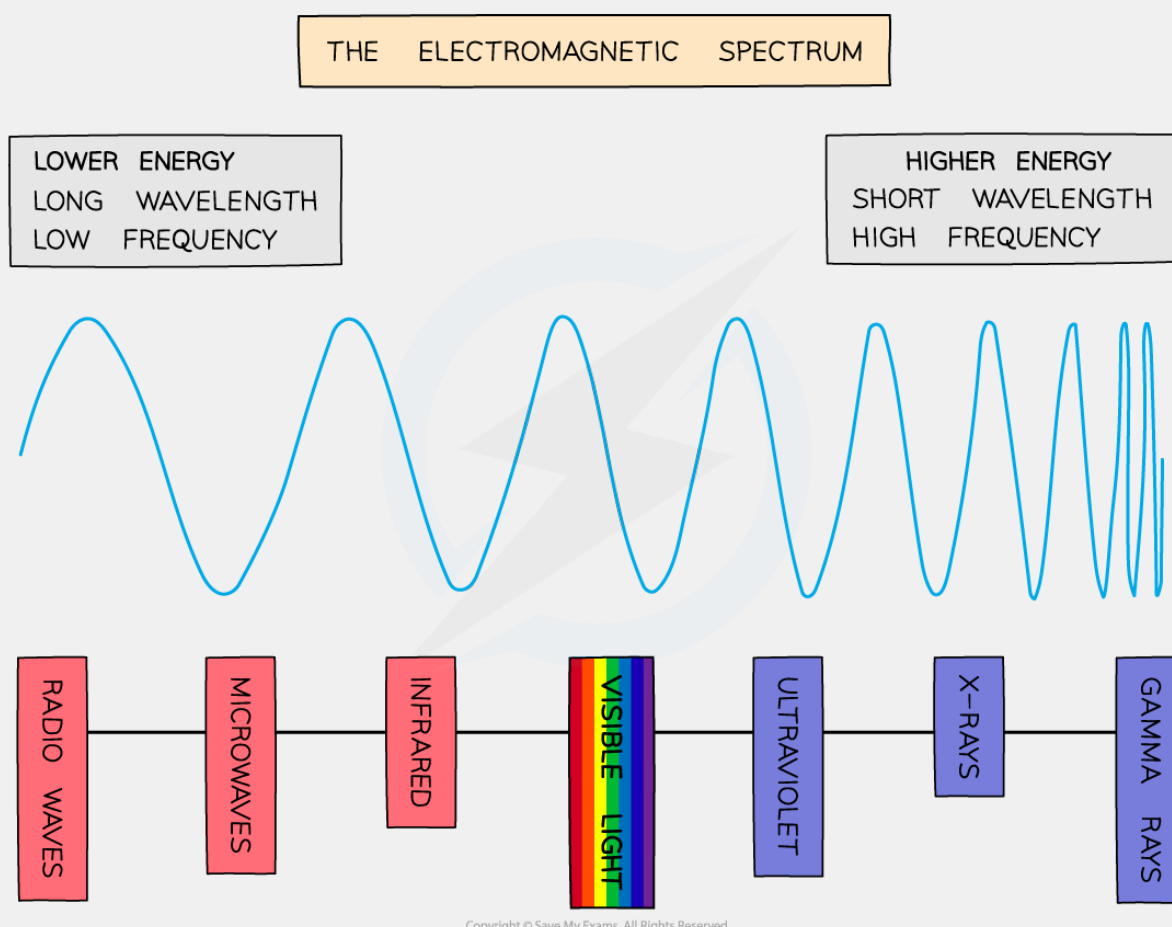


3.3 Electromagnetic Spectrum

Electromagnetic Waves

- The electromagnetic spectrum is arranged in a specific order based on the wavelengths or frequencies of the radiation in each region
 - Regions with a **long wavelength** have a **low frequency** and vice versa
- The main regions of the continuous electromagnetic (EM) spectrum from longest to shortest wavelength are:
 - Radio waves
 - Microwaves
 - Infrared
 - Visible (red, orange, yellow, green, blue, indigo, violet)
 - Ultraviolet
 - X-rays
 - Gamma rays

The electromagnetic spectrum in order of decreasing wavelength



Visible light is just one small part of a much bigger spectrum: The electromagnetic spectrum

Examiner Tips and Tricks

See if you can make up a mnemonic to help you remember the EM spectrum!

One possibility is:

Raging **M**artians **I**nvaded **V**enus **U**sing **X**-ray **G**uns

The electromagnetic spectrum is usually given in order of **decreasing wavelength** and **increasing frequency** i.e. from radio waves to gamma waves

Remember:

- Radios are **big** (long wavelength)
- Gamma rays are emitted from atoms which are **very small** (short wavelength)

Properties of electromagnetic waves

- All electromagnetic waves travel at the same **high speed** in a **vacuum**
 - **Vacuum** is a space that contains no matter
- Electromagnetic waves are defined as:

Transverse waves that transfer energy from the source of the waves to an absorber

The Speed of Electromagnetic Waves

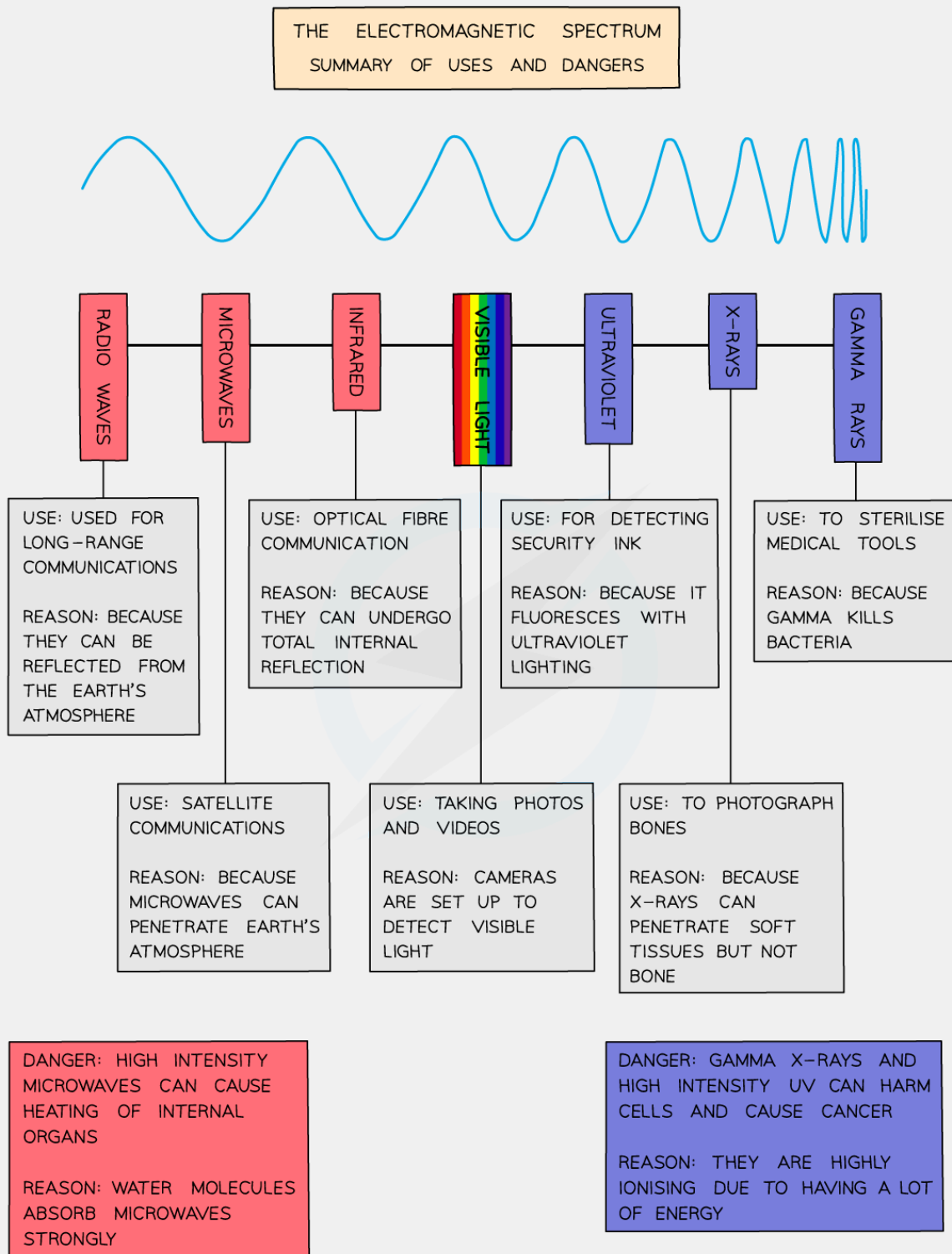
- The speed of electromagnetic waves in a vacuum is
$$3.0 \times 10^8 \text{ m/s}$$
- This is approximately the same speed as electromagnetic waves in air
- This speed is often represented with the symbol c

Uses of Electromagnetic Waves

Typical uses of the different regions of the electromagnetic spectrum

Wave	Use
Radio	Radio and television transmissions Astronomy Radio frequency identification (RFID)
Microwave	Satellite television Mobile (cell) phones Microwave ovens
Infrared	Electric grills Television remote controllers Intruder alarms Thermal imaging Optical fibres
Visible light	Vision Photography Illumination
Ultraviolet	Security marking Detecting fake bank notes Sterilising water
X-rays	Medical scanning Security scanners
Gamma rays	Sterilising food Sterilising medical equipment Detection of cancer Treatment of cancer

Typical uses of the different regions of the electromagnetic spectrum



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Uses and dangers of the electromagnetic spectrum

Uses of radio and microwaves

- The main uses of radio and microwaves are for wireless communication
 - Many things people often assume use radio waves use microwaves (e.g. WiFi, radar, mobile phones, satellite communications)
- At very high intensities microwaves can also be used to heat things
 - This is what happens in a microwave oven

Uses of infrared

- Warm objects emit infrared radiation
- Infrared can be detected using thermal imaging cameras
 - In security cameras, for research and also in medicine
- Remote controls have small infrared LEDs that send invisible signals to an infrared receiver on a device such as a TV
- Infrared travels down fibre optic cables more efficiently than visible light
 - So most fibre optic communication systems use infrared

Uses of visible light

- Visible light is the only part of the electromagnetic spectrum that the human eye can see
- Visible light is used for photography, videography and illumination

Uses of ultraviolet light

- Ultraviolet is responsible for giving you a sun tan, which is your body's way of protecting itself against the ultraviolet rays
- When certain substances are exposed to ultraviolet, they absorb and re-emit it as visible light (making them glow)
 - This process is known as fluorescence
 - Fluorescence can be used to mark things using special ink secretly
 - Most bank notes have invisible fluorescent markings on them
- Fluorescent light bulbs also use this principle to emit visible light

Uses of X-rays

- The most obvious use of x-rays is in medicine

- X-rays pass through body tissues but are absorbed by denser body parts such as bones
 - Bones absorb X-rays, leaving a shadow which can be seen using photographic film

Uses of gamma rays

- Gamma rays are used to kill cells and living tissue
- This property is utilised in both cancer detection and treatment
 - If gamma rays are carefully aimed at cancerous tissue, they can be effective at destroying the cancerous cells
- Gamma rays can also be used to sterilise food and medical equipment by killing off the bacteria

Dangers of Electromagnetic Waves

- **Excessive exposure** to electromagnetic radiation has **harmful effects** on people
 - As the frequency of the electromagnetic (EM) waves increases, so does their energy
- Beyond the visible part of the spectrum (ultraviolet waves, X-rays and gamma rays), the energy is large enough to **ionise** atoms
 - The **higher** the **frequency**, the more **ionising** the radiation
- The effects of ionisation also depend on the **type of radiation** and the **size** of the **dose**

Harmful effects of EM radiation

Wave	Danger
Radio	No known danger
Microwaves	Internal heating of body cells
Infrared	Skin burns
Ultraviolet	Damage to surface cells and eyes leads to skin cancer and eye conditions
X-rays and gamma rays	Mutation or damage to cells in the body

Harmful effects of excessive microwave exposure

- Certain frequencies of microwaves are absorbed by **water molecules**
- Humans contain a lot of water, so there is a risk of **internal heating** from microwaves
- This might worry some people, but the longer wavelength (lower energy) microwaves used in everyday circumstances are proven to be safe
 - Microwaves used for **communications** (including mobile phones) emit very small amounts of energy which are not known to cause any harm

- Microwave ovens, on the other hand, emit very large amounts of energy, however, that energy is **prevented** from escaping the oven by the metal walls and metal grid in the glass door

Harmful effects of excessive ultraviolet exposure

- Ultraviolet is similar to visible light, except it is invisible to the human eye and carries a much higher energy
- If eyes are exposed to high levels of UV it can cause **severe** eye damage
 - Good quality sunglasses will absorb ultraviolet, preventing it from entering the eyes
- Ultraviolet can kill cells or cause them to malfunction
 - This can cause **premature ageing**, and diseases such as **skin cancer**
 - Sunscreen absorbs ultraviolet light, preventing it from damaging the skin

Harmful effects of excessive X-ray and gamma-ray exposure

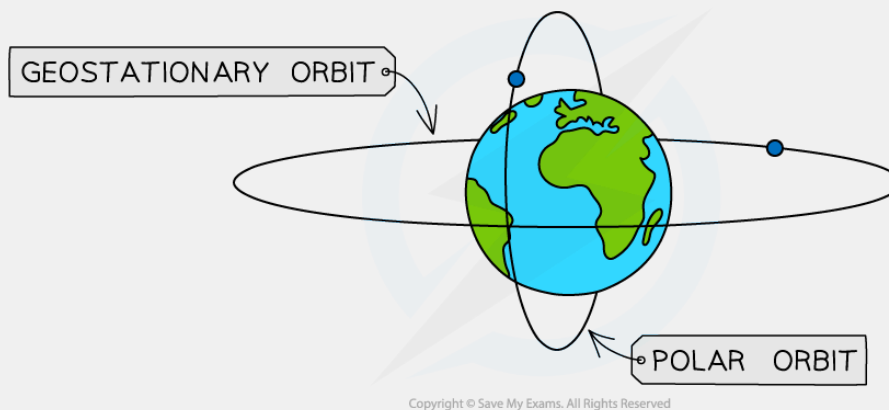
- X-rays and gamma rays are the most ionising types of EM waves
 - They can penetrate the body and cause **internal** damage
 - They can cause the **mutation** of DNA, causing **cancer**

Communication

Communications with satellites

- Communications with **artificial satellites** use **microwaves**:
 - Some satellite phones use low-orbit artificial satellites
 - Some satellite phones and direct broadcast satellite televisions use geostationary satellites

Geostationary and polar-orbiting satellites



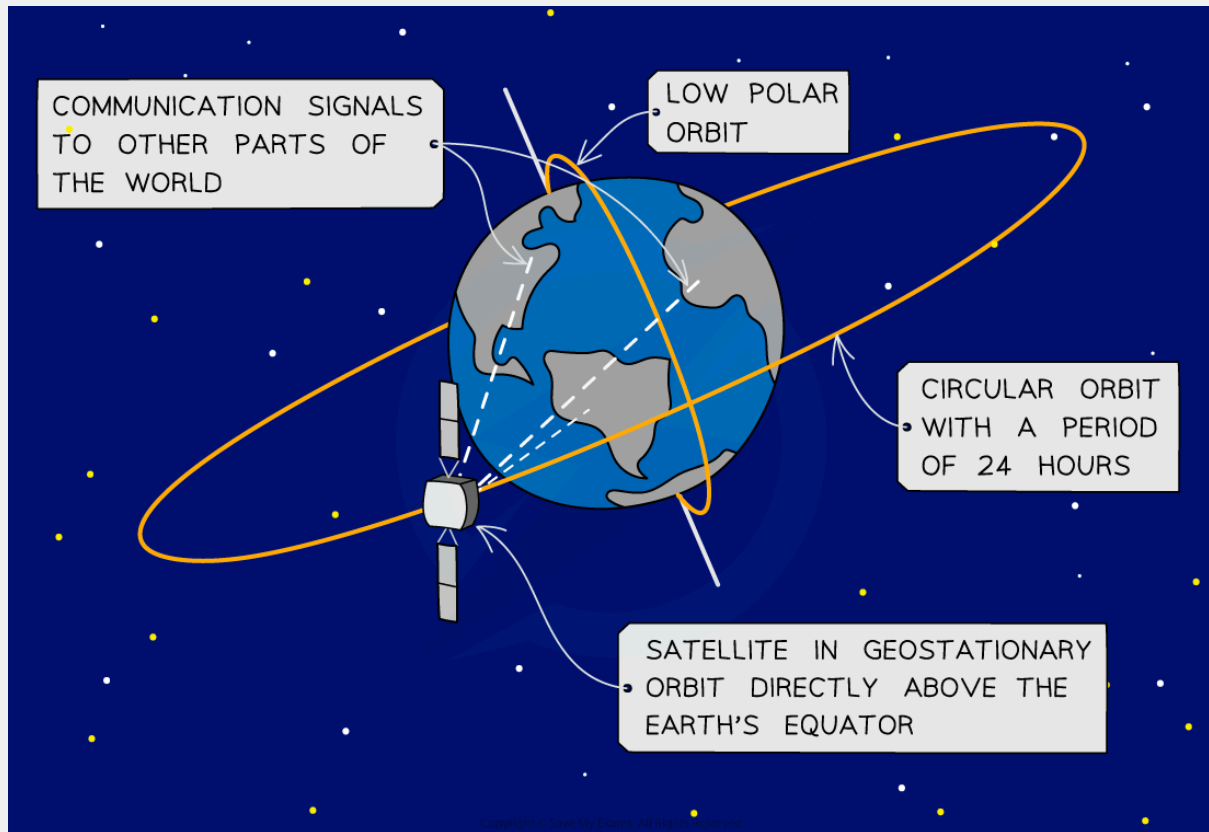
Geostationary and polar orbits around the Earth

Low orbit satellites

- Low orbit satellites orbit much lower than geostationary satellites, at around 200 km above sea level
 - Used for monitoring the weather, military applications, and taking images of the Earth's surface
 - There is a much shorter time delay for signals compared to geostationary orbit signals
 - The signals and images are much clearer due to the lower orbit
 - However, there is limited use in any one orbit because more than one satellite is required for continuous operation

- Polar orbit satellites are a type of low Earth orbit satellite that orbit around the poles

Low orbit satellites

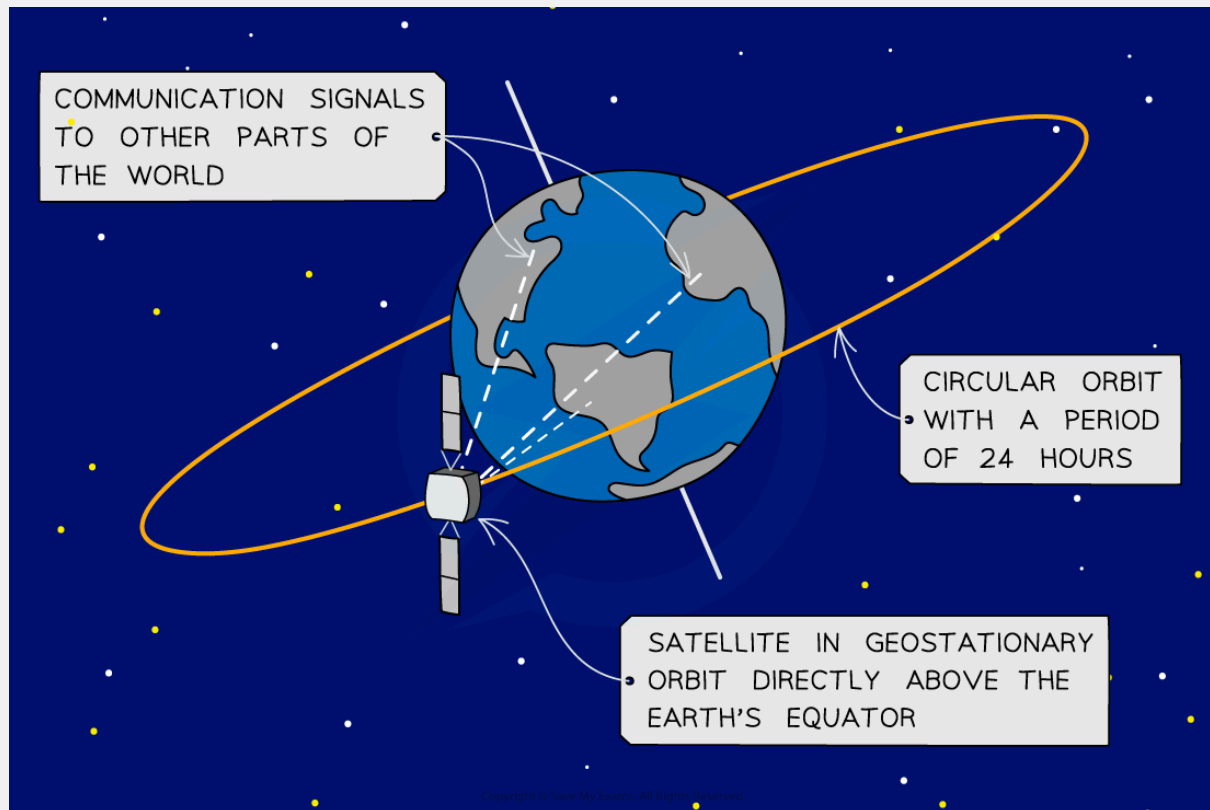


Some satellite phones use low-orbit artificial satellites if a more detailed signal is required

Geostationary satellites

- Geostationary satellites orbit **above the Earth's equator**
 - The orbit of the satellite is 24 hours
 - At a height of 36 000 km above the Earth's surface, much higher than polar satellites
 - Used for radio and telecommunication broadcasting around the world due to its high orbit

Orbit of geostationary satellite



Some satellite phones and direct broadcast satellite television use geostationary satellites

Systems of communications

- Many important systems of communication rely on **long-wave** electromagnetic radiation, including:
 - Mobile phones, wireless internet & satellite television (using **microwaves**)
 - Bluetooth, terrestrial television signals & local radio stations (using **radio waves**)
 - Optical fibres (using **visible** or **infrared** waves)

Microwaves

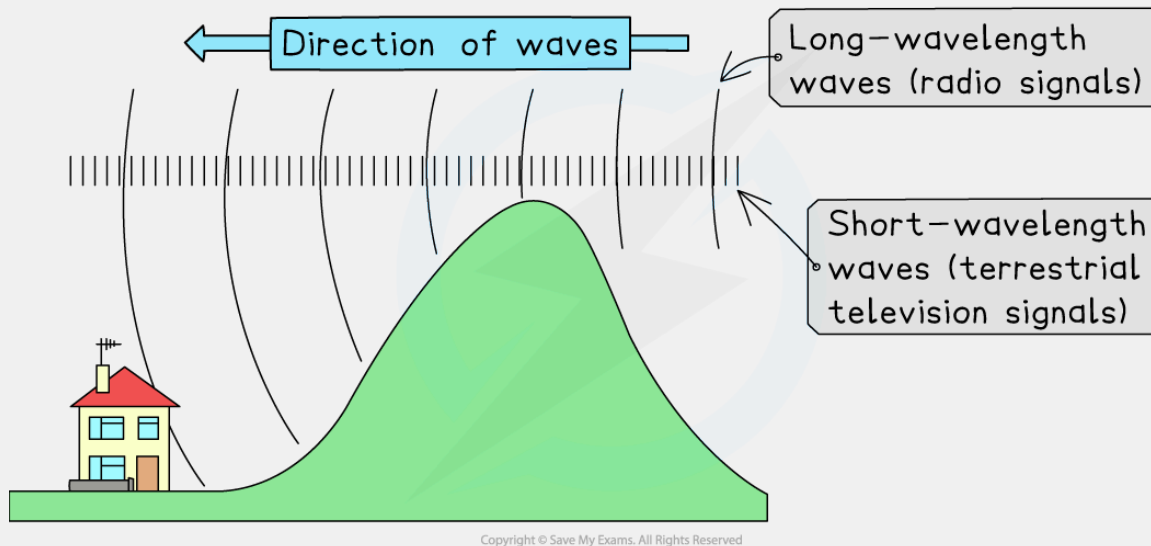
- Microwaves can be used to transmit signals over **large** distances
- As with radio waves, microwave signals will be clearer if there are no obstacles in the way which may cause **diffraction** of the beam
- On the ground, mobile phone signals use a network of **microwave transmitter masts** to relay the signals from the nearest mast to the receiving phone
 - They cannot be spaced so far apart that, for example, hills or the curvature of the Earth diffract the beam
- Mobile phones and wireless internet use microwaves because microwaves are not refracted, reflected or absorbed by the **atmosphere** or **ionosphere**
 - This means satellites can relay signals around the Earth allowing communication 24 hours a day all around the world
 - Also, they can penetrate most walls and only require a short aerial for transmission and reception

Radio waves

- Radio waves can be used to transmit signals over **short** distances
- Radio waves have wavelengths of around a kilometre
- Radio waves can **diffract** around the hills
 - This is because radio waves have wavelengths similar to the size of the hill
 - Also, longer wavelengths will diffract a greater angle than shorter wavelengths
- Bluetooth uses radio waves instead of wires or cables to transmit information between electronic devices, over short distances, such as phones and speakers
 - Bluetooth signals tend to have **shorter** wavelengths than radio or television signals
 - This enables high rates of data transmission that can only be used over a short distance (for example, within a household)

- This means they can pass through walls but the signal is significantly **weakened** on doing so

Radio waves diffract around hills



Radio signals diffract around hills because they are a similar wavelength to the hill

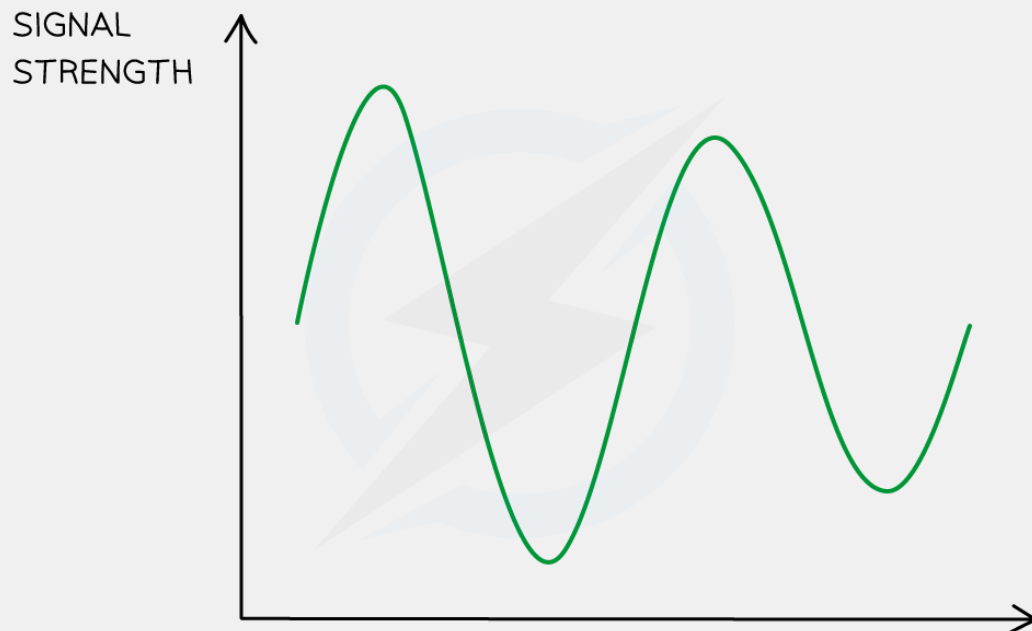
Optical fibres

- Optical fibres use visible light and short-wavelength infrared radiation for cable television and high-speed broadband
 - Visible light and infrared radiation can carry high rates of data due to their high frequency

Digital & Analogue Signals

- There are two types of signals:
 - Analogue
 - Digital
- **Analogue signals vary continuously** - they can take any value

An analogue signal

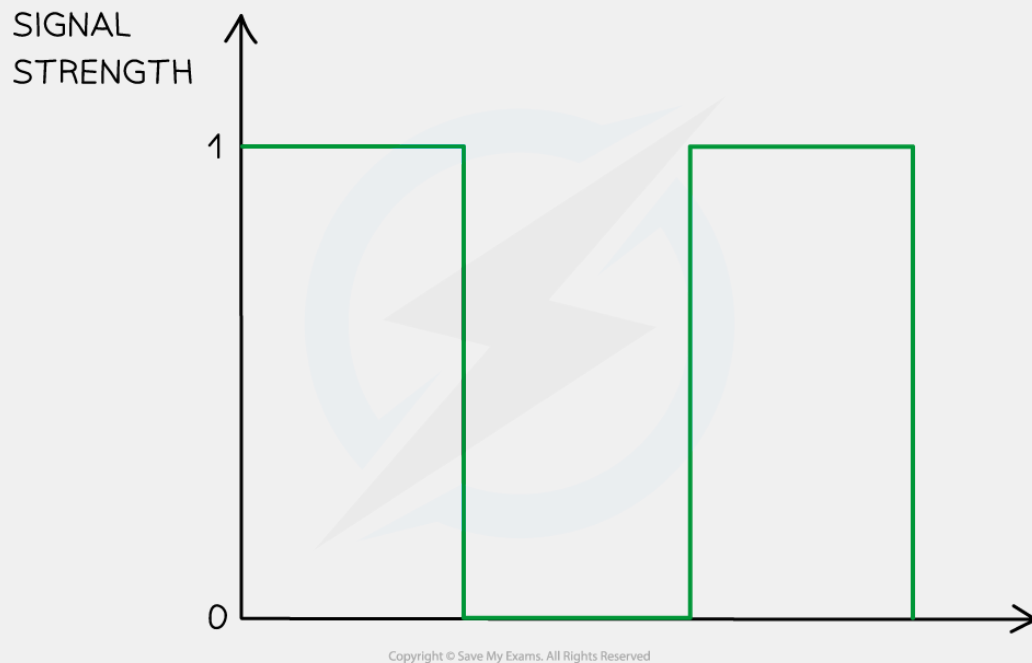


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An analogue signal is continuously varying, taking any value

- **A digital signal can only take one of two (discrete) states**
 - These are usually referred to as;
 - **1s and 0s**
 - **Highs and lows, or**
 - **Ons and offs**

A digital signal



A digital signal can only take one of two values – 0 or 1

Transmission of sound

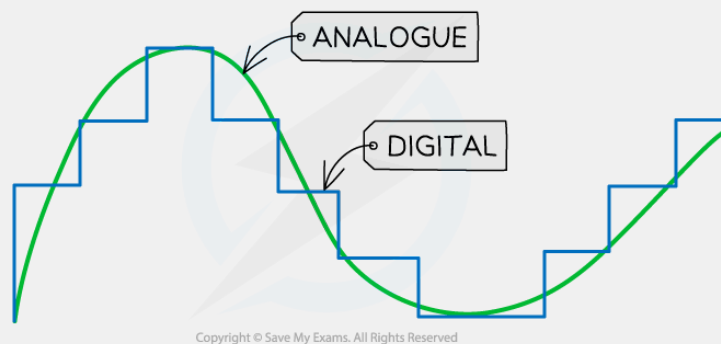
- Sound waves that can be transmitted as a **digital** or **analogue** signal
- Signals for speech or music are made up of varying frequencies
 - To make out the information clearly, the signal needs to be transmitted with as little interference as possible
- The signal undergoes **digital sampling**
- It is converted **both before transmission** and **after being received**
 - Before transmission: the signal is converted from **analogue** to **digital**

- After being received: the signal is converted back from **digital** to **analogue**

Benefits of digital signalling

- The benefits of digitally sampling a signal include:
 - **Increased rate** of data transmission
 - **Increased range** due to accurate signal regeneration

Digital sampling an analogue signal



Analogue v digital signal

- The key **advantages** of data transmission in **digital** form compared to analogue are:
 - The signal can be **regenerated** so there is minimal **noise**
 - Due to accurate signal regeneration, the **range** of digital signals is **larger** than the range of analogue signals (they can **cover larger distances**)
 - Digital signals enable an **increased rate of transmission of data** compared to analogue
 - Extra data can be added so that the signal can be checked for errors

Examiner Tips and Tricks

Digital sampling is when an analogue signal is converted into a digital signal by recording sound at set time intervals.

