

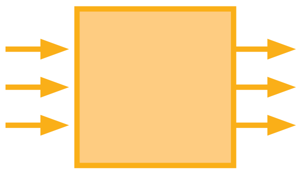
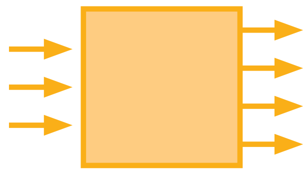
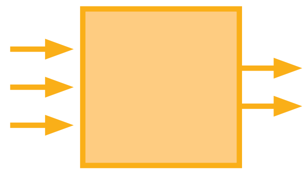
Black Body Radiation

All objects **emit** and **absorb infrared radiation**. The hotter an object is, the greater the amount of radiation emitted.



An object which absorbs all the radiation it is exposed to is called a **perfect black body**. No radiation is reflected from or transmitted through it. A perfect black body would be the most **effective emitter** as an object which is a good absorber is also a good emitter.

(Higher tier only)

		
An object **absorbing and emitting infrared radiation** at the **same rate** has a **constant temperature**.	An object **emitting more than it is absorbing** will **decrease** in **temperature**.	An object **absorbing more than it is emitting** will **increase** in **temperature**.

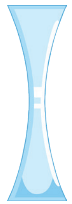
Lenses

Lenses use **refraction** in order to work. **Projectors, microscopes** and **telescopes** all use lenses to allow an object or image to be enlarged or viewed more easily.

The **human eye** contains a lens which enables us to see objects at a range of distances.

Depending on the type of **lens**, the light waves will be **refracted** differently to produce a different image.

The two main lenses are **convex lenses** and **concave lenses**. The table below compares them briefly.

convex lens	**Lens**	concave lens
	**Ray Diagram**	
	**Illustration**	
Causes parallel waves to **converge** at the principal focus.	**Action**	Causes parallel waves to **diverge** from the principal focus.
real or virtual	**Type of Image**	always virtual

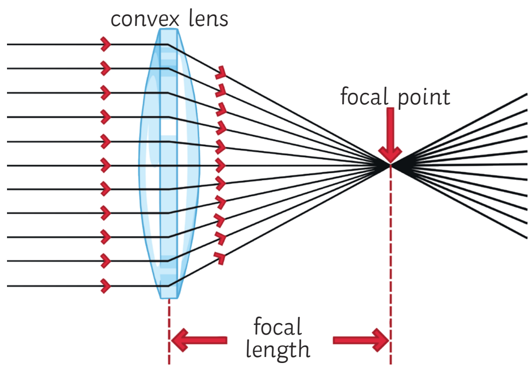
A **real image** is when light reflected from an object **converges** to form an image on a surface. For example, on the retina of the human eye.

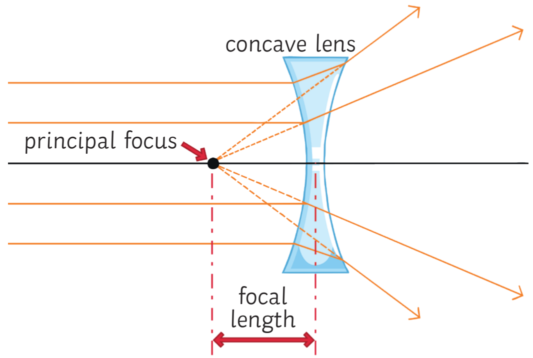
A **virtual image** occurs when the light waves are **diverging** and so appears to be coming from a different place. A virtual image cannot be projected onto a screen. For example, a mirror produces a virtual image.

A magnifying glass uses a converging (convex) lens. It produces a virtual image which appears larger than the actual object. The magnification can be calculated using the equation:

$$\text{magnification} = \frac{\text{image height (mm)}}{\text{object height (mm)}}$$

An imaginary horizontal line through the middle of the lines is called the **axis** and this is where the **principal focus** forms. In a **convex lens**, the light rays enter the lens **parallel** to one another and then **converge** at the principal focus **after** the lens. In a **concave lens**, the light rays enter the lens **parallel** to one another and then **diverge**. The principal focus is the virtual source of the diverging rays **before** the lens.





$$\text{power (D)} = \frac{1}{\text{focal length (m)}}$$

- D stands for dioptres which is the unit of measurement for lens power.
- In a **converging** lens the power is a **positive** value.
- In a **diverging** lens the power is a **negative** value.

Focal length depends on two factors: the **refractive index** of a material and how **curved** the surfaces of the lenses are. A higher refractive index makes the lens **flatter** in shape. To make a powerful lens thinner, a material with a higher refractive index can be used.

Objects which are a distance **greater than one focal length** away from a converging lens will produce a **real image**. Objects which are closer **than one focal length** from the converging lens will produce a **virtual image**.

The **lens equation** can be used to show the relationship between focal length, position of the **object** and position of the **image**:

$$\frac{1}{\text{focal length}} = \frac{1}{\text{distance between lens and object}} + \frac{1}{\text{distance between lens and image}}$$

This equation can also be written as:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$