Edexcel GCSE Physics

Your notes

Electromagnetic Waves

Contents

Properties of Electromagnetic Waves

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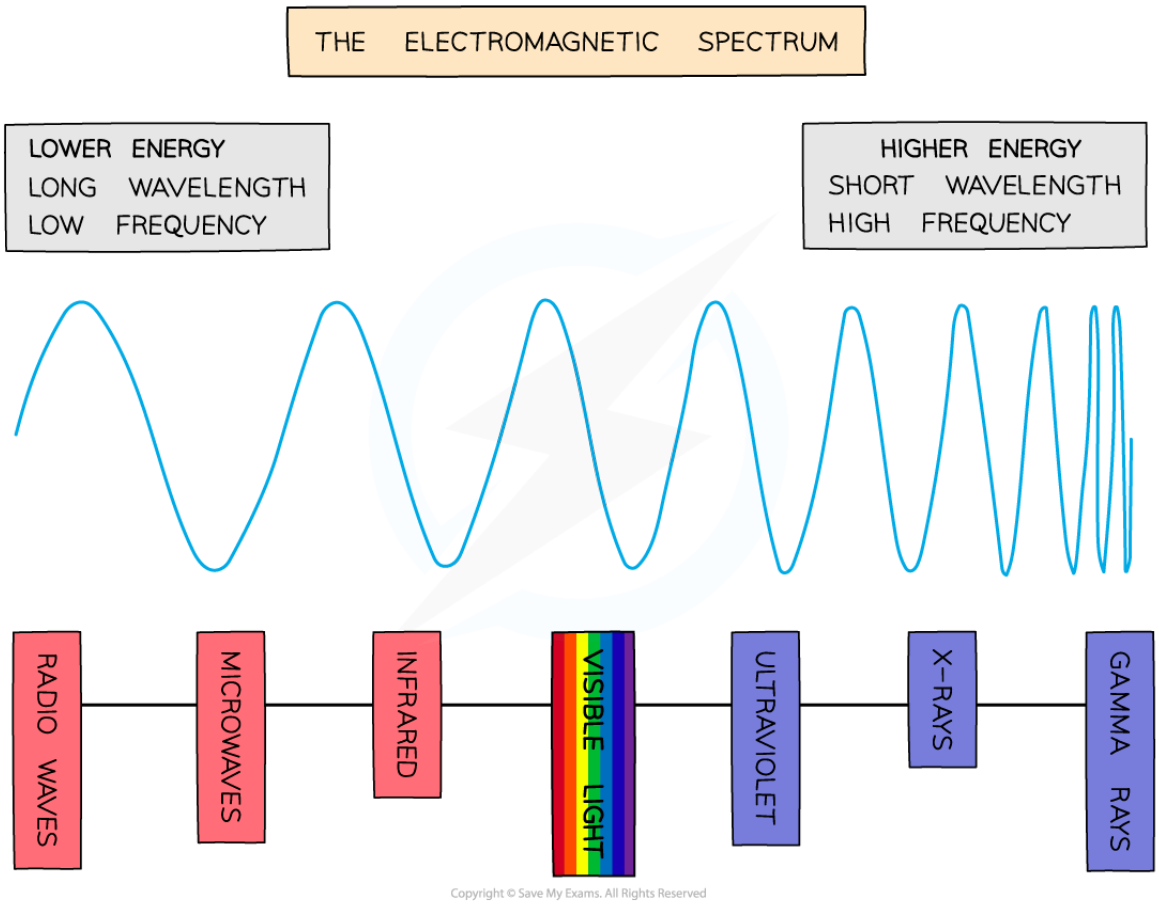
Properties of EM Waves

- 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
- There are 7 types of electromagnetic waves, which all together form a **continuous spectrum**



The electromagnetic spectrum

Transfer of Energy by EM Waves

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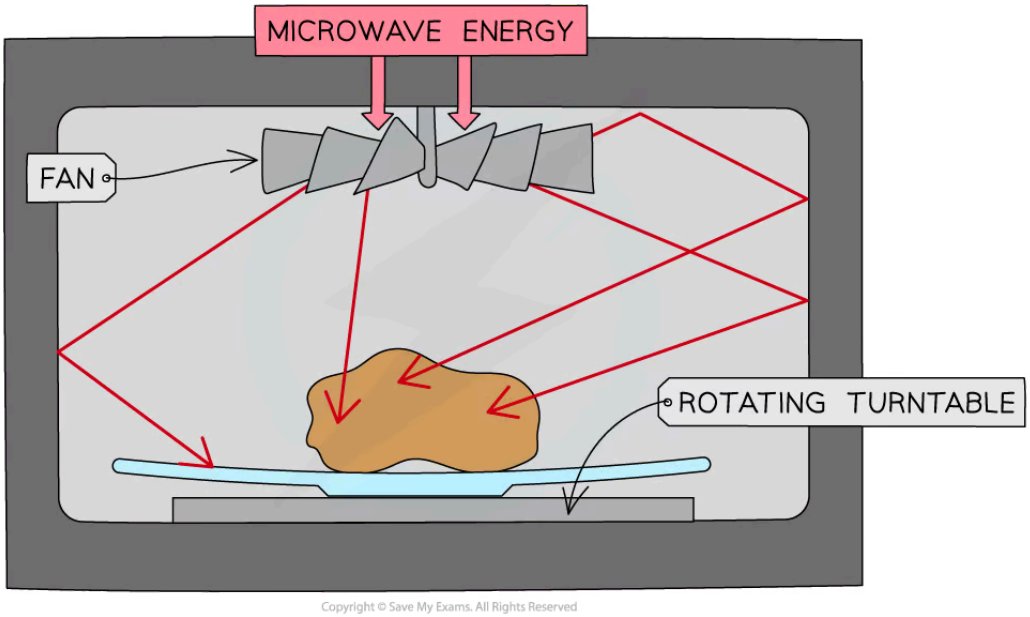
- Electromagnetic (EM) waves carry **energy** and so can transfer energy from one point to another point
- EM waves with a **shorter** wavelength carry a **higher** energy
  - This includes UV, X-rays and gamma rays
- The higher the energy of the EM wave, the more dangerous it is

Energy Transfer by Microwaves

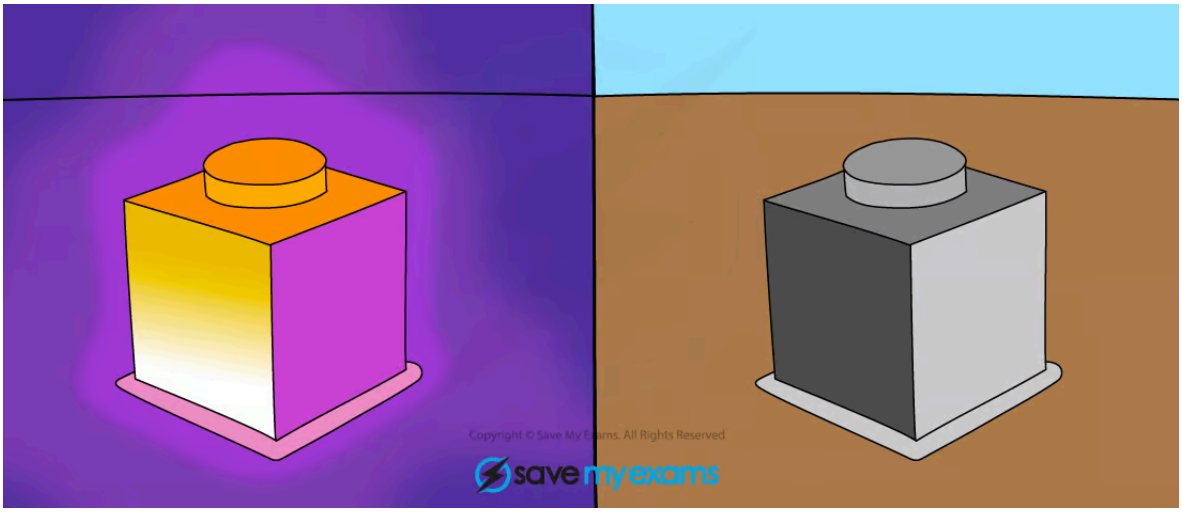
- Water molecules **absorb** certain wavelengths of **microwave** radiation
- Therefore, microwave ovens transfer energy from the electronics to **heat** the food placed inside it



Energy transfer in a microwave oven

Energy Transfer by Infrared

- All **hot** objects emit infrared radiation
- The emitted waves can then be absorbed by other objects, warming them up



Infrared camera vs. normal camera on a Leslie cube

Energy Transfers from the Sun

- The Sun emits several types of EM radiation, including:
  - **Visible light** waves allow living creatures to **see**
  - **Infrared** waves **heat** up the Earth
  - **Ultraviolet** waves provide plants with the **energy** for **photosynthesis** which they need to grow

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The Electromagnetic Spectrum

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The EM Spectrum

- 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

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

To remember the colours of the visible spectrum you could remember either:

- The name "Roy G. Biv"
- Or the saying "Richard Of York Gave Battle In Vain"

You could even combine both to have a mega mnemonic:

Raging **M**artians **I**nvaded **Roy G**. **Biv** **U**sing **X**-ray **G**uns!

EM Wavelength & Frequency

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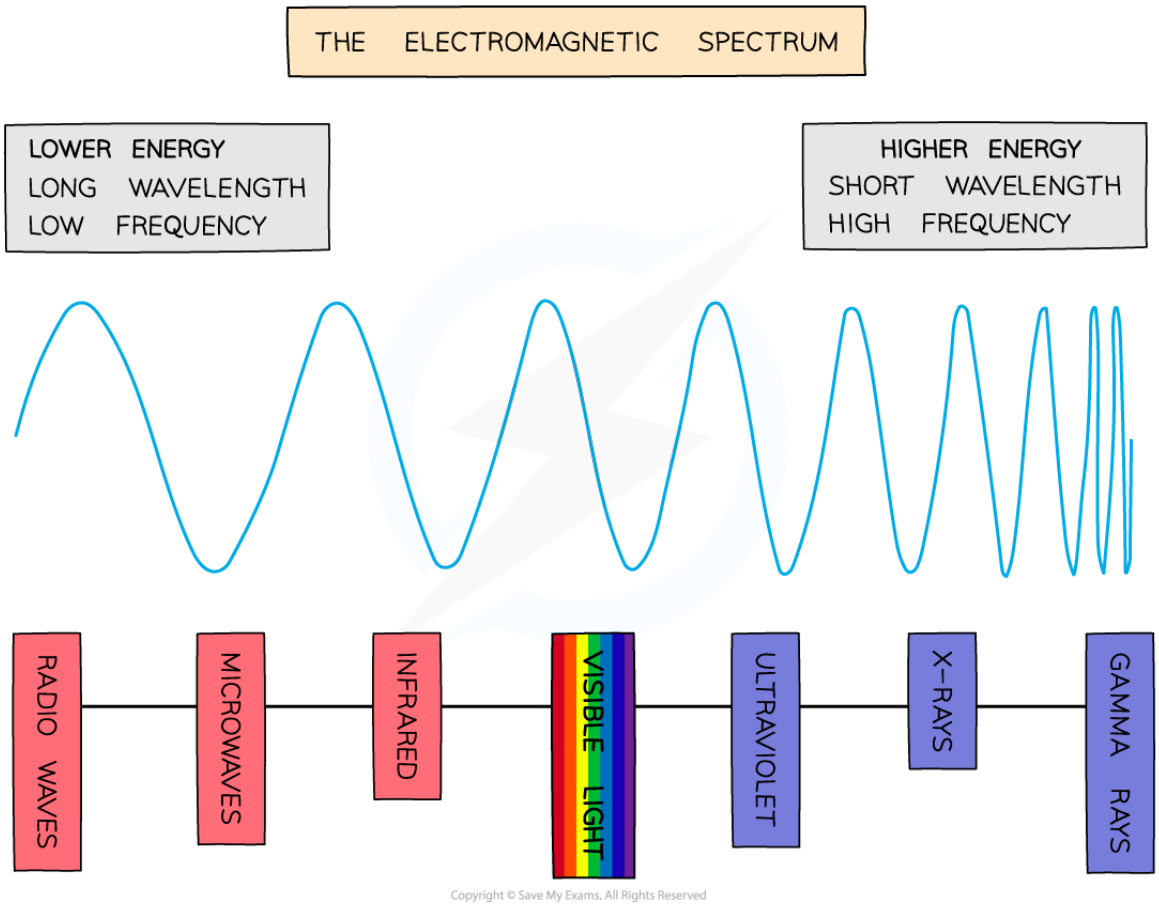
- The electromagnetic spectrum is arranged in a specific order based on the wavelengths or frequencies
- This order is shown in the diagram below from **longest** wavelength (lowest frequency) to **shortest** wavelength (highest frequency)



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:
  - Useful for communications
  - Less harmful to humans

Examiner Tips and Tricks

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

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

Visible Light

- Visible light is defined as the range of wavelengths which are visible to humans
- Visible light is the **only** part of the spectrum detectable by the human eye
  - However, it only takes up 0.0035% of the **whole** electromagnetic spectrum
  - In the natural world, many animals, such as birds, bees and certain fish, are able to perceive beyond visible light and can see infra-red and UV wavelengths of light
- Each colour within the visible light spectrum corresponds to a narrow band of **wavelength** and **frequency**
- The different colours of waves correspond to different wavelengths:
  - **Red** has the **longest** wavelength (and the lowest frequency and energy)
  - **Violet** has the **shortest** wavelength (and the highest frequency and energy)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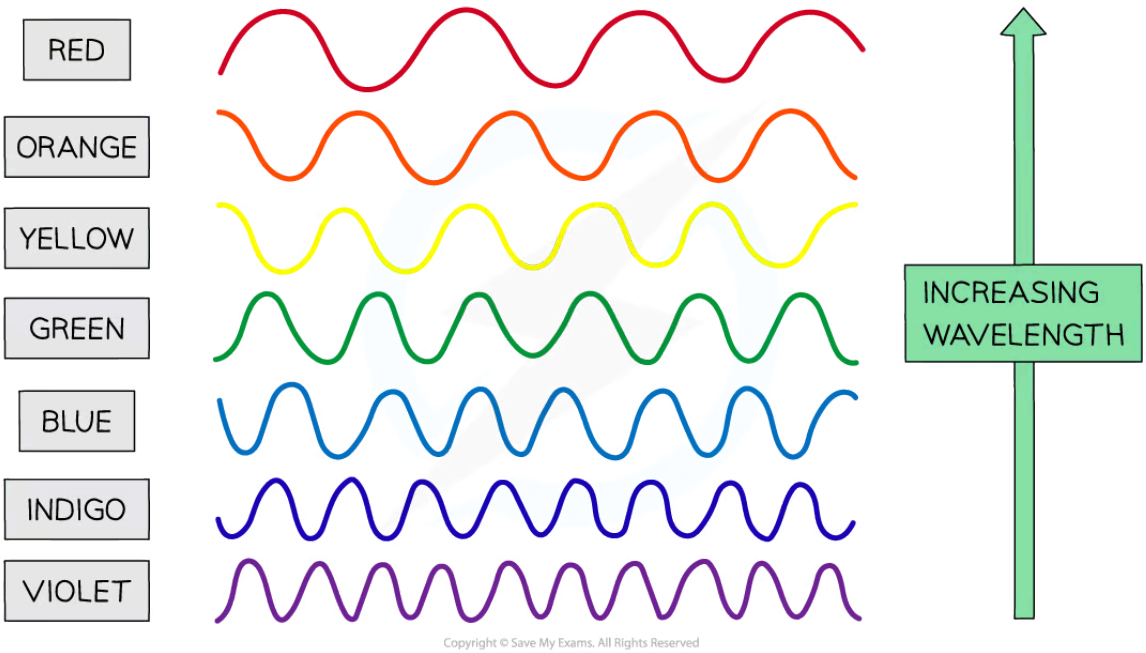

The colours of the visible spectrum: red has the longest wavelength; violet has the shortest

- Wavelength and frequency are **inversely proportional**, this means that:
  - An **increase** in wavelength is a **decrease** in frequency (towards the red end of the spectrum)
  - A **decrease** in wavelength is an **increase** in frequency (towards the violet end of the spectrum)

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EM Waves & Matter

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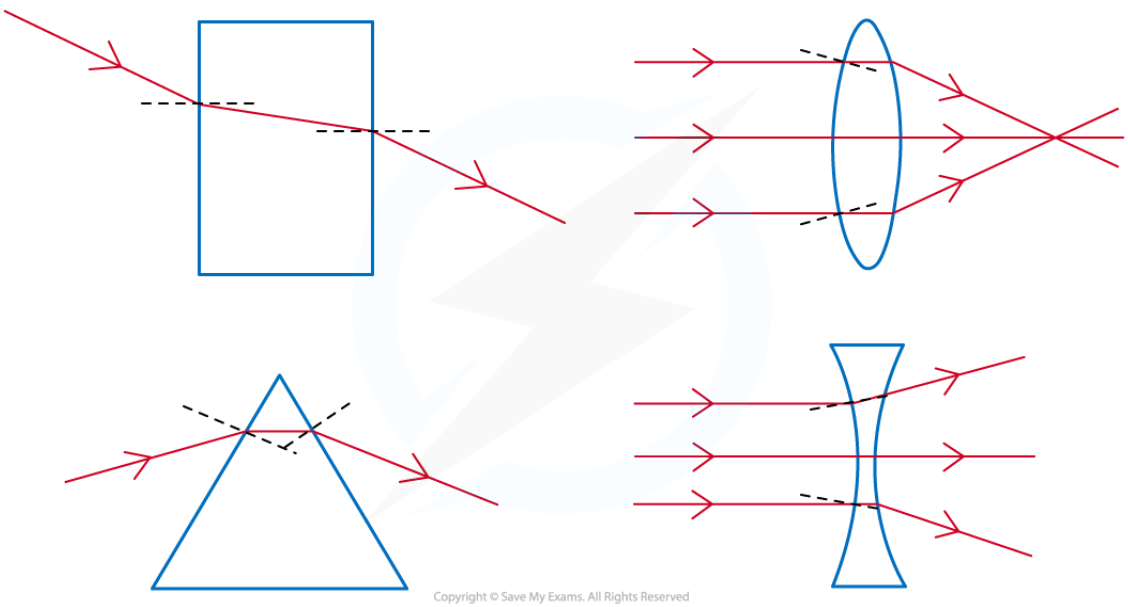
Refraction of EM Waves

- When EM waves interact with matter, they might move from one medium to another
- Sometimes EM waves will undergo refraction
  - This happens due to the difference in **velocity** of the waves in different substances
- Although all electromagnetic waves travel at the same speed in a vacuum, when they encounter certain materials (such as water, glass or oil) they will **slow down**
  - How much they slow down depends on the material
  - This slowing of electromagnetic waves causes them to **refract**
- A simple example of this is the refraction of visible light when it enters (or leaves) a glass block, although other electromagnetic waves can also refract



When electromagnetic waves pass through matter, their interactions slow them down causing them to refract. The red lines are the rays and black lines are the normals

The Speed of EM Waves

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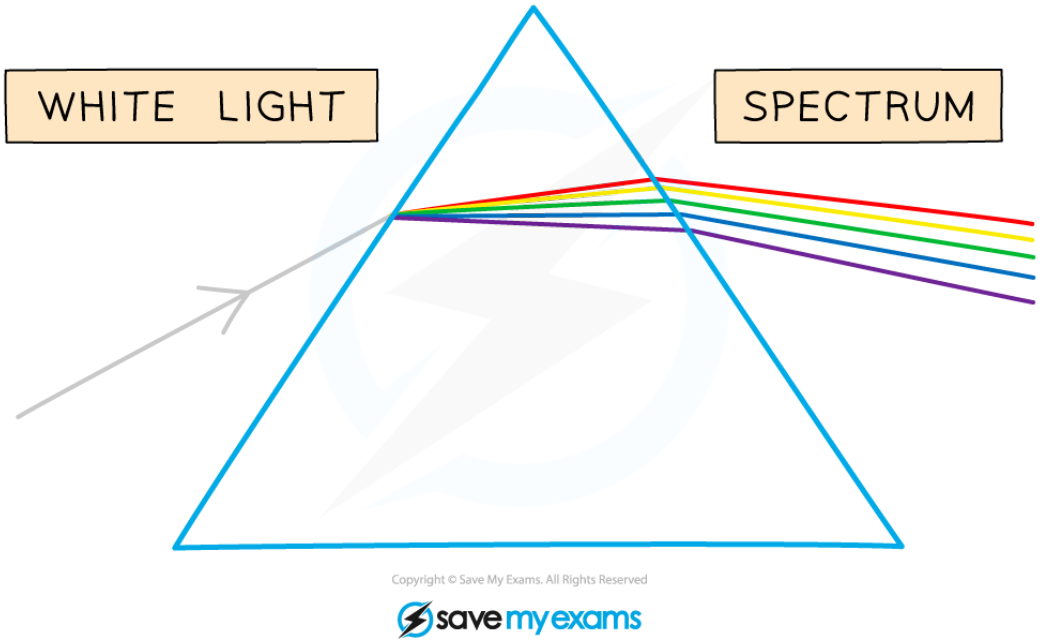
- When EM interact with matter, they slow down
  - The denser the substance, the slower the wave
- Different wavelengths can slow down by different amounts – an effect known as **dispersion**
- This effect is seen clearly with visible light and is responsible for the separation of white light into its constituent colours when it passes through a prism
  - This is done by **refraction**
  - Violet light is refracted the **most**, whilst red light is refracted the **least**
  - This splits up the colours to form a **spectrum**
- This process is similar to how a rainbow is created



White light may be separated into all its colours by passing it through a prism

Interaction of Different Substances

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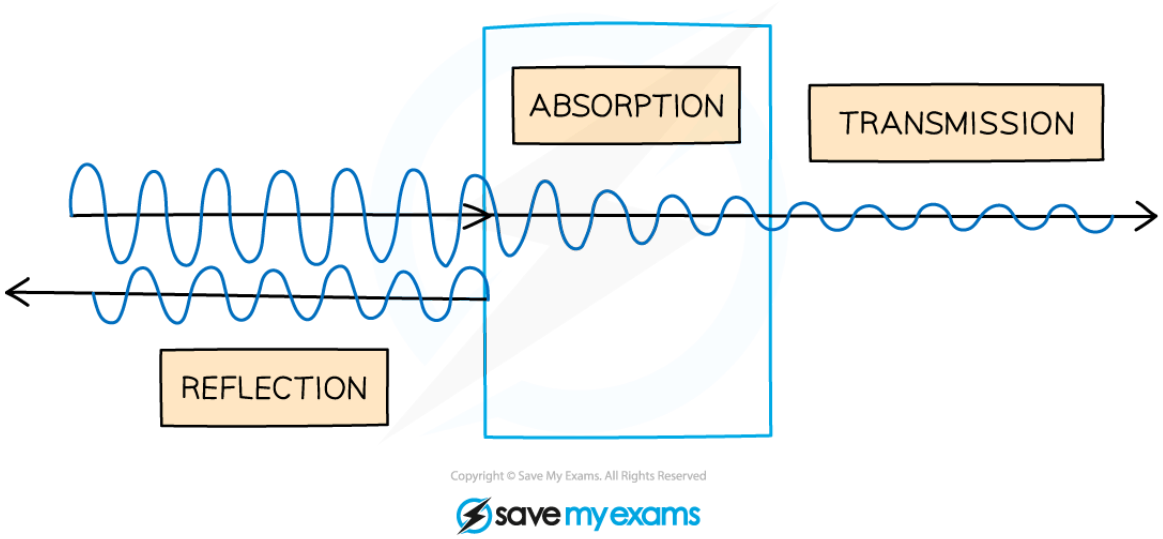
- When EM waves move from one medium to another the waves might be:
  - Transmitted
  - Absorbed
  - Reflected
  - Refracted



When waves move from one medium to another they can be transmitted, reflected, refracted or absorbed

- The material interacts differently with different parts of EM spectrum because of the difference in wavelength
- Whilst some wavelengths might be transmitted, others might be reflected, refracted or absorbed
- Which of the interactions happen depends on:
  - The **wavelength** of the waves
  - The **material** the wave is travelling through
- For example, glass will:
  - **Transmit** and/or **refract** visible light
  - **Absorb** UV radiation

- **Reflect** IR radiation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Dangers of High-Energy EM Waves

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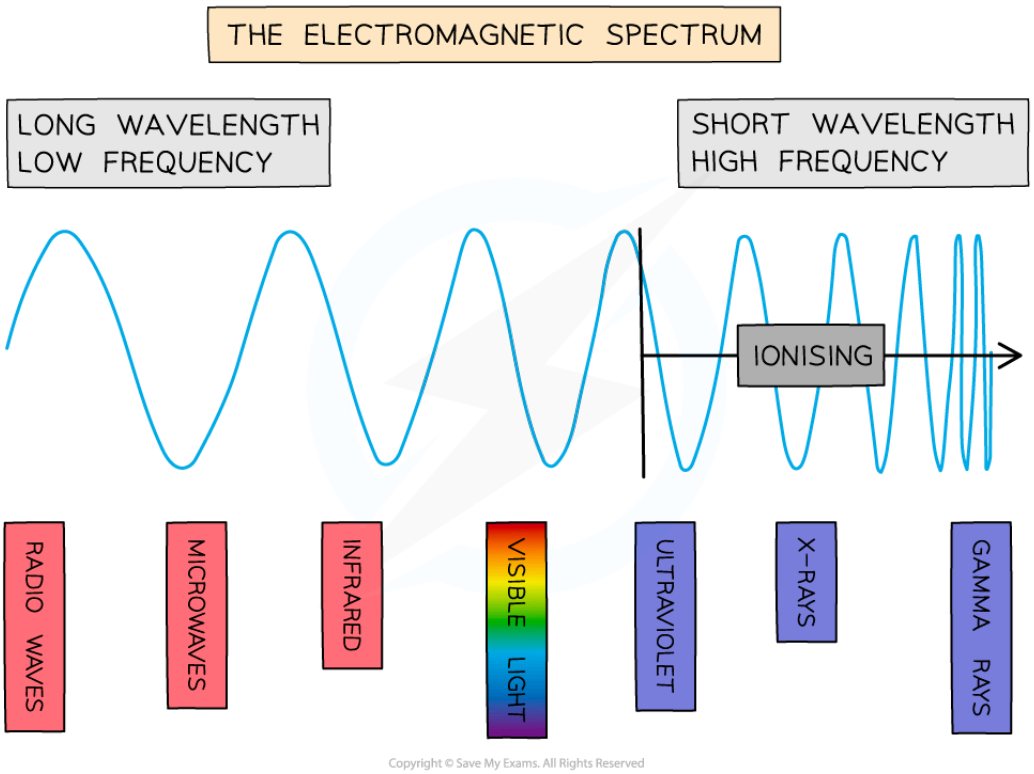
The Effect of Frequency

- 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 **higher** the frequency, 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

Dangers of UV, X-rays & Gamma Rays

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- 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:

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

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

- 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


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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

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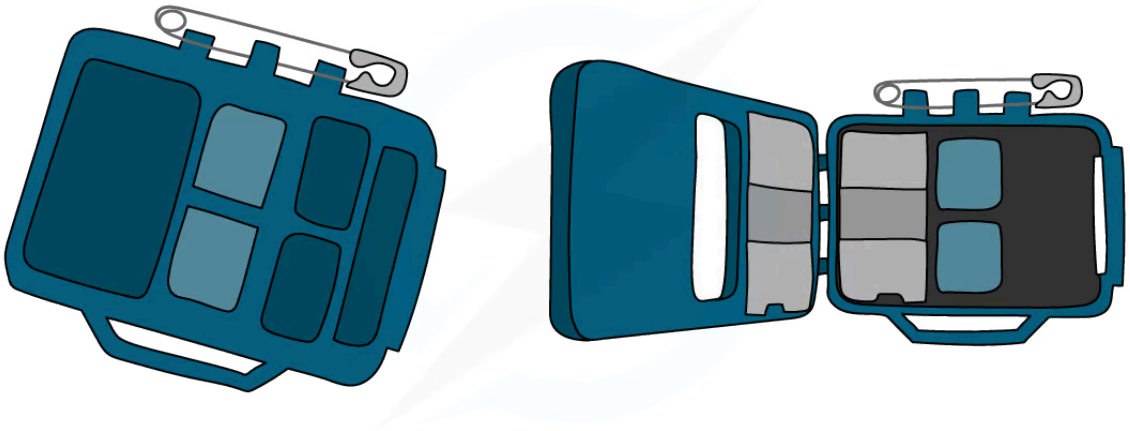

Radiation badges are used by people working closely with radiation to monitor X-ray exposure

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Applications of EM 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

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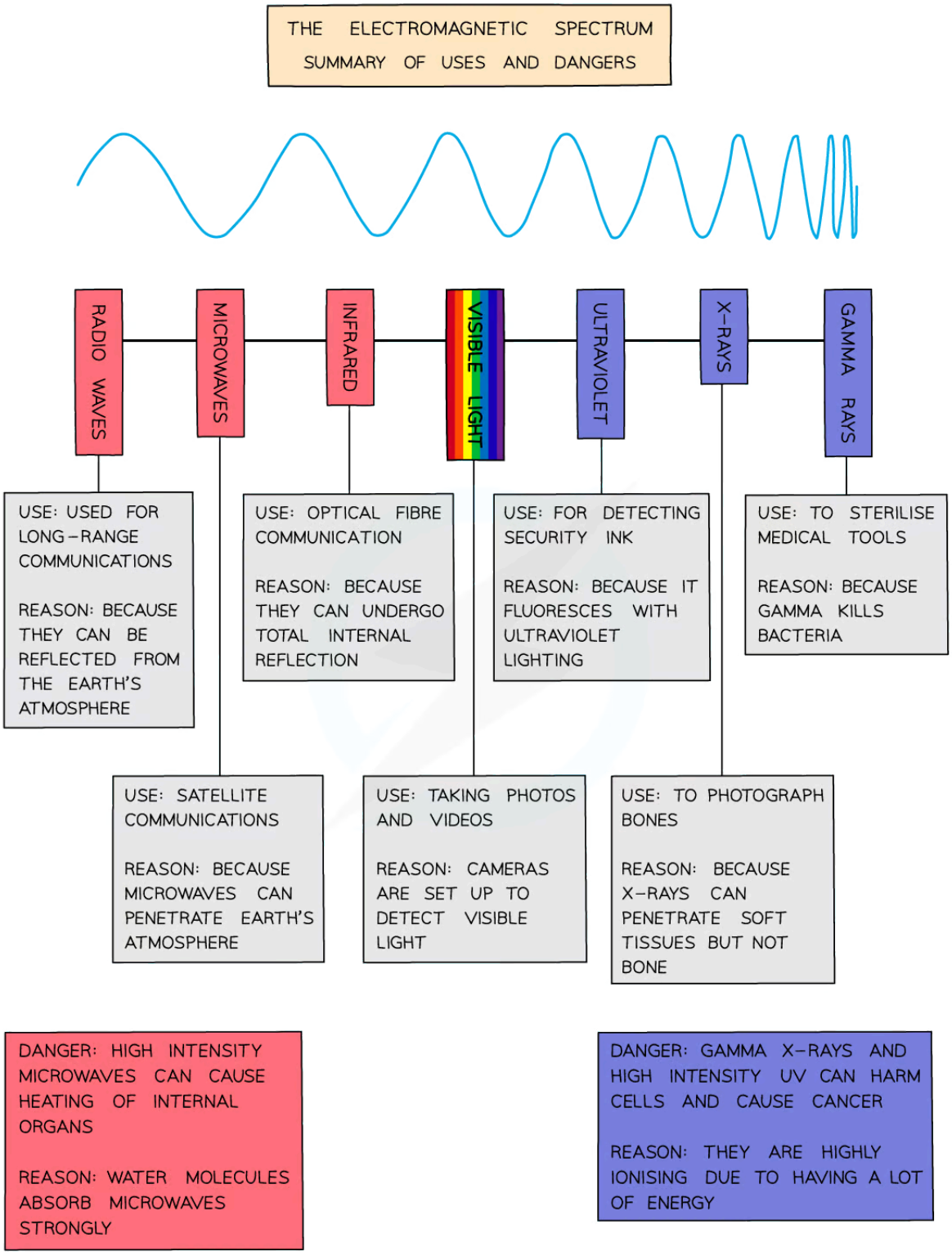
- A summary of the uses and dangers of different EM waves are summarised in the diagram below:

Your notes



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Examiner Tips and Tricks

Make sure to memorise these applications, as this is a common exam question!

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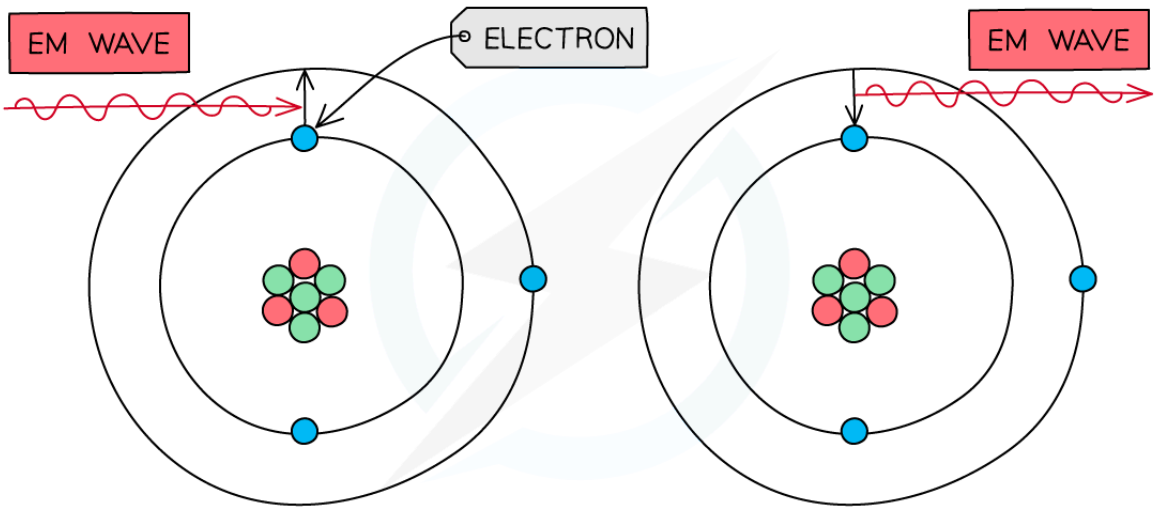
EM Waves & Atoms

- Atoms can interact with electromagnetic (EM) waves in one of two ways, they can be:
  - Absorbed
  - Emitted
- When an EM wave hits an atom, it can be **absorbed** by one of the electrons giving it energy
  - This causes the electron to move **up** to a higher energy level
- Then an electron will move back down to a lower energy level and will **emit** an EM wave in the process



The electrons orbiting atoms can absorb and emit EM waves by moving between different energy levels

- In this way, atoms can absorb and emit electromagnetic waves over a wide range of frequencies depending on the gap between the energy level that the electron has moved
- The energies associated with electron transitions tend to be in the **visible** and **ultraviolet** range (and sometimes X-rays)
- Higher energies (ie. **gamma** rays) can only be achieved when EM waves interact with the **nucleus**

- The nucleus of an atom can **absorb** and **emit** EM waves in a similar way to electrons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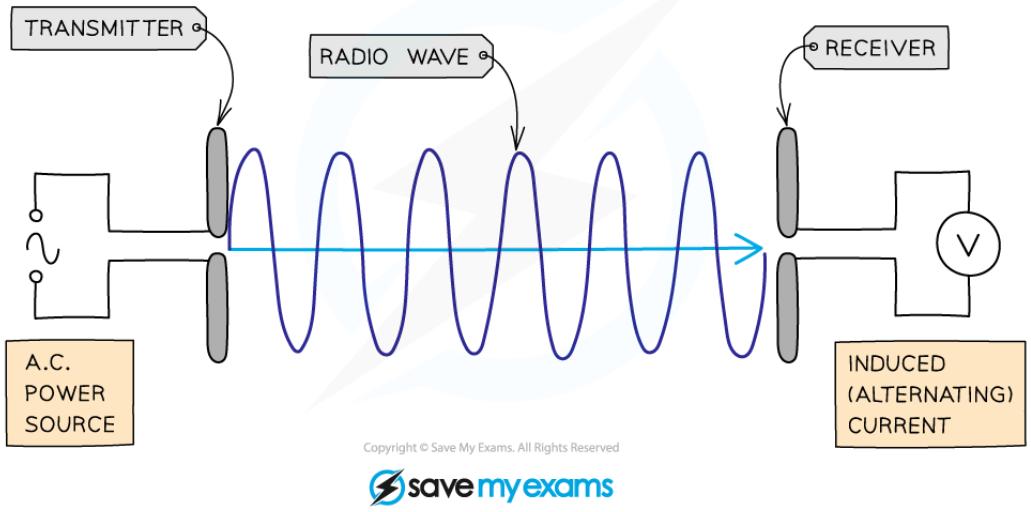
Radio Waves

Higher Tier Only

- Radio waves can be produced by connecting an antenna to a high frequency **alternating current** (a.c.) power source
  - The **oscillation** of charge in the a.c. circuit produces radio waves with the same **frequency** of oscillation



Radio waves are produced by high-frequency alternating currents and induce similar currents when they are received

- In the **transmitting** antenna:
  - The charge from the alternating current oscillates up and down the antenna
  - This produces radio waves that can be absorbed by a similar aerial some distance away
- In a **receiving** aerial:
  - The metal aerial absorbs the radio waves
  - This creates an alternating current with the same frequency as the transmitted wave