BioMedical Admissions Test (BMAT)

Section 2: Physics

Topic P6 - Waves

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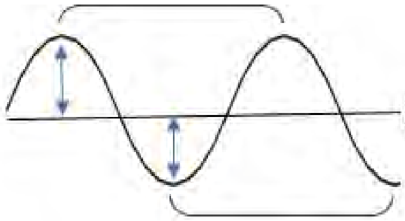
Wave characteristics

All waves transfer **energy** by causing particles of **matter** to **oscillate** (move in one direction then the opposite direction from one side to the other of a fixed point – a pendulum is an example of an object that oscillates)

➔ There are two types of waves, **transverse** and **longitudinal:**

Longitudinal wave	Transverse wave
Oscillations are **parallel** to (in the same plane as) the direction of energy transfer. Imagine a spring being compressed and then stretching out again: direction of travel of wave  = 1 wavelength Compressed region = **compression** Stretched region = **rarefaction**	Oscillations are **perpendicular** to direction of energy transfer. Direction of travel   = amplitude  = 1 wavelength
E.g. **sound** waves, **p waves** (type of seismic wave)	E.g. **Electromagnetic** (EM) waves (microwaves, light, UV etc)

Wavelength (m) is the distance between a point on the wave and the closest next point which is **exactly identical** (e.g. crest to crest or trough to trough for transverse waves, centre of compression to centre of the next compression for longitudinal waves). It is represented by the Greek letter λ (lambda)

Amplitude (measured in m as it is a distance) is the maximum distance a particle can be displaced from the rest position - measure from the **rest position** to a crest (highest point of wave) or trough (lowest point)

Frequency of a wave is the number of waves passing a point per second, measured in Hertz (Hz) - 1Hz is equivalent to 1 complete wavelength per second, 50Hz means 50 complete wavelengths per second

- For sound waves, a **higher amplitude** means a **louder** sound, and a **higher frequency** means a **higher pitch**
- Frequency is calculated using the equation **f = 1/period**

*where **period** is the time taken in seconds (s) for 1 complete wavelength (oscillation)*

Speed of all waves is defined as the **distance (m)** travelled by the wave over the **time (s)** taken

- **Speed** (ms^{-1}) of a wave can also be calculated using the equation:

speed = frequency (Hz) x wavelength / λ (m)

Rearranging this equation gives **frequency** = **speed** / **wavelength** which means that frequency and wavelength are **inversely proportional** (as wavelength decreases, frequency increases for example).

> ***Exam Tip*** - BMAT questions sometimes ask you to choose an appropriate equivalent for a particular unit. To answer these questions, think about the calculation or calculations that can be used to find the value which the unit measures.
>
> For example, frequency (Hz) can be calculated using the equation 1/period (s) so an equivalent unit for Hz could be s^{-1}.
>
> Alternatively frequency is calculated using speed/wavelength so $\frac{m/s}{m}$ also cancels to s^{-1} (think of metres per second as ms^{-1} and cancel m)

Longitudinal waves (such as sound waves) travel **faster** through **solids** than liquids, and **slowest** through **gases**. This is because waves transfer **energy** by causing particles of **matter** to **oscillate**.

➔ An object with a higher density of particles such as a solid allows the wave to travel faster than an object with low particle density such as a gas as there are more particles of matter to oscillate.

This also means that sound waves **cannot** travel through a **vacuum**.

➔ Conversely, the particles oscillating in an EM wave are the electrons of the wave itself, which means it does not require additional matter and is able to travel through a vacuum

> ***Exam Tip*** - The **speed** of an EM wave can also change as the **medium** through which it is travelling changes (e.g. air to glass or water). The speed of light travelling through a certain material is a specific property of that material, different from its mass density (see notes below on refraction).
>
> **Frequency** of a wave is usually **constant**, which means that **changes** in the **speed** of a wave usually result in **changes in wavelength** (speed and wavelength are **directly proportional**)

The EM Spectrum

	Radio waves	Microwaves	Infrared	Visible light Red Blue	Ultraviolet	X ray	Gamma
Wavelength	>10cm	10^{-2}m	10^{-5}m	10^{-7}m	10^{-8}m	10^{-10}m	10^{-12}m
Uses	Communication	Wavelengths that pass through water– communication Wavelengths absorbed by water – cooking	Heat is radiated as infrared – used for heat cameras, cooking e.g. grilling, toasting Remote controls	Optical fibres	Fluorescent marking (chemicals are used which absorb UV light and emit visible)	Medical imaging	Sterilising Cancer radiotherapy Medical imaging
Dangers		Must be kept inside microwave by a metal grille or could heat body	Infrared responsible for burns and **greenhouse effect**	Eye damage (e.g. looking directly at sun)	Skin cancer Ionising radiation	Ionising radiation	Ionising radiation

Frequency and energy increasing, wavelength decreasing

EM waves make up a **continuous spectrum** of the same type of wave – divided into categories based on their wavelength (radio waves have the longest wavelength, gamma shortest)

The **energy** of an EM wave is **directly proportional** to its **frequency** and **inversely proportional** to its **wavelength**.

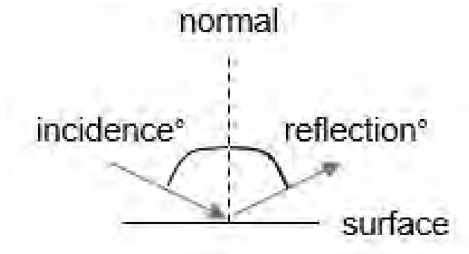
- Gamma rays have the most energy (highest frequency, shortest wavelength) and radio waves have the least (lowest frequency, longest wavelength)
- **High energy** EM waves (**UV**, **X ray** and **gamma**) are **ionising radiation**. This means they have enough energy to remove an electron from an atom and create a charged particle. If this happens in cells it can cause DNA mutation and increase the risk of cancer
- **All EM** waves travel at the **same speed** (speed of light, ~300 000 000ms^{-1} in a vacuum). As speed = frequency x wavelength, EM waves with a higher frequency must have a shorter wavelength, and vice versa, to maintain the same speed

Exam Tip – If you struggle to remember the order of the EM spectrum make a mnemonic with the letters RMIVUXG

Wave properties

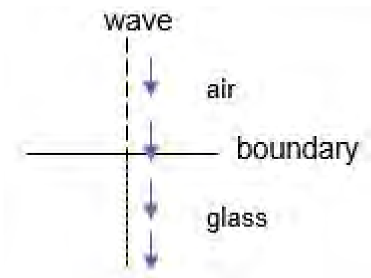
Reflection occurs when a wave bounces off a surface without being absorbed by it. This usually causes the wave to change direction

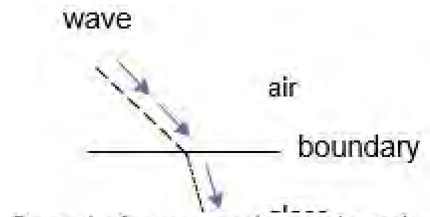
➔ **Law of reflection**:
angle of incidence = angle of reflection



Angles are measured between wave and normal line (imaginary line at 90° to the surface)

Refraction occurs when a wave enters a medium with a different optic density (e.g. air to glass) and changes direction due to a change in speed. A wave entering a new medium at exactly 90° to the surface of the medium will change speed, but not direction





Speed of wave and wavelength decrease as wave enters glass. Wave refracts (changes direction) towards the normal (imaginary line at 90° to the boundary between the two surfaces) because part of the wave front has entered the new medium first and started to slow down, while the other part is still travelling at its speed in air.

Exam Tip

➔ The **angle of incidence** is the angle between the **normal** (imaginary line at 90 degrees to the surface) and the **incident ray**.
➔ **Angle of refraction** is the angle between the **normal** and the **refracted ray**.
➔ Remember these are both measured relative to the **normal** and not the boundary of the surface itself

When a ray of white light enters a prism it splits into a rainbow, or **spectrum**, from red through to violet. Light at the red end of the spectrum is refracted **least** and **blue** light **most**, because red light has a longer wavelength (longer wavelength = more refraction). A way to remember this could be 'blue bends, red resists'

Sound waves also reflect and refract – remember that they will **speed up** when entering a **denser** material, so if the wave front hits the surface at an angle, refraction will occur

The Doppler Effect

When there is **relative motion** between a source of waves and an observer, the wavelength and frequency of the waves detected by the observer is different from the wavelength and frequency of the waves received when there is no relative motion.

- ➔ When the source moves towards the observer, the frequency increases and wavelength decreases.
- ➔ When the source moves away from the observer, the frequency decreases and the wavelength increases.

This is known as the **Doppler effect** and the faster the movement, the greater the Doppler shift.

Sound Waves

Sound waves are produced by a **vibrating** source. The vibrating source causes the surrounding medium to vibrate and this pattern of vibrations travels away from the source as **sound waves**.

- ➔ The sound waves have the same **frequency** (pitch) as the vibrations of the source.
- ➔ The **amplitude** (loudness) of the sound waves depends on the amplitude of the vibrations of the source.
- ➔ The speed of the sound waves is determined by the **medium** through which they travel and **not** by the source.

When sound arrives at a detector (e.g. a microphone or the human ear), the sequence of compressions and rarefactions causes the **pressure** at the detector to vary. This exerts a varying force on the detector and this is what is detected (e.g. the eardrum is moved by this force).

Sound waves obey the law of **reflection** where the angle of incidence **equals** the angle of reflection.

An **echo** is a sound heard after sound waves reflect from one or more surfaces.
Reflection of sound or ultrasound waves can be used to measure distances by using the following equation:

Distance (m) = [velocity (m/s) x time (s)] / 2

Dividing by two accounts for the fact that the time measured is the time taken for the wave to travel from the emitter/receiver to the object **and** back again.

This principle is used in both **sonar** and **ultrasound**.

Ultrasound

The human hearing range is approximately 20Hz - 20KHz which corresponds to a range of sound speeds and wavelengths which can be calculated using V=Fλ.

- ➔ **Ultrasound** consists of sound waves with frequencies greater than 20KHz.

Ultrasound is used in depth detection in sonar. It is also used in non invasive medical imaging.

- ➔ In medical imaging, ultrasound can detect the **boundary** between different tissue types as certain fractions of ultrasound waves are **reflected** at each boundary.
- ➔ The time taken for the reflected waves to reach the detectors corresponds to the **depth** of each boundary (tissue type).
- ➔ These metrics can be combined to produce an image of the soft tissues within the body.