Exercise walk-through

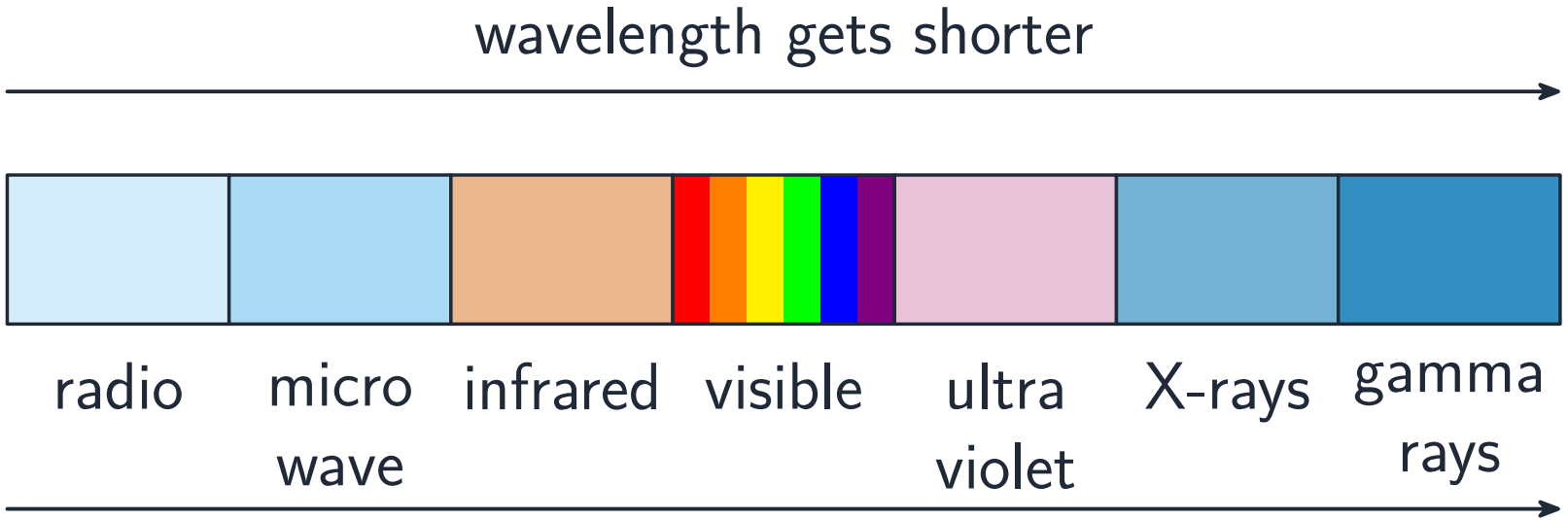
3.3 Electromagnetic spectrum

IGCSE Physics

The electromagnetic spectrum

All travel at $3.0 \times 10^8\,\mathrm{m/s}$ in a vacuum.

> Radio $\rightarrow$ gamma: frequency & energy rise, wavelength falls.



The spectrum: one use and one danger each

radio waves	broadcasting and communications – little known danger at normal intensity
microwaves	mobile phones, satellite TV, cooking – heating of body cells
infrared	remote controls, thermal imaging, grills – skin burns
visible light	seeing, optical fibres, photography
ultraviolet	sterilising water, checking bank notes – skin cancer and eye damage
X-rays and gamma	medical and security scans; sterilising equipment and treating cancer – cell damage and mutation

All travel at the same speed in a vacuum. Frequency rises left to right, and so does the danger – which is not a coincidence: higher frequency means more energy per photon.

Two more words the spectrum needs

Gamma rays	**Gamma rays** : shortest wavelength, highest energy. Used for sterilising equipment and treating cancer – and they can cause mutation of cells.
Monochromatic	Light of a single frequency – one pure colour – is **monochromatic** . A laser is; a filament lamp is not.
One family	All of it travels at the same speed in a vacuum; only the wavelength and frequency change along the spectrum.

Order the spectrum by wavelength once and the uses and dangers follow: shorter wavelength, higher energy, greater hazard.

Try it: recover a message after noise

A microphone produces an **analogue** signal that varies continuously. The sound can instead be encoded as **digital** data using two signal levels, 0 and 1.

In this simplified receiver, values below 0.5 are read as 0; values above 0.5 are read as 1. Received levels are:

$$0.12 \qquad 0.86 \qquad 0.73 \qquad 0.19$$

Write the four recovered digits and the clean levels the receiver should send on.

If noise changes the third received level to 0.41, will the same rule still recover the original digit? Explain.

Regeneration restores levels when decisions are correct

Received level	0.12	0.86	0.73	0.19
Decision	0	1	1	0
Regenerated level	0	1	1	0

The receiver decides low or high, then sends a fresh signal at the clean level. Small variations are removed rather than passed along to the next stage.

But 0.41 is below the decision boundary: the receiver sends 0 instead of the original 1. Regeneration alone cannot identify that mistake.

> Regeneration restores clean levels if each digit is read correctly. Excessive noise can cause a wrong digit.

Exercises 2.1–2.3

2.1 List the regions of the electromagnetic spectrum in order of increasing frequency. [2]

2.2 State the speed of electromagnetic waves in a vacuum. [1]

2.3 Give one use of infrared radiation and one harmful effect of too much ultraviolet. [2]

Exercises 2.1–2.3

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2.1

- radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays

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2.2 State the speed of electromagnetic waves in a vacuum. [1]

2.2

- $3.0 \times 10^{8}\ \dfrac{\text{m}}{\text{s}}$

2.3 Give one use of infrared radiation and one harmful effect of too much ultraviolet. [2]

2.3

- any one use of infrared: remote controls, thermal imaging, grills, optical fibres
- ultraviolet: skin cancer or eye damage

Exercises 2.4·2.5

2.4 State the difference between a digital and an analogue signal. [2]

2.5 State two benefits of sending information as a digital signal. [2]

Exercises 2.4·2.5

2.4 State the difference between a digital and an analogue signal. [2]

2.4

- an analogue signal varies continuously and can take any value
- a digital signal has only two values, on or off, 1 or 0

2.5 State two benefits of sending information as a digital signal. [2]

2.5

- a higher rate of data transmission
- a greater range, because the signal can be regenerated without the noise

Exercises 2.6·2.7

2.6 State which region of the spectrum is used to communicate with satellites, and give one reason why. [2]

2.7 A radio wave has a frequency of 1.5×10^8 Hz. Calculate its wavelength in a vacuum. [3]

Exercises 2.6·2.7

2.6 State which region of the spectrum is used to communicate with satellites, and give one reason why. [2]

2.6

- microwaves
- 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

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2.7 A radio wave has a frequency of 1.5×10^8 Hz. Calculate its wavelength in a vacuum. [3]

2.7

- $\lambda = v/f$

$$\lambda = \frac{3.0 \times 10^8 \ \dfrac{\text{m}}{\text{s}}}{1.5 \times 10^8 \ \text{Hz}} = \mathbf{2.0} \ \text{m}$$

Exercise 3.1

3.1 Which row is correct for two regions of the electromagnetic spectrum? [1]

☐ **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.

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- **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.

3.1 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; **D** reverses the energy order

Exercise 3.2

3.2 A digital signal and an analogue signal both travel a long distance and pick up noise. Which statement is correct? [1]

☐ **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.

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- **D** Both can be regenerated equally well.

3.2 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

Exercise 3.3 (a)

3.3 Electromagnetic waves have many uses.

(a) Draw one line from each use to the region of the spectrum that it uses. [2]

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

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Bluetooth	ultraviolet
optical fibres	infrared
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(a) security marking → ultraviolet; Bluetooth → radio waves; optical fibres → infrared; detecting cancer → gamma rays

Exercise 3.3 (b)

3.3 Electromagnetic waves have many uses.

(b) State one advantage of using microwaves rather than radio waves to transmit mobile phone signals. [1]

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(b) State one advantage of using microwaves rather than radio waves to transmit mobile phone signals. [1]

(b) any one of: microwaves need only a short aerial; they pass through the atmosphere to satellites; they transmit data at a higher rate

Exercise 3.3 (c)

3.3 Electromagnetic waves have many uses.

(c) Describe the difference between a satellite in a low orbit and one in a geostationary orbit, and state one use of each. [4]

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(c) Describe the difference between a satellite in a low orbit and one in a geostationary orbit, and state one use of each. [4]

(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

- 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
- low orbit: satellite phones
- geostationary: direct broadcast satellite television

Exercise 3.3 (d)

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(d) State the harmful effect on people of too much exposure to microwaves, and to X-rays. [2]

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(d) microwaves: internal heating of body cells

- X-rays: damage to cells, which can cause cancer

Exercise 3.4 (a)

3.4 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. [2]

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3.4 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. [2]

(a) analogue: the signal varies continuously and can take any value

- digital: the signal has only two values, 1 and 0

Exercise 3.4 (b)

3.4 A telephone company replaces a copper cable carrying analogue signals with an optical fibre carrying digital signals.

(b) Explain, in terms of noise and regeneration, why the digital system can send a signal a greater distance without losing quality. [3]

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(b) Explain, in terms of noise and regeneration, why the digital system can send a signal a greater distance without losing quality. [3]

(b) both signals pick up noise as they travel

- a digital signal is regenerated at intervals, and because only two levels must be told apart the original 1s and 0s are recovered exactly
- an analogue signal cannot be separated from its noise, so amplifying it amplifies the noise too and the quality falls with distance

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(c) a higher rate of data transmission

Exercise 3.4 (d)

3.4 A telephone company replaces a copper cable carrying analogue signals with an optical fibre carrying digital signals.

(d) The infrared signal in the fibre has a wavelength of 1.5×10^{-6} m. Calculate its frequency. Take the speed as $3.0 \times 10^{8}\ \dfrac{\text{m}}{\text{s}}$. [3]

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(d) $f = v/\lambda$

$$f = \frac{3.0 \times 10^{8}\ \frac{\text{m}}{\text{s}}}{1.5 \times 10^{-6}\ \text{m}} = \mathbf{2.0 \times 10^{14}}\ \text{Hz}$$

Exercise 3.4 (e)

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(e) The company says the signal “travels faster because it is digital”. Explain why this statement is wrong. [2]

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(e) all electromagnetic waves travel at the same speed in a given medium, whether the signal is digital or analogue

- what digital gives is a higher rate of data transfer and a greater range, not a higher wave speed