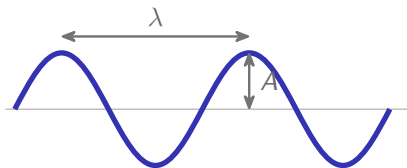


# Waves

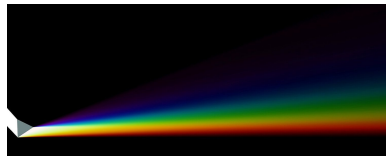
## IGCSE Physics ■ Topic 3

### IGCSE Physics



# What we will cover

- 1 Wave properties
- 2 Reflection & refraction
- 3 Lenses & dispersion
- 4 Electromagnetic spectrum
- 5 Sound
- 6 Recap

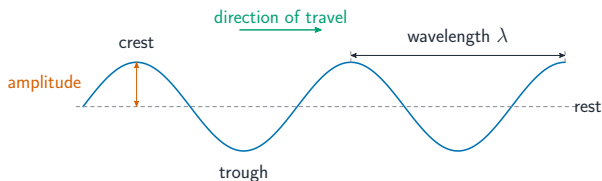


1

# Wave properties

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# Describing a wave



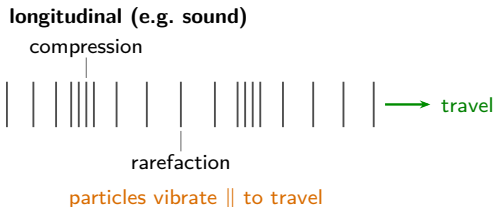
A **wave** 波 carries energy, not matter.

$$v = f\lambda.$$

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

$$\lambda = \frac{340}{170} = 2.0 \text{ m}$$

## Two types; three behaviours



*transverse  $\perp$ , longitudinal  $\parallel$*

- **transverse** 横波 – particles  $\perp$  travel (light, water)
- **longitudinal** 纵波 – particles  $\parallel$  travel (sound)

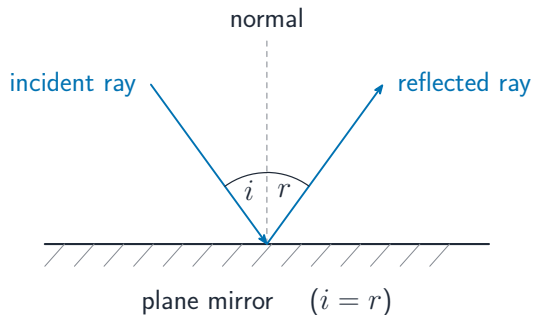
All waves **reflect**, **refract** and **diffract**. Speed  $v = f\lambda$ .

2

Light

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## Try it: measure from the mirror or the normal?



Schematic; do not measure this drawing.

An incident ray makes an angle of  $30^\circ$  with a plane mirror's **surface**.

Use the **normal** 法线 to find the angle of incidence  $i$  and angle of reflection  $r$ .

A student writes  $i = r = 30^\circ$ . Explain the mistake and describe how to draw the reflected ray.

## Construct the normal before using the law

The **normal** 法线 is perpendicular to the mirror at the point where the incident ray meets it. It makes  $90^\circ$  with the surface.

The given surface angle  $\theta = 30^\circ$  is not the angle of incidence:

$$i = 90^\circ - \theta = 90^\circ - 30^\circ = 60^\circ$$

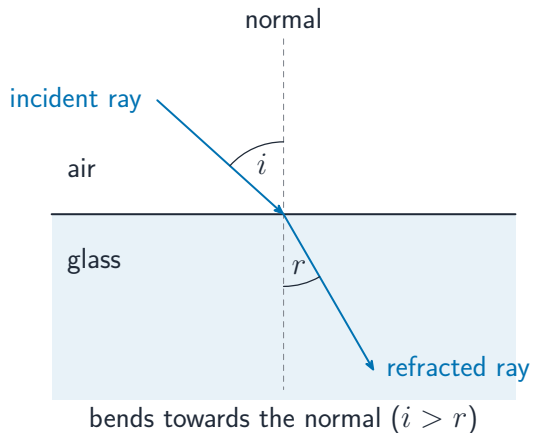
Reflection gives equal angles on opposite sides of the normal:

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

Draw the reflected ray away from the mirror at  $60^\circ$  to the normal. The incident ray, normal and reflected ray lie in one plane.

Measure  $i$  and  $r$  from the normal. The reflected ray makes  $30^\circ$  with the mirror surface, just like the incident ray.

# Refraction



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.

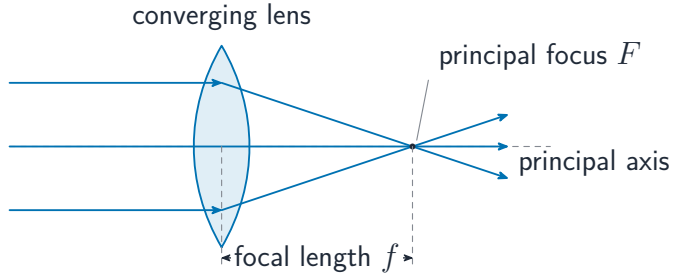
Always measure from the normal, never from the surface. Half the lost marks in this topic are that one habit.

# 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

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

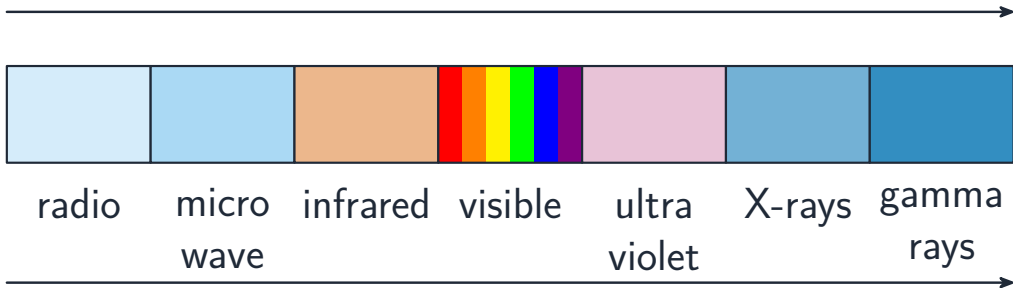
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# The electromagnetic spectrum

All travel at  $3.0 \times 10^8$  m/s in a vacuum.

Radio → gamma: frequency & energy **rise**, wavelength **falls**.

wavelength gets shorter



# The spectrum: one use and one danger each

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**radio waves**

broadcasting and communications – little known danger at normal intensity

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**microwaves** 微波

mobile phones, satellite TV, cooking – heating of body cells

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**infrared** 红外线

remote controls, thermal imaging, grills – skin burns

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**visible light**

seeing, optical fibres, photography

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**ultraviolet** 紫外线

sterilising water, checking bank notes – skin cancer and eye damage

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**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

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### 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.

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### Monochromatic

Light of a single frequency – one pure colour – is **monochromatic** 单色的. A laser is; a filament lamp is not.

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### One family

All of it travels at the same speed in a vacuum; only the wavelength and frequency change along the spectrum.

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Order the spectrum by wavelength once and the uses and dangers follow: shorter wavelength, higher energy, greater hazard.

## Try it: recover a message after noise

A microphone produces an **analogue** 模拟 signal that varies continuously. The sound can instead be encoded as **digital** 数字 data using two signal levels, 0 and 1.

In this simplified receiver, values below 0.5 are read as 0; values above 0.5 are read as 1. Received levels are:

0.12      0.86      0.73      0.19

Write the four recovered digits and the clean levels the receiver should send on.

If noise changes the third received level to 0.41, will the same rule still recover the original digit? Explain.

## Regeneration restores levels when decisions are correct

|                          |      |      |      |      |
|--------------------------|------|------|------|------|
| <b>Received level</b>    | 0.12 | 0.86 | 0.73 | 0.19 |
| <b>Decision</b>          | 0    | 1    | 1    | 0    |
| <b>Regenerated level</b> | 0    | 1    | 1    | 0    |

The receiver decides low or high, then sends a fresh signal at the clean level. Small variations are removed rather than passed along to the next stage.

But 0.41 is below the decision boundary: the receiver sends 0 instead of the original 1. Regeneration alone cannot identify that mistake.

Regeneration restores clean levels if each digit is read correctly. Excessive noise can cause a wrong digit.

# Explain the communication benefits

## Analogue

A level received as 0.73 could be a true 0.73, or another value changed by noise. There are **no two fixed levels** to restore – amplifying it also amplifies its noise.

## Digital

Repeaters **decide each digit** and resend clean levels: **increased range** without passing small disturbances on, provided the decisions stay correct. It can also support a **higher rate of data transmission** – the actual rate depends on equipment and channel.

**Check:** why is “a repeater makes every damaged message correct” an unsafe explanation?

# 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

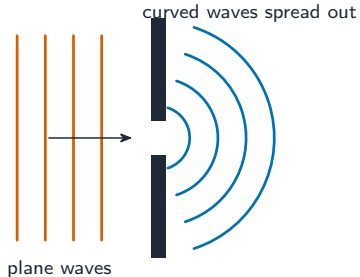
$$v = \frac{2 \times 85}{0.50} = 340 \text{ m/s}$$

# Lenses



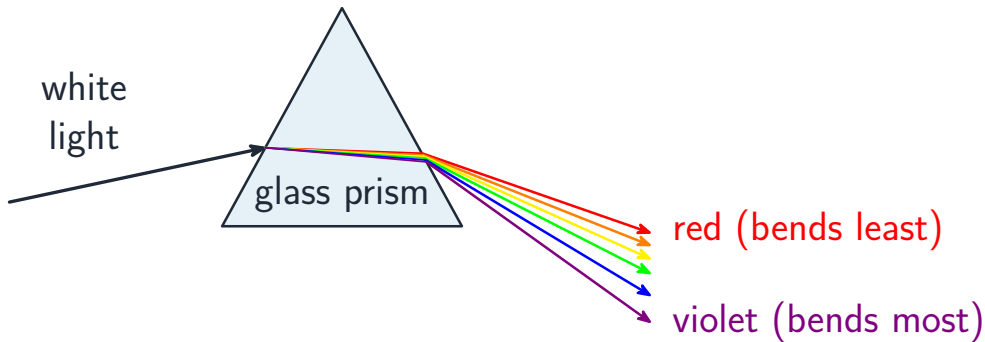
Held away from the eye, a converging lens forms a real image – here the houses behind it appear upside down

# Wave behaviour



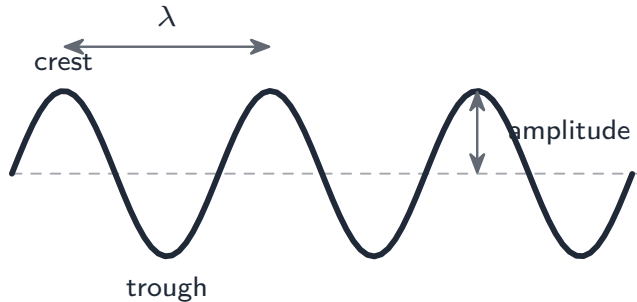
Plane waves passing through a narrow gap spread out into curved waves – diffraction is strongest when the gap is about one wavelength wide

# Dispersion



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

# Wavelength, amplitude, crest and trough



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

# The words a wave question uses

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

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

# A microphone turns sound into a signal



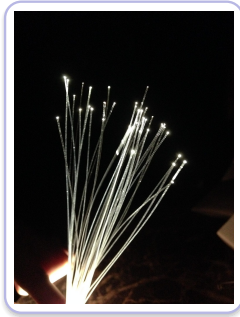
A microphone converts sound vibrations in air into an electrical signal

# Loudness, pitch, and ultrasound

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

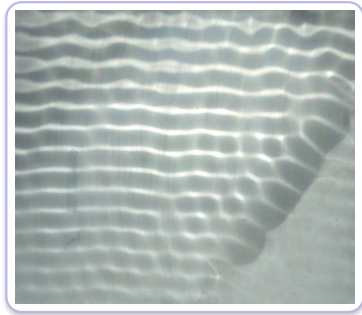
An echo at 85 m returning in 0.50 s gives  $v = 2(85)/0.50 = 340$  m/s; a sonar pulse back in 0.10 s at 1500 m/s gives a depth of 75 m. **Halve or double – but never forget the factor of two.**

# Total internal reflection in optical fibres



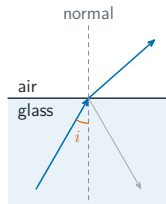
Total internal reflection keeps light bouncing along each fibre until it shines out at the tip

## Waves in a ripple tank

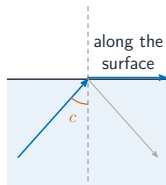


Two dippers in a ripple tank make circular water waves that overlap – a quick way to study how waves behave

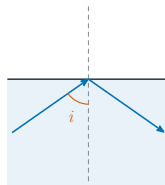
## Refraction, continued (2)



(a)  $i < c$ :  
light refracts out



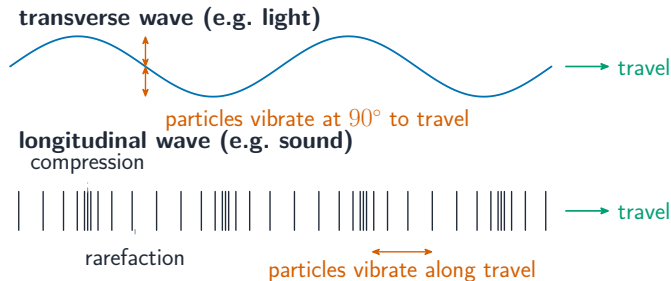
(b)  $i = c$ , the critical  
angle:  $\sin c = 1/n$



(c)  $i > c$ : total  
internal reflection

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

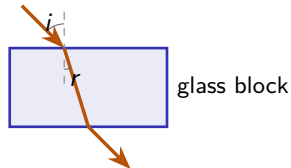
## Two types of wave



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 or a long spring show the same motion as the ripple tank; a wave's top is the crest, or **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

|                                | <b>blurred / focus</b>                                      | <b>correcting lens</b>                            |
|--------------------------------|-------------------------------------------------------------|---------------------------------------------------|
| <b>short-sightedness</b><br>近视 | distant things;<br><b>in front of</b> the <b>retina</b> 视网膜 | <b>diverging</b> :<br>spreads the rays first      |
| <b>long-sightedness</b><br>远视  | near things;<br><b>behind</b> the retina                    | <b>converging</b> :<br>brings 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 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 repeat and average

$$v = \frac{d}{t} \text{ direct} \qquad v = \frac{2d}{t} \text{ echo}$$

speed of sound 声速

## 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  $90^\circ$  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  $\rightarrow$  glass) light slows down and bends *towards* the normal; leaving it (glass  $\rightarrow$  air) light speeds up and bends *away*.

4

Recap

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## 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

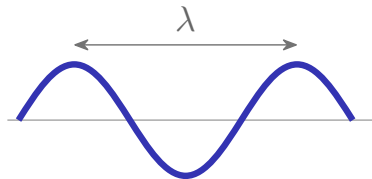
4

### Spectrum

radio  $\rightarrow$  gamma: energy rises

## Check yourself

- 1 A wave:  $f = 50 \text{ Hz}$ ,  $\lambda = 4 \text{ m}$  – 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.  $v = f\lambda = 200 \text{ m/s}$  2. longitudinal 3. total internal reflection 4. light