13.1 What Are Electromagnetic Wave ?

In this chapter, we will learn that continuous electromagnetic wave spectrum covers a large range of wavelengths and frequencies.

Type of Wave:

Radio waves, Microwaves, Infrared, Visible Light, Ultraviolet, X-Rays, Gamma rays

The following lists some facts about electromagnetic waves:

1. All electromagnetic waves are transverse wave.

2. Electromagnetic waves are made up of oscillating electric and magnetic fields (Figure 3.1). They do not carry electric charges.

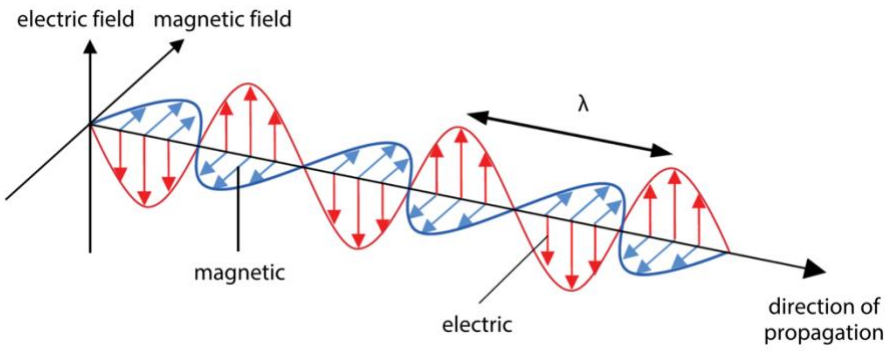


Figure 13.1 Electromagnetic wave with oscillating electric and magnetic fields

3. All electromagnetic waves can travel without a medium, with the same speed of 3×10^8 m/s in a vacuum.

4. The wave speed equation, $\boldsymbol{v = f\lambda}$, applies to all electromagnetic waves.

5. When an electromagnetic wave travels from a vacuum to other media, the **wave speed** and **wavelength decreases**. The decrease in speed is different for different frequencies. However the frequencies stays the same as at the source when the wave goes into a different medium.

6. Electromagnetic waves undergo reflections and refractions.

7. Ionising waves are those with **higher frequencies** and hence **higher energies**. They can eject electrons from atoms and molecules to create ions. The ions can cause harm by disrupting cell functions and even killing them.

8. All materials body emit range of electromagnetic waves. In general, higher temperature bodies tend to emit more and higher frequency electromagnetic waves.

Quick Check 1:

1. **(a)** Describe the direction of oscillation of electromagnetic waves with respect to their direction of travel.

   The oscillation are perpendicular to the direction of travel.

   (b) State what happens to the speed, wavelength and frequency of electromagnetic waves when they travel from a vacuum to a material such as glass.

   The speed and wavelength are reduced while the frequency is unchanged.

2. Arrange the following types of electromagnetic waves in order of increasing frequency.

Radio waves	Microwaves	Infrared	Visible Light	Ultraviolet	X-rays	Gamma Rays

13.2 What Are The Uses And Dangers Of Electromagnetic Waves ?

Uses of Electromagnetic Waves

1. **Radio waves**

   When you tune in to a radio station, sound is transmitted through the air to your radio set via radio waves.

   Information in radio waves can be transmitted by two methods. The first is called amplitude modulation (AM) as information is conveyed by varying the wave amplitude. The second is called frequency modulation (FM) as information is conveyed by varying the frequency.

2. **Microwaves**

   Microwaves are used very extensively for communication. The best-known example is in mobile phone communication where many transmitters and receivers relay information across the whole network.

   Other uses include the Global Positioning System (GPS), satellite communication and radar. Beyond communications, microwaves can be used for cancer treatment.

3. **Infrared**

   When we stand near a fire or hot object, we feel warm even when there is no contact with hot object. This is because our skin has thermoreceptors that are sensitive to infrared waves.

   Infrared waves can be used for data transfer between devices like mobile phones and laptops. Since higher frequency waves carry more data, infrared can typically transfer data faster than microwaves. More importantly, infrared waves are used in long distance fibre-optic cables for high-speed data transfer.

   Other common uses of infrared are in remote controls, camera auto-focusing and thermometers that measure body temperature by sensing the emitted infrared radiation to produce a thermal image. These thermometers can also be enhanced to detect potential intruders at protected premises and sound alarms. In cold places, greenhouses made of glass are used to trap long-wavelength infrared to maintain a warm interior for plants to grow.

4. Visible Light

Taking a photograph on a mobile phone requires visible light. Visible light can also be used to transmit data directly through the air. During surgeries, optical fires are very useful for transmitting light to illuminate internal organs.

Scientific research is ongoing to find out the role of differently coloured light in leaf growth, flowering and root formation. This will help farmers to effectively control the factors for ideal crop production using artificial light sources instead of relying on natural but unpredictable weather conditions. This could be crucial for feeding a growing world population.

Example of light induced chemical change is in photographic film. This has been largely replaced by electronic sensors in digital cameras. The film is coated with chemicals that react to visible light of different frequencies. This allows the film to record an image formed by a lens. These films respond to UV, X-rays, and gamma rays too.

5. Ultraviolet

Ultraviolet (UV) light can be seen by some insects and animals thus giving them a keener sense of sight.

In Singapore's water treatment plants, UV plays an important role in disinfection and sterilisation as it can kill bacteria and viruses.

Exposure to a suitable dose of UV light from the sun enables our body to produce vitamin D that is good for our bones, muscles, and immune system.

In places where there is little sunlight, people use sun-tanning beds to get a more tanned skin tone. However, users must exercise caution and follow usage guidelines, as over exposure can have harmful effects, including skin cancer and premature aging.

6. X-Rays

The intensity of X-rays passing through different tissue types varies. Parts of the body that absorb more X-rays appear brighter on the image. Thus, the different shades can reveal internal structures such as fractures and cancerous growths in the body.

Energetic X-rays are also useful for killing cancer cells in radiotherapy. In addition, its high penetrative power makes it a useful tool to scan for manufacturing defects in metal parts and at airports to scan luggage for prohibited items.

7. Gamma Rays

Gamma rays are the most energetic waves in the electromagnetic spectrum, making them very effective for killing germs in food and sterilising medical equipment. Like X-rays, gamma rays can be used for radiotherapy and detecting defects in manufacturing, including in metal objects.

Gamma rays have been used to treat cancer, in a procedure known as the Gamma Knife radio surgery. In the procedure, gamma rays are directed at brain tumours to kill cancer cells.

Harmful Effects of Electromagnetic Waves

1. Ionising Radiation

Ionising radiation can be high frequency electromagnetic waves or high energy particles. They come from outer space, natural radioactive materials in our environment or man-made sources. High energy electromagnetic waves can penetrate our body more easily than high energy particles.

Living things are made up of many types of cells such as nerve cells, skin cells and muscle cells. The cells are in turn made up of molecules and atoms. When a high frequency electromagnetic wave interacts with a particular atom or molecule and knocks an electron out from it, a charged ion is produced.

The charged ion will not behave in the same way as the original atom or molecule that was electrically neutral. Thus, the ion may hinder a certain chemical reaction which in turn affects a particular cell process. Depending on the scale of such disruptions and the specific biological system affected, the result could be cell death, mutations leading to diseases and organ failure.

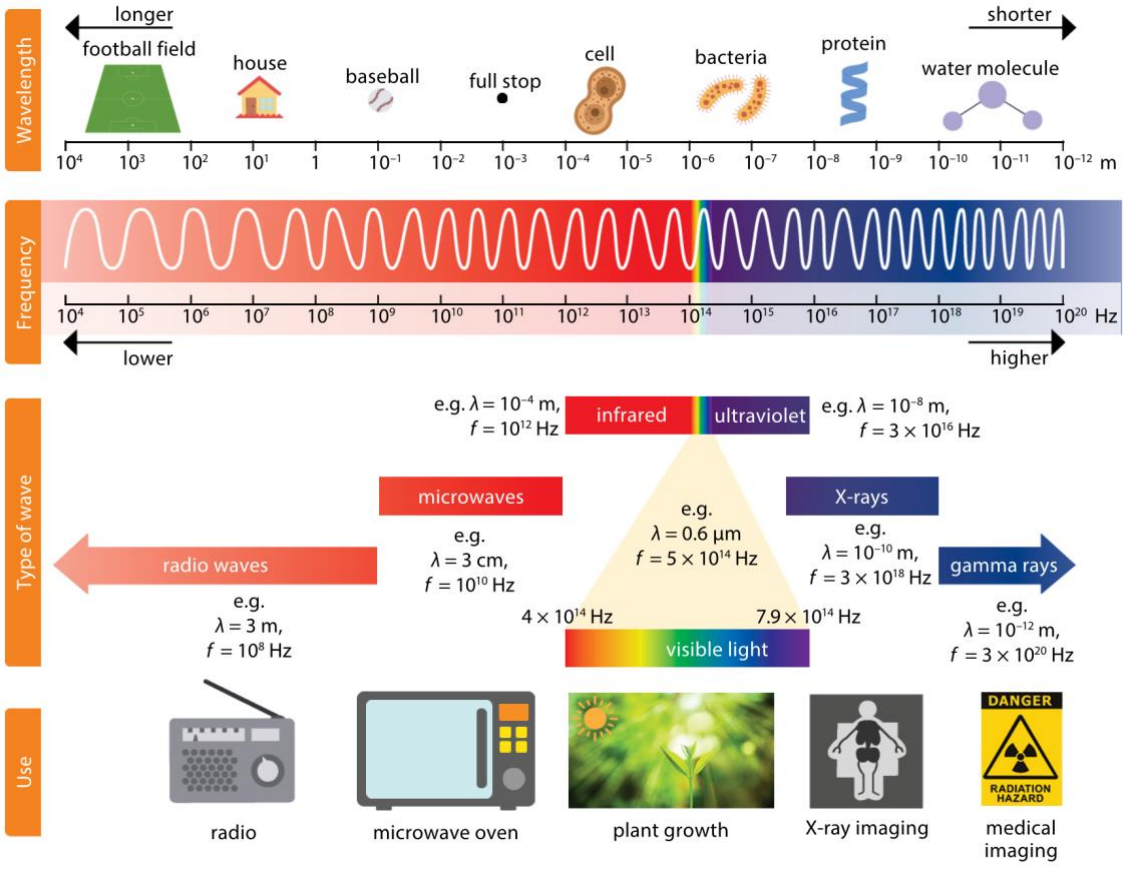
Higher frequency electromagnetic waves can penetrate deep into the body more easily to create ions. High frequency electromagnetic waves are thus more harmful than high energy particles that do not penetrate as deep.

2. Heating

The exposure to strong ionising electromagnetic radiation such as ultraviolet light causes heating effects.

As mentioned, the over-exposure to ultraviolet light can have harmful effects such as skin cancer and premature aging. Thus, in Singapore where there is a high level of UV radiation all year round, we should protect ourselves against UV.

Summary of Electromagnetic Waves



Quick Check 2:

1. Fill in the blanks.

Wave	Have Uses In
Radio waves	Radio and satellite communication, TV broadcast
Microwaves	Microwave oven, wifi signals, radar
Infrared	Heating, short range data transfer
Visible light	Artificial light for plants, data transfer in optical fibre
Ultraviolet	Sterilisation or killing bacteria and virus
X-rays	Medical imaging, find defects in manufactured parts
Gamma-rays	Radiotherapy and Sterilisation

2. Five components of the electromagnetic spectrum are listed.

Radio waves Microwaves Visible light X-rays Gamma rays

(a) **(i)** Two other components of the electromagnetic spectrum are missing from the list.
Write the names of the missing components in the appropriate row in the table.

Name of Component	Wavelength/m
Infrared	1×10^{-7}
Ultraviolet	1×10^{-5}

(ii) State one component of the electromagnetic spectrum that is an ionising radiation.

Gamma Rays

(iii) State one use of an ionising radiation.

To kill cancer cells during cancer treatment.

(b) All electromagnetic waves transfer energy and travel through a vacuum at a speed of 3.0×10^8 m/s

(i) State one other property common to all components of the electromagnetic spectrum.

They are all transverse wave.

(ii) The wavelength of a microwave is 2.0×10^{-2} m.
Calculate the frequency of this wave.

Use the formula: $f = \frac{v}{\lambda}$

$v = 3.0 \times 10^8$

$\lambda = 2.0 \times 10^{-2}$

Answer: 1.5×10^{10} Hz