

Waves

IGCSE Physics 0625 · Unit 3 revision notes

How waves carry energy without matter: wave properties, reflection, refraction, lenses, the electromagnetic spectrum and sound.

37 definitions to learn word for word, 10 equations in their own column, 21 diagrams and graphs. Read it, cover it, test yourself.

1. 3.1a Describing waves
2. 3.1b Reflection, refraction and diffraction of waves
3. 3.2a Reflection of light
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8. 3.3a The electromagnetic spectrum
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10. 3.4a Sound waves
11. 3.4b Speed of sound, echoes and ultrasound

Definitions (mark-scheme wording) Equations Exam traps Extended = Extended tier only

3.1a Describing waves

Definitions

Wavelength (λ): the distance between a point on one wave and the equivalent point on the next wave (e.g. crest to crest).

Amplitude: the maximum displacement of a point on the wave from its rest (undisturbed) position.

Frequency (f): the number of complete waves passing a point per second.

Wave speed: the distance travelled by a wavefront per unit time.

Wavefront: a line joining points on a wave that are in step, e.g. along a crest.

Transverse wave: a wave in which the vibrations are perpendicular to the direction of energy transfer.

Longitudinal wave: a wave in which the vibrations are parallel to the direction of energy transfer.

Equations

$$v = f\lambda$$

wave speed = frequency $\times$ wavelength
m/s

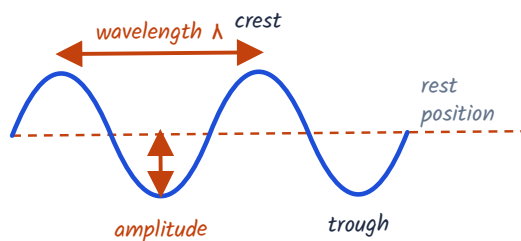
$$f = 1 / T$$

Beyond the syllabus: frequency = 1 / time for one wave (period)

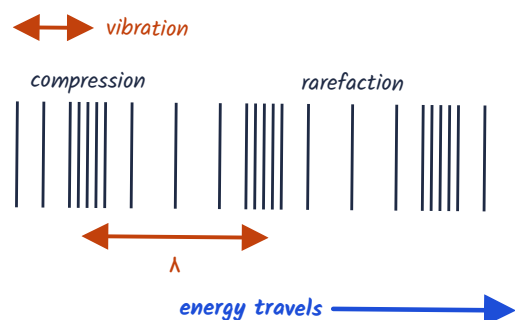
Hz

Key points

- ✓ Waves transfer **energy without transferring matter**; the medium only vibrates about a fixed position.
- ✓ Demonstrate with ropes, slinky springs and a **ripple tank**.
- ✓ Highest point = **crest** (peak); lowest point = **trough**.
- ✓ **Transverse** examples: all electromagnetic waves, water ripples, seismic S-waves.
- ✓ **Longitudinal** examples: sound, seismic P-waves.
- ✓ Frequency is set by the **source**; it does not change when the wave enters a new medium.



Transverse wave: wavelength is crest to crest; amplitude is from the rest position to a crest or trough.



Longitudinal wave: particles vibrate along the direction of travel, making compressions and rarefactions; λ is compression to compression.

Watch out!

- ! Amplitude is rest position to crest, **not** crest to trough (that is twice the amplitude).
- ! Wavelength must be measured between **equivalent points**: crest to crest, not crest to trough.

3.1b Reflection, refraction and diffraction of waves

Definitions

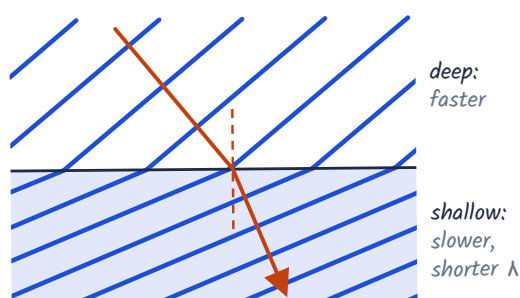
Reflection: the change in direction of a wave when it bounces off a surface.

Refraction: the change in direction of a wave when it changes speed on passing from one medium into another.

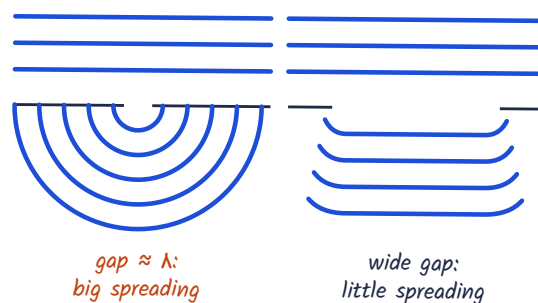
Diffraction: the spreading out of a wave as it passes through a gap or around the edge of an obstacle.

Key points

- ✓ Ripple tank: **reflection** at a straight barrier; **refraction** where the water gets shallower; **diffraction** through a gap and at an edge.
- ✓ Waves **slow down in shallow water**: wavelength gets shorter and the wavefronts change direction.
- ✓ In refraction, **frequency stays the same**; speed and wavelength change together.
- ✓ In reflection and diffraction the speed, frequency and wavelength are all **unchanged**.
- ✓ **Extended** diffraction is greatest when the **gap width is similar to the wavelength**; a wide gap gives little spreading.
- ✓ **Extended** at an edge, a **longer wavelength** diffracts (bends round) more.
- ✓ **Extended** sound (λ about 1 m) diffracts round doorways; light (λ below 1 μm) does not noticeably.



Refraction in a ripple tank: in shallow water the waves slow down, so the wavefronts are closer together and bend towards the normal.



Extended: diffraction. A gap about one wavelength wide spreads the waves into semicircles; a wide gap lets them through almost straight.

Watch out!

- ! Diffraction does **not** change the wavelength; draw the spread wavefronts with the same spacing.
- ! Refraction does not change the **frequency**; only speed and wavelength change.

3.2a Reflection of light

Definitions

Normal: a line at 90° to the surface at the point where the ray meets it.

Angle of incidence: the angle between the incident ray and the normal.

Angle of reflection: the angle between the reflected ray and the normal.

Law of reflection: the angle of incidence equals the angle of reflection.

Virtual image: an image that cannot be formed on a screen; the rays only appear to come from it.

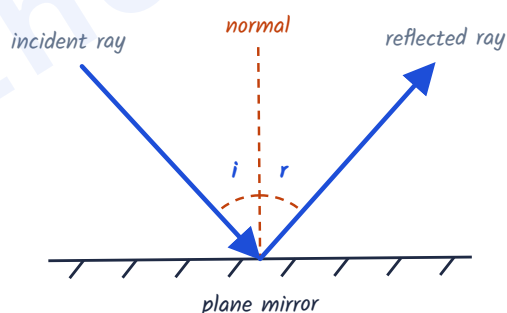
Equations

$$i = r$$

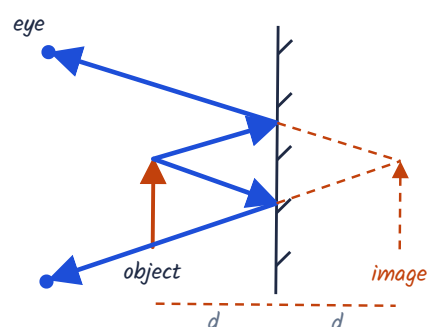
angle of incidence = angle of reflection

Key points

- ✓ Plane-mirror image: **same size, upright, virtual**, laterally inverted (left-right swapped).
- ✓ The image is **as far behind** the mirror as the object is in front.
- ✓ Experiment: ray box, plane mirror and protractor; mark the rays, draw the normal, measure i and r .
- ✓ **Extended** to locate an image, extend reflected rays **backwards** behind the mirror (dashed) until they meet.
- ✓ **Extended** use $i = r$ to draw accurate ray diagrams and calculate angles.



Law of reflection: $i = r$, both measured from the normal, never from the mirror surface.



Extended: the image is found where the reflected rays, traced back (dashed), meet: as far behind the mirror as the object is in front.

Watch out!

- ! Angles are measured from the **normal**; a ray at 30° to the mirror has $i = 60^\circ$.
- ! A plane-mirror image is **virtual**; it cannot be caught on a screen.

3.2b Refraction of light

Definitions

Refraction of light: the change in direction of light as it passes from one medium into another, caused by a change in speed.

Angle of refraction: the angle between the refracted ray and the normal.

Refractive index (n): Extended the ratio of the speeds of a wave in two different regions (e.g. speed of light in air / speed in glass).

Equations

$$n = \sin i / \sin r$$

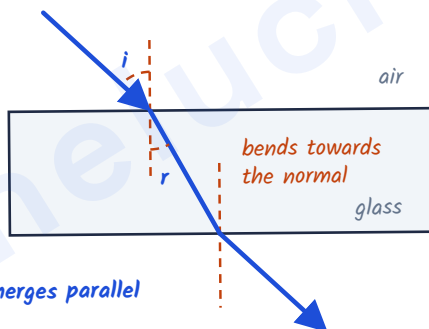
Extended refractive index from the angles (i in air)
no unit

$$n = c / v$$

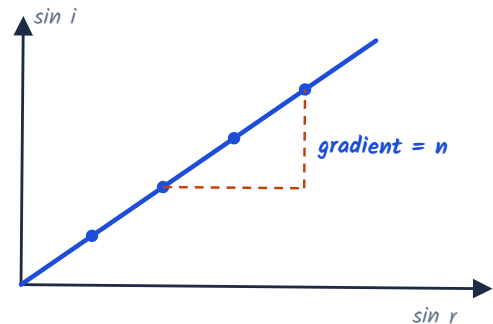
Extended speed of light in vacuum / speed in the medium
no unit

Key points

- ✓ Into a denser medium (air to glass) light **slows down** and bends **towards the normal**.
- ✓ Out of a denser medium it **speeds up** and bends **away from the normal**.
- ✓ A ray along the normal ($i = 0$) passes straight through, but still changes speed.
- ✓ Frequency is unchanged; the **wavelength is shorter** in glass.
- ✓ Experiment: ray box and rectangular glass block; trace rays, draw normals, measure i and r ; repeat with **semicircular and triangular** blocks.
- ✓ Through a parallel-sided block the emerging ray is **parallel** to the incident ray (shifted sideways).
- ✓ Extended plot $\sin i$ against $\sin r$; the gradient of the straight line is n .



Rectangular glass block: bends towards the normal on entry, away on exit; the emerging ray is parallel to the incident ray.



Extended: $\sin i$ against $\sin r$ gives a straight line through the origin; gradient = refractive index n .

Watch out!

- ! Extended: in $n = \sin i / \sin r$, i is the angle in **air** (the less dense medium).
- ! Speed changes at the boundary even when the ray does not bend ($i = 0$).

3.2c Total internal reflection and optical fibres

Definitions

Critical angle (c): the angle of incidence in the denser medium for which the angle of refraction is 90° .

Total internal reflection: the complete reflection of light at a boundary when the angle of incidence in the denser medium is greater than the critical angle.

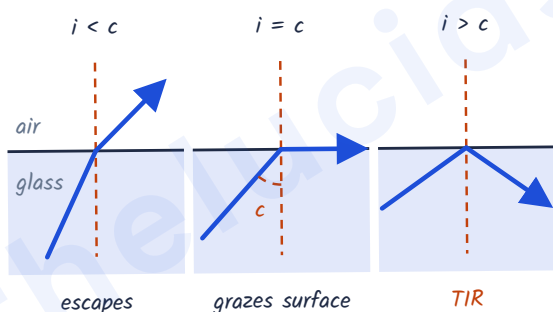
Equations

$$n = 1 / \sin c$$

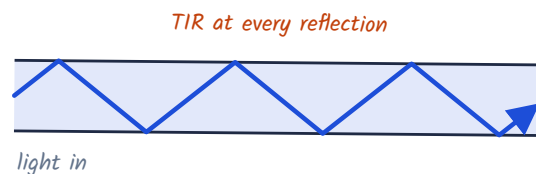
Extended refractive index from the critical angle
no unit

Key points

- ✓ TIR needs light travelling from a **denser to a less dense** medium (glass to air) **and** $i > c$.
- ✓ At $i = c$ the refracted ray **grazes along the surface** (angle of refraction 90°).
- ✓ Critical angle of glass is about **42°** .
- ✓ Below c the light mostly refracts out, but some is **internally reflected** (a weak partial reflection).
- ✓ Experiment: aim a ray at the centre of the flat face of a **semicircular block** through its curved side; increase i until TIR.
- ✓ Optical fibres carry light by **repeated TIR**.
- ✓ **Extended** optical fibres are used in **telecommunications** (internet, phone, cable TV) and medical **endoscopes**.
- ✓ 45° glass prisms use TIR in periscopes and bicycle reflectors.
- ✓ **Extended** a higher refractive index gives a **smaller** critical angle.



Glass to air: below c the ray escapes; at c it grazes the surface; above c it is totally internally reflected.



uses: communications, endoscopes

Optical fibre: light hits the wall at more than the critical angle every time, so it is totally internally reflected all the way along.

Watch out!

- ! TIR cannot happen going **into** a denser medium (air to glass).
- ! c is measured from the **normal** inside the glass, like every other angle.

3.2d Thin lenses

Definitions

Principal axis: the line through the centre of the lens at right angles to it.

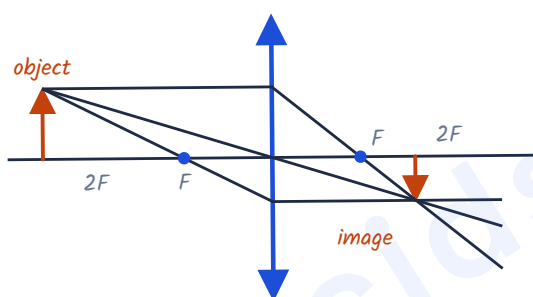
Principal focus (F): the point where rays parallel to the principal axis meet after passing through a converging lens (or appear to come from, for a diverging lens).

Focal length (f): the distance from the centre of the lens to the principal focus.

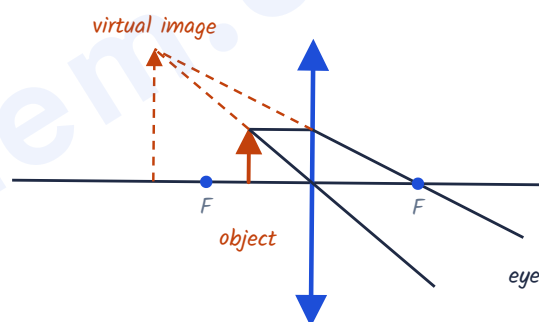
Real image: an image formed where rays actually meet; it can be shown on a screen.

Key points

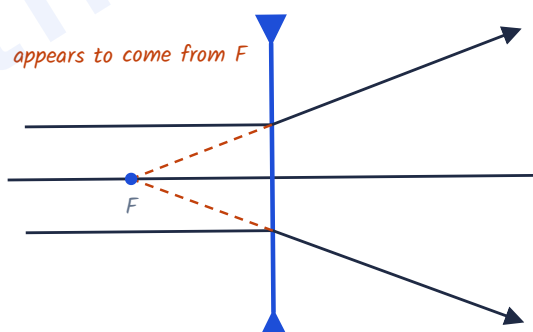
- ✓ **Converging** (convex) lens brings parallel rays to F; **diverging** (concave) lens spreads them out.
- ✓ Ray rules: parallel to the axis → through F; through the **centre** → straight on; through F → parallel.
- ✓ Object beyond 2F: image **real, inverted, diminished** (camera, eye).
- ✓ Object between F and 2F: image **real, inverted, enlarged** (projector).
- ✓ Describe an image by **size, way up, and real or virtual**.
- ✓ **Extended** object closer than F: image **virtual, upright, enlarged**; the lens is a **magnifying glass**.
- ✓ **Extended** short sight is corrected with a **diverging** lens; long sight with a **converging** lens.



Converging lens, object beyond 2F: the three rays meet to form a real, inverted, diminished image.



Extended: magnifying glass. Object inside F; the rays diverge, and traced back (dashed) they give a virtual, upright, enlarged image.



Diverging lens: parallel rays spread out as if they came from the principal focus F on the same side.

Watch out!

- ! Extended: a converging lens can give a virtual image too, when the object is **inside F**.
- ! Draw rays with a ruler and stop them at the lens line, not at the curved surface.

3.2e Dispersion of light

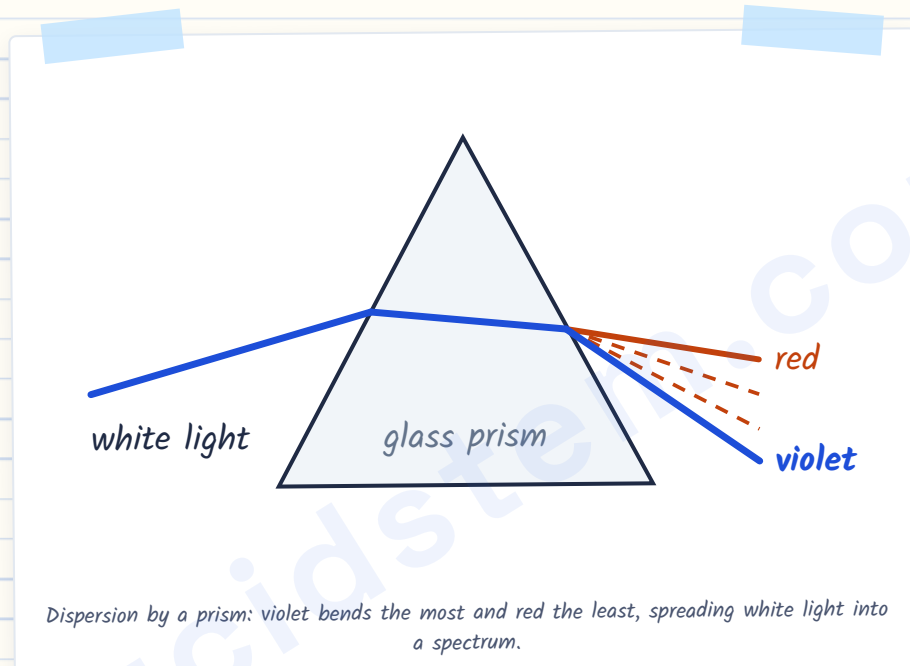
Definitions

Dispersion: the splitting of white light into its colours because each colour is refracted by a different amount.

Monochromatic light: **Extended** light of a single frequency (one colour).

Key points

- ✓ White light is a **mixture of colours**; a glass prism separates them into a spectrum.
- ✓ Order: **red, orange, yellow, green, blue, indigo, violet**.
- ✓ Red to violet: frequency increases, wavelength decreases.
- ✓ **Violet is refracted most** (slowed most in glass); red is refracted least.



Watch out!

! The prism does not add colour; it only **separates** colours already in white light.

3.3a The electromagnetic spectrum

Definitions

Electromagnetic wave: a transverse wave that can travel through a vacuum; all electromagnetic waves travel at the same high speed in a vacuum.

Electromagnetic spectrum: the family of electromagnetic waves arranged in order of frequency (or wavelength).

Key points

- ✓ Order of **increasing frequency** (decreasing wavelength): radio, microwaves, infrared, visible, ultraviolet, X-rays, gamma.
- ✓ All EM waves are **transverse**, transfer energy, and travel at the **same speed** in a vacuum.

Equations

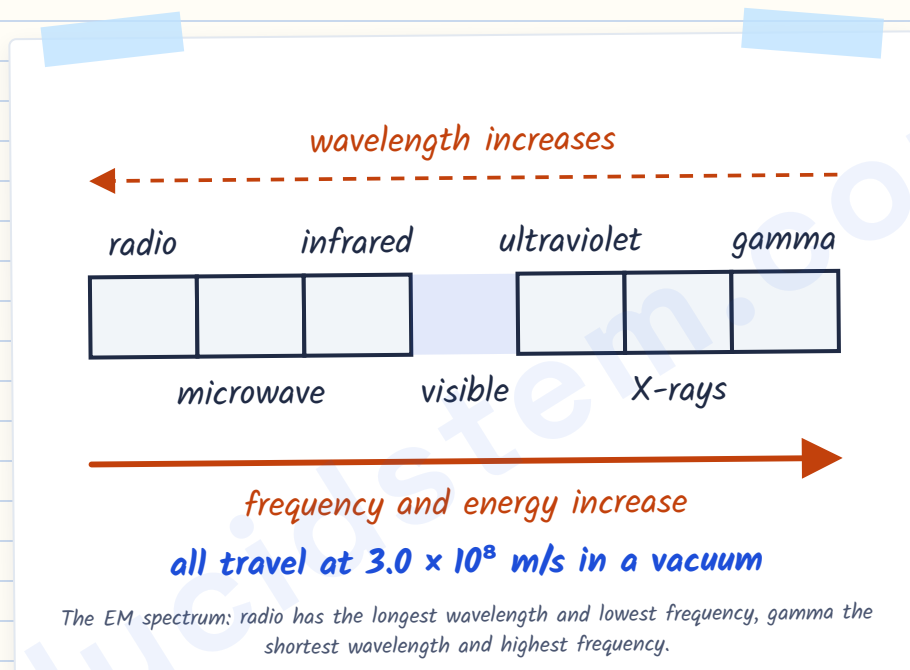
$$c = 3.0 \times 10^8 \text{ m/s}$$

Extended speed of every EM wave in a vacuum (approximately the same in air)
m/s

$$c = f\lambda$$

higher frequency means shorter wavelength
m/s

- ✓ **Radio:** radio and TV broadcasting, astronomy, RFID. **Microwaves:** satellite TV, mobile phones, microwave ovens.
- ✓ **Infrared:** remote controls, thermal imaging, grills, intruder alarms, optical fibres. **Visible:** vision, photography, illumination.
- ✓ **Ultraviolet:** security marking, detecting fake bank notes, sterilising water. **X-rays:** medical imaging, airport security.
- ✓ **Gamma:** sterilising food and medical equipment, detecting and treating cancer.
- ✓ Harm: microwaves cause **internal heating**; infrared causes **skin burns**; UV damages surface cells and eyes (skin cancer).
- ✓ X-rays and gamma are **ionising**: they cause cell mutation and cancer.
- ✓ Satellite communication is mainly by **microwaves**: some satellite phones use **low orbit** satellites; other satellite phones and direct broadcast satellite TV use **geostationary** satellites.



Watch out!

- ! Gamma rays are **not faster** than radio waves; all EM waves have the same speed in a vacuum.
- ! Learn the order both ways: by frequency and by wavelength.

3.3b Communication and signals Extended

Definitions

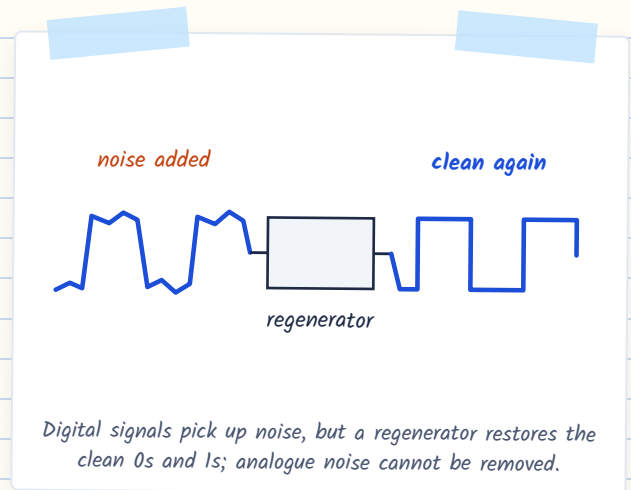
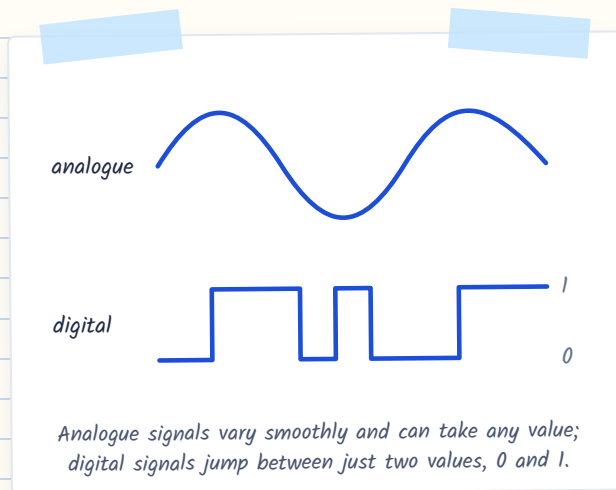
Analogue signal: a signal that varies continuously and can take any value.

Digital signal: a signal that has only a few discrete values, usually two (0 and 1, off and on).

Key points

- ✓ **Microwaves:** mobile phones and wireless internet (pass through walls, need only short aerials).
- ✓ **Radio waves:** Bluetooth (pass through walls but are weakened).
- ✓ **Visible light and infrared** in optical fibres: cable TV and high-speed broadband (glass is transparent to them).
- ✓ Sound can be sent as an **analogue or a digital** signal.

- ✓ Digital benefits: **regenerated** exactly, so noise is removed and the **range** is increased; faster transmission and more data.



Watch out!

- ! Regeneration works for **digital** signals only; amplifying an analogue signal amplifies the noise too.

3.4a Sound waves

Definitions

Sound: a longitudinal wave produced by a vibrating source.

Pitch: how high or low a sound is; it depends on the frequency.

Loudness: how loud a sound is; it depends on the amplitude.

Compression: **Extended** a region of a longitudinal wave where the particles are closer together (higher pressure).

Rarefaction: **Extended** a region of a longitudinal wave where the particles are further apart (lower pressure).

Key points

- ✓ Sound is made by **vibrating** objects and travels as a **longitudinal** wave.
- ✓ Sound needs a **medium**; it cannot travel through a vacuum (bell-in-a-jar experiment).
- ✓ Human audible range: **20 Hz to 20 000 Hz** (20 kHz).
- ✓ **Larger amplitude** → louder; **higher frequency** → higher pitch.
- ✓ On an oscilloscope trace, taller waves = louder; more waves on the screen = higher pitch.
- ✓ **Extended** sound is a series of **compressions and rarefactions** travelling through the medium.

original



louder:
bigger amplitude

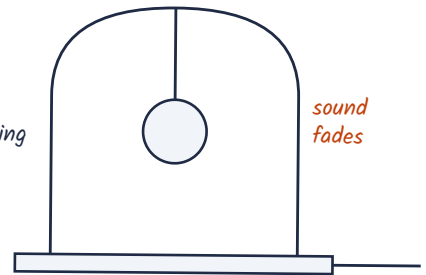


higher pitch:
higher frequency



Oscilloscope traces: a louder sound has a bigger amplitude; a higher-pitched sound has more waves in the same time.

bell still
seen ringing



to vacuum pump

Bell in a jar: as the air is pumped out the bell is still seen vibrating, but the sound fades. Sound needs a medium.

Watch out!

- ! Pitch depends on **frequency**, loudness on **amplitude**; do not swap them.
- ! Sound is longitudinal: the air particles vibrate **along** the direction of travel, they do not travel with the wave.

3.4b Speed of sound, echoes and ultrasound

Definitions

Echo: a reflected sound wave.

Ultrasound: sound with a frequency higher than 20 kHz (above the range of human hearing).

Key points

- ✓ Speed of sound in air is about **330-350 m/s**.
- ✓ Measure it outdoors: two people 100 m or more apart; time from **seeing** a clap or flash to **hearing** it; $v = d/t$.
- ✓ Echo method: clap at a wall; the sound travels **there and back**, so the distance is $2d$.
- ✓ **Extended** sound is fastest in **solids**, slower in liquids and slowest in gases.
- ✓ **Extended** ultrasound partly reflects at boundaries between materials; the echo time gives the distance.
- ✓ **Extended** uses of ultrasound: **non-destructive testing** of materials, **medical scanning** of soft tissue, **sonar**.

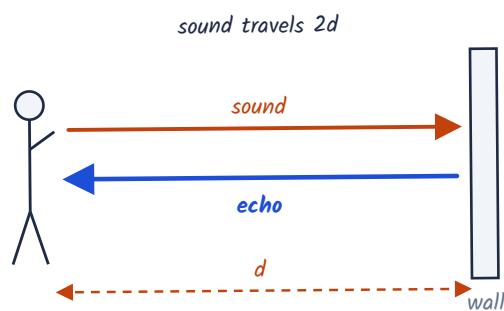
Equations

$$v = d / t$$

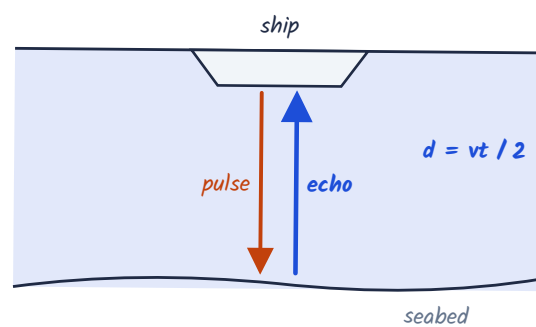
speed = distance / time
m/s

$$v = 2d / t$$

echo: sound travels to the reflector and back
m/s



Echo: the sound goes to the wall and back, a total distance of $2d$, so $v = 2d / t$.



Extended: sonar. An ultrasound pulse reflects off the seabed; depth $d = vt / 2$.

Watch out!

- ! In echo questions divide by 2: the time measured is for the **return** journey.
- ! Ultrasound is still sound (longitudinal, needs a medium); it is **not** an EM wave.