Learning Objectives

At the end of this unit you should be able to;

- State the parts of the EM spectrum in order
- Understand the differences and similarities between EM waves from different parts of the spectrum
- Calculate frequency, wavelength and photon energy of an EM wave
- Describe the nature of white and coloured light
- Explain which parts of the EM spectrum are hazardous and why
- Describe the uses and applications of each band of the EM spectrum
- Describe and explain the process of ionisation
- Describe the main uses of ionising radiation, outlining possible risks and safety precautions that could be used

Introduction.

Until the 1800's, visible light was the only known form of electromagnetic wave. That was until William Herschel discovered what he termed 'calorific rays', later to be called infrared, whilst studying the temperature of light of different colours. Ultraviolet was discovered soon after. But the first indications of the existence of the entire electromagnetic spectrum as currently understood did not come until the 1860's when James Maxwell, the Scottish theoretical physicist formulated his equations for electromagnetism, which later formed the building blocks of Einstein's theories on relativity.

Maxwell's four elegant partial differential equations predicted the existence of very low frequency (radio) waves up to the very high frequency (gamma) waves and everything in between. This spurned a flurry of activity amongst experimentalists to find these so far elusive forms of radiation. In 1886, the German physicist Heinrich Hertz who's name was given to the S.I. unit of frequency, was first to design a system that both created and detected radio waves and then later microwaves, and proved that that travelled at the speed of light, just as Maxwell had predicted. In 1895 Wilhelm Rontgen accidently found X-rays when he was conducting an experiment. He called it radiation 'X' because he didn't know what he had found, and didn't have a name for it.

The last part of the spectrum jigsaw, the gamma ray and most energetic of all electromagnetic waves was found by Paul Villard in 1900, although he originally thought that he had discovered a new particle. It wasn't until 1910 that British physicist William Bragg proved that gamma 'particles' were in fact electromagnetic waves.

Key Facts and Principles.

EM waves

- Are always transverse
- Can travel through a vacuum
- Can be polarised
- Transfer energy but NOT matter
- Always travel at the same speed in a vacuum
- Have no electrical charge

The speed of light in a vacuum, c, is 3×10^8m/s.

The velocity of any wave v is equal to the product of the wavelength λ and frequency f. Since for all EM waves travelling in a vacuum the speed is a constant and equal to c;

$$c = f\lambda$$

where f *= frequency*
λ *= wavelength*
$c = 3\times10^8 m/s$

All EM waves belong to the electromagnetic spectrum since they are all the same type of wave. The only difference between waves that exist in different parts of the electromagnetic spectrum is the wavelength, and therefore frequency and energy. That is, the only difference between radio waves and visible light is that visible light has a shorter wavelength, higher frequency, and therefore higher energy.

The EM spectrum is a continuum, containing all frequencies and wavelengths. The energy of an electromagnetic wave is delivered in set values or packets called *photons*. For all electromagnetic waves, the photon energies are given by the product of a set constant (called Plank's constant) and frequency;

$$E = hf = \frac{hc}{\lambda}$$

Where f *= frequency in hertz*
c *= speed of light in metres per second*
λ *= wavelength in metres*
h *= plank's constant =* $6.626\times10^{-34} m^2 kg/s$

Radio wave frequencies range from 3Hz to 3GHz (10,000km > λ > 10cm). Radio waves are heavily diffracted by buildings and natural land features and so do not have large regions of signal shadow.

Microwave frequencies range from 3MHz to 300GHz (1m > λ > 1mm). Microwaves are higher in frequency and lower in wavelength than radio waves and therefore have higher energies. Microwaves are used in communication technologies such as mobile phones.

Infrared ranges from 300GHz to 400THz (1mm > λ > 750nm). Most of the thermal energy emitted (radiated heat) by objects at room temperature is infrared radiation. Infrared is used in thermal imaging and also wireless communications such as television remote controls.

Visible light ranges from 790THz to 400THz (750nm > λ > 380nm) The only difference between the different colours of light is wavelength (red light has a wavelength of approximately 750nm whilst blue light a wavelength of 550nm). Light of a single wavelength is termed *monochromatic.* Electromagnetic radiation that is higher in frequency than visible light is termed *ionising radiation* because it has high enough energy to remove the electrons from the atoms in our bodies, leaving behind charged ions.

Ultraviolet (UV) radiation occupies a band between 750THz to 30PHz (380nm > λ > 10nm) with a wavelength on the order of cells and large molecules. Although not energetic enough to ionize atoms, UV light can have enough energy to cause blindness, sunburn, prematurely age the skin, and overexposure can lead to skin cancers. UV can also induce the production of vitamin D in the skin.

X-rays occupy a band of the EM spectrum between 3×10^{16}Hz and 3×10^{19}Hz (10nm > λ > 0.01nm) and a wavelength typically on the order of the diameter of an atom. *X*-rays are highly ionising, and are produced by electrons, either when the electron slows down rapidly, or moves between energy levels.

Gamma-rays (γ-rays) have a frequency higher than 1×10^{19}Hz ($\lambda<10^{-11}$m). They are therefore the most energetic electromagnetic waves in the EM spectrum and have a wavelength on the order of the diameter of atomic nuclei. γ-rays are produced by the nucleus when it changes energy state, or undergoes radioactive decay. γ-rays are highly ionising and are very hazardous, since they damage living tissue as they pass through it.

Glossary

Anode – A positively charged electrode (for example the positively charged terminal of a battery)

Cathode - A negatively charged electrode (for example the negatively charged terminal of a battery)

Continuum - anything that goes through a gradual transition from one condition, to a different condition, without any abrupt changes

Dosimetery – the measurement and assessment of the radiation dose received by the human body

Fluorescents - the emission of light or other radiation from atoms or molecules that are bombarded by particles or EM waves. The bombarding radiation produces excited atoms, molecules, or ions and these emit photons as they fall back to their unexcited state.

Ion – an atom with an overall electric charge

Ionisation – the process in which a neutral atom gains an overall charge

Monochromatic – of a single colour or wavelength (realistically a narrow band of wavelengths)

Nuclei – the dense centre of the atom containing protons and neutrons

Pasteurisation – a process or treatment to kill micro-organisms in food or drink (usually involving heating)

Photon - the smallest elemental unit of electromagnetic energy, or the smallest discrete amount of electromagnetic energy