

Section 1.1.2 – 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**.

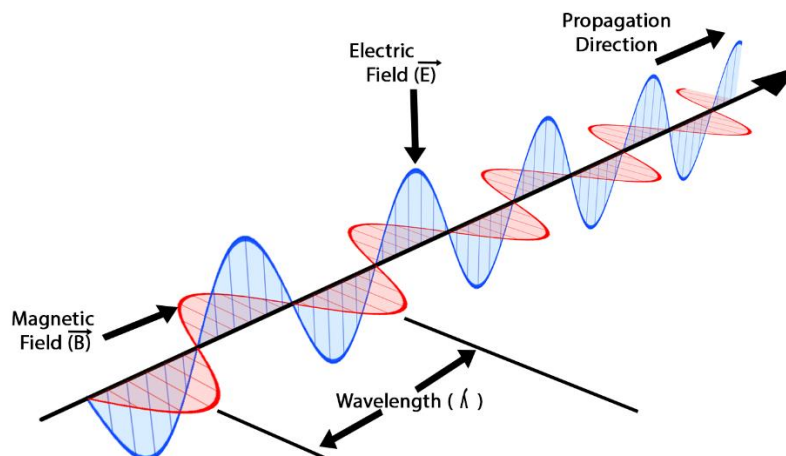


Figure 1 An electromagnetic wave

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.

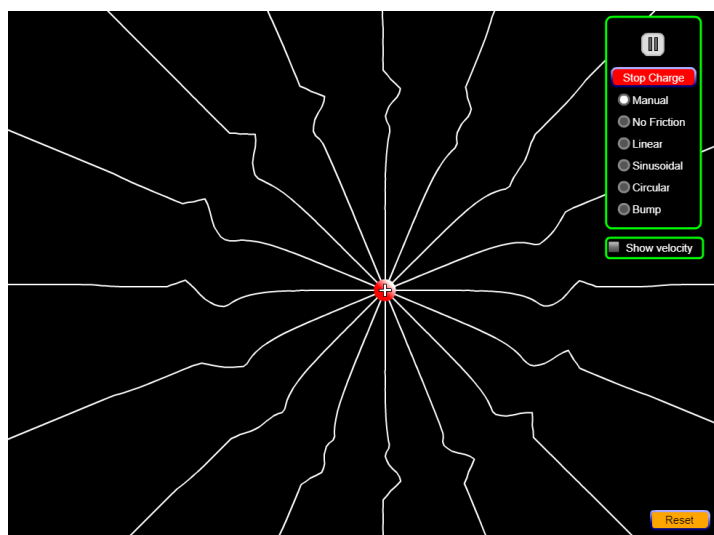


Figure 2 An electric field (E) disturbance

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 electromagnetic 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:

$$3.0 \times 10^8 \text{ ms}^{-1} \text{ (c the speed of light)}$$

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

$$c = \lambda f$$

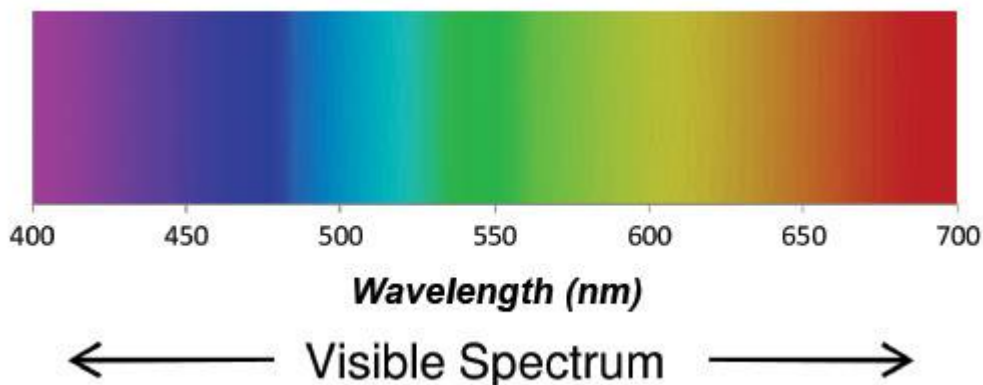
Where c is the speed of light in a vacuum ($3.0 \times 10^8 \text{ ms}^{-1}$)

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

Violet

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

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

$$f = ?$$

$$c = \lambda f$$

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

$$= \frac{3.0 \times 10^8}{400 \times 10^{-9}}$$

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

$$\text{(Or } 750 \times 10^{12} \text{ Hz)}$$

Red

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

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

$$f = ?$$

$$c = \lambda f$$

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

$$= \frac{3.0 \times 10^8}{700 \times 10^{-9}}$$

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

$$\text{(Or } 429 \times 10^{12} \text{ Hz)}$$

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.

$$\begin{aligned}
 1. \quad T &= ? \\
 f &= 6.0 \times 10^{14} \text{ Hz} \\
 T &= \frac{1}{f} \\
 &= \frac{1}{6.0 \times 10^{14}} \\
 &= 1.67 \times 10^{-15} \text{ sec}
 \end{aligned}$$

$$\begin{aligned}
 2. \quad \lambda &= ? \\
 f &= 6.0 \times 10^{14} \text{ Hz} \\
 c &= 3.0 \times 10^8 \text{ ms}^{-1} \\
 c &= \lambda f \\
 \therefore \lambda &= \frac{c}{f} \\
 \therefore \lambda &= \frac{3.0 \times 10^8}{6.0 \times 10^{14}} \\
 &= 5.0 \times 10^{-7} \text{ m} \\
 &= 500 \text{ nm}
 \end{aligned}$$

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**.

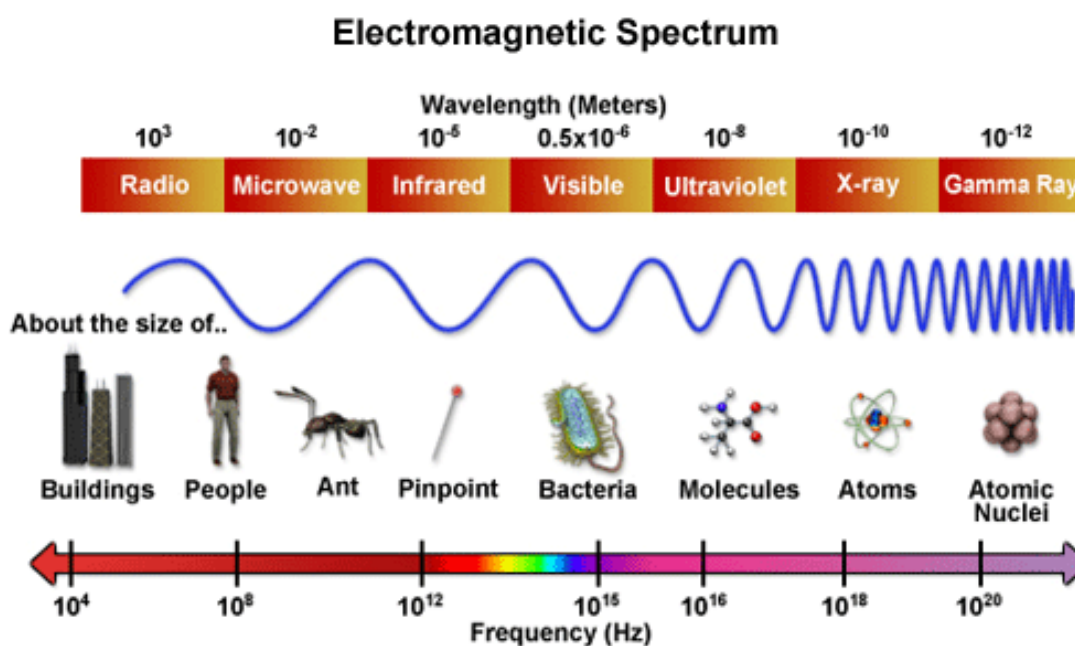


Figure 3 The electromagnetic spectrum

Electromagnetic Radiation - Summary Table

| | Classifications | Uses |
|---|--------------------|---|
| Long Wavelength ↓ Low Frequency Low Energy | 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. |
| Wavelength (λ) ↓ Frequency (Hz) Energy (J) | 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. |
| Short Wavelength ↓ High Frequency High Energy | 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. |

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

Longest

Shortest

| | | | | | |
|--|--|--|--|--|--|
| | | | | | |
|--|--|--|--|--|--|
