

Waves: energy that travels

Ripples on a pond, the sound of a voice, the light of a distant star – all are waves carrying energy from a source to an absorber. This reference covers **AQA GCSE Physics 8463, topic 4.6 Waves**.

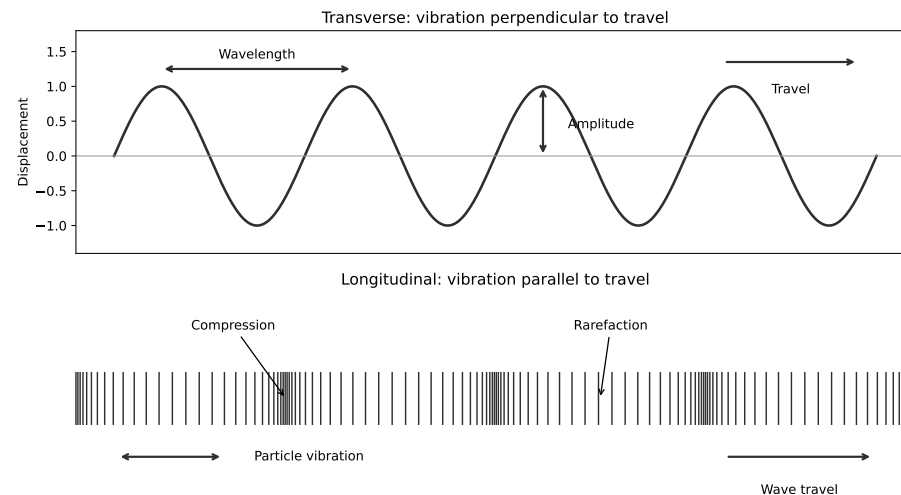
How the exam treats this topic:

- Paper 2 carries this topic. $T = 1/f$, $v = f\lambda$ and magnification may be supplied on the equation sheet; check the examination series.
- Reflection (RP9), sound, detection waves, lenses, visible light and black-body radiation are **physics only**; sound and detection are also **HT only**; parts of EM properties are **HT only**.
- Required practicals: RP8 (wave speed in a ripple tank and a solid) RP9 (reflection and refraction, physics only), and RP10 (infrared absorption and emission by surfaces).
- You must **construct ray diagrams** for reflection, refraction and lenses.

Transverse and longitudinal waves

Type	Vibration direction	Examples
transverse	across the travel direction	water ripples, all electromagnetic waves
longitudinal	along the travel direction	sound in air

Longitudinal waves show **compressions** (particles squashed) and **rarefactions** (particles spread).



Evidence that the wave travels, not the material: a ripple moves across a pond but particles oscillate about their equilibrium positions, with no net transport of the medium in this model. A floating ball bobs as ripples pass; air particles vibrate as sound passes.

Properties of waves and the wave equation

Quantity	Meaning	Unit
amplitude	maximum displacement from the undisturbed position	m
wavelength	distance from a point on one wave to the equivalent point on the next	m
frequency	number of waves passing a point each second	Hz
period	time for one wave	s

$$T = \frac{1}{f} \quad v = f\lambda$$

- Wave speed is the speed at which **energy is transferred** through the medium.
- Read amplitude and wavelength straight off a labelled diagram.

Worked example. A water wave has frequency 2.0 Hz and wavelength 0.35 m.

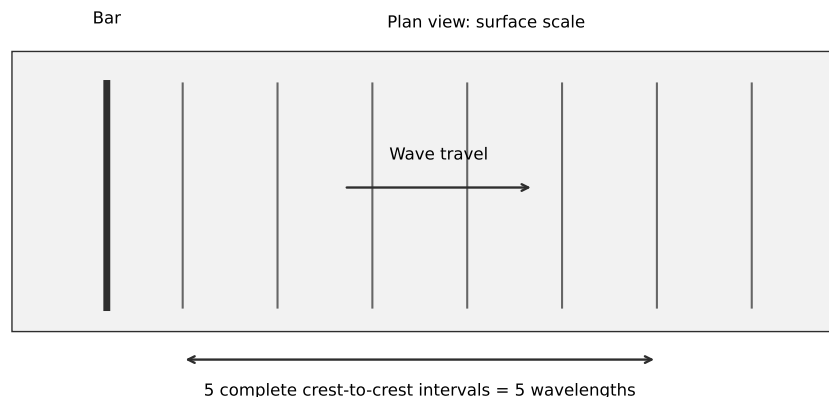
$$v = f\lambda = 2.0 \times 0.35 = 0.70 \text{ m/s}$$

Worked example (kHz). Sound of frequency 4.0 kHz travels at 330 m/s.

- Convert: $f = 4000 \text{ Hz}$.

$$\lambda = \frac{v}{f} = \frac{330}{4000} = 0.0825 \approx 8.3 \times 10^{-2} \text{ m}$$

■ Measuring wave speeds (RP8)



- **Ripples:** a straight-bar motor makes straight wavefronts. Measure the distance across several complete crest-to-crest intervals at the water surface using a calibrated scale, then divide by the number of intervals. If measuring a projected pattern, correct for its magnification. Time several complete cycles at a fixed point: $f = N/t$, then $v = f\lambda$. Keep water depth fixed and repeat.
- **Waves in a solid:** drive a stretched string with a signal generator. Adjust frequency to give clear stationary loops; each loop is half a wavelength. For n loops over length L , $\lambda = 2L/n$. Read f from the generator and calculate $v = f\lambda$; control tension and string type.
- **Speed of sound:** measure perpendicular distance d from a large wall. Time the interval t from a sharp sound to its echo; the sound travels $2d$, so $v = 2d/t$. Repeat and average; electronic recording reduces reaction-time error. Alternatively use two electronic detectors a measured distance apart for a one-way time.

(Physics only) Sound changing medium: at a stationary boundary with a stationary source, frequency stays the same. If speed changes, wavelength changes in the same ratio because $\lambda = v/f$.

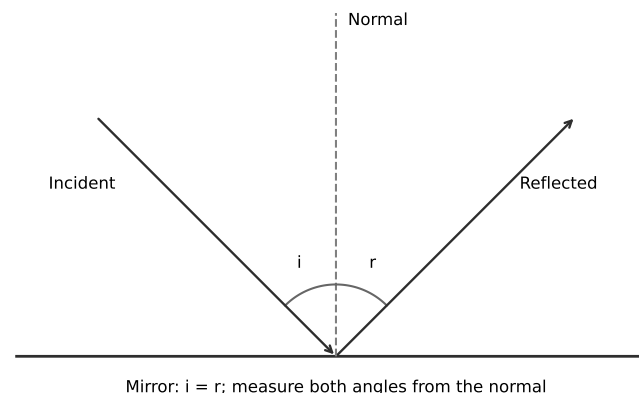
Reflection (physics only)

At a boundary parts of the incident energy may be **reflected**, **absorbed** and **transmitted**:

- **specular reflection** : from a smooth surface, one direction;
- **diffuse reflection** : from a rough surface, scattered;
- **absorption**: energy stays in the material; **transmission**: passes through.

Construct the reflection ray diagram: the **normal** at right angles to the surface at the point of incidence; the angle of incidence equals the angle of reflection – both measured

from the normal.



RP9: shine a ray box at plane mirror / rough surfaces; trace incident and reflected rays with a pencil, measure angles with a protractor; for refraction, pass light through a glass block and trace the bent path at each boundary.

Sound waves and hearing (physics only, HT)

Sound travels through solids as vibrations. In the ear, sound waves vibrate the ear drum and other parts – the vibrations are passed through ear structures and converted into signals that the brain interprets. This works only over a limited frequency range: **human hearing spans 20 Hz to 20 kHz**. Examples of conversion: a microphone's diaphragm, a drum skin, windows rattling near a bass speaker.

Waves for detection (physics only, HT)

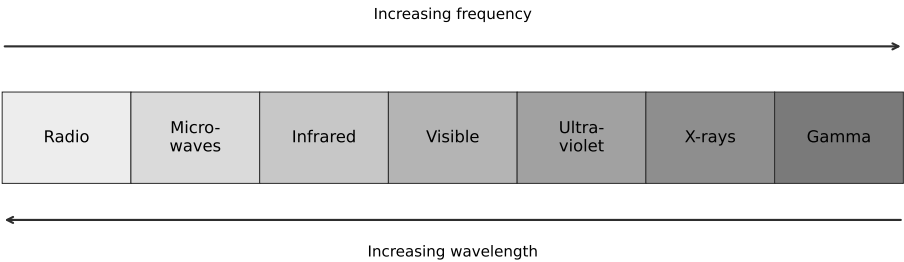
- **Ultrasound:** frequency above 20 kHz; **partially reflected at boundaries** between media; the echo time gives the distance to a boundary ($s = vt$, with the path often there-and-back). Uses: medical prenatal scanning (non-ionising, avoiding the ionisation risk of X-rays), industrial flaw detection.
- **Seismic waves:** earthquakes produce **P-waves (longitudinal)** and **S-waves (transverse)**, travelling at different speeds through the Earth; P-waves pass through liquids, S-waves do not – the shadow zones reveal the Earth's layered structure. **Echo sounding** with ultrasound/sound pulses maps seabeds.

Electromagnetic waves

All EM waves are **transverse**, transferring energy from source to absorber. They form a **continuous spectrum** and all travel at the **same speed in vacuum (approximately the same in air)** (3×10^8 m/s). From long to short wavelength:

radio → microwave → infrared → visible (red to violet) → ultraviolet → X-ray → gamma

Eyes detect only visible light – a tiny band.



Wave	Typical use	Why (HT)
radio	TV and radio	(HT) circuit oscillations produce radio waves; reception induces alternating currents of the same frequency
microwave	satellite TV, cooking	passes through the atmosphere; absorbed by water in food
infrared	heaters, night vision, remote controls	emitted by warm bodies; absorbed as heat
visible	vision, fibre optics, photography	detected by eyes and cameras
ultraviolet	fluorescence lamps, tanning, sterilising	energises chemicals;
X-ray	medical imaging of bones	penetrates flesh, absorbed by bone
gamma	sterilising medical equipment, cancer treatment	kills bacteria and cells

Hazards: UV ages skin prematurely and raises skin-cancer risk; **X-rays and gamma rays are ionising** – they can mutate genes and cause cancer. **Radiation dose** in sieverts measures the risk of harm (1000 mSv = 1 Sv; recall of the unit not required). Draw conclusions from dose data.

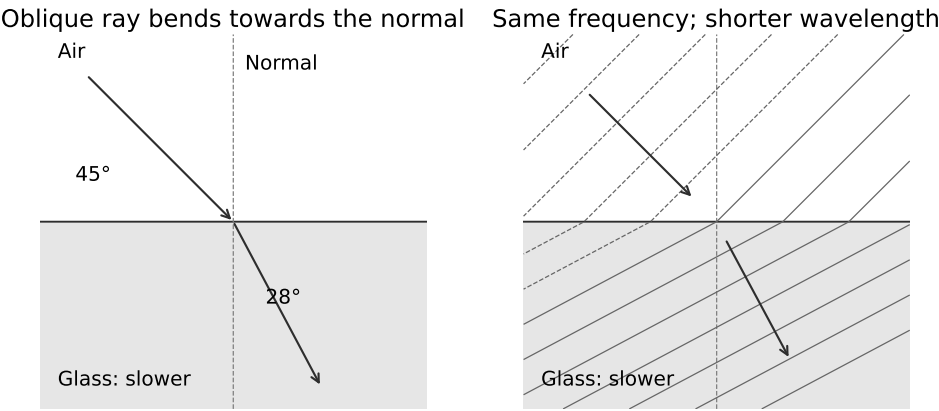
■ Infrared surfaces (RP10)

Compare infrared emission from different surfaces of a Leslie cube containing hot water. Use a non-contact infrared detector at the **same distance and angle** from each face; keep the water temperature as constant as possible, subtract the background reading where needed, repeat and compare mean readings. Avoid touching hot surfaces. Matt black and shiny metal surfaces differ in infrared emissivity; visible colour alone does not determine infrared emission.

To compare **absorption**, expose otherwise identical containers with different surfaces to the same infrared source. Keep source distance, exposure time, starting temperature, water mass and container material the same; record the temperature rise and repeat. A larger rise under these controls indicates greater absorption. The emission and absorption experiments measure different quantities; do not treat detector readings as temperatures.

(HT) Oscillations in an electrical circuit produce radio waves. Absorbed radio waves induce an alternating current of the **same frequency** in a receiving circuit. Changes in atomic nuclei can produce gamma radiation.

(HT) Substances absorb, transmit, refract or reflect EM waves **in ways that vary with wavelength**; refraction comes from the **change of speed** between substances. Show refraction on a ray diagram (bending towards the normal when slowing at oblique incidence; no direction change at normal incidence) and on **wavefront diagrams** (wavefronts closer together in the slower medium).

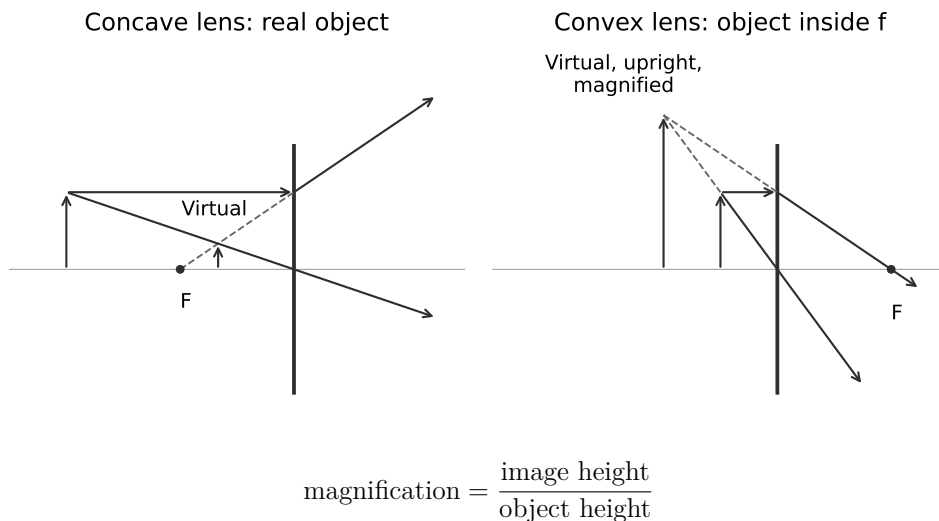
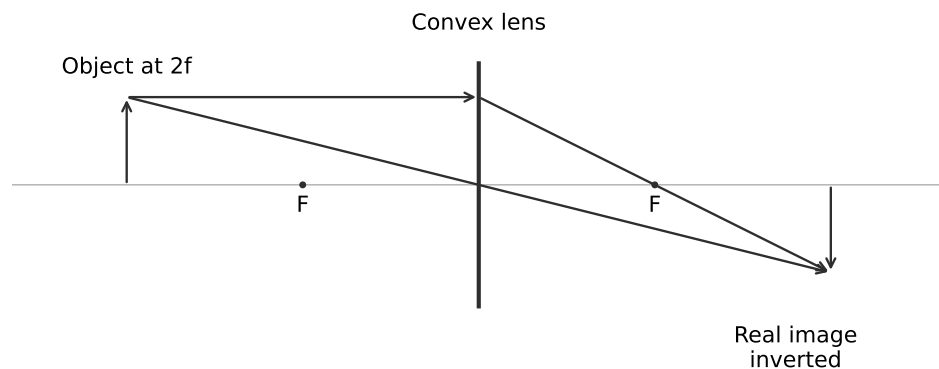


Lenses (physics only)

A lens forms an image by **refracting** light:

- **convex** : parallel rays converge at the **principal focus**; focal length = lens-to-focus distance; images real or virtual.
- **concave** : rays spread; for a real object, the image is **virtual, upright and diminished**.

Ray-diagram rules (two rays locate the image): a ray parallel to the axis refracts through the focus (convex) or appears to come from it (concave); a ray through the centre of the lens goes straight on.



- A ratio, **no units**; both heights in mm or both in cm.

Worked example. An object 5.0 mm high forms an image 20 mm high.

$$m = \frac{20}{5.0} = 4.0 \text{ (no unit)}$$

Visible light and colour (physics only)

Spectral colours correspond to ranges of wavelength (red longest, violet shortest in the visible band). Mixtures of wavelengths can also produce perceived colours.

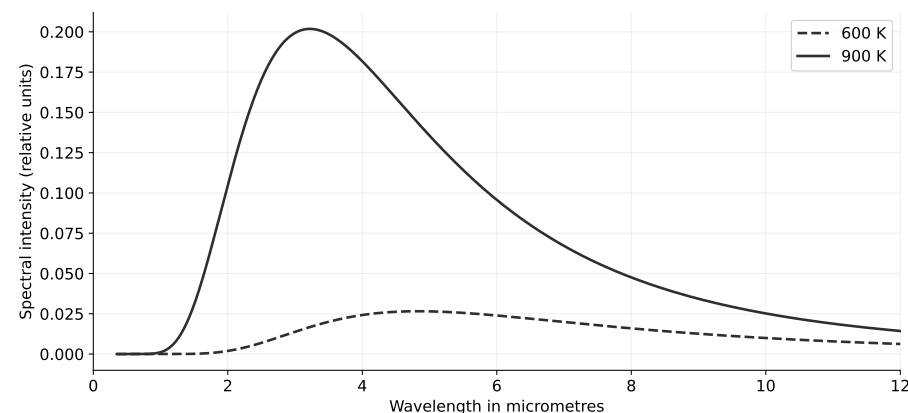
- **Filters** absorb some wavelengths and transmit others (a red filter transmits red).
- An **opaque** object's colour = the wavelengths it **strongly reflects**; the rest are absorbed. Under white illumination, a surface reflecting all visible wavelengths strongly appears white; one absorbing nearly all appears black. Predict coloured-light cases from the wavelengths actually present.
- **Transparent/translucent** objects transmit light.
- Specular vs diffuse reflection (from the reflection section) explains why a smooth red surface looks glossy but paper looks matt.

Black body radiation (physics only)

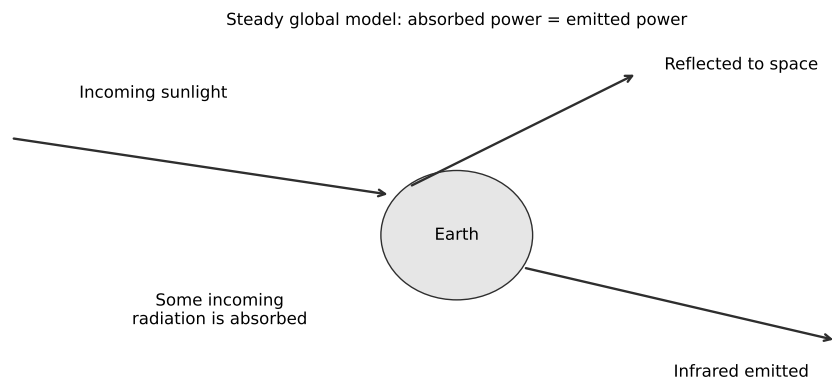
Bodies above absolute zero **emit thermal radiation** and can absorb infrared. At everyday temperatures much of their emission is infrared. The hotter the body, the more radiation it emits per second.

A **perfect black body** absorbs all incident radiation – no reflection, no transmission – and (good absorber = good emitter) is also the **best possible emitter**.

The **intensity and wavelength distribution** of the emitted radiation depend on the body's temperature: hotter → more intense, and the peak shifts to shorter wavelength.



(HT) In a model where radiation is the only net energy transfer, a body at constant temperature **absorbs at the same rate as it emits**. In real objects, also consider conduction and convection.



In the radiation-only model, absorbing faster than emitting $\rightarrow$ temperature rises.

The **Earth's temperature** depends on the balance of absorbed and emitted radiation and on reflection back to space – use it to explain warming and ice-albedo style examples, and read the standard diagram.

Checklist before you call this topic done

- Define amplitude, wavelength, frequency, period; use $T = 1/f$ and $v = f\lambda$ with prefixes.
- Describe RP8 in a ripple tank and on a string; describe a speed-of-sound method.
- (physics only) Draw reflection and refraction ray diagrams with the normal; RP9.
- Describe RP10 with controlled distance, temperature and exposure; distinguish emission from absorption.
- Recite the EM spectrum order; match uses and hazards with reasons; compare dose data.
- (physics only) Draw lens ray diagrams (convex/concave); magnification as a unitless ratio.
- (physics only) Explain colour by reflection, filters by transmission.
- (physics only) Black-body emission, absorption and the Earth's radiation balance (HT).