CIE Physics IGCSE

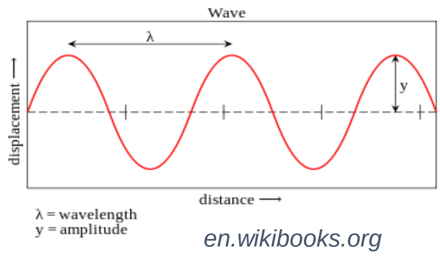
Topic 3: Waves

Summary Notes

General wave properties

Waves transfer energy without transferring matter; particles oscillate about a fixed point.

Amplitude – the distance from the equilibrium position to the maximum displacement
Wavelength – the distance between a point on one wave and the same point on the next wave
Frequency – the number of waves that pass a single point per second
Speed – the distance travelled by a wave each second



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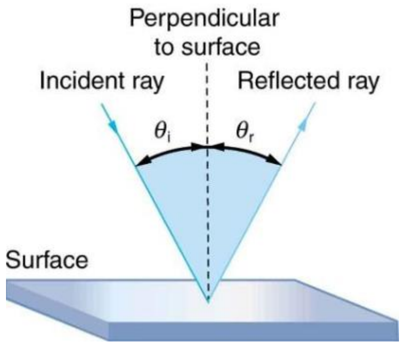
- **Speed is related to frequency and wavelength by:** $speed = frequency \times wavelength$ $\quad v = f\lambda$

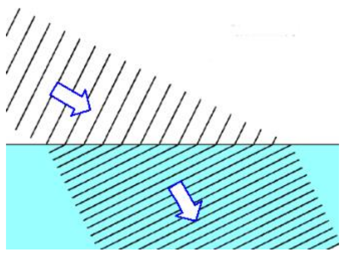
Types of waves:
- Transverse waves
  - Has peaks and troughs
  - Vibrations are at right angles to the direction of travel
  - An example is light
- Longitudinal waves
  - **Consists of compressions (particles pushed together) and rarefactions (particles moved apart)**
  - Vibrations are in the same direction as the direction of travel
  - An example is sound

A wavefront is a surface containing points affected in the same way by a wave at a given time such as crests or troughs.

Reflection:
- Waves reflect off smooth, plane surfaces rather than getting absorbed
  - Angle of incidence = angle of reflection
- Rough surfaces scatter the light in all directions, so they appear matte and unreflective
- Frequency, wavelength, and speed are all unchanged



Refraction:
- The speed of a wave changes when it enters a new medium
- If the wave enters a more optically dense medium, its speed decreases and it bends towards the normal
- If the wave enters a less optically dense medium, its speed increases and it bends away from the normal
- In all cases, the frequency stays the same but the wavelength changes.



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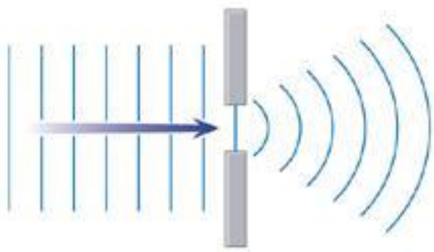
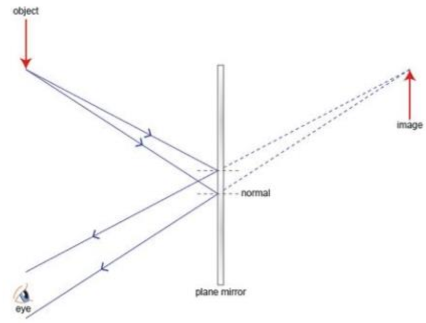
Diffraction:
- Waves spread out when they go around the sides of an obstacle or through a gap
- **The narrower the gap or the greater the wavelength, the more the diffraction**
- Frequency, wavelength, and speed are all unchanged



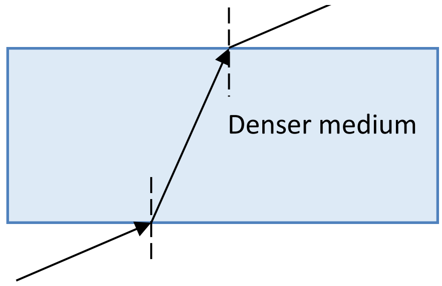
Light

Reflection



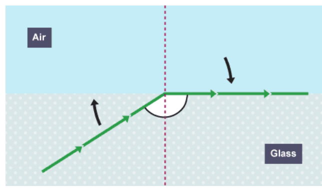
- When light is reflected off a plane mirror, it forms an image with these characteristics:
  - Upright
  - Same distance from the mirror as the object
  - Same size
  - **Virtual**

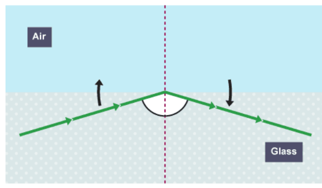
Refraction



- Refraction can be shown when light is passed through a glass slab at an angle to its normal
- When light enters a more optically dense medium, the angle of incidence (the angle between the incident ray and the normal) is greater than the angle of refraction (the angle between the refracted ray and the normal). The opposite is true when light enters a less optically dense medium.
- **The refractive index n of a medium is defined as the ratio between the speed of light in a vacuum and the speed of light in the medium:** $n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ the\ medium}$
- **Snell's law relates the angle of incidence and the angle of refraction to the refractive index by:** $n = \frac{\sin i}{\sin r}$ **where i is the angle of incidence and r is the angle of refraction.**

Total internal reflection:



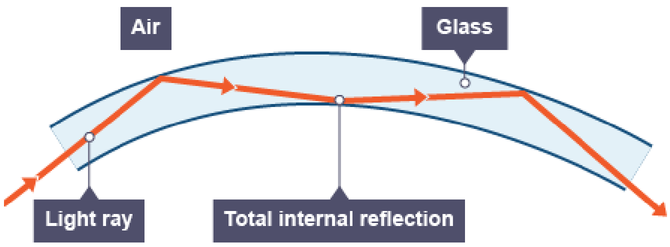


- At a certain angle of incidence called the critical angle, the light will travel along the boundary between the two media.
- Total internal reflection occurs when the angle of incidence is greater than the critical angle and the light reflects back into the medium.
- For total internal reflection to occur, the light must also be travelling from a more optically dense medium into a less optically dense medium (most common example is glass to air).
- **The critical angle can be related to the refractive index by:**

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

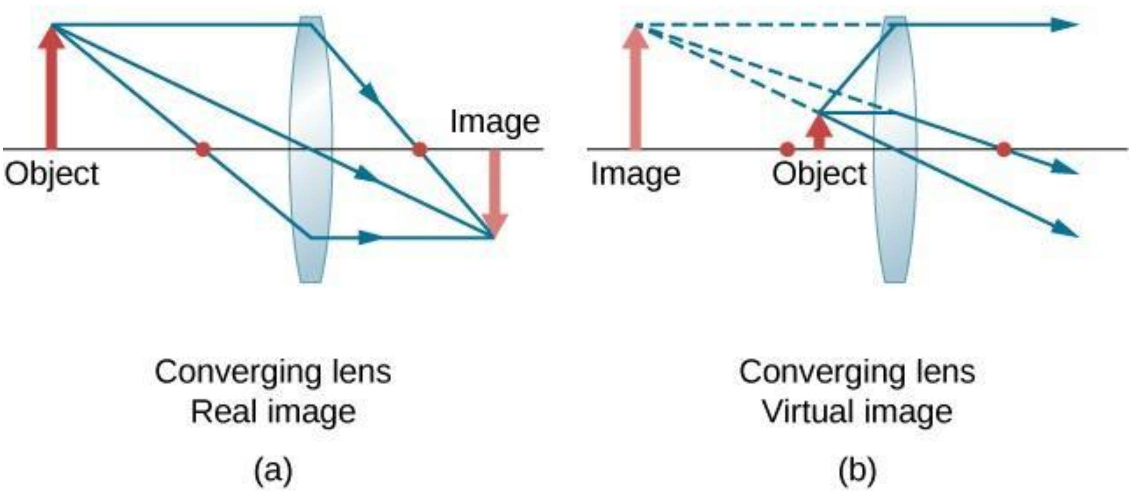
Optical fibres:

- **An optical fibre is a long thin rod of glass surrounded by cladding which uses total internal reflection to transfer information by light, even when bent.**
- **Extensive use in medicine (endoscopes, inside-body flexible cameras) and communications (high speed data transfer).**



Converging lens:

- A converging lens is a transparent block which brings light rays together at a point called the principal focus by utilising refraction.
- The focal length is the distance between the centre of the lens and the principal focus.
- **The image formed by a converging lens can be either real or virtual.**
    - **Real images are formed when the distance of the object from the centre of the lens is greater than the focal length. They are images where light actually converges to a position and can be projected onto a screen.**
    - **Virtual images are formed when the distance of the object from the centre of the lens is smaller than the focal length. They are images where light only appears to have converged and they cannot be projected onto a screen.**
- You can draw ray diagrams for real images (shown on the left below) and **virtual images (shown on the right below).**

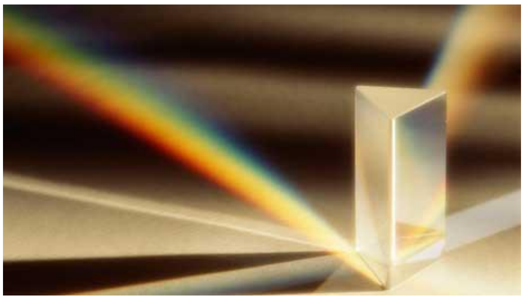


- The image formed is enlarged/same size/diminished and upright/inverted.
    - The image on the left above is diminished and inverted.
    - The image on the right above is enlarged and upright.
- Converging lenses are used in magnifying glasses and binoculars (to enlarge the image).

Dispersion

When white light is passed through a glass prism, it splits up into its constituent colours. This happens because the different colours travel at different speeds in the glass, so they refract by different amounts.

- The seven colours in order of decreasing wavelength are red, orange, yellow, green, blue, indigo and violet (ROYGBIV).
- The greater the wavelength, the slower the speed in glass and the greater the refractive index.



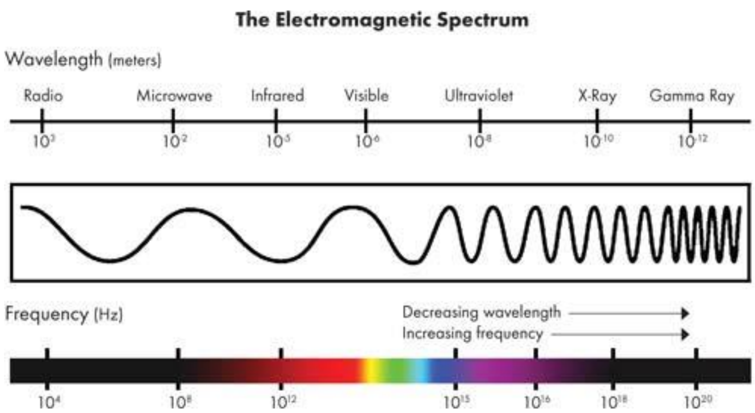
Light of a single frequency is described as monochromatic.

Electromagnetic spectrum

Properties of electromagnetic waves:

- Transverse waves
- Do not need a medium
- All electromagnetic waves travel with the same high speed of **3.0×10^8 ms^{-1}** in a vacuum and **approximately the same speed in air.**

You need to learn the main groups of the electromagnetic spectrum in order of wavelength.



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As speed is constant for all electromagnetic waves, as wavelength decreases, frequency must increase. The higher the frequency of an EM wave, the greater its energy.

Uses of electromagnetic waves:

- Radio waves are used for radio and television communications. They have a long wavelength and are reflected by the ionosphere.
- Microwaves are used for satellite communication and in microwave oven. They pass through the ionosphere and penetrate deep into food.
- Infrared radiation is used in remote controllers and infrared cameras.
- Visible light is used in fibre optics.
- Ultraviolet light is used in tanning beds.
- X-rays are used in medical imaging and in security as they can penetrate material easily.
- Gamma radiation is used in medical treatment due to its high energy.

Hazards:

- Too much exposure to ultraviolet light skin increases the risk of skin cancer.
    - Sun cream prevents over-exposure in summer.
- X-rays and gamma rays are ionising radiation that can cause mutations leading to cancer.
    - Exposure to these kinds of radiation should be minimised.
- Microwaves can cause internal heating of body tissues.
- Infrared radiation can cause skin burns.

Sound Waves

Sound waves are longitudinal waves created by vibrating sources. A medium is needed to transmit sound waves (such as air).

- The greater the amplitude of a sound wave, the louder it is.
- The greater the frequency of a sound wave, the higher its pitch.

To measure the speed of sound in air, you can make a noise at a known, large distance from a solid wall and record the time for the echo (reflected sound) to be heard, then use speed = distance/time, taking into account the fact that the sound had to go there and back.

The speed of sound in air is 343 ms^{-1}, the speed of sound in water is 1493 ms^{-1}, and the speed of sound in steel is 5130 ms^{-1}.

The range of audible frequencies for a healthy human ear is 20 Hz to 20000 Hz. Ultrasound is sound with a frequency greater than 20000 Hz:

- When ultrasound reaches a boundary between two media it is partially reflected back. The remainder of the waves continue to pass through.
- A transceiver can emit ultrasound and record the reflected waves to find the distance of things below the surface.
- Ultrasound is used for things such as SONAR and for medical imaging without using ionising radiation.