3.3 Electromagnetic spectrum

Name: _____ Class: _____ Date: _____ **Total: 36 marks**

0 Vocabulary

Word	Example
energy /'enədʒi/ 能量	Food gives your body the **energy** it needs to move. 食物为你的身体提供运动所需的**能量**。
optical fibre /'ɒptɪkl 'faɪbə/ 光纤	An **optical fibre** carries internet data as light. **光纤**以光的形式传输互联网数据。
converging lens 凸透镜 /kən'vɜ:dʒɪŋ lenz/	A **converging lens** brings light rays together. **凸透镜**使光线会聚。
real image /rɪəl 'ɪmɪdʒ/ 实像	A **real image** can be shown on a screen. **实像**可以呈现在屏幕上。
prism /'prɪzəm/ 棱镜	A glass **prism** splits white light into colours. 玻璃**棱镜**能将白光分解成各种颜色的光。
spectrum /'spektrəm/ 光谱	A prism splits light into a **spectrum**. 棱镜将光分解成**光谱**。
dispersion /dɪ'spɜ:ʃn/ 色散	**Dispersion** separates white light into a rainbow. **色散**将白光分解成彩虹般的色彩。
monochromatic 单色 /ˌmɒnəʊkrəʊ'mætɪk/	Laser light is **monochromatic**: it has one colour. 激光是**单色**光：它只有一种颜色。
electromagnetic spectrum 电磁波谱 /ɪˌlektrəʊməg'netɪk 'spektrəm/	Radio waves and X-rays are both in the **electromagnetic spectrum**. 无线电波和 X 射线都属于**电磁波谱**。
vacuum /'vækju:m/ 真空	There is no air in a **vacuum**, so sound cannot travel through it. **真空**中没有空气，所以声音无法在其中传播。
radio waves /'reɪdɪəʊ weɪvz/ 无线电波	**Radio waves** carry TV and radio signals. **无线电波**传送电视和广播信号。
microwave /'maɪkrəʊweɪv/ 微波	A **microwave** can carry a signal to a satellite. **微波**可以向卫星传送信号。

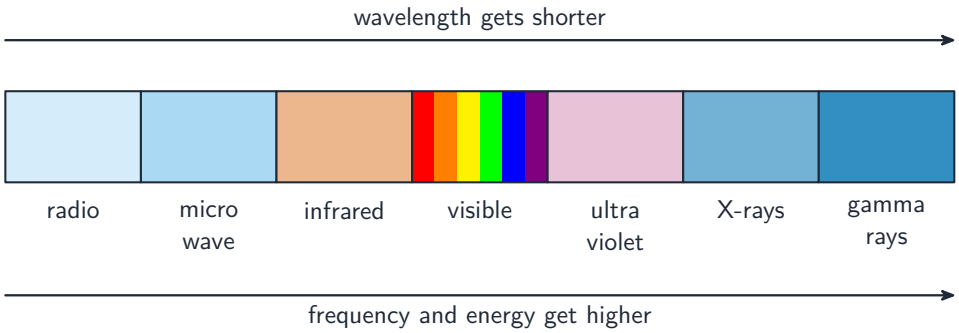
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Word	Example
infrared /ˌɪnfrəˈred/ 红外线	A TV remote uses **infrared** light. 电视遥控器使用**红外线**。
ultraviolet /ˌʊltrəˈvaɪəlɪt/ 紫外线	**Ultraviolet** light from the Sun can burn your skin. 太阳发出的**紫外线**会灼伤皮肤。
X-rays /eks reɪz/ X 射线	Doctors use **X-rays** to see broken bones. 医生使用 X **射线**查看骨折。
gamma rays /ˈgæmə reɪz/ 伽马射线	**Gamma rays** kill cancer cells. **伽马射线**可以杀死癌细胞。
artificial satellites 人造卫星 /ˌɑːtɪˈfɪʃl ˈsætəlaɪts/	**Artificial satellites** send TV signals and weather pictures. **人造卫星**传送电视信号和气象图片。
low orbit /ləʊ ˈɔːbɪt/ 低轨道	A satellite in **low orbit** goes round the Earth in about 90 minutes. 位于**低轨道**的卫星绕地球一周大约需要 90 分钟。
geostationary orbit 地球静止轨道 /ˌdʒiːəʊˈsteɪʃənəri ˈɔːbɪt/	A TV satellite is in **geostationary orbit**. 电视卫星处于**地球静止轨道**上。
analogue /ˈænəlɒg/ 模拟	An **analogue** signal changes smoothly. **模拟**信号连续平滑地变化。
digital /ˈdɪdʒɪtl/ 数字	A **digital** signal uses only 0 and 1. **数字**信号只使用 0 和 1。

1 Key knowledge and worked examples

■ The spectrum, in order

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



From radio to gamma rays: wavelength falls, frequency and 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

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**.

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.

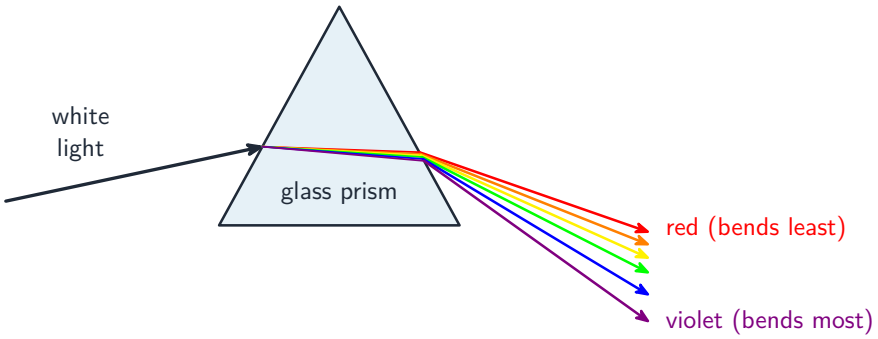
Digital and analogue signals

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.



Visible light is one narrow band of the spectrum; a prism spreads it into its colours

2 Practice

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

electromagnetic spectrum

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

EM waves in a vacuum

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

infrared ultraviolet

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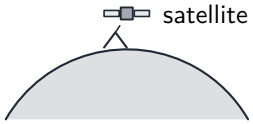
2.4 State the difference between a digital and an analogue signal. [2]

digital analogue

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

digital signal

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]

1.5×10^8 Hz

3 Exam-style questions

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.

EM spectrum regions

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.

digital + noise analogue + noise

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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

radio	micro	infrared	visible	UV	X-rays	gamma

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

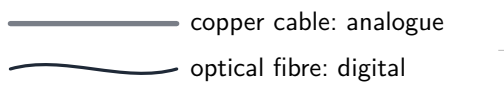
(c) Describe the difference between a satellite in a low orbit and one in a geostationary orbit, and state one use of each. [4]

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



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

(c) State one other benefit of the digital system. [1]

(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} $\frac{\text{m}}{\text{s}}$. [3]

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

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Solutions

Each answer shows the steps, then the **result**.

2.1

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

2.2

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

2.3

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

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

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

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

2.7

- $\lambda = v / f$

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

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

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

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3.3

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

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

(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

(d) microwaves: internal heating of body cells

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

3.4

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

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

(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

(c) a higher rate of data transmission

(d) $f = v/\lambda$

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

(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