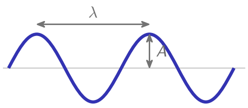
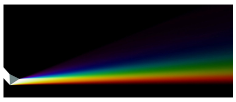
Waves

IGCSE Physics ▪ Topic 3

IGCSE Physics

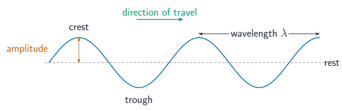


What we will cover



1 Wave properties

Describing a wave



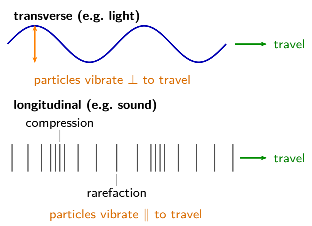
A **wave** 波 carries energy, not matter.

$v = f\lambda.$

Sound: $v = 340\,\mathrm{m/s},\ f = 170\,\mathrm{Hz}$

$\lambda = \frac{340}{170} = 2.0\,\mathrm{m}$

Two types; three behaviours



transverse ⊥, longitudinal ∥

- **transverse** 横波 – particles ⊥ travel (light, water)
- **longitudinal** 纵波 – particles ∥ travel (sound)

All waves reflect, refract and diffract. Speed $v = f\lambda$.

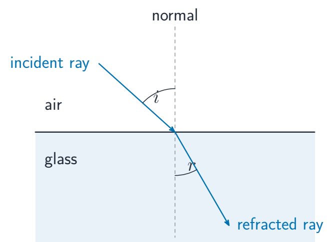
2 Light

Reflection

- angle of incidence = angle of reflection, from the **normal** 法线
- the incident ray, reflected ray and normal lie in one plane

> The **normal** 法线 is the line at 90° to the surface at the point of incidence.

Refraction



bends towards the normal $(i > r)$

Light bends as it changes speed.
Refractive index 折射率:

$$n = \frac{\sin i}{\sin r}.$$

$i = 60^\circ$, $r = 35^\circ$

$$n = \frac{0.87}{0.57} = 1.5$$

The words a refraction question uses

The two angles	The angle of incidence is measured in the first material, the **angle of refraction** 折射角 in the second – both from the *normal*.
Which way it bends	Into a denser material: slower, and bent *towards* the normal. Out into a less dense one: faster, and bent away.
Wave speed	The frequency never changes; it is the **wave speed** 波速 and the wavelength that do – and $v = f\lambda$ ties them together.
Propagation	Refraction is a change in the direction of **propagation** 传播, caused entirely by the change in speed.

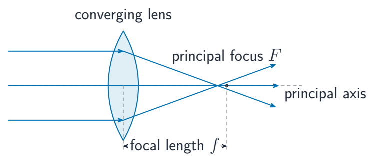
> Always measure from the normal, never from the surface. Half the lost marks in this topic are that one habit.

Total internal reflection

Light going from a denser medium towards a less dense one: if the angle of incidence is greater than the **critical angle** 临界角, it reflects entirely. Optical fibres use this to carry signals.

$$\sin c = \frac{1}{n}$$

Lenses and dispersion



converging lens *凸透镜: rays to the* ***focus*** *焦点*

Violet bends most, red least: red, orange, yellow, green, blue, indigo, violet.

Lenses: the words, and the two kinds of image

principal focus 主焦点	where rays parallel to the axis converge after passing through the lens
focal length 焦距	the distance from the lens to the principal focus
a real image 实像	the rays really meet – it can be caught on a screen, and it is inverted
a virtual image 虚像	formed when the object is closer than the focal length; the rays only appear to come from it, so no screen will show it
a magnifying glass 放大镜	a converging lens used exactly that way – upright, enlarged, virtual
a diverging lens 凹透镜	always gives a virtual, upright, diminished image

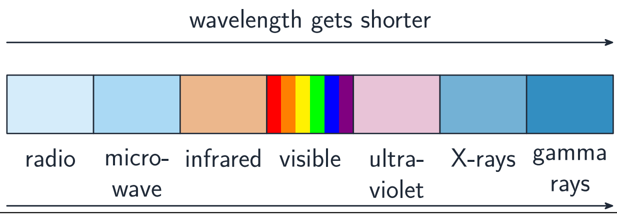
> "Can it be caught on a screen?" is the whole test. Real yes, virtual no – and that single question also settles whether the image is inverted.

3 EM spectrum and sound

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 微波	mobile phones, satellite TV, cooking – heating of body cells
infrared 红外线	remote controls, thermal imaging, grills – skin burns
visible light	seeing, optical fibres, photography
ultraviolet 紫外线	sterilising water, checking bank notes – skin cancer and eye damage
X-rays X 射线 and gamma 伽马射线	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** 伽马射线: 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** 单色的. 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.

Digital and analogue signals

Radio waves and microwaves carry information as signals, and a signal is either **analogue 模拟** or **digital 数字**.

- a **higher rate** of data transmission;
- a **greater range**: a weak digital signal can be **regenerated** back to a clean 1/0 exactly, because only two levels have to be told apart.

Why modern communication is digital

an analogue signal	varies continuously, so any added noise becomes part of the signal permanently
a digital signal	only two levels, high and low
reason one	digital signals can be regenerated: the receiver only has to decide high or low, so noise is removed at every repeater
reason two	more information can be sent per second along the same cable or channel
and	digital data can be processed, stored and encrypted by computer without further conversion

> Those two reasons are what the exam asks for by name. "It is more modern" earns nothing.

Sound

Sound is a **longitudinal** 纵波 wave of **compressions** 压缩 and **rarefactions** 稀疏.

- needs a **medium** 介质 – not a vacuum
- we hear 20 to 20 000 Hz

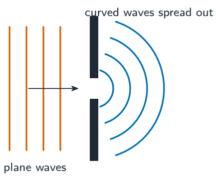
Echo: 85 m **wall,** 0.50 s

$$v = \frac{2 \times 85}{0.50} = 340\,\mathrm{m/s}$$

Lenses

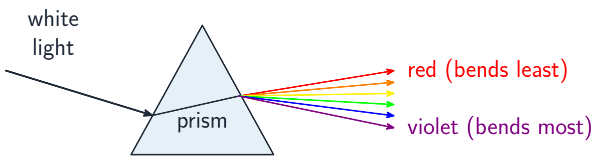
Held away from the eye, a converging lens forms a real image – here the houses behind it appear upside down

Wave behaviour



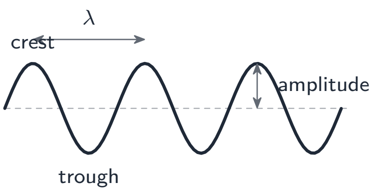
Plane waves passing through a narrow gap spread out into curved waves – diffraction is strongest when the gap is about one wavelength wide

Dispersion



A prism refracts violet light most and red light least, so white light spreads into a spectrum

Describing a wave, continued



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

The words a wave question uses

wavefront 波前	a line joining points on a wave that move together – for example, the top of one ripple
wavelength 波长 λ	the distance between two neighbouring wavefronts – one full wave
amplitude 振幅	the largest distance a point moves from its rest position
frequency 频率 f	waves passing a point per second, in hertz
period T	the time for one wave to pass – $T = 1/f$
the wave equation	$v = f\lambda$

Amplitude is measured from the rest position, not from trough to crest. Half the mistakes on this topic are that factor of two.

Sound 声音, continued

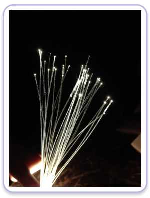
A microphone converts sound vibrations in air into an electrical signal

Loudness, pitch, and ultrasound

loudness 响度	a larger amplitude makes a louder sound
pitch 音调	a higher frequency makes a higher pitch – so a dolphin's click is high-pitched, not loud
human hearing	roughly 20 Hz to $20\,000$ Hz
ultrasound 超声波	sound above $20\,000$ Hz – too high for humans to hear
its uses rely on reflection	sonar measures depth; medical scanning images a fetus; industry finds cracks
the calculation	the pulse travels there and back, so the distance is $\frac{1}{2}vt$

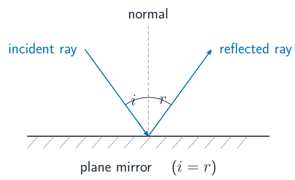
An echo at 85 m returning in 0.50 s gives $v = 2(85)/0.50 = 340$ m/s; a sonar pulse back in 0.10 s at 1500 m/s gives a depth of 75 m. Halve or double – but never forget the factor of two.

Refraction, continued



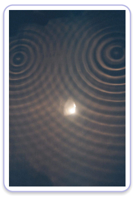
Total internal reflection keeps light bouncing along each fibre until it shines out at the tip

Reflection, continued



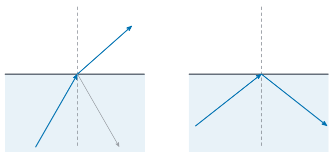
At a plane mirror the angle of incidence i equals the angle of reflection r, both measured from the normal

Wave behaviour, continued



Two dippers in a ripple tank make circular water waves that overlap – a quick way to study how waves behave

Refraction, continued (2)

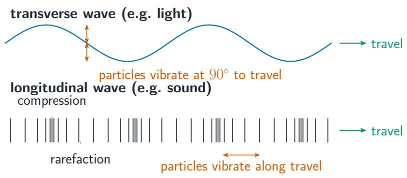


angle $<$ critical: light refracts out

angle $>$ critical: total internal reflection

Below the critical angle the light refracts out; above it the light is totally internally reflected

Two types of wave



> In a transverse wave the particles vibrate across the travel direction; in a longitudinal wave they vibrate along it, making compressions and rarefactions

Seeing refraction: the glass-block experiment

1. stand a rectangular glass block on paper; shine a narrow ray from a **ray box** 光线盒 into it
2. mark the ray going in and the ray coming out; remove the block; join the marks to draw the ray inside
3. draw the normal where the ray enters; measure i and r with a protractor
4. repeat with a semicircular block or a prism

> Entering glass the ray bends towards the normal; leaving it, away from the normal.

Waves on a rope (shake one end) and on a long spring (push one end) show the same wave motion as the ripple tank. The top of a wave is the crest, also called the **peak** 峰.

Describing an image, and correcting sight

Three pairs of words

- **enlarged** 放大的 / **diminished** 缩小的 (or same size)
- **upright** 正立 / **inverted** 倒立
- real / virtual

The **principal axis** 主光轴 is the line through the centre of the lens at right angles to it; the principal focus lies on it. Object far beyond F: diminished, inverted, real (a camera). Object inside F: enlarged, upright, virtual (a magnifying glass).

Correcting sight

- **short-sightedness** 近视: distant things blurred; the eye focuses in front of the **retina** 视网膜; a diverging lens spreads the rays first
- **long-sightedness** 远视: near things blurred; the eye focuses behind the retina; a converging lens brings the rays together first

Satellites, and measuring the speed of sound

Communication with satellites

- **artificial satellites** 人造卫星 are reached mainly by microwaves, which pass through the atmosphere
- some satellite phones use satellites in **low orbit** 低轨道
- other satellite phones and direct broadcast TV use **geostationary orbit** 地球静止轨道: the satellite stays above one point on the Earth
- sound can travel as an analogue or a digital signal

Speed of sound in air

1. two students a measured distance apart (say $500\,\mathrm{m}$)
2. one bangs two blocks together
3. the other starts a stopwatch on seeing the blocks hit and stops it on hearing the bang
4. speed = distance ÷ time; repeat and average

Echo method: clap a known distance from a wall, time the echo, remember the sound goes there and back.

Exam tips

- Learn $v = f\lambda$ and be ready to rearrange it. Measure all angles of incidence, reflection and refraction from the **normal** (the line at 90° to the surface), never from the surface itself.
- **Transverse** waves vibrate across the direction of travel (light, water); **longitudinal** waves vibrate along it (sound). Sound needs a **medium**, so it cannot cross a vacuum; light can.
- **Total internal reflection** happens only when light travels from a denser material to a less dense one *and* the angle inside is bigger than the **critical angle**.
- Know the **electromagnetic spectrum** in order – radio, microwave, infrared, visible, ultraviolet, X-ray, gamma. All travel at the same speed in a vacuum; frequency and energy rise from radio to gamma.
- Going into a denser material (air → glass) light slows down and bends *towards* the normal; leaving it (glass → air) light speeds up and bends *away*.

4 Recap

Topic 3 – key takeaways

1 Wave equation

$v = f\lambda$; transverse vs longitudinal

2 Light

reflection $i = r$; refraction $n = \sin i / \sin r$

3 TIR

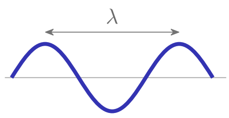
above the critical angle; optical fibres

4 Spectrum

radio → gamma: energy rises

Check yourself

1. A wave: $f = 50\,\mathrm{Hz}$, $\lambda = 4\,\mathrm{m}$ – find v.
2. Is sound transverse or longitudinal?
3. What happens above the critical angle?
4. Which travels faster in air: light or sound?



Answers **1.** $v = f\lambda = 200\,\mathrm{m/s}$ **2.** longitudinal **3.** total internal reflection **4.** light