Section 4.1.5 – Electromagnetic Waves

Production of an electromagnetic wave

Visible light forms one small section of the **electromagnetic spectrum**. Visible light consists of an **electric field (E)** and a **perpendicular magnetic field (B)** as shown below in Figure 1. This model of light can be considered as a **transverse wave.**

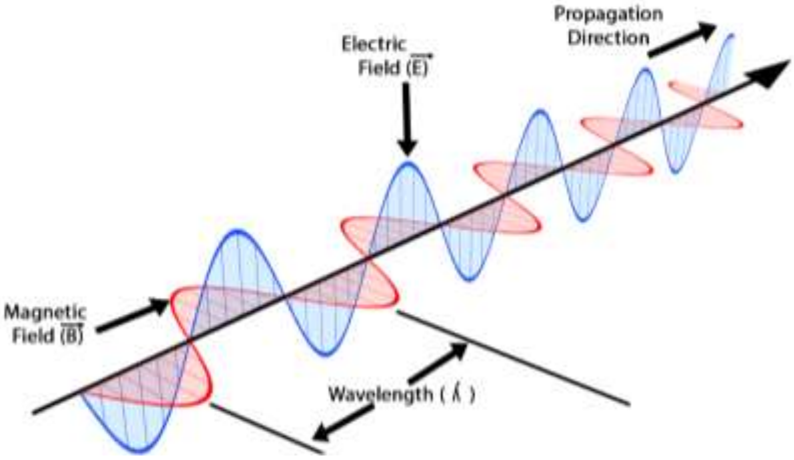


Figure 1 *An electromagnetic wave*

Like mechanical waves, electromagnetic waves transfer energy from one point to another without a transfer of matter.

However, unlike mechanical waves **electromagnetic waves do not require a medium** in which to travel. An electromagnetic wave is a self-sustaining wave that requires no medium in which to propagate.

An electromagnetic wave can be created by simply **accelerating a charged particle**. When a charged particle is accelerated (including oscillations), its electric field changes.

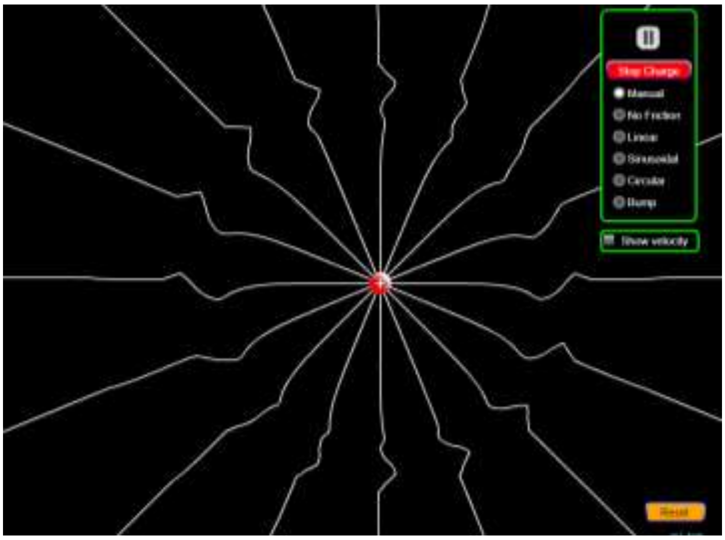


Figure 2 *An electric field (E) disturbance*

[Link: https://phet.colorado.edu/sims/radiating-charge/radiating-charge_en.html]

As we studied back in Unit 3, a **changing electric field creates a changing magnetic field** and vice versa. Together, this varying electric and magnetic fields produces an electromagnetic wave.

So the acceleration of a charged particle emits electromagnetic radiation that travels radially outwards from the charged particle.

NB: Light is a form of electromagnetic radiation.

Speed of an electromagnetic wave

All **electromagnetic waves** travel through a vacuum at the **same speed** regardless of their wavelength (λ) or frequency (f).

It doesn't matter if the charge producing the electromagnet wave is oscillating rapidly (ie. high frequency and short wavelength) or slowly (ie. low frequency and long wavelengths). The speed of all electromagnetic waves through a vacuum is:

3.0×10^8 ms^{-1} (c the speed of light)

NB: This is not only the speed of visible light, but the speed of all forms of electromagnetic radiation.

Recall: the wave equation $v = \lambda f$

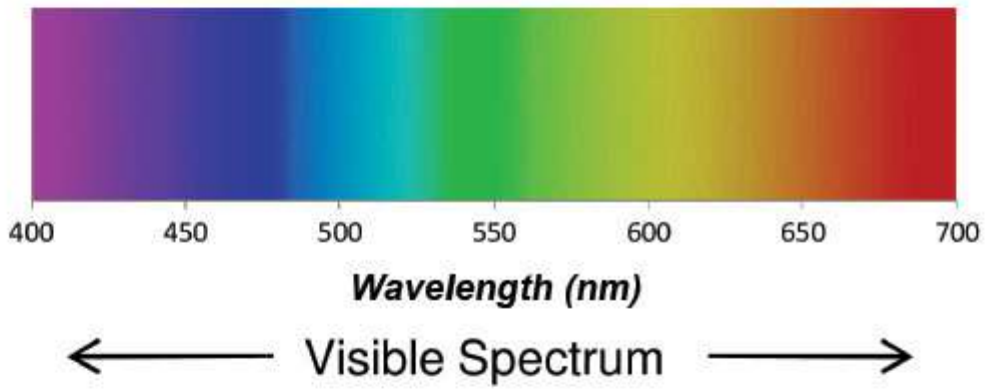
As all electromagnetci radiation travels at the speed of light c, the wave equation can be written as:

$$c = \lambda f$$

Where c is the speed of light in a vacuum (3.0×10^8 ms^{-1})
λ is the wavelength (m)
f is the frequency (Hz)

Task.1

Use the above equation to calculate the frequencies of light for each of the wavelengths given in the below table.



Colour	Violet	Blue	Green	Yellow	Orange	Red
Wavelength (nm)	400	460	525	580	625	700
Frequency [$\times 10^{12}$ (Hz)]	750					429

Sample calculations

<u>Violet</u>

$c = 3.0 \times 10^8$ ms^{-1}

$\lambda = 400 \times 10^{-9}$ m

f = ?

$c = \lambda f$

$\therefore f = \frac{c}{\lambda}$

$= \frac{3.0\times10^8}{400\times10^{-9}}$

$= 7.5 \times 10^{14}$ Hz

(Or 750×10^{12} Hz)

<u>Red</u>

$c = 3.0 \times 10^8$ ms^{-1}

$\lambda = 700 \times 10^{-9}$ m

f = ?

$c = \lambda f$

$\therefore f = \frac{c}{\lambda}$

$= \frac{3.0\times10^8}{700\times10^{-9}}$

$= 4.29 \times 10^{14}$ Hz

(Or 429×10^{12} Hz)

Example.1

When light of frequency 6.0×10^{14} Hz travels through a vacuum, what is its:

1. Period (sec)
2. Wavelength (nm)

NB: The speed of light in a vacuum is 3.0×10^{8} ms^{-1}.

1. T = ?
   $f = 6.0 \times 10^{14}$ Hz

$$T = \frac{1}{f}$$
$$= \frac{1}{6.0 \times 10^{14}}$$
$$= 1.67 \times 10^{-15} \text{ sec}$$

2. λ = ?
   $f = 6.0 \times 10^{14}$ Hz
   $c = 3.0 \times 10^{8}$ ms^{-1}

$$c = \lambda f$$
$$\therefore \lambda = \frac{c}{f}$$
$$\therefore \lambda = \frac{3.0 \times 10^{8}}{6.0 \times 10^{14}}$$
$$= 5.0 \times 10^{-7} \text{ m}$$
$$= 500 \text{ nm}$$

Components of the electromagnetic spectrum

As can be seen in Figure 3, visible light only makes up a very small fraction of the entire **electromagnetic spectrum.**

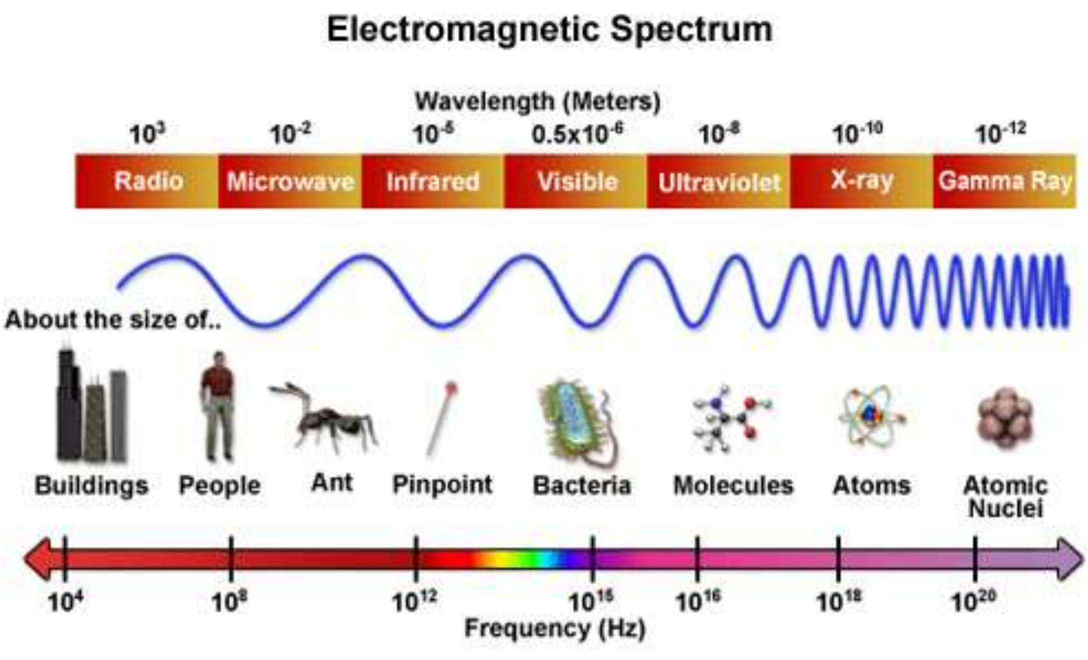


Figure 3 *The electromagnetic spectrum*

Electromagnetic Radiation - Summary Table

Classifications	Uses
Radio waves	Radio waves are the lowest frequencies in the electromagnetic spectrum, and are used mainly for communications: AM & FM.
Microwaves	Microwaves cause water and fat molecules to vibrate, which makes the substances hot. So we can use microwaves to cook many types of food. Mobile phones, WIFI, fixed speed cameras and radar all use microwaves.
Infrared	They are used for remote controls for TVs and video recorders, and physiotherapists use heat lamps to help heal sports injuries. IR is also used for short-range communications, for example between mobile phones, or for the Dolby Screen talk headset system used in some cinemas.
Visible	Visible light provides us with vision. Light waves can also be made using a laser. This works differently to a light bulb, and produces "coherent" light. Lasers are used in Compact Disc & DVD players, where the light is reflected from the tiny pits in the disc, and the pattern is detected and translated into sound or data.
Ultraviolet	Uses for UV light include getting a sun tan, detecting forged bank notes in shops, and hardening some types of dental filling. Ultraviolet rays can be used to kill microbes. Hospitals use UV lamps to sterilise surgical equipment and the air in operating theatres.
X-rays	X-rays are used by doctors to see inside people. They pass easily through soft tissues, but not so easily through bones. X-Rays are also used in airport security checks, to see inside your luggage. They are also used by astronomers.
Gamma	Gamma rays are used to kill cancer cells without having to resort to difficult surgery.

Polarisation

As can be seen from Figure 4 below, light consists of **transverse waves** that exist upon **multiple planes**. If a light source was directed towards you, as a viewer, some of the radiation would be aligned upon a vertical plane, some aligned upon a horizontal plane and some at every other angle in between.

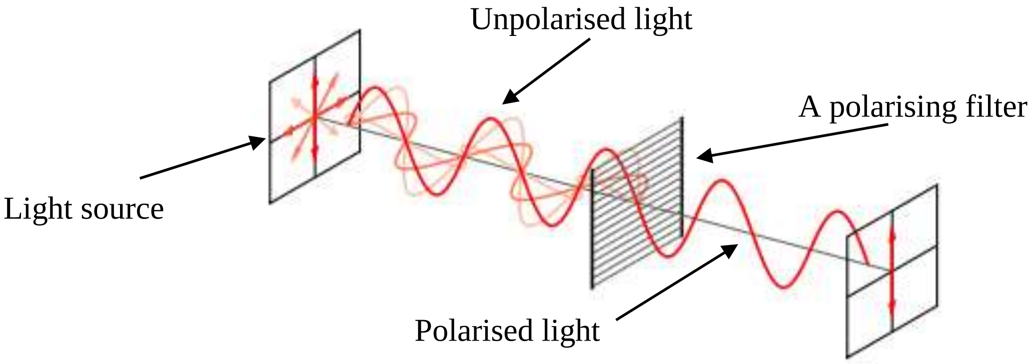


Figure 4 *The polarisation of visible light*

A **polarised wave** describes a transverse wave for which the oscillations occur in a single plane.

A **polarising filter** is a material that allows transverse wave oscillations only in a certain plane.

A polarising filter will:

- Make an unpolarised wave become polarised
- Completely block a wave which is polarised in a perpendicular plane to the filter
- Not affect a wave which is polarised in the same plane as the filter

The **polarisation of light** is a property of **transverse waves**. Light from most sources is unpolarised. This means the oscillations in the electric field occur in multiple planes. Polarising filters for light allow **oscillations of the electric field in only one plane**, and absorb oscillations in other planes.

NB: When two polarising filters are aligned perpendicular to one another (ie. 90°) 100% of the light will be blocked, 0% will be transmitted with such an alignment.

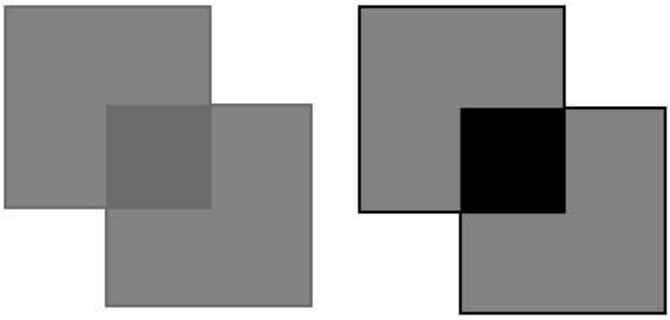


Figure 5 *Polarising filters aligned both parallel and perpendicular to one another*

Exam Styled Questions

Question 1

List the following bands of the electromagnetic spectrum in order from longest wavelength to shortest wavelength by writing each corresponding number in the appropriate box below:

1. infra-red radiation
2. microwaves
3. radio waves
4. ultraviolet radiation
5. visible light
6. X-rays

Longest					Shortest