IGCSE Physics CIE

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3.3 Electromagnetic Spectrum

CONTENTS

3.3.1 Electromagnetic Waves

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Electromagnetic Waves

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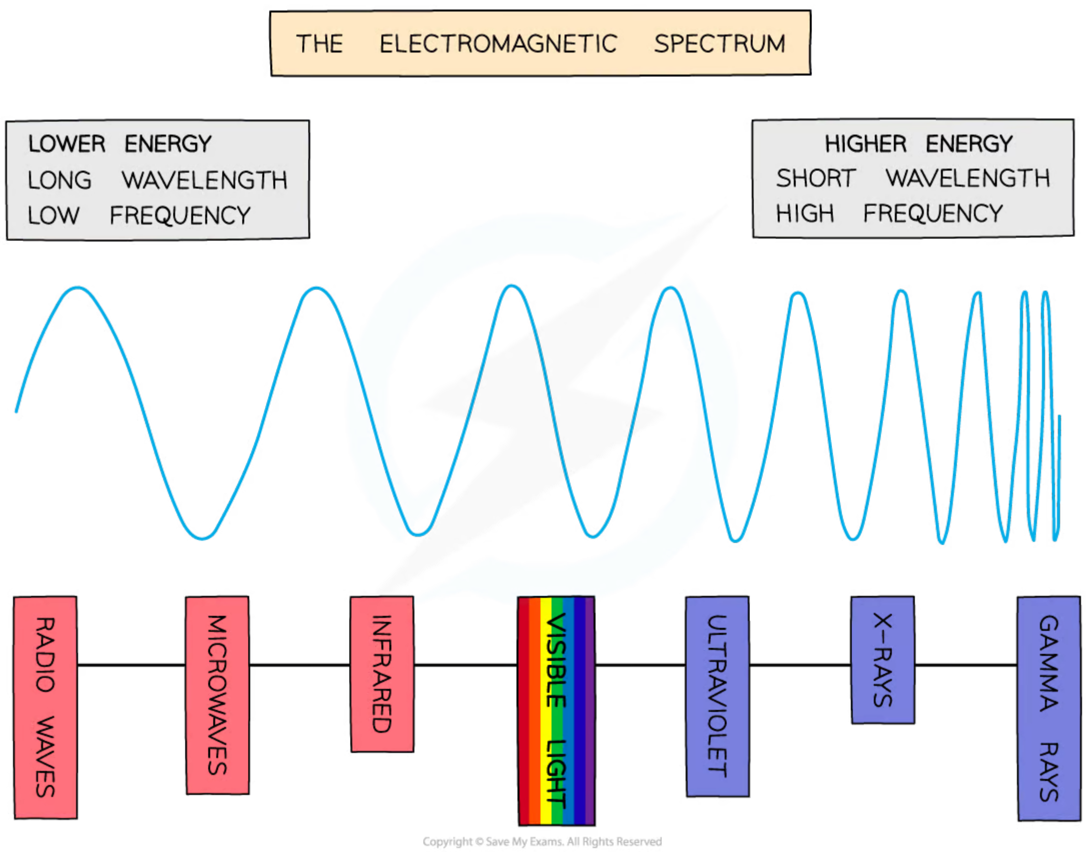
- The electromagnetic spectrum is arranged in a specific order based on the wavelengths or frequencies
- The main groupings of the continuous electromagnetic (EM) spectrum are:
  - Radio waves
  - Microwaves
  - Infrared
  - Visible (red, orange, yellow, green, blue, indigo, violet)
  - Ultraviolet
  - X-rays
  - Gamma rays
- This order is shown in the diagram below from longest wavelength (lowest frequency) to shortest wavelength (highest frequency)



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

- The **higher** the **frequency**, the higher the **energy** of the radiation
- Radiation with higher energy is:
  - Highly ionising
  - Harmful to cells and tissues causing cancer (e.g. UV, X-rays, Gamma rays)
- Radiation with lower energy is:

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- Useful for communications
- Less harmful to humans

Exam Tip

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

- Electromagnetic waves are defined as:

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

- All electromagnetic waves share the following properties:
  - They are all **transverse**
  - They can all travel through a **vacuum**
  - They all travel at the **same speed** in a vacuum
- The 7 types of electromagnetic waves together form a **continuous spectrum**

The Speed of Electromagnetic Waves

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- The speed of electromagnetic waves in a vacuum is

$$\mathbf{3.0 \times 10^8\ m/s}$$

- This is approximately the same speed as electromagnetic waves in air

3.3.2 Uses of Electromagnetic Waves

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Uses of Electromagnetic Waves

- Electromagnetic waves have a variety of uses and applications
- The main ones are summarised in the table below:

Applications of EM Waves Table

Wave	Use
Radio	∘ Communication (radio and TV)
Microwave	∘ Heating food ∘ Communication (WiFi, mobile phones, satellites)
Infrared	∘ Remote controls ∘ Fibre optic communication ∘ Thermal imaging (medicine and industry) ∘ Night vision ∘ Heating or cooking things ∘ Motion sensors (for security alarms) ∘ Electrical heaters ∘ Infrared cameras
Visible light	∘ Seeing and taking photographs/videos ∘ Fibre optic communications
Ultraviolet	∘ Security marking (fluorescence) ∘ Fluorescent bulbs (energy efficient lamps) ∘ Getting a suntan
X-Rays	∘ X-Ray images (medicine, airport security and industry)
Gamma Rays	∘ Sterilising medical instruments ∘ Treating cancer

- A summary of the uses and dangers of different EM waves are summarised in the diagram below:

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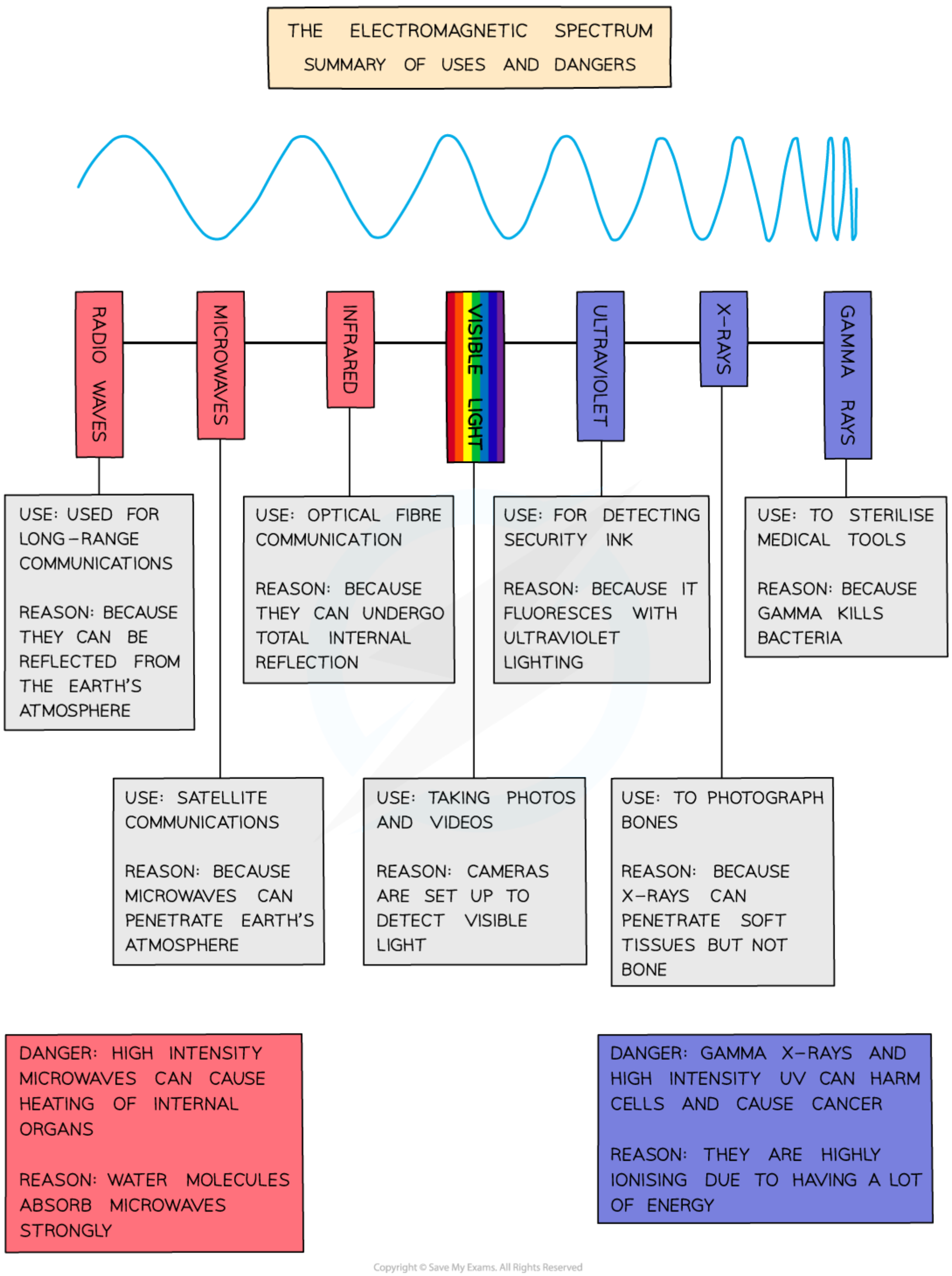

Uses and dangers of the electromagnetic spectrum

Radio Waves & Microwaves

- These two parts of the spectrum share a lot of similarities and applications

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- Their main uses concern wireless communication – in fact, many things that people often assume use radio waves actually 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

Infrared

- Infrared is emitted by warm objects and can be detected using special cameras (thermal imaging cameras). These can be used in industry, in research and also in medicine
- Many security cameras are capable of seeing slightly into the infrared part of the spectrum and this can be used to allow them to see in the dark
  - Infrared lights are used to illuminate an area without being seen, which is then detected using the camera
- Remote controls also have small infrared LEDs that can 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, and so most fibre optic communication systems use infrared

Visible

- Visible light is the only part of the electromagnetic spectrum that the human eye can see
- The human eye can detect wavelengths from 750 nanometres (red light) up to 380 nanometres (violet light)

Ultraviolet

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

- Fluorescent light bulbs also use this principle to emit visible light

X-rays

- The most obvious use of x-rays is in medicine
- X-rays are able to pass through most body tissues but are absorbed by the denser parts of the body, such as bones
  - When exposed to x-rays, the bones absorb the x-rays, leaving a shadow which can be seen using a special x-ray detector or photographic film

Gamma Rays

- Gamma rays are very dangerous and can be used to kill cells and living tissue
- This property can be utilised in both cancer detection and treatment
  - If these gamma rays are carefully aimed at cancerous tissue, they can be very effective at destroying the cancerous cells

- Gamma rays can also be used to sterilise food and medical equipment by killing off the bacteria

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3.3.3 Dangers of Electromagnetic Waves

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Dangers of Electromagnetic Waves

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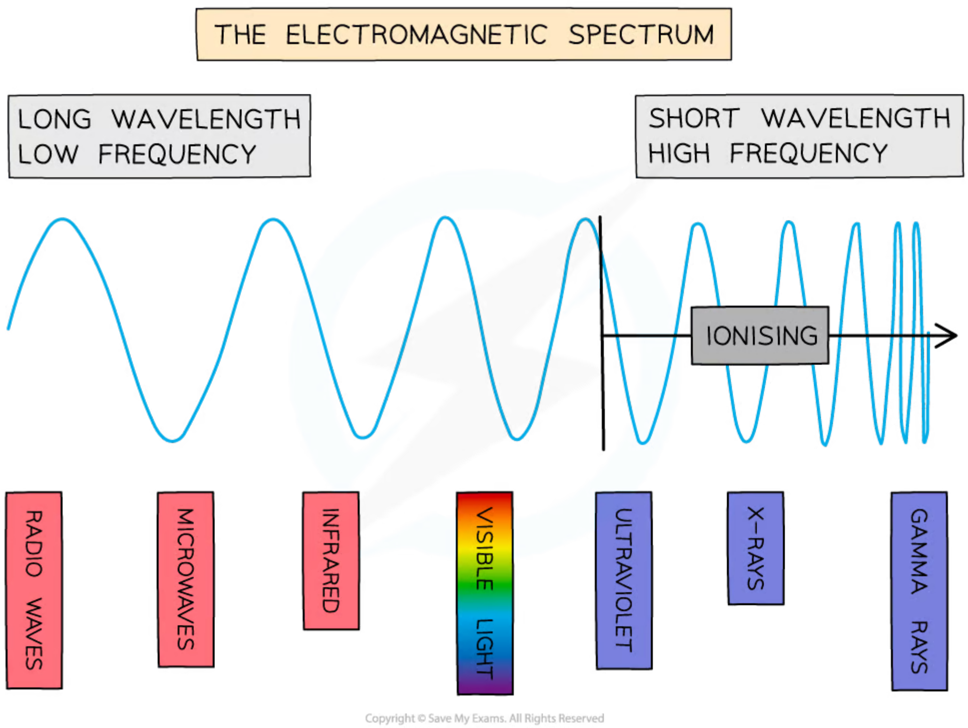
- As the frequency of electromagnetic (EM) waves increases, so does the energy
- Beyond the visible part of the spectrum, the energy becomes large enough to **ionise** atoms
- As a result of this, the danger associated with EM waves increases along with the frequency
  - The **shorter** the wavelength, the more **ionising** the radiation
  - Although the **intensity** of a wave also plays a very important role



Ultraviolet, X-rays and gamma rays can all ionise atoms

- Because of ionisation, ultraviolet waves, X-rays and gamma rays can have **hazardous** effects on human body tissue
  - The effects depend on the type of radiation and the size of the dose
- They can damage cells and cause mutations, making them cancerous
- In general, electromagnetic waves become more dangerous the **shorter** their wavelength
  - For example, radio waves have no known harmful effects whilst gamma rays can cause cancer and are regarded as extremely dangerous
- The main risks associated with electromagnetic waves are summarised in the table below:

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Dangers of EM Waves Table

Wave	Danger
Radio	◦ No known danger
Microwave	◦ Possible heat damage to internal organs
Infrared	◦ Skin burns
Visible light	◦ Bright light can cause eye damage
Ultraviolet	◦ Eye damage ◦ Sunburn ◦ Skin cancer
X-rays	◦ Kills cells ◦ Mutations ◦ Cancer
Gamma Rays	◦ Kills cells ◦ Mutations ◦ Cancer

- A summary of the uses and dangers of different EM waves are summarised in the diagram below:

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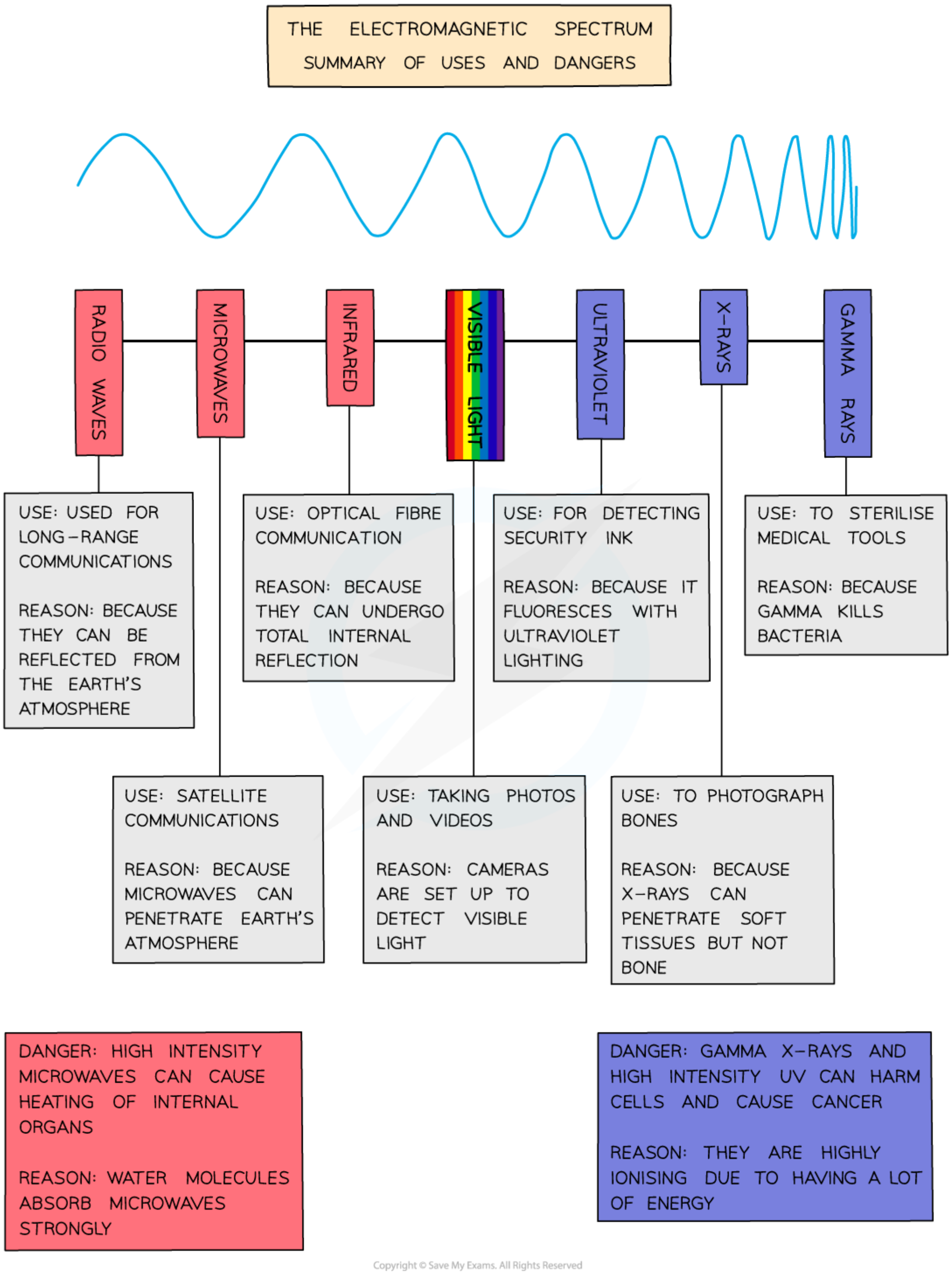

Uses and dangers of the electromagnetic spectrum

Microwaves

- Certain frequencies of microwaves are absorbed by **water molecules**
- Since humans contain a lot of water, there is a risk of **internal heating** from microwaves

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- This might worry some people, but 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

Ultraviolet

- 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

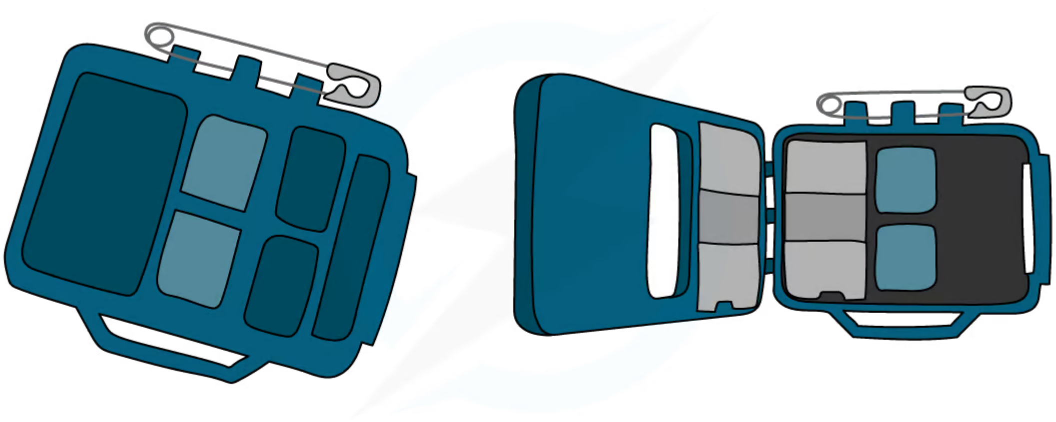
- Ultraviolet is **ionising** meaning it can kill cells or cause them to malfunction, resulting in **premature ageing**, and diseases such as **skin cancer**
  - Sunscreen absorbs ultraviolet light, preventing it from damaging the skin

X-rays & Gamma Rays

- X-rays and gamma rays are the most ionising types of EM waves
  - They are able to penetrate the body and cause **internal** damage
  - They can cause the **mutation** of genes and cause **cancer**

- Fortunately, the level of X-rays used in medicine is kept to minimum levels at which the risk is very low
  - Doctors, however, will leave the room when taking X-rays in order to avoid unnecessary exposure to them

- People working with gamma rays have to take several precautions to minimise their exposure and are routinely tested to check their radiation dose levels
- For example, radiation badges are worn by medical professionals such as radiographers to measure the amount of radiation exposure in their body



Radiation badges are used by people working closely with radiation to monitor exposure

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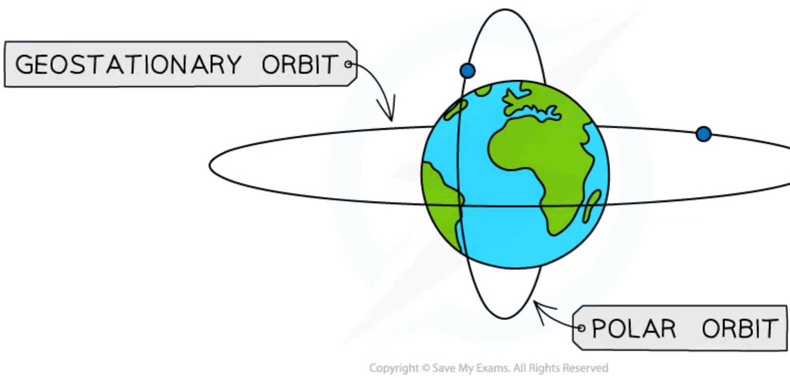
Communications with Satellites

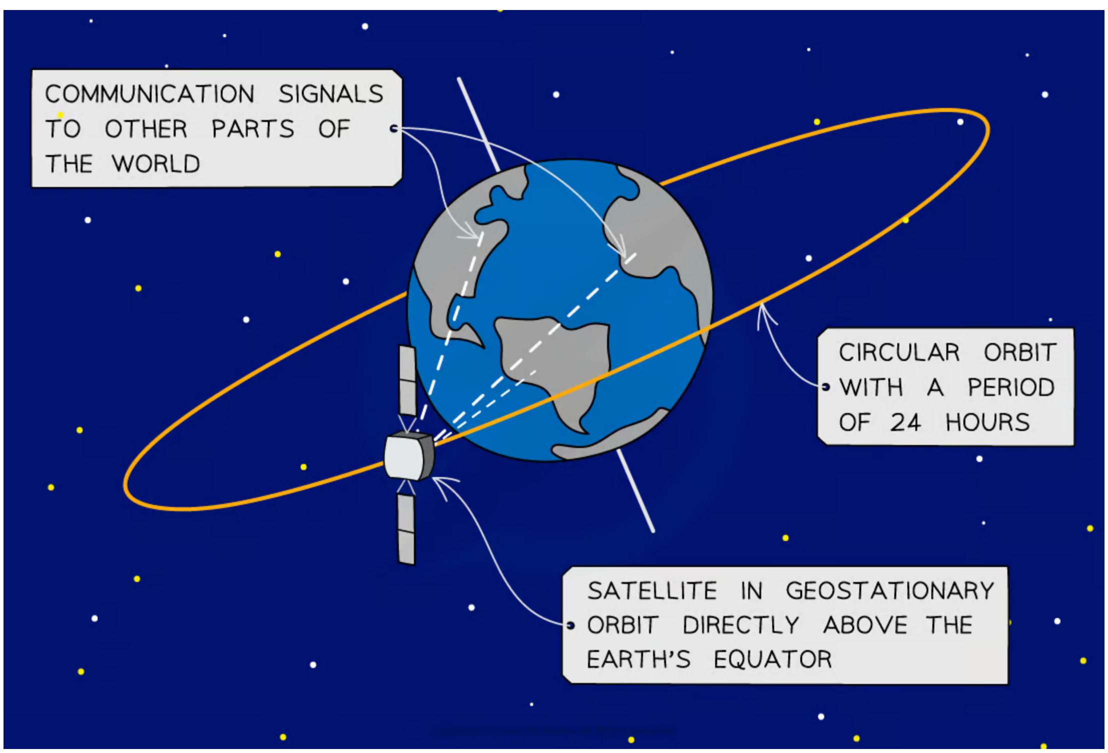
- Geostationary and polar orbiting (low orbit) satellites are both used for communicating information



Geostationary and polar orbits around the Earth

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



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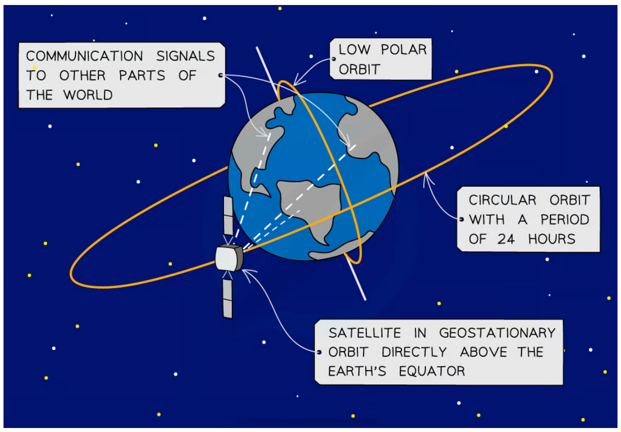
Some satellite phones and direct broadcast satellite television use geostationary satellites

Polar Satellites

- Polar, or low orbit, satellites orbit around the **Earth's north and south poles**
- These 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



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

Systems of Communications

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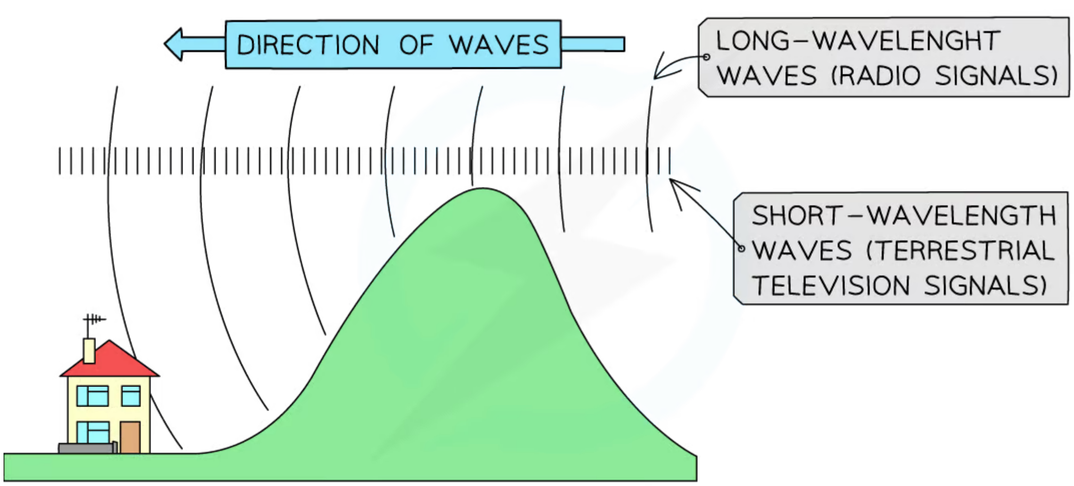
- Many important systems of communications rely on **long wave** electromagnetic radiation, including:
  - Mobile phones, wireless internet & satellite television (using **microwaves**)
  - Bluetooth, terrestrial television signals & local radio stations (using **radio** waves)
  - Optical fibres (using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

Radio Waves

- Radio waves can be used to transmit signals over **short** distances
  - Terrestrial (local) television signals, radio station transmissions and Bluetooth all work using radio waves
- Radio station signals are transmitted at a **longer** wavelength than terrestrial television signals
- In hilly areas, it may be possible to receive radio signals but **not** receive terrestrial television signals
  - This is because radio signals are more prone to **diffraction** around the hills
- Radio signals tend to have wavelengths of around a kilometer, so the radio signals are more likely to have wavelengths **similar** to the size of the hill
  - This leads to **diffraction**, so radio signals can reach locations not in the line of sight of the transmitter, whereas TV signals are not diffracted
- 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, but 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 signals diffract around hills because they are a similar wavelength to the hill

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Microwaves

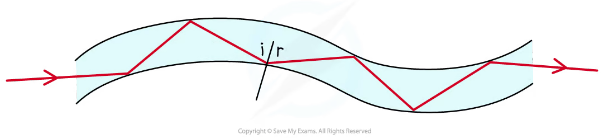
- Microwaves can be used to transmit signals over **large** distances
  - Microwaves are used to send signals to and from **satellites**
  - Mobile phones, wireless internet, satellite (global) television and monitoring Earth systems (for example, weather forecasting) all utilise microwave communication
- 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

- When microwaves are transmitted from a dish, the wavelength must be small compared to the dish diameter to reduce diffraction
  - Also, the dish must be made of metal because metal reflects microwaves well

- 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 enabling 24-hour-a-day communication all around the world
  - Also, they can penetrate most walls and only require a short aerial for transmission and reception

Optical Fibres

- Optical fibres (visible light or infrared) are used for cable television and high-speed broadband
  - This is because glass is transparent to visible light and some infrared
  - Also, visible light and short-wavelength infrared can carry high rates of data due to their high frequency



Optical fibres use visible light or infrared for transmitting cable television and high-speed broadband signals

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Digital & Analogue Signals

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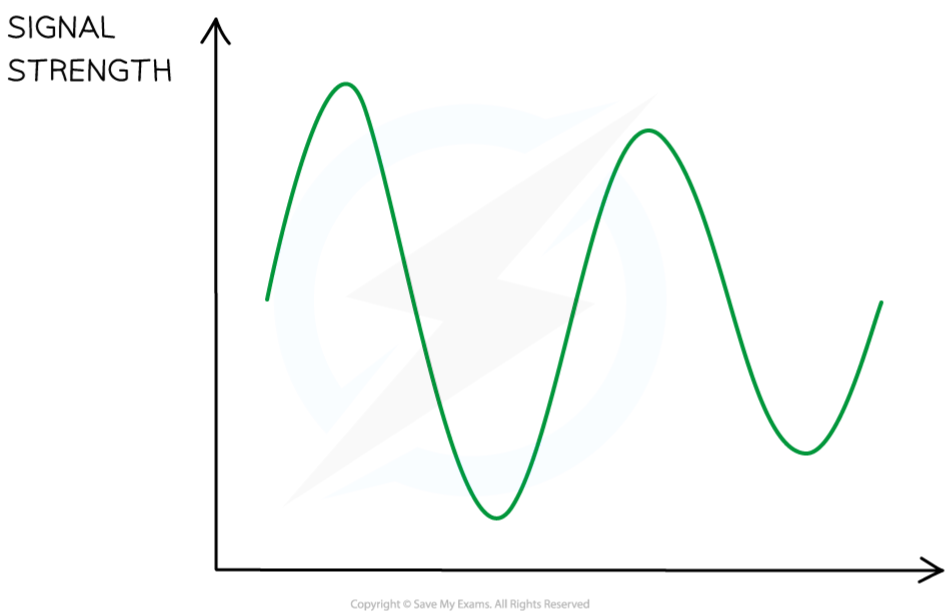
- There are two types of signals:
  - Analogue
  - Digital
- **Analogue signals vary continuously** - they can take any value



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;
    - **1**s and **0**s
    - **High**s and **low**s, or
    - **On**s and **off**s

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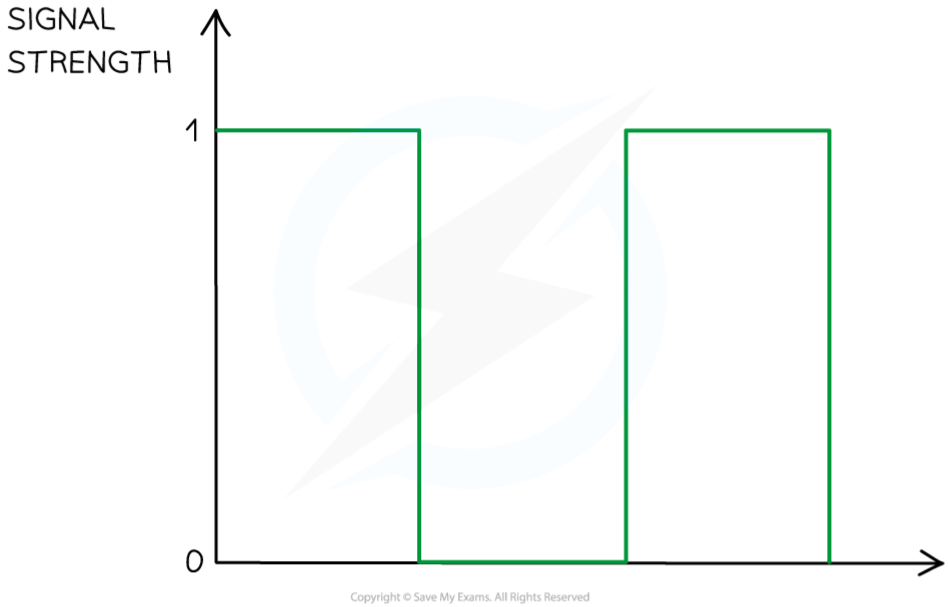

A digital signal can only take one of two values – 0 or 1

Transmission of Sound

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- Sound waves that can be transmitted as a **digital** or **analogue** signal

- Signals for speech or music are made up of varying frequencies
  - In order to make out the information clearly, the signal needs to be transmitted with as little interference as possible
- The signal goes 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 from **digital** to **analogue**

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Benefits of Digital Signalling

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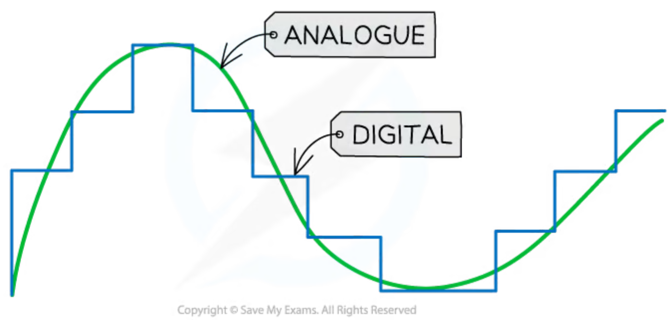
- An analogue signal consists of varying frequency or amplitude
  - Examples of analogue technology include telephone transmission and some broadcasting
- A digital signal is generated and processed in two states:
  - 1 or 0 (high or low states respectively)



Analogue v digital signal

- The key **advantages** of transmission of data 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