PCFGSTUDY

AQA GCSE Physics — Physics

Topic 6

Waves

Specification 8463 · AQA

Free edition

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These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes

Definitions

Diagrams

Notes and warnings

Sub-topic headings

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Define Transverse wave

- oscillations perpendicular to the direction of energy transfer.

Define Longitudinal wave

- oscillations parallel to the direction of energy transfer.

Define Compression

- region of a longitudinal wave where particles are pushed together.

Define Rarefaction

- region of a longitudinal wave where particles are spread apart.

Define Amplitude

- the maximum displacement of a point on a wave from its undisturbed position.

Define Wavelength

- the distance from a point on one wave to the equivalent point on the adjacent wave.

Define Frequency

- the number of waves passing a point each second, in hertz (Hz).

Define Period

- the time for one complete wave to pass a point, in seconds (s).

Define Wave speed

- the speed at which the energy is transferred (or the wave moves) through the medium.

Define Reflection

- a wave bouncing back at a boundary between two materials.

Define Specular reflection

- reflection from a smooth surface in a single direction.

Define Refraction

- a wave changing direction at a boundary because its velocity changes.

Define Diffuse reflection

- reflection from a rough surface, causing scattering.

Define Ultrasound

- sound of frequency above the upper limit of human hearing.

Define P-wave

- longitudinal seismic wave; travels through solids and liquids.

Define S-wave

- transverse seismic wave; cannot travel through a liquid.

Define Principal focus

- the point where a convex lens brings parallel rays to a focus.

Define Focal length

- the distance from the lens to the principal focus.

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Define Radiation dose

- a measure, in sieverts, of the risk of harm from exposure to radiation.

Define Perfect black body

- an object that absorbs all radiation incident on it, reflecting and transmitting none.

6.1 Waves in air, fluids and solids

6.1.1 Transverse and longitudinal waves

Waves may be either **transverse** or **longitudinal**. Both transfer energy from a source to an absorber.

	Transverse	Longitudinal
Oscillation	Perpendicular to energy transfer	Parallel to energy transfer
Features	Peaks and troughs	**Compressions** and **rarefactions**
Examples	Ripples on water, all electromagnetic waves, S-waves	Sound in air, P-waves

Evidence that the wave travels, not the medium

- A cork on a pond bobs **up and down** as ripples pass but is not carried to the far bank.
- A loudspeaker makes air particles vibrate about fixed positions. If the air itself travelled to your ear there would be a wind, and the room would empty of air.

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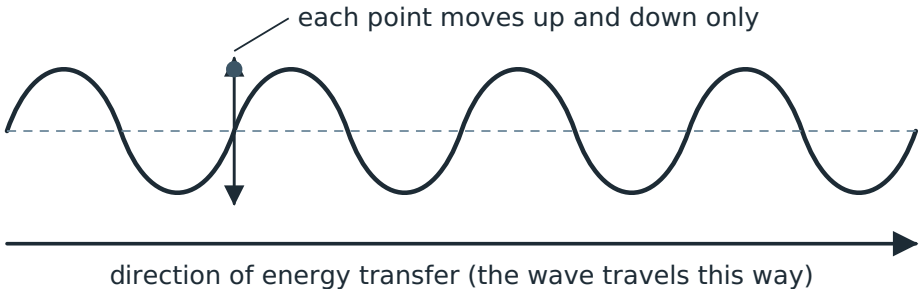
Transverse and longitudinal waves compared

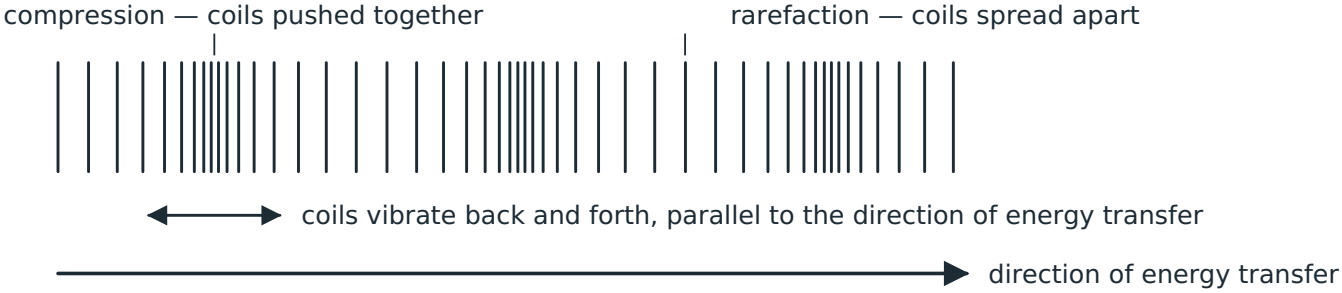
Transverse wave — a wave sent along a rope



The oscillations are at right angles (90°) to the direction of energy transfer.

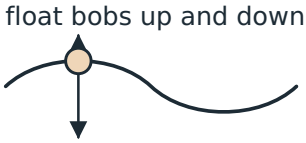
Examples: ripples on water, all electromagnetic waves, S-waves.

Longitudinal wave — a wave sent along a slinky spring



Examples: sound waves travelling through air, P-waves (seismic waves).

Waves transfer energy (and information) — they do not transfer matter



A float resting on water ripples, or a piece of paper in front of a loudspeaker, just oscillates about a fixed point — it is not carried along with the wave. This is evidence that it is the wave (the disturbance) that travels, and not the water or the air itself.

ANALOGY

Rope vs slinky. Flick a **rope** and a hump runs along it — your hand moves at right angles to the hump's travel: transverse. Push and pull a **slinky** and a squashed patch runs along it — your hand moves along the line the wave travels: longitudinal. Both end up where they started; only energy moves along.

WATCH OUT

"Waves carry the water or air along with them." Waves transfer **energy**, not **matter**. Particles of the medium oscillate about a fixed undisturbed position and stay there. Answer as "the wave transfers energy from the source to an absorber; the particles only vibrate".

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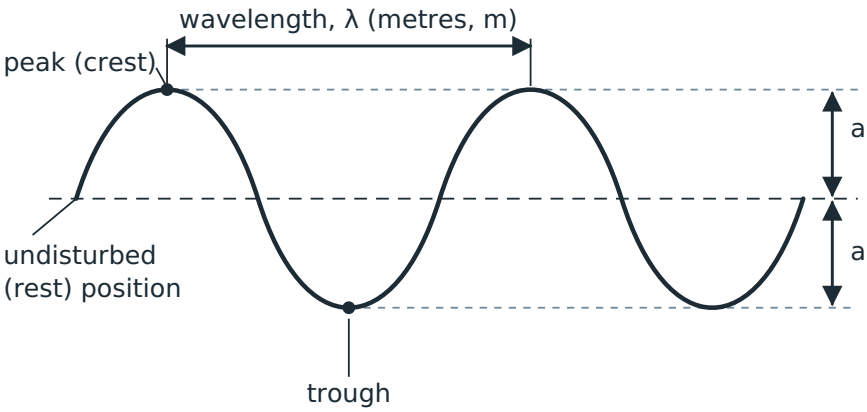
6.1.2 Properties of waves

- **Amplitude** is measured from the middle (undisturbed) line to a peak — **not** peak to trough.
- **Wavelength** (λ) is peak to peak, or compression to compression.
- **Wave speed** is the speed at which energy is transferred through the medium.
- You must identify amplitude and wavelength from given diagrams. On a displacement–distance graph the *x*-axis gives the wavelength; on a displacement–time graph one wave gives the **period**.

The parts of a wave: wavelength, amplitude, peak and trough

Parts of a wave



wavelength: the distance from a point on one wave to the equivalent point on the adjacent wave.

amplitude: the maximum displacement of a point away from the undisturbed position (not peak to trough).

The equations

wave speed = frequency × wavelength

v = f λ

wave speed, v, in metres per second, m/s
frequency, f, in hertz, Hz
wavelength, λ, in metres, m

period = 1 ÷ frequency

T = 1 / f

period, T, in seconds, s
frequency, f, in hertz, Hz
frequency = waves passing a point each second

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Measuring the speed of sound waves in air

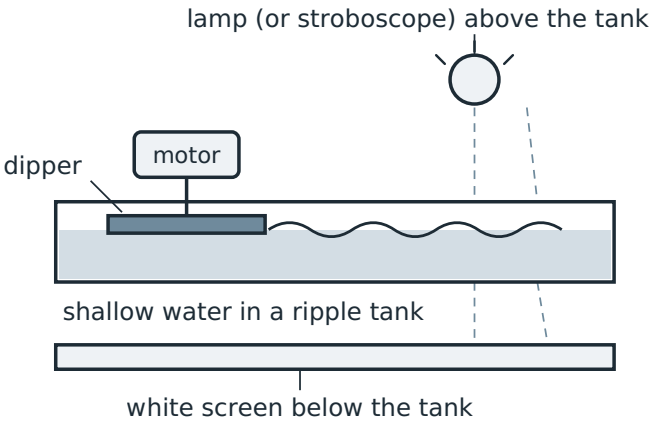
1. Connect two microphones a measured distance apart (about 1 m) to an oscilloscope.
2. Make a sharp sound beyond the first microphone; measure the **time delay** between the two traces.
3. speed = distance ÷ time delay. Repeat and mean (about 330–340 m/s).
4. Or clap a measured distance from a large wall and time 20 echoes; total distance = 2 × distance × 20.

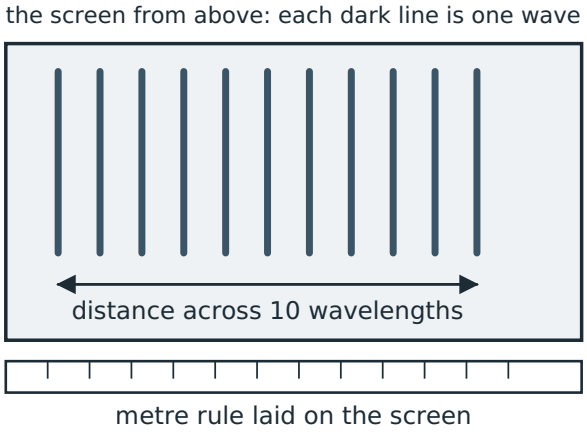
Measuring the speed of ripples on a water surface. Use a **ripple tank**, as in required practical 8.

PHYSICS ONLY Passing from one medium into another, the **frequency stays the same** (set by the source), so from $v = f\lambda$ a higher velocity means a proportionately longer wavelength.

Measuring frequency, wavelength and speed in a ripple tank

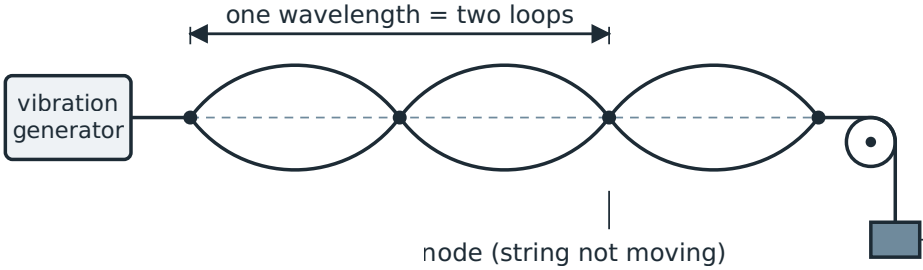
Required practical 8 — measuring waves in a ripple tank





Frequency f: count the waves passing a point in 10 s and divide by 10.
Wavelength λ: measure across 10 wavelengths with the metre rule and divide by 10.
Wave speed: v = f λ. A stroboscope freezes the pattern, making it easier to measure.

Waves in a solid — a stretched string



Read the frequency f from the signal generator driving the vibrator. Measure the loops with a metre rule: λ = 2 × one loop. Then v = f λ.

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6.1.3 Reflection of waves PHYSICS ONLY

PHYSICS ONLY At a boundary between two materials a wave can be:

- **reflected** — it bounces back into the first material;
- **transmitted** — it passes into the second material, usually refracting as it does;
- **absorbed** — its energy is transferred to the second material's energy stores, heating it.

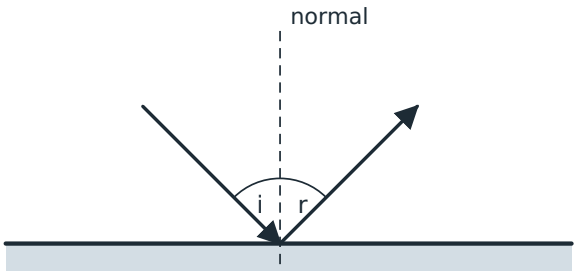
PHYSICS ONLY Which happens depends on the two materials and on the wavelength; usually all three occur at once.

PHYSICS ONLY **Ray diagrams for reflection.** Draw the surface and the **incident ray**; add the **normal** (dashed, at 90° to the surface where the ray strikes); draw the **reflected ray** on the other side of the normal with the angle of reflection **equal** to the angle of incidence, with arrows. Angles are always measured **from the normal**.

Specular and diffuse reflection, and refraction through a glass block

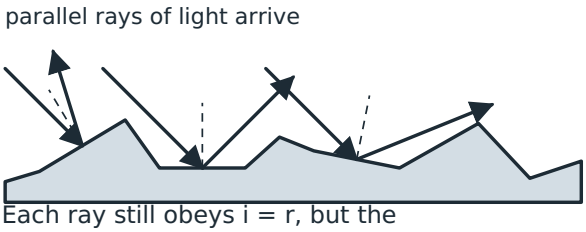
Physics only

Specular reflection — smooth surface



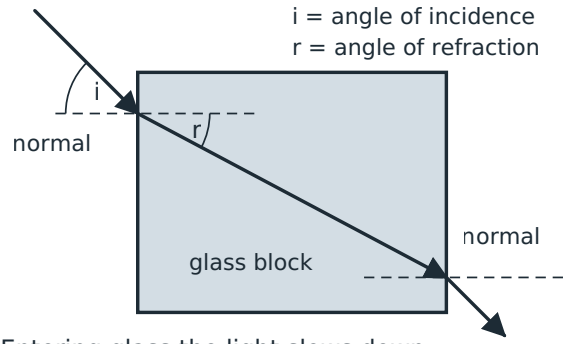
All the reflected rays travel in the same direction, so a clear image is formed.

Diffuse reflection — rough surface



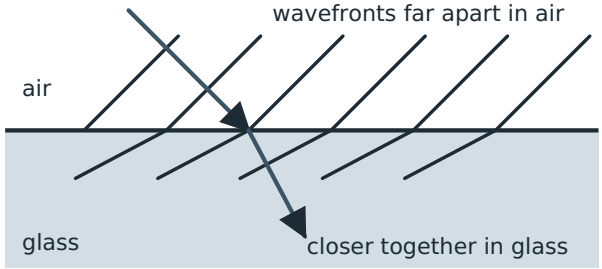
Each ray still obeys i = r, but the dashed normal points a different way at each point, so light is scattered.

Refraction through a glass block



Entering glass the light slows down and bends towards the normal. Leaving, it speeds up and bends away again.

Why it happens — wavefronts



The edge of each wavefront that reaches the glass first slows down, so the whole wave swings round and changes direction.

The normal is a construction line drawn at 90° to the surface, where the ray meets it.
i = angle of incidence; r = angle of reflection, or angle of refraction.

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6.1.4 Sound waves PHYSICS ONLY

HT ONLY

PHYSICS ONLY HT ONLY Sound waves can travel through **solids**, causing vibrations in the solid. Within the **ear**, sound waves cause the **ear drum** and other parts to vibrate, causing the sensation of sound.

PHYSICS ONLY HT ONLY This conversion only works over a **limited frequency range**, which restricts the limits of human hearing: normal human hearing runs from **20 Hz to 20 kHz**. Frequencies outside it do not make the parts of the ear vibrate efficiently, so are not heard.

PHYSICS ONLY HT ONLY Sound travels at **different speeds in different media** because the speed depends on how strongly the particles are coupled: in a solid they are close and strongly bonded, so a disturbance passes on quickly; in a gas they are far apart, so it travels slowly. Sound is fastest in solids, slowest in gases.

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6.1.5 Waves for detection and exploration PHYSICS ONLY

HT ONLY

PHYSICS ONLY HT ONLY Differences in **velocity, absorption and reflection** between different types of wave in solids and liquids let us detect and explore structures hidden from direct observation.

Ultrasound

- **Ultrasound waves** have a frequency higher than the upper limit of hearing for humans (above 20 kHz).
- They are **partially reflected** at a boundary between two different media; the **time taken** for the reflections to reach a detector gives the distance to that boundary.
- Used for **medical imaging** (pre-natal scans, soft tissue) and **industrial imaging** (cracks inside castings).

Echo sounding uses **high frequency sound waves** to detect objects in deep water and measure water depth.

Seismic waves

- Seismic waves are produced by **earthquakes**. **P-waves** are longitudinal and travel at different speeds through solids and liquids, passing through both; **S-waves** are transverse and **cannot travel through a liquid**.
- An **S-wave shadow zone** on the far side of the Earth, where no S-waves arrive, is evidence that part of the core is **liquid**. P-waves arrive but are **refracted** as their speed changes; the shadow zones give the **size of the core**.
- **P-waves and S-waves provide evidence for the structure and size of the Earth's core** — parts of the Earth that are **not directly observable**.

6.2 Electromagnetic waves

6.2.1 Types of electromagnetic waves

- Electromagnetic waves are **transverse** waves that transfer energy from the **source** of the waves to an **absorber**. They form a **continuous spectrum**, and all types travel at the same velocity through a vacuum (space) or air — 3×10^8 m/s.
- Grouped by **wavelength** and **frequency**, from **long to short wavelength** (**low to high frequency**): radio, microwave, infrared, visible light (red to violet), ultraviolet, X-rays, gamma rays.
- Our **eyes only detect visible light**, so we detect a limited range of electromagnetic waves.
- Energy transfer examples: a microwave oven heating food; sunlight warming a pavement; an aerial absorbing radio waves to produce a current.

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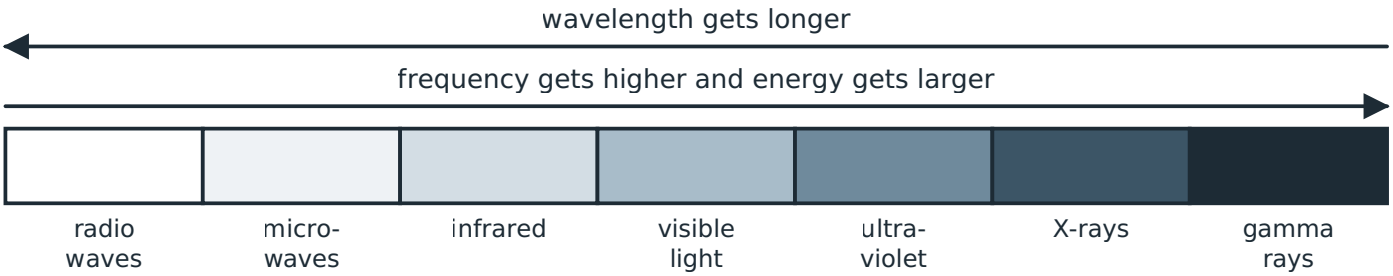
The electromagnetic spectrum, from radio waves to gamma rays



Group	One use	One hazard
radio waves	television and radio broadcasts	very large doses heat tissue
microwaves	satellite links, cooking food	internal heating of body tissue
infrared	electric heaters, infrared cameras	skin burns
visible light	fibre optic communications	retina damage if very bright
ultraviolet	energy efficient lamps, tanning	skin ages early; skin cancer
X-rays	medical imaging (X-ray photos)	ionising: mutation and cancer
gamma rays	sterilising food, treating cancer	ionising: mutation and cancer

All electromagnetic waves are transverse and transfer energy from a source to an absorber. They form a continuous spectrum and all travel at the same speed through a vacuum (space) or air. Visible light runs from red (longest wavelength) to violet (shortest); our eyes detect only this narrow band.

WATCH OUT

Getting the spectrum the wrong way round. Use **R**ich **M**en **I**n **V**egas **U**se e**X**pensive **G**old. In that order **wavelength decreases**, **frequency increases** and the **energy carried increases** — which is why the ionising ones (UV, X-rays, gamma) are at the gamma end. What does **not** change is the **speed**: in a vacuum every part travels at the same speed, so gamma rays are not "faster" than radio waves, only higher in frequency.

ANALOGY

A car driving onto sand. A car leaves the road onto soft sand at an angle: the wheel reaching the sand first slows while the other is still on tarmac, so the car **slews round**. Drive straight on (along the normal) and both wheels slow together, so it slows but carries straight on. Refraction happens for exactly that reason — the **change of speed**.

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6.2.2 Properties of electromagnetic waves 1

HT ONLY Different substances may **absorb, transmit, refract or reflect** electromagnetic waves in ways that **vary with wavelength** — glass transmits visible light but absorbs most ultraviolet.

HT ONLY Some effects, for example **refraction**, are due to the difference in velocity of the waves in different substances. When a wave meets a boundary at an angle, one side of the wavefront changes speed **before** the other, swinging it round so the direction of travel changes. Slowing down bends the ray **towards** the normal, speeding up bends it **away**; a wave arriving **along** the normal changes speed and wavelength but not direction.

Ray diagrams for refraction. Draw the boundary and the **normal** (dashed, at 90° to it), then the incident ray marking the **angle of incidence** from the normal, then the refracted ray bent towards or away from the normal as above.

HT ONLY On a **wavefront diagram**, draw wavefronts as parallel lines at right angles to the ray: in the slower medium they are **closer together** (shorter wavelength, frequency unchanged) and **tilted** relative to the first medium.

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6.2.3 Properties of electromagnetic waves 2

HT ONLY Radio waves can be produced by oscillations in electrical circuits. An alternating current in a transmitting aerial makes electrons oscillate, and these oscillating charges emit radio waves of the **same frequency** as the current.

HT ONLY The reverse also happens: when radio waves are **absorbed** they may create an alternating current with the same frequency as the radio wave itself, so radio waves can induce oscillations in an electrical circuit.

- Changes in **atoms and the nuclei of atoms** can generate or absorb electromagnetic waves over a wide frequency range; gamma rays originate from changes in the nucleus of an atom.
- Ultraviolet waves, X-rays and gamma rays can have hazardous effects on human body tissue, depending on the **type of radiation** and the **size of the dose**.
- **Radiation dose (in sieverts)** measures the **risk of harm** from exposure of the body to radiation; 1000 millisieverts (mSv) = 1 sievert (Sv). You need not recall this unit, but may be asked to draw conclusions from given data about the risks of exposure.
- **Ultraviolet** can cause skin to **age prematurely** and increases the risk of **skin cancer**. **X-rays and gamma rays** are **ionising radiation** that can cause the **mutation of genes** and **cancer**.

6.2.4 Uses and applications of electromagnetic waves

Part of spectrum	Use	Hazard
Radio waves	Television and radio	No significant hazard — lowest frequency and energy
Microwaves	Satellite communications; cooking food	Internal heating of body tissue
Infrared	Electrical heaters; cooking food; infrared cameras	Skin burns
Visible light	Fibre optic communications	Retinal damage if very intense
Ultraviolet	Energy efficient lamps; sun tanning	Premature skin ageing; skin cancer
X-rays	Medical imaging and treatments	Ionising: mutation of genes, cancer
Gamma rays	Medical imaging and treatments	Ionising: mutation of genes, cancer

NOTE

The specification only names hazards for **ultraviolet, X-rays and gamma rays**; the others are given for completeness and are not required.

6.2.5 Lenses PHYSICS ONLY

PHYSICS ONLY A **lens** forms an image by **refracting** light. In a **convex** lens, parallel rays are brought to a focus at the **principal focus**, a distance equal to the **focal length** from the lens.

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HT ONLY Why each type suits its application:

- **Radio** — barely absorbed by the atmosphere, so covers wide areas.
- **Microwaves** — pass **through** the atmosphere to satellites; oven wavelengths are absorbed by water in food.
- **Infrared** — strongly absorbed by surfaces, heating them; all warm objects emit it, so cameras detect heat.
- **Visible light** — weakly absorbed by glass fibres and reflects along them, so data is carried with little loss.
- **Ultraviolet** — makes fluorescent coatings glow, wasting less energy.
- **X-rays** — pass through flesh but are absorbed by bone, giving a shadow image; **gamma rays** penetrate the body and kill cancer cells.

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	Convex (converging)	Concave (diverging)
Shape	Thicker in the middle	Thinner in the middle
Parallel rays	Brought together at the principal focus	Spread out, appearing to come from the principal focus
Image	**Real or virtual**	**Always virtual**
Symbol	Line with **outward**-pointing arrowheads	Line with **inward**-pointing arrowheads

PHYSICS ONLY **Drawing the ray diagrams**

1. Draw the principal axis and lens symbol, marking **F** at the focal length on both sides; draw the object as an upright arrow.
2. **Ray 1:** from the top of the object, parallel to the axis, then through F (convex) or appearing to come from F (concave).
3. **Ray 2:** from the top of the object straight through the **centre** of the lens, undeviated.
4. The rays cross at the top of the image. A **real** image forms where rays actually meet: it can be projected and is inverted. A **virtual** image forms where rays only **appear** to come from, traced **back** as dashed lines: it cannot be projected and is upright.

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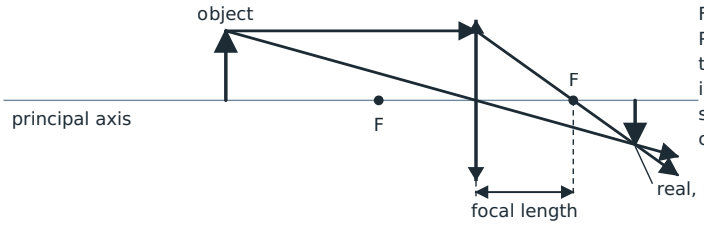
Ray diagrams for a convex lens and a concave lens

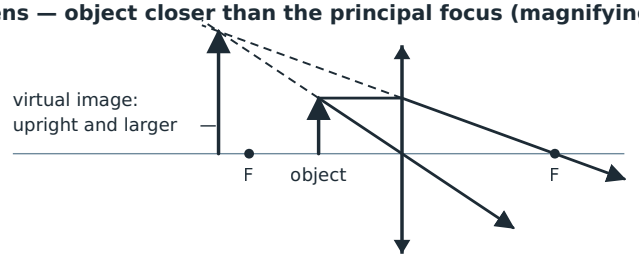
Physics only

Convex (converging) lens — object well beyond the principal focus



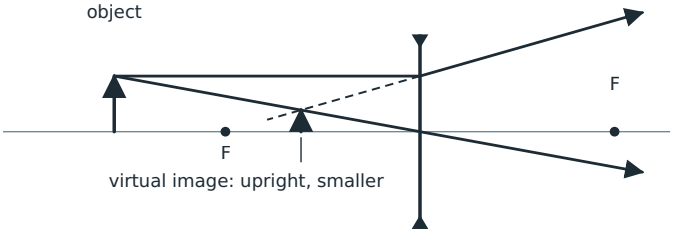
F = the principal focus. Parallel rays are brought to a focus at F. The image is real, inverted and smaller, and it can be caught on a screen.

Convex lens — object closer than the principal focus (magnifying glass)



The rays still spread out after the lens, so they only appear to come from the dashed lines. The image is virtual — it cannot be put on a screen.

Concave (diverging) lens — the image is always virtual



The lens spreads the rays out, so the image from a concave lens is always virtual, upright and smaller.

Magnification

magnification = image height ÷ object height

Magnification is a ratio, so it has no units. Measure both heights in the same unit (mm or cm).

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6.2.6 Visible light PHYSICS ONLY

PHYSICS ONLY Each **colour** in the visible light spectrum has its own **narrow band of wavelength and frequency** — red the longest wavelength and lowest frequency, violet the shortest and highest. Reflection from a **smooth** surface in a single direction is **specular reflection**; reflection from a **rough** surface causes scattering, called **diffuse reflection**.

PHYSICS ONLY The colour of an **opaque** object is determined by **which wavelengths are more strongly reflected**; the rest are absorbed. If **all** are reflected equally it appears **white**; if all are absorbed it appears **black**. A red jumper reflects red and absorbs the rest, so in pure blue light it looks black.

PHYSICS ONLY Objects that transmit light are either **transparent** (a clear image through them) or **translucent** (light passes but is scattered, blurring the image).

PHYSICS ONLY **Colour filters** work by absorbing certain wavelengths (and colour) and transmitting other wavelengths (and colour): a red filter transmits red and absorbs the rest, so white light comes out red. Red and blue filters together let almost nothing through.

6.3 Black body radiation PHYSICS ONLY

6.3.1 Emission and absorption of infrared radiation

PHYSICS ONLY All bodies (objects), no matter what temperature, emit and absorb infrared radiation, and the **hotter** the body the **more** infrared radiation it radiates in a given time.

PHYSICS ONLY A **perfect black body** absorbs **all** the radiation incident on it and does **not reflect or transmit** any. Since a good absorber is also a good emitter, a perfect black body would be the best possible emitter.

ANALOGY

Why black is best at both. Think of a surface as a doorway between the radiation outside and the energy stores inside. Matt black is a wide-open door: radiation walks straight in and nothing bounces off, so it is the best **absorber** — but an open door lets traffic both ways, so energy leaves as easily, making it the best **emitter** too. Shiny silver is a closed, mirrored door: poor at both.

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6.3.2 Perfect black bodies and radiation

PHYSICS ONLY **All bodies emit radiation**, whatever their temperature, and the **intensity** and **wavelength distribution** of the emission **depend on the temperature** of the body: as a body gets hotter it emits more radiation overall **and** the peak moves to **shorter wavelengths** — a heating element glows dull red, then orange, then white.

PHYSICS ONLY HT ONLY A body at **constant temperature** is absorbing radiation at the **same rate** as it is emitting radiation; its temperature **increases** when it absorbs faster than it emits, and falls when it emits faster. Tea cools because it emits more than it absorbs; a sunlit road warms because it absorbs more, until the rates balance.

PHYSICS ONLY HT ONLY **The temperature of the Earth** depends on many factors, including:

- the **rate of absorption** of radiation — mainly short-wavelength radiation from the Sun absorbed by the surface;
- the **rate of emission** of radiation — the Earth emits longer-wavelength **infrared** back towards space;
- the **reflection of radiation into space** by clouds, ice and light-coloured surfaces before it is absorbed.

PHYSICS ONLY HT ONLY The surface warms by day, when absorption exceeds emission, and cools at night;

the average temperature stays constant only while radiation absorbed equals radiation emitted. Atmospheric gases absorb some outgoing infrared and re-radiate part back to the surface, slowing energy loss, so if these gases increase the average temperature **rises** until balance is restored. More reflective ice or cloud lowers it.

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