Electromagnetic Spectrum

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Electromagnetic Spectrum

Properties of All Electromagnetic Waves

All electromagnetic (EM) waves share the same fundamental properties:

- They are **transverse waves**, oscillations are perpendicular to the direction of travel.
- They travel at the **speed of light** in a vacuum: $c = 3 \times 10^8$ m s{.
- They can travel through a **vacuum**, no medium is needed.
- They carry **energy**.
- They obey $v = f\lambda$ (in vacuum, $c = f\lambda$).
- They can be **reflected**, **refracted**, **diffracted**, and undergo **interference**.

The Spectrum

EM waves differ in frequency (and therefore wavelength). The spectrum is continuous, there are no sharp boundaries between the named regions.

$$c = f\lambda \qquad \Longrightarrow \qquad \lambda = \frac{c}{f}$$

Higher frequency corresponds to shorter wavelength and higher energy per photon.

Type	Typical wavelength	Typical frequency	Source	Uses	Hazards
Gamma ([Math: \gamma])	[Math: < 10^{-11}] m	[Math: > 10^{19}] Hz	Radioactive nuclei	Cancer treatment, sterilising medical instruments, food irradiation	Ionising, causes cancer, cell damage, genetic mutation

X-rays	[Math: 10^{-11}] to [Math: 10^{-8}] m	[Math: 10^{16}] to [Math: 10^{19}] Hz	High-voltage X-ray tubes	Medical imaging of bones, airport security scanners	Ionising, excess exposure damages cells
Ultraviolet (UV)	[Math: 10^{-8}] to [Math: 4 \times 10^{-7}] m	[Math: 10^{15}] to [Math: 10^{16}] Hz	Sun, UV lamps	Detecting forged banknotes, tanning, sterilisation	Causes sunburn, cataracts, skin cancer
Visible light	[Math: 4 \times 10^{-7}] to [Math: 7 \times 10^{-7}] m	[Math: 4 \times 10^{14}] to [Math: 7 \times 10^{14}] Hz	Luminous objects, the Sun	Sight, photography, optical fibres	Generally safe at normal intensities
Infrared (IR)	[Math: 7 \times 10^{-7}] to [Math: 10^{-3}] m	[Math: 10^{11}] to [Math: 4 \times 10^{14}] Hz	All warm objects, heat lamps	Remote controls, thermal imaging, cooking (microwave ovens use adjacent range), solar heaters	Skin burns at high intensities
Microwaves	[Math: 10^{-3}] to [Math: 0.1] m	[Math: 10^{9}] to [Math: 10^{11}] Hz	Microwave generators	Cooking, satellite communication, mobile phone networks, radar	Internal heating of body tissue
Radio waves	[Math: 0.1] m to [Math: 10^4] m	[Math: 10^4] to [Math: 10^9] Hz	Radio transmitters, oscillating currents	Radio and TV broadcasting, long-range communication	Generally safe

Memory aid for order (high frequency to low):

Gamma, **X**-ray, **U**ltraviolet, **V**isible, **I**nfrared, **M**icrowave, **R**adio

"**G**orillas e**X**cel **U**nder **V**ery **I**cy **M**ountain **R**anges"

Wavelength calculation (2016 Paper 02, Q4)

Visible light occupies wavelengths of approximately 4×10^{-7} m to 7×10^{-7} m.

A rattlesnake can detect EM radiation of frequency 3.5×10^{14} Hz. Calculate its wavelength.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^{8}}{3.5 \times 10^{14}} = \frac{3}{3.5} \times 10^{8-14} = 0.857 \times 10^{-6}\text{m} \approx 8.6 \times 10^{-7}\text{m}$$

Since 8.6×10^{-7} m is just beyond the red end of the visible range (7×10^{-7} m), this radiation is **infrared**, consistent with heat sensing in pit vipers.

Exam Tip

The order of the spectrum must be memorised. Know that gamma rays have the highest frequency and shortest wavelength; radio waves have the lowest frequency and longest wavelength.

When asked which region is most dangerous, the answer depends on context: gamma and X-rays are ionising and most hazardous for cell damage. UV causes skin cancer and sunburn. Infrared and microwaves can burn tissue but are non-ionising.

For wavelength calculations: use $\lambda = c/f$ with $c = 3 \times 10^{8}$ m s{. Always check your answer, visible light wavelengths are in the range 10^{-7} m, so a calculation giving a very different order of magnitude signals an error.