Exercise walk-through

Electromagnetic spectrum ▪ 3.3

eXercise

You must be able to

- give the regions in order of wavelength and of frequency
- state the speed of electromagnetic waves in a vacuum and in air
- give a typical use and a harmful effect for each region
- describe how satellites in low and geostationary orbits are used
- explain the difference between digital and analogue signals, and the benefits of digital

Method — The spectrum, in order

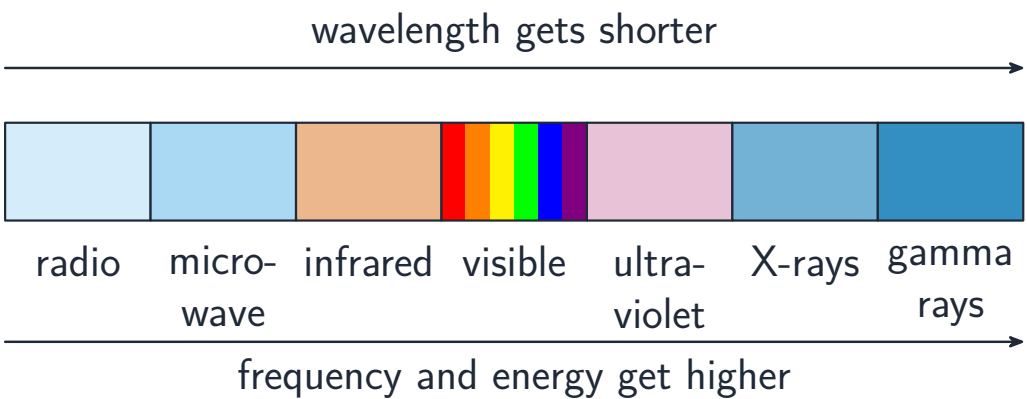
All electromagnetic waves are transverse, transfer energy, and travel at the same speed in a **vacuum 真空**: 3.0×10^8 m/s (almost the same in air). Going from radio waves to gamma rays, the wavelength falls while the frequency and the energy rise.

Region	**A typical use**	**Harm from too much**
radio waves	radio and TV, astronomy, RFID tags	—
microwaves	mobile phones, satellite TV, cooking	internal heating of body cells
infrared	remote controls, thermal imaging, grills, optical fibres	skin burns
visible light	seeing, photography	—
ultraviolet	sterilising water, security marking, checking bank notes	skin cancer, eye damage
X-rays	medical and security scans	damage to cells
gamma rays	sterilising equipment, detecting and treating cancer	mutation of cells

Method — The spectrum, in order

Read a "match the use to the region" question from the use: security marking uses **ultraviolet** (the ink glows); Bluetooth uses **radio waves**; optical fibres carry **infrared**; detecting and treating cancer uses **gamma rays**.

Method — The spectrum, in order



A coloured band from radio waves to gamma rays

Method — Satellites

Communication with artificial satellites is mainly by **microwaves**, because they pass through the atmosphere and the ionosphere, need only a short aerial, and carry data at a high rate. Some satellite phones use satellites in **low orbit** 低轨道, close to the Earth. Direct broadcast satellite television, and some satellite phones, use satellites in **geostationary orbit** 地球静止轨道, which stay above the same point on the Earth so the dish never has to move.

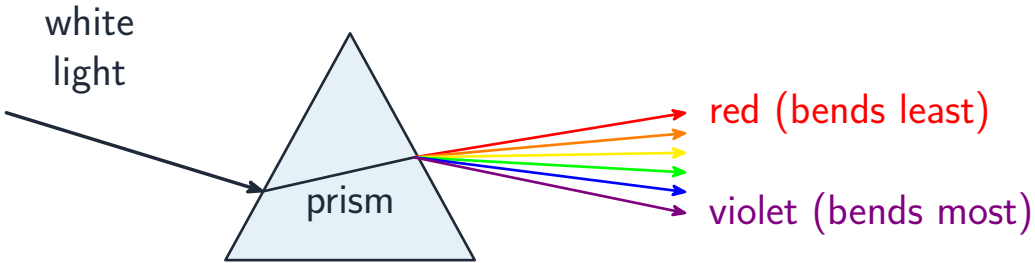
Method — Digital and analogue signals

An **analogue signal** varies continuously and can take any value. A **digital signal** is a stream of only two values, on or off (1 or 0). A sound can be sent either way: a microphone produces an analogue signal, which can be converted to digital.
Digital signalling is better for two reasons the exam wants:

- a **higher rate** of data transmission;
- a **greater range**, because a weak digital signal can be **regenerated** back to clean 1s and 0s: only two levels have to be told apart, so the noise picked up on the way is removed. An analogue signal cannot be cleaned up like this, so its noise builds up along the route.

Worked example. A signal travels 600 km along an optical fibre and is regenerated three times. Explain why the message arrives without noise. Each regenerator only has to decide whether the level is nearer 1 or nearer 0; it then transmits a fresh, clean pulse, so the noise added in the previous section is discarded rather than passed on.

Method — Digital and analogue signals



A prism disperses white light into the visible spectrum

Practice 2.1 ▪ 2 marks

List the regions of the electromagnetic spectrum in order of increasing frequency.

Solution 2.1

Method: The spectrum, in order

Worked steps

Radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays B2

one mark if one pair is swapped.

Practice 2.2 ▪ 1 mark

State the speed of electromagnetic waves in a vacuum.

Solution 2.2

Method: The spectrum, in order

Worked steps

3.0×10^8 m/s B1.

Practice 2.3 ▪ 2 marks

Give one use of infrared radiation and one harmful effect of too much ultraviolet.

Solution 2.3

Method: The spectrum, in order

Worked steps

Any one use of infrared: remote controls, thermal imaging, grills, optical fibres B1.
Ultraviolet: skin cancer or eye damage B1.

Practice 2.4 ▪ 2 marks

State the difference between a digital and an analogue signal.

Solution 2.4

Method: Digital and analogue signals

Worked steps

An analogue signal varies continuously and can take any value B1; a digital signal has only two values, on or off, 1 or 0 B1.

Practice 2.5 ▪ 2 marks

State two benefits of sending information as a digital signal.

Solution 2.5

Method: Digital and analogue signals

Worked steps

A higher rate of data transmission B1; a greater range, because the signal can be regenerated without the noise B1.

Practice 2.6 ▪ 2 marks

State which region of the spectrum is used to communicate with satellites, and give one reason why.

Solution 2.6

Method: The spectrum, in order

Worked steps

Microwaves B1; any one of: they pass through the atmosphere and ionosphere; only a short aerial is needed; they carry a large amount of data at high speed B1.

Practice 2.7 ▪ 3 marks

A radio wave has a frequency of 1.5×10^8 Hz. Calculate its wavelength in a vacuum.

Solution 2.7

Method: The spectrum, in order

Worked steps

$$\lambda = \frac{v}{f} \quad \text{M1} \quad = \frac{3.0 \times 10^8}{1.5 \times 10^8} \quad \text{M1} \quad = 2.0 \text{ m} \quad \text{A1}.$$

Exam-style 3.1 ▪ 1 mark

Which row is correct for two regions of the electromagnetic spectrum?

A X-rays have a longer wavelength than radio waves.

B Microwaves travel faster than gamma rays in a vacuum.

C Ultraviolet has a higher frequency than infrared.

D Gamma rays have the lowest energy of all the regions.

Solution 3.1

Method: The spectrum, in order

A X-rays have a longer wavelength than radio waves.

B Microwaves travel faster than gamma rays in a vacuum.

C Ultraviolet has a higher frequency than infrared. ✓

D Gamma rays have the lowest energy of all the regions.

Worked steps

C. Ultraviolet sits above infrared in frequency. A reverses the order, B is wrong because all electromagnetic waves travel at the same speed in a vacuum, and D reverses the energy order.

Exam-style 3.2 ▪ 1 mark

A digital signal and an analogue signal both travel a long distance and pick up noise. Which statement is correct?

A Only the analogue signal can be regenerated to remove the noise.

B Only the digital signal can be regenerated, because it has just two levels.

C Neither signal can be regenerated once noise is added.

D Both can be regenerated equally well.

Solution 3.2

Method: Digital and analogue signals

A Only the analogue signal can be regenerated to remove the noise.

B Only the digital signal can be regenerated, because it has just two levels. ✓

C Neither signal can be regenerated once noise is added.

D Both can be regenerated equally well.

Worked steps

B. A digital signal has only two levels, so a regenerator can decide which was sent and transmit a clean pulse; an analogue signal has no such reference, so its noise is amplified along with the signal.

Exam-style 3.3 ▪ 2 marks

Electromagnetic waves have many uses.
(a) Draw one line from each use to the region of the spectrum that it uses.

Use	**Region**
security marking	gamma rays
Bluetooth	ultraviolet
optical fibres	infrared
detecting cancer	radio waves

Exam-style 3.3 ▪ 2 marks

(b) State one advantage of using microwaves rather than radio waves to transmit mobile phone signals.
(c) Describe the difference between a satellite in a low orbit and one in a geostationary orbit, and state one use of each.
(d) State the harmful effect on people of too much exposure to microwaves, and to X-rays.

Solution 3.3

Method: The spectrum, in order

Worked steps

(a) security marking → ultraviolet; Bluetooth → radio waves; optical fibres → infrared; detecting cancer → gamma rays **B2** *one mark for any two correct.*
(b) Any one of: microwaves need only a short aerial; they pass through the atmosphere to satellites; they transmit data at a higher rate **B1**.
(c) A low-orbit satellite is close to the Earth and moves quickly across the sky, so it is only in view for a short time **B1**; a geostationary satellite orbits above the equator once a day, so it stays above the same point and a dish can point permanently at it **B1**. Low orbit: satellite phones **B1**. Geostationary: direct broadcast satellite

Solution 3.3

television B1.
(d) Microwaves: internal heating of body cells B1. X-rays: damage to cells, which can cause cancer B1.

Exam-style 3.4 ▪ 2 marks

A telephone company replaces a copper cable carrying analogue signals with an optical fibre carrying digital signals.
(a) Explain what is meant by an analogue signal and by a digital signal.
(b) Explain, in terms of noise and regeneration, why the digital system can send a signal a greater distance without losing quality.
(c) State one other benefit of the digital system.
(d) The infrared signal in the fibre has a wavelength of 1.5×10^{-6} m. Calculate its frequency. Take the speed as 3.0×10^{8} m/s.
(e) The company says the signal "travels faster because it is digital". Explain why this statement is wrong.

Solution 3.4

Method: Digital and analogue signals

Worked steps

(a) Analogue: the signal varies continuously and can take any value B1. Digital: the signal has only two values, 1 and 0 B1.
(b) Both signals pick up noise as they travel B1; a digital signal is regenerated at intervals, and because only two levels must be told apart the original 1s and 0s are recovered exactly and a clean signal is sent on B1; an analogue signal cannot be separated from its noise, so amplifying it amplifies the noise too and the quality falls with distance B1.
(c) A higher rate of data transmission B1.

Solution 3.4

(d) $f = \frac{v}{\lambda}$ M1 $= \frac{3.0 \times 10^{8}}{1.5 \times 10^{-6}}$ M1 $= 2.0 \times 10^{14}$ Hz A1.

(e) All electromagnetic waves travel at the same speed in a given medium, whether the signal is digital or analogue B1; what digital gives is a higher rate of data transfer and a greater range, not a higher wave speed B1.