Chapter 14 – Electromagnetic Waves

Subject content

Content

- Properties of electromagnetic waves
- Applications of electromagnetic waves
- Effects of electromagnetic waves on cells and tissue

Learning outcomes

(a) State that all electromagnetic waves are transverse waves that travel with the same speed in vacuum and state the magnitude of this speed

(b) Describe the main components of the electromagnetic spectrum

(c) State examples of the use of the following components:

(i) radio waves (e.g. radio and television communication)

(ii) microwaves (e.g. microwave oven and satellite television)

(iii) infra-red (e.g. infra-red remote controllers and intruder alarms)

(iv) light (e.g. optical fibres for medical uses and telecommunications)

(v) ultra-violet (e.g. sunbeds and sterilisation)

(vi) X-rays (e.g. radiological and engineering applications)

(vii) gamma rays (e.g. medical treatment)

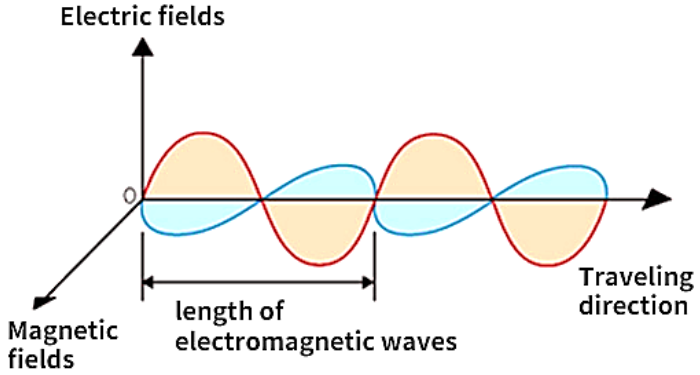
(d) Describe the effects of absorbing electromagnetic waves, e.g. heating, ionisation and damage to living cells and tissue

Definitions

Phrase	Definition
Electromagnetic spectrum	A family of electromagnetic waves
Ionisation	Physical process of converting atom / molecule into ion by adding or removing charged particles (electrons / other ions)

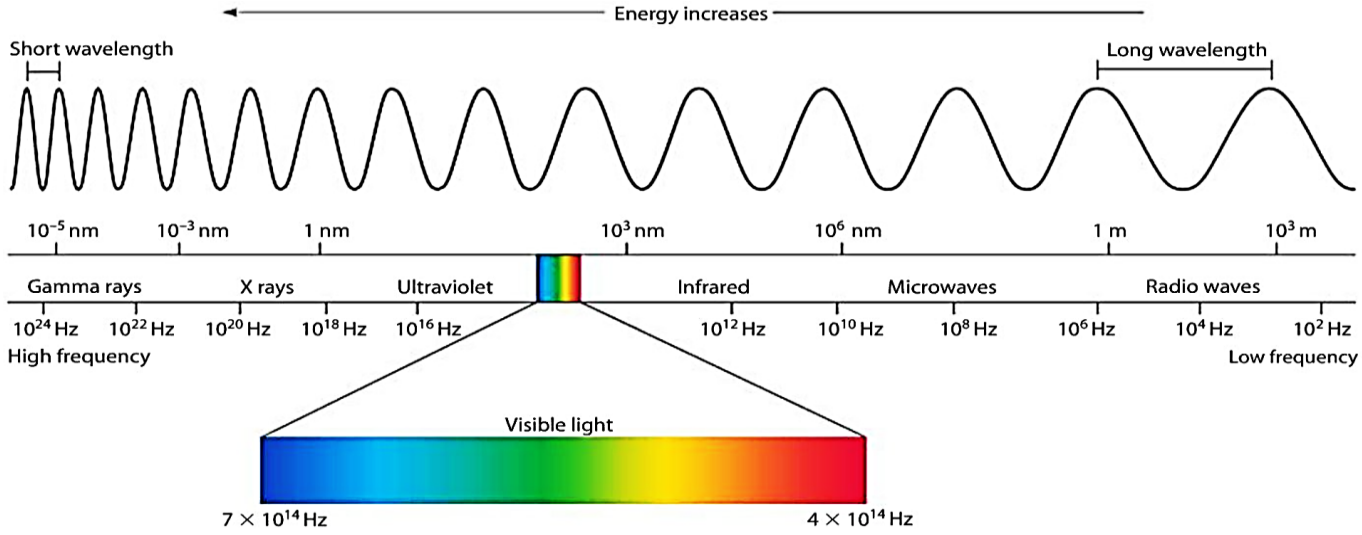
14.1 Electromagnetic Waves

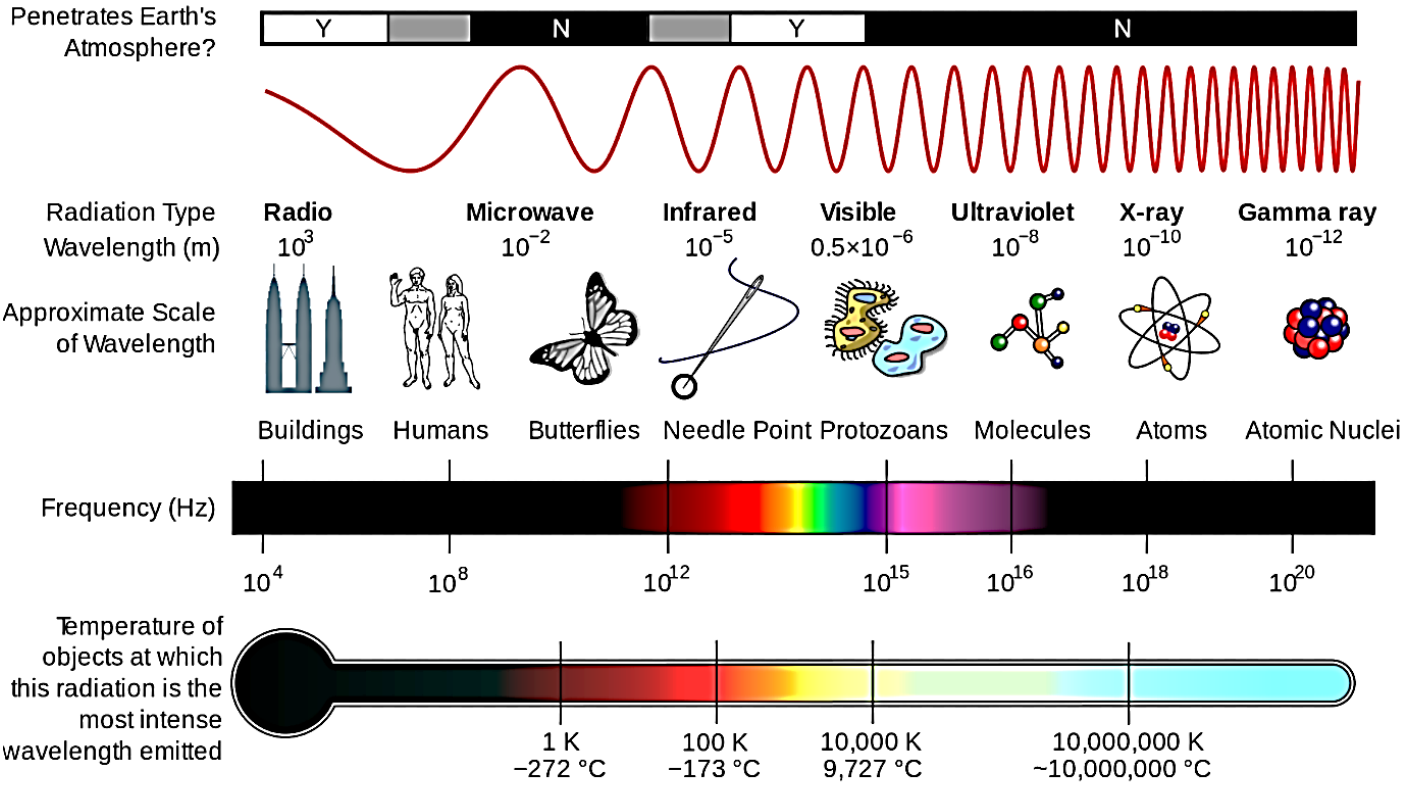
Electromagnetic wave



Electromagnetic spectrum

EM wave	Frequency (f)	Wavelength (λ)
1. **Radio waves**	lowest	longest
2. **Microwaves**		
3. **Infrared**		
4. **Visible light**	increasing	increasing
5. **Ultraviolet**		
6. **X-rays**		
7. **Gamma rays** (γ-rays)	highest	shortest





Properties of electromagnetic waves

Property	Explanation
1. **Transverse waves**	Oscillate <u>perpendicularly</u> (at 90°) to each other 1) Electric waves 2) Magnetic waves
2. Travel through **vacuum**	Do not require medium to travel
3. **Transfer energy** from a place to another	
4. Speed in vacuum: $\mathbf{3.0 \times 10^8\ ms^{-1}}$	
5. **Wave speed** equation	$v = f\lambda$
6. **Travels** from one **medium** to another	• Speed (v) and wavelength (λ) change • Frequency (f) does not change
7. Obey laws of **reflection + refraction**	
8. Carry **no electric charge**	Pass through electric and magnetic fields being undeviated

14.2 Applications and Effects of Electromagnetic Waves

Characteristics of each region of the electromagnetic wave

EM wave	Wavelength (10^x m)	Frequency (10^x Hz)	Application	Explanation	Health effects
1. **Radio waves**	4 ~ 9	-1 ~ 4	AM and FM **radios**	Radio and television communication	Not used for satellite telecommunication
2. **Microwaves**	9 ~ 13	-4 ~ -1	**Microwave ovens**	Penetrate into food, cause water molecules to vibrate vigorously and generate heat which cooks the food	Can penetrate the atmosphere, haze, clouds
			Satellite telecommunication	Carry signals to and from satellites for satellite television / Global Positioning System (GPS) / mobile phone network	
3. **Infrared rays**	12 ~ 14	-6 ~ -4	**Intruder alarm**	Detect the presence of people	Hotter objects emit more IR
			Remote controller	Control electrical devices (a) TV (b) air conditioners (c) hi-fi systems	
			Ear thermometers	Determine body temperature	
4. **Visible light**	14	-6	**Optical fibres**	For medical purposes, e.g. endoscopy and telecommunication where digital signals are sent	Causes <u>blindness</u> due to direct strong exposure on retina Highest f + shortest λ: violet Lowest f + longest λ: red
5. **Ultraviolet**	14 ~ 16	-8 ~ -6	**Counterfeit detector machines**	Detection of counterfeit money	Causes <u>sunburn</u>, <u>skin cancer</u>
			Sunbed	Artificial tanning	
			Germicidal lamps	Sterilisation of medical and laboratory equipment	
6. **X-rays**	15 ~ 18	-10 ~ -7	**X-ray imaging** (medical)	<u>Medical diagnosis</u> (dental inspection)	Causes cell destruction, <u>mutation</u> of normal cells → <u>cancer</u>
			Radiation therapy (medical)	Kill <u>cancer cells</u> / tumours	
			Industrial radiography	Check for <u>cracks</u> in welds of metal parts	

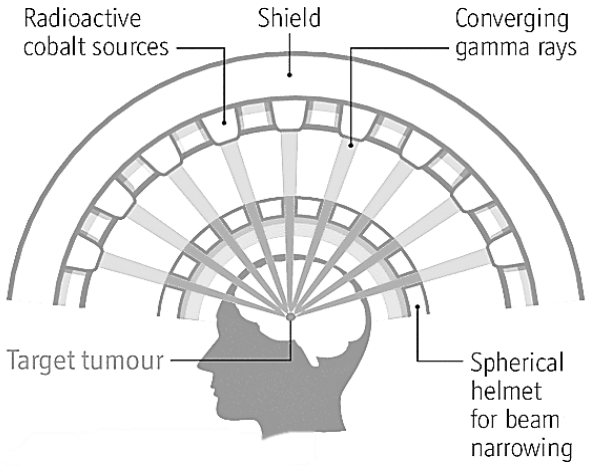
			X-ray screening	Screening of baggage for potential threats in X-ray machines	
7. **Gamma rays**	18 ~ 20	-12 ~ -10	**Radiation therapy**	• e.g. Gamma knife radio surgery • Kill cancer cells / tumours	Causes cell destruction, mutation of normal cells, causes cancer
			Steriliser (controlled doses)	Sterilisation of medical and laboratory equipment (high energy emitted kills germs and bacteria)	
			Industrial **radiography**	Check for cracks in welds of metal parts	

Radio waves

Type of radio wave	Wavelength (m)	Uses
1. Long Wave (LW) 2. Medium Wave (MV) 3. Short Wave (SW)	Longer (10 ~ 2,000)	• AM radio • Submarine communication
4. Very High Frequency (VHF) 5. Ultra High Frequency (UHF)	Shorter (0.1 ~ 10)	• FM radio • Over-the-air television (terrestrial television)

Gamma Knife radio surgery

- Non-invasive
  1. Lower costs
  2. Speedier recovery
- Process (**tumour**: cancer cells)
  1. Weak beams of γ-rays are emitted from cobalt-60 sources
  2. Beams are focused on the brain tumour through holes in protective helmet
  3. Each individual beam: too weak to damage normal tissues it passes on its way to tumour
  4. Weak beams converge → combined energy sufficient to kill tumour



Effects of EM waves

Ionisation

Physical process of converting atom / molecule → ion by adding or removing charged particles (electrons / other ions)

Effects of exposure to radiation on living cells and tissues

EM wave	Ionising	Effect
1. **Gamma rays**	✓	• Damage living cells through ionising effect • Leads to mutation and abnormal cell division → **cancer**
2. **X-rays**	✓	
3. **UV rays**	✓	• **Premature aging of skin** + **skin cancer** • Cataracts and eye damage / **blindness** due to direct strong exposure on retina
4. **Microwaves**	×	• Heat up water molecules by causing it to vibrate vigorously • Exposed to high levels of microwaves → heat up living cells and tissues → **damage cells**

Typical questions

Multiple choice questions

1. Statements 1 and 2 are about signals passing through an optical fibre of refractive index 1.5.

statement	
1	The speed of the signal in the optical fibre is 3.0×10^8 m/s.
2	There is less signal loss in the optical fibre than in a copper cable.

Which statements are correct? (2017 P1 Q25)

A neither of the statements
B both statements 1 and 2
C statement 1 only
D statement 2 only

Structured questions

1. The figure below gives the names of five components of the electromagnetic spectrum.

(2011 P2A Q5)

X-rays	Microwaves	Ultra-violet	Infra-red	Radio waves

(a) One component of the electromagnetic spectrum in the figure above is not in the correct position. State the name of this component. [1]
Microwaves

(b) State which of the five components.
(i) has the smallest frequency, Radio waves
(ii) is used in a television remote control, Infra-red
(iii) is used for satellite television, Microwaves

(c) Explain why ultrasound is not a component of the electromagnetic spectrum. [1]
Ultrasound is not able to pass though a vacuum / does not travel at 3.0×10^8 m/s in a vacuum.
Ultrasound is also not a transverse wave.

(d) Ultrasound and X-rays are used in hospitals to produce images of regions inside the human body. Both procedures need a source of waves and a detector.

ultrasound X-ray

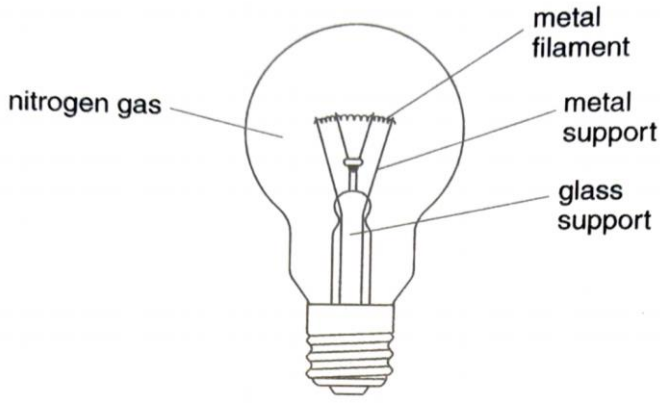
Draw and label the positions of the source and the detector

(i) on the left figure, when ultrasound produces an image of region P, [1]

(ii) on the right figure, when X-rays produce an image of region Q. [1]

Explanation:
An ultrasound scan uses the reflection of ultrasound from the body tissues to generate an image, thus the source and detector are on the same side of the body.
An X-ray scan uses the effect of X-rays causing a change on an X-ray film to allow us to see inside the body, as the X-rays are absorbed by the bones, and thus appears as a white (unexposed) spot on the X-ray film.

2. When switched on, the filament lamp shown in the figure below loses energy by conduction, convection and radiation. (2012 P2A Q3a, b)



The radiation emitted is part of the electromagnetic spectrum.

(a) State one property of electromagnetic waves that distinguished them from all other types of waves. [1]

Electromagnetic waves all travel at the speed of 3.0×10^8 m/s in a vacuum.

(b) (i) State two components of the electromagnetic spectrum emitted by the filament in the lamp. [1]

Visible light
Infra-red waves

(ii) The current in the lamp is reduced. The colour of the filament changes from white to red. Describe the changes in the radiation emitted by the lamp. [2]

When the current of the lamp is reduced, the brightness of the bulb is reduced. As a result, less visible light is emitted by the lamp. As the temperature of the filament is reduced as well, less infra-red waves are emitted. The red colour shows that the wavelength of the visible light is primarily in the red region of visible light.

3. (a) State the type of electromagnetic radiation used (2019 P2B Q10a, c)

(i) in the remote control of a television set, microwaves [1]

(ii) in a sunbed. ultraviolet [1]

(b) X-rays are a type of electromagnetic radiation used to produce images of the inside of the human body. State three possible effects on the living cells in the human body when X-rays are absorbed by body tissue. [3]

Causes the cell to heat up

Causes cell mutation / damage

Ionisation within the cell