

CAIE Physics IGCSE

Topic 3: Waves Summary Notes

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3.1 General properties of waves

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**

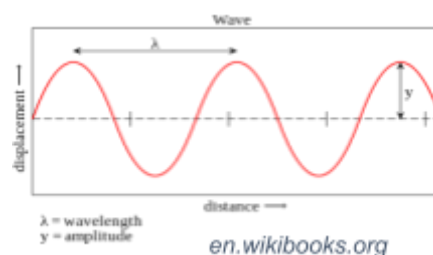
Wave motion refers to the transfer of energy from one point to another without the transfer of matter, typically involving oscillations or vibrations.

- **Speed is related to frequency and wavelength by:**

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

Types of waves:

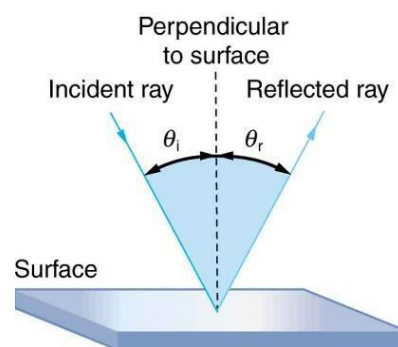
- **Transverse** waves
 - Has **peaks** and **troughs**
 - Vibrations are at **right angles** to the direction of travel
 - An example is light
- **Longitudinal** waves
 - **Consists of compressions (particles pushed together) and rarefactions (particles moved apart)**
 - Vibrations are in the **same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

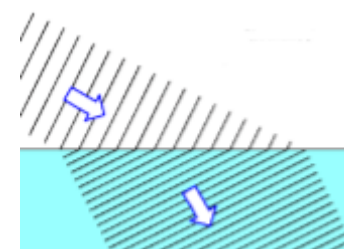
Reflection:

- 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**



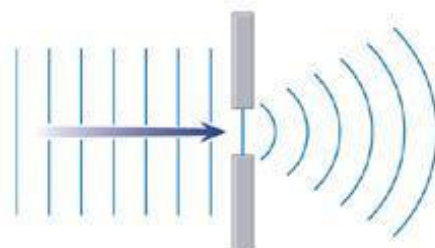
Refraction:

- 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.



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**



A **ripple tank** is a shallow tank of water used to study **wave motion**. It is equipped with a vibrating paddle to generate **waves** and often has a lamp above to project the wave patterns onto a screen or surface below.

Reflection at a Plane Surface:

- **Setup:** Place a straight barrier (e.g., a ruler) at an angle in the ripple tank.
- **Observation:** Waves strike the barrier and bounce off, obeying the law of **reflection**:
 - **Angle of incidence = Angle of reflection.**
- The reflected waves can be observed moving away from the barrier at the same angle they approached.

Refraction Due to a Change in Depth:

- **Setup:** Place a **transparent shallow block** in the ripple tank to create a region with different water depth.
- **Observation:**
 - Waves slow down and have shorter wavelengths in the shallow region.
 - The direction of the waves bends (**refraction**) as they pass from deeper to shallower water or vice versa.
- This illustrates how wave speed changes with depth, causing refraction.

Diffraction Due to a Gap:

- **Setup:** Place two barriers with a small gap between them in the tank.
- **Observation:**
 - When waves pass through the gap, they spread out into semicircles.
 - The amount of **diffraction** increases as the gap size decreases relative to the wavelength.

Diffraction Due to an Edge:

- **Setup:** Place a single barrier or object in the path of the waves.
- **Observation:**
 - As waves encounter the edge of the barrier, they bend around it, spreading into the region behind the barrier.
 - This illustrates how **diffraction** occurs even without a gap, showing the wave's ability to bend around obstacles.
 - Waves with longer wavelengths (e.g., sound waves) diffract more significantly around edges.
 - This is because longer wavelengths are more comparable in size to the edge, allowing the wave to bend around it effectively.



3.2 Light

3.2.1 Reflection of light

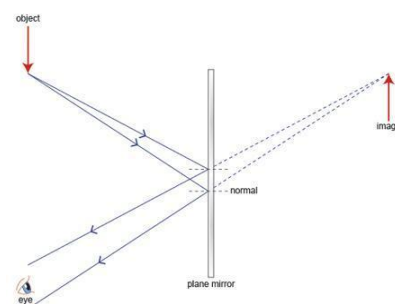
Reflection of light is the process by which light rays bounce off a surface and change direction, staying in the same medium. The angle of incidence (angle between the incoming ray and the normal) equals the angle of reflection (angle between the reflected ray and the normal).

Definitions:

- **Normal:** A line perpendicular to the reflecting surface at the point where the light ray strikes.
- **Angle of Incidence (i):** The angle between the incident ray and the normal.
- **Angle of Reflection (r):** The angle between the reflected ray and the normal.

Formation of an Optical Image by a Plane Mirror:

- Characteristics of the image:
 - **Same size** as the object.
 - **Same distance** behind the mirror as the object is in front.
 - **Virtual:** The image cannot be projected onto a screen.
 - **Laterally inverted:** Left and right are reversed.



Law of Reflection:

- **Angle of Incidence = Angle of Reflection ($i = r$).**
- This law applies to all reflective surfaces.

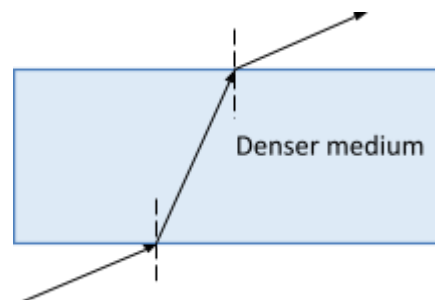
Constructions, Measurements, and Calculations:

- **Ray Diagrams for Plane Mirrors:**
 - Draw the object and the mirror.
 - Construct incident rays from the object to the mirror, ensuring the angles with the normal are equal for reflection.
 - Extend the reflected rays behind the mirror to locate the virtual image.
- **Measurements:**
 - Use a protractor to verify $i = r$.
- **Calculations:**
 - Determine image location and distances using geometry (e.g., image distance = object distance from the mirror).



3.2.2 Refraction of light

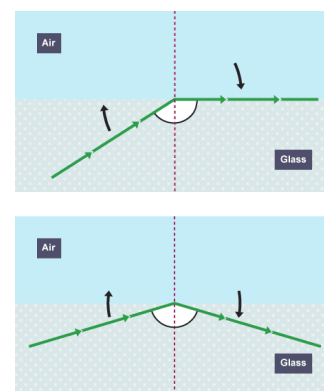
- **Refraction** can be shown when light is passed through a glass slab at an angle to its normal (the imaginary line 90° to the surface of the material).
- When light enters a more optically dense medium, the **angle of incidence** (the angle between the incident ray and the normal) is **greater** than 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**: $n = \frac{\text{speed of light in vacuum}}{\text{speed of light in the medium}}$
- **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:

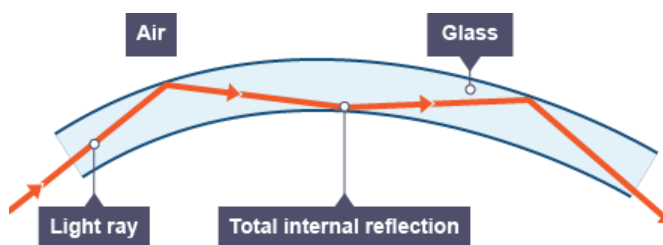
- At a certain angle of incidence called the **critical angle**, the light will travel along the boundary between the two media.
- **Total internal reflection** occurs when the angle of incidence is **greater** than the critical angle and the light **reflects** back into the medium.
- For total internal 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:

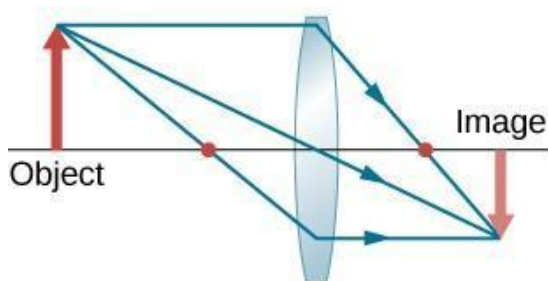
- An **optical fibre** is a long thin rod of **glass** surrounded by cladding which uses total internal reflection to transfer information by light, even when bent.
- Extensive use in **medicine** (endoscopes, inside-body flexible cameras) and **communications** (high speed data transfer).



3.2.3 Thin Lenses

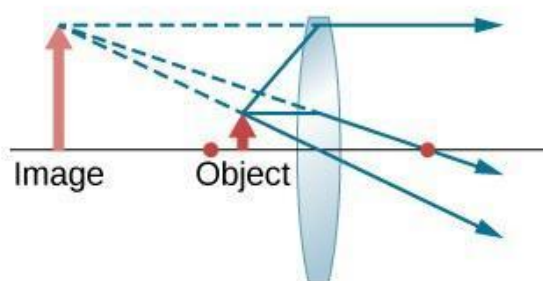
Converging lens:

- 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).



Converging lens
Real image

(a)



Converging lens
Virtual image

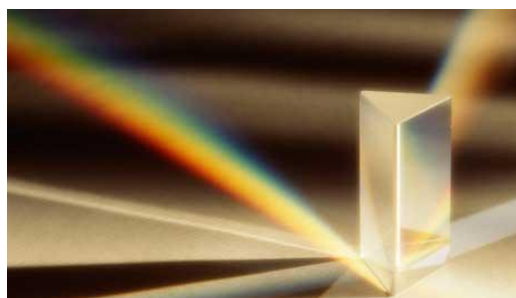
(b)

- 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).
- Converging lenses bring light closer together, aiding long-sighted eyes (Hyperopia).
- Diverging lenses spread light apart, aiding short-sighted eyes (Myopia).

3.2.4 Dispersion of light

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**.

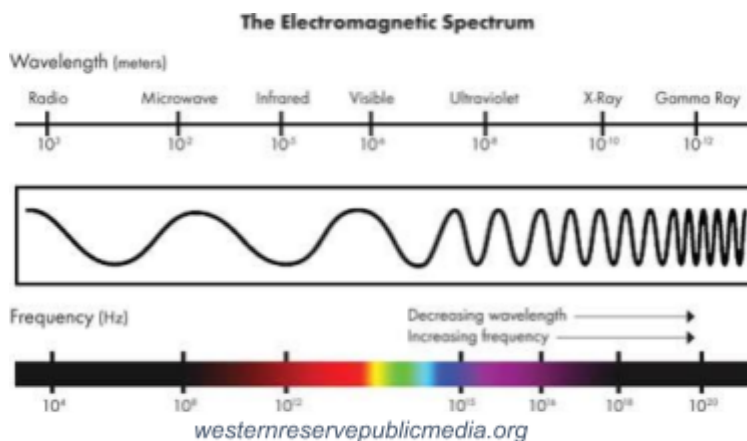


3.3 Electromagnetic spectrum

Properties of electromagnetic waves:

- **Transverse** waves
- Do **not** need a medium
- All electromagnetic waves travel with the **same high speed** of $3.0 \times 10^8 \text{ ms}^{-1}$ 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.



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**.



Communication with Artificial Satellites:

- **Microwaves** are the primary method for communication with satellites because they can penetrate the Earth's atmosphere.
- **Satellite phones:**
 - **Low orbit satellites:** Used for some satellite phones, requiring multiple satellites to provide coverage.
 - **Geostationary satellites:** Used for direct broadcast satellite TV and some satellite phones, remaining fixed relative to a point on Earth.

Speed of Electromagnetic Waves:

- Electromagnetic waves travel at 3.0×10^8 m/s in a vacuum and approximately the same in air.

Communication Systems and Electromagnetic Radiation:

- **Mobile Phones and Wireless Internet:**
 - Use **microwaves**, which can **penetrate walls and require only short aerials** for transmission and reception.
- **Bluetooth:**
 - Uses **low-energy radio waves or microwaves**, which **can pass through walls but weaken when doing so**.
- **Optical Fibres:**
 - Use **visible light or infrared** for **cable TV and high-speed broadband**.
 - Glass is transparent to these wavelengths, which can carry high data rates efficiently.

Digital vs Analogue Signals:

- **Analogue Signal:** **Continuously varying signals** that represent data (e.g., sound waves).
- **Digital Signal:** **Consists of discrete binary values** (0s and 1s) for transmitting data.

Sound Transmission:

- Sound can be transmitted as either:
 - An **analogue signal** (direct representation of sound waves).
 - A **digital signal** (converted into binary for processing and transmission).

Benefits of Digital Signaling:

- **Higher Data Transmission Rates:** Digital signals can carry more information per second.
- **Accurate Signal Regeneration:** **Digital signals can be regenerated accurately** over long distances, reducing noise and improving signal quality.
- **Increased Range:** **Better performance in long-distance communication** due to less degradation compared to analogue signals.



3.4 Sound

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 $\text{speed} = \text{distance}/\text{time}$, 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.

Compression and rarefactions are variations of pressure within a sound wave. Regions in a sound wave where particles are **pushed closer together**, creating areas of **high pressure**. Regions where particles are **spread further apart**, creating areas of **low pressure**. Together, compressions and rarefactions form **longitudinal waves**, the typical motion of sound waves in a medium.

Speed of Sound in Different Media:

- **Sound travels faster in solids than in liquids and faster in liquids than in gases:**
 - **Solids:** **Strong intermolecular forces** and closely packed particles allow **efficient energy transfer**.
 - **Liquids:** Particles are less tightly packed than in solids, leading to slower sound propagation.
 - **Gases:** Particles are far apart, resulting in the slowest sound transmission.

Sonar can be used to detect flaws in materials (e.g., cracks in metal or plastic) without damaging them. Ultrasound waves reflect from boundaries between materials or defects, identifying issues.

Sonar can also be used in medical scanning to image soft tissues (e.g., organs or a fetus during pregnancy). Ultrasound waves reflect at boundaries between different tissues, forming an image.

Sonar can also be used to measure water depth or locate underwater objects (e.g., submarines, fish). A pulse of ultrasound is sent underwater and the time taken for the echo to return is measured. **Depth Calculation:** $\text{Depth or Distance} = (\text{Speed of Sound} \times \text{Time}) / 2$

