Waves

IGCSE Physics

General properties of waves

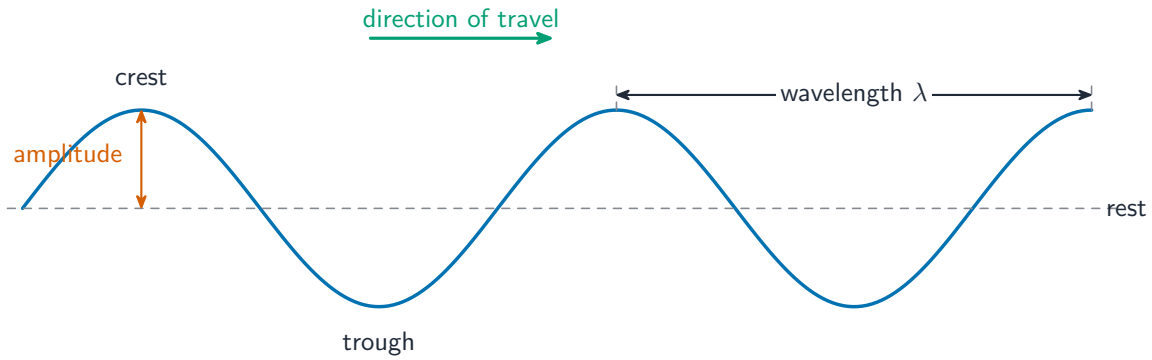
A **wave** 波 carries **energy** 能量 from place to place **without** carrying matter. For example, a water wave makes a floating cork bob up and down, but the cork does not travel along with the wave.

Describing a wave

- **wavefront** 波前: a line joining points on a wave that move together (for example, the top of one ripple)
- **wavelength** 波长 (λ): the distance between two neighbouring wavefronts (one full wave)
- **frequency** 频率 (f): the number of waves passing a point each second, measured in hertz (Hz)
- **crest** 波峰 (top) and **trough** 波谷 (bottom)
- **amplitude** 振幅: the largest distance a point moves from its rest position
- **wave speed** 波速 (v): how fast a wavefront travels

These are linked by the **wave equation**:

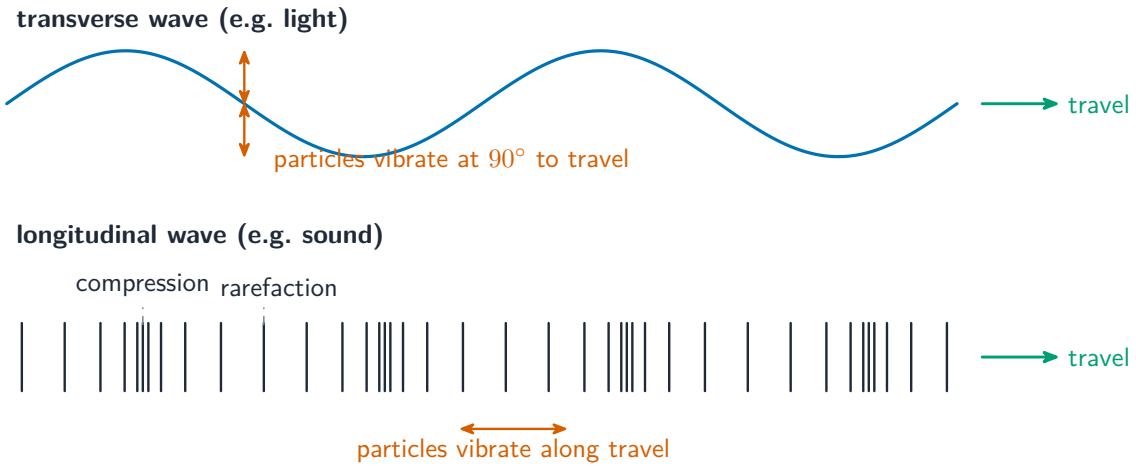
$$v = f\lambda$$



The wavelength is the distance between two crests; the amplitude is the height from the rest position to a crest

Two types of wave

- In a **transverse wave** 横波 the particles vibrate at right angles (90°) to the direction the wave travels (its **propagation** 传播). Light and water waves are transverse.
- In a **longitudinal wave** 纵波 the particles vibrate along the same direction as the wave travels. Sound is longitudinal.

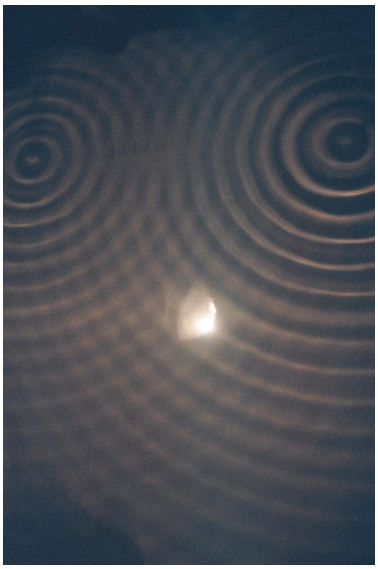


In a transverse wave the particles vibrate across the travel direction; in a longitudinal wave they vibrate along it, making compressions and rarefactions

Wave behaviour

All waves can show three behaviours, which you can see in a **ripple tank** 波纹水槽:

- **reflection** 反射: the wave bounces off a surface.
- **refraction** 折射: the wave changes speed (and usually direction) when it enters a different material or depth.
- **diffraction** 衍射: the wave spreads out after passing through a gap or around an edge. The spreading is greatest when the gap is about the same size as the wavelength.



Two dippers in a ripple tank make circular water waves that overlap —a quick way to study how waves behave

Image: The original uploader was RenamedUser2 at English Wikipedia, BSD (commons.wikimedia.org)

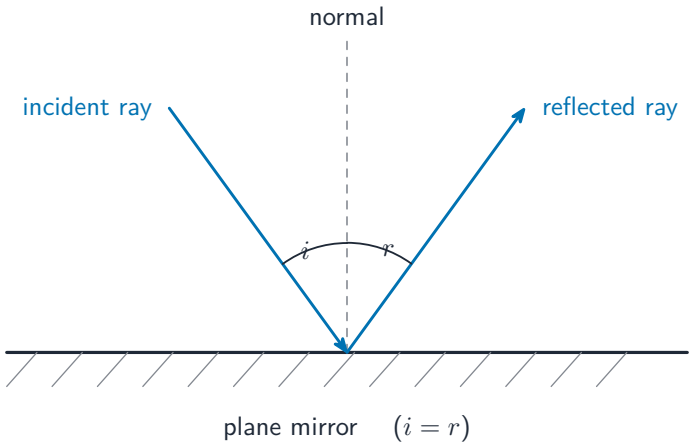
Light 光

Reflection

When light hits a mirror, it reflects. We measure angles from the **normal** 法线 (a line at 90° to the surface).

The **law of reflection**: the **angle of incidence** 入射角 equals the **angle of reflection** 反射角.

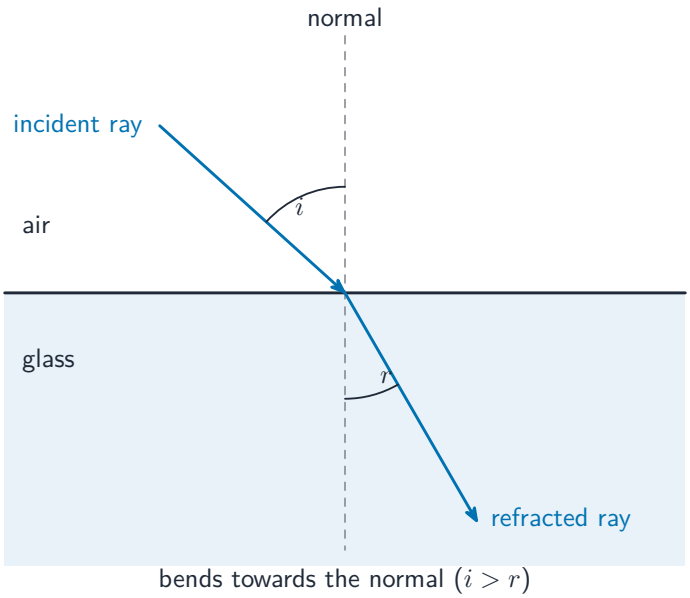
A **plane mirror** 平面镜 forms an image that is the same size as the object, the same distance behind the mirror, and **virtual** (it cannot be caught on a screen).



At a plane mirror the angle of incidence i equals the angle of reflection r, both measured from the normal

Refraction

When light passes from one material into another, it changes speed and bends. The angle in the second material is the **angle of refraction** 折射角.



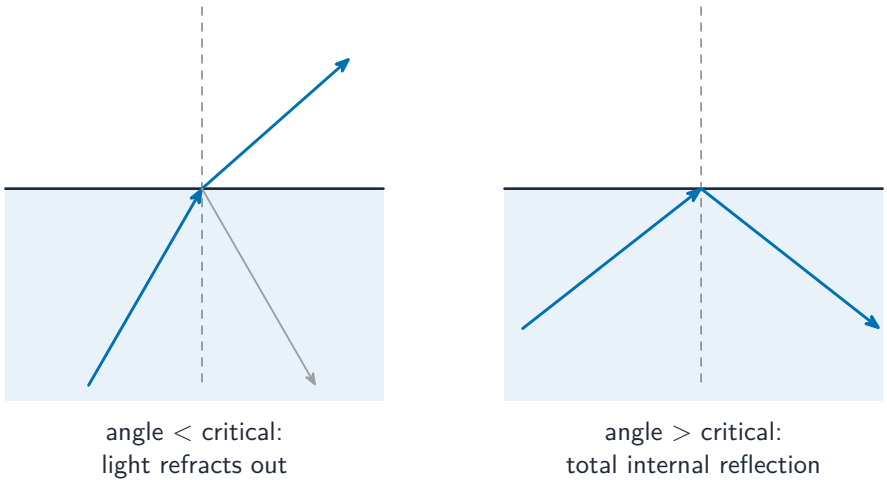
Going from air into glass the light slows down and bends towards the normal, so $i > r$

The **refractive index** 折射率 n compares the speed of light in the two materials:

$$n = \frac{\sin i}{\sin r}$$

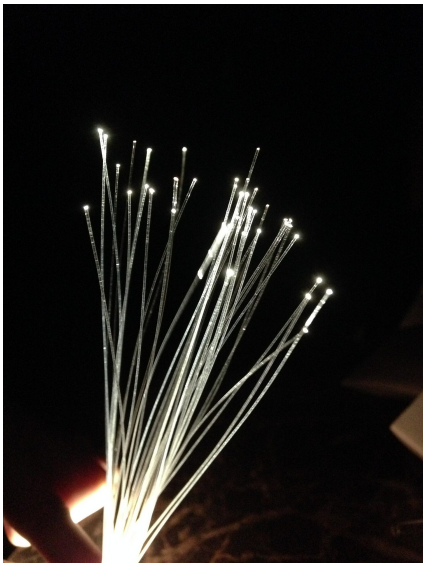
When light tries to leave glass or water and the angle is too large, it cannot get out and instead reflects completely. This is **total internal reflection** 全反射. It happens when the angle inside is bigger than the **critical angle** 临界角 c:

$$n = \frac{1}{\sin c}$$



Below the critical angle the light refracts out; above it the light is totally internally reflected

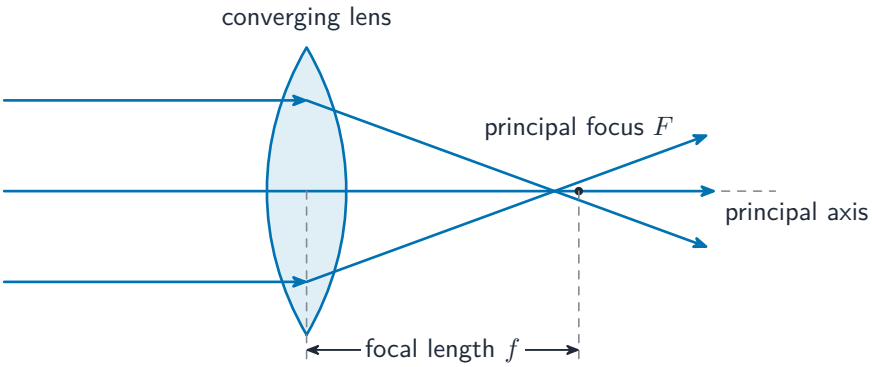
This effect is used in **optical fibres** 光纤, thin glass threads that carry light signals for telephones and the internet.



Total internal reflection keeps light bouncing along each fibre until it shines out at the tip

Lenses

A **converging lens** 凸透镜 (fat in the middle) bends parallel rays inwards to a point called the **principal focus** 焦点. The distance from the lens to this point is the **focal length** 焦距. A **diverging lens** 凹透镜 (thin in the middle) spreads rays out.

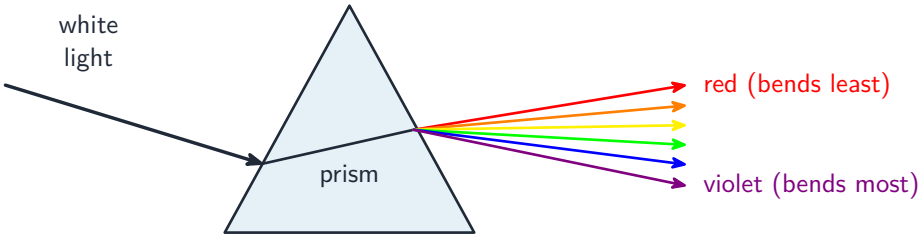


A converging lens bends parallel rays to meet at the principal focus; the focal length f is the lens-to-focus distance

A converging lens can form a **real image** 实像 (rays really meet; can be shown on a screen) or, when the object is very close, a **virtual image** 虚像 (rays only seem to come from it). Used close to the eye, a converging lens is a **magnifying glass** 放大镜.

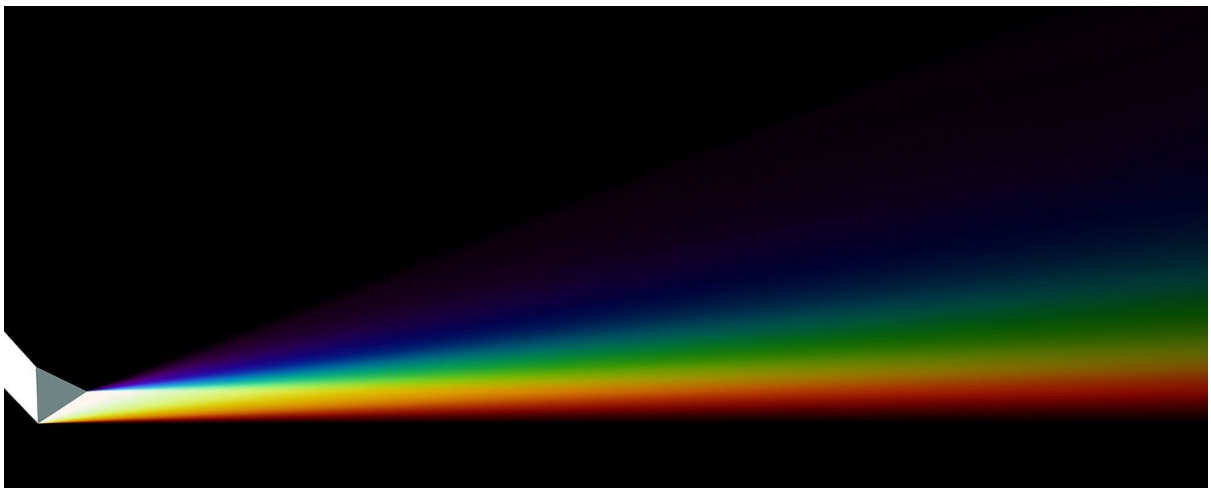
Dispersion

A glass **prism** 棱镜 splits white light into the colours of the **spectrum** 光谱. This splitting is called **dispersion** 色散.



A prism refracts violet light most and red light least, so white light spreads into a spectrum

The order of colours is red, orange, yellow, green, blue, indigo, violet. Red light has the longest wavelength and the lowest frequency; violet is the opposite. Light of a single frequency (one pure colour) is **monochromatic** 单色.



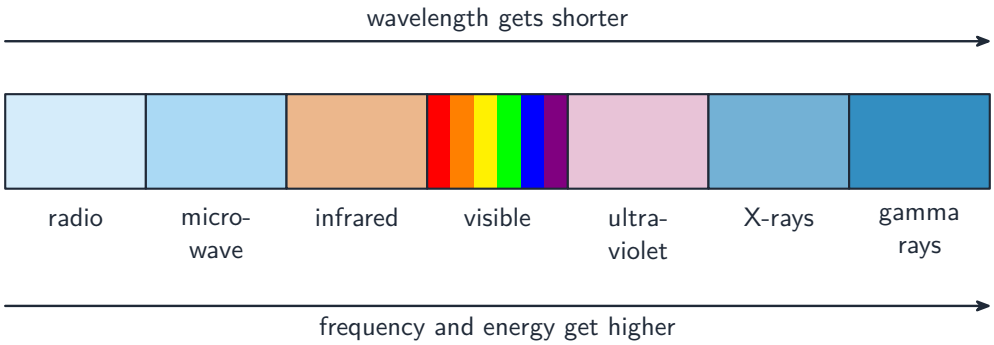
White light entering a real glass prism spreads into the full spectrum of colours

The electromagnetic spectrum 电磁波谱

The **electromagnetic spectrum** is a family of waves that all travel at the same high speed in a **vacuum** 真空, 3.0×10^8 m/s. In order from longest wavelength (lowest frequency) to shortest:

Region	A typical use	Danger from too much
radio waves 无线电波	radio and TV signals	—
microwaves 微波	mobile phones, satellite TV, cooking	heating of body cells
infrared 红外线	remote controls, thermal imaging, grills	skin burns
visible light	seeing, photography	—
ultraviolet 紫外线	sterilising water, checking bank notes	skin cancer, eye damage
X-rays X 射线	medical and security scans	damage to cells
gamma rays 伽马射线	sterilising equipment, treating cancer	mutation of cells

As you go from radio waves to gamma rays, the frequency rises, the wavelength falls, and the energy (and danger) rises.



From radio waves to gamma rays the wavelength falls while the frequency and energy rise

Sound 声音

Sound is made by a vibrating object. It is a **longitudinal wave**: the air is squeezed into a **compression** 压缩 (particles close together) and stretched into a **rarefaction** 稀疏 (particles far apart).

- Sound needs a **medium** 介质 (a material) to travel through, so it cannot travel through a vacuum.
- Humans can hear frequencies from about 20 Hz to 20 000 Hz.
- Sound travels much slower than light (about 340 m/s in air), and faster in liquids and solids than in gases.

A reflected sound is an **echo** 回声. You can find the speed of sound by timing an echo over a known distance.