

Waves

A-Level Physics 9702 · Topic 7 revision notes · AS

Progressive waves and how to measure them, intensity, transverse and longitudinal waves, the Doppler effect, the electromagnetic spectrum and polarisation.

17 definitions to learn word for word, 11 equations in their own column, 9 diagrams and graphs. Read it, cover it, test yourself.

1. 7.1a Progressive waves: describing a wave
2. 7.1b Intensity and measuring waves with a CRO
3. 7.2 Transverse and longitudinal waves
4. 7.3 Doppler effect for sound waves
5. 7.4 Electromagnetic spectrum
6. 7.5 Polarisation

Definitions (mark-scheme wording) Equations Exam traps

7.1a Progressive waves: describing a wave

Definitions

Progressive wave: a wave that transfers energy from one place to another without transferring matter.

Displacement: the distance of a point on the wave from its equilibrium position (in a specified direction).

Amplitude: the maximum displacement of a particle from its equilibrium position.

Wavelength: the distance between two adjacent points on the wave that are in phase (e.g. crest to crest).

Period: the time taken for one complete oscillation of a point on the wave.

Frequency: the number of oscillations per unit time.

Phase difference: the fraction of a cycle (expressed as an angle) by which one oscillation leads or lags another.

Wave speed: the distance travelled by the wave (energy) per unit time.

Equations

$$v = f\lambda$$

wave speed = frequency $\times$ wavelength
 m s^{-1}

$$f = 1/T$$

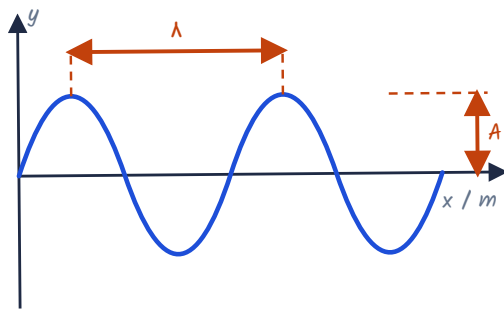
frequency = 1 / period
Hz

$$\phi = (x/\lambda) \times 360^\circ$$

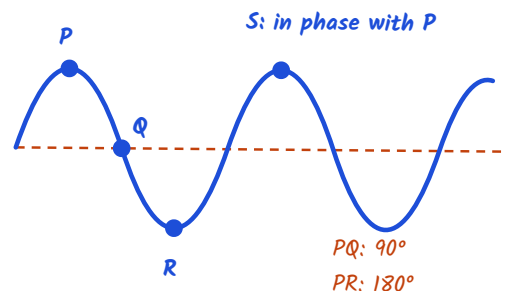
phase difference between points a distance x apart
 $^\circ$ or rad

Key points

- ✓ Displacement-**distance** graph: crest-to-crest spacing = λ .
- ✓ Displacement-**time** graph: crest-to-crest spacing = T .
- ✓ One wavelength = $360^\circ = 2\pi$ rad of phase; points $\lambda/2$ apart are in **antiphase** (180°).
- ✓ Phase difference between two points = $(x/\lambda) \times 360^\circ$.
- ✓ Derivation of $v = f\lambda$: the wave moves one wavelength in one period, $v = \lambda/T = f\lambda$.



Displacement against distance: the repeat length is the wavelength; A is measured from the equilibrium line.



Phase difference: P and Q are $\lambda/4$ apart (90°); P and R are $\lambda/2$ apart, in antiphase (180°); S is λ from P , in phase.

Watch out!

- ! Check the horizontal axis: crest-to-crest on a **time** axis is T , not λ .
- ! Amplitude is measured from the **equilibrium line**, not crest to trough.

7.1b Intensity and measuring waves with a CRO

Definitions

Intensity: the power transmitted per unit area (the area being perpendicular to the direction of travel of the wave).

Key points

- ✓ Intensity is proportional to **amplitude squared**: double A gives $4 \times I$.
- ✓ Cathode-ray oscilloscope: **y-gain** (V/div) sets the vertical scale; **time-base** (s/div) sets the horizontal scale.
- ✓ Period from a CRO: $T = (\text{divisions for one cycle}) \times \text{time-base setting}$; then $f = 1/T$.
- ✓ Measure **several cycles** and divide, to reduce the percentage uncertainty.
- ✓ Amplitude from a CRO: (divisions from centre to peak) $\times$ y-gain.
- ✓ Speed of sound: two microphones to a CRO; move one until traces are back in phase; distance moved = λ , then $v = f\lambda$.

Equations

$$I = P / A$$

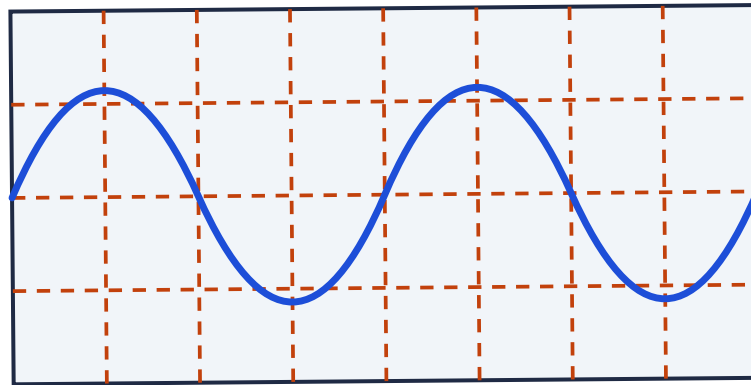
intensity = power / area
 W m^{-2}

$$I \propto A^2$$

intensity proportional to amplitude squared

$$T = n_{\text{div}} \times \text{time-base}$$

period read from a CRO trace
s



CRO trace, time-base 2 ms/div: one cycle spans 4 divisions, so $T = 8 \text{ ms}$ and $f = 125 \text{ Hz}$.

Watch out!

- ! Reading T from the CRO as the crest-to-trough spacing (that is only $T/2$).
- ! $I \propto A^2$: halving the amplitude reduces intensity to a **quarter**, not a half.

7.2 Transverse and longitudinal waves

Definitions

Transverse wave: a wave in which the particles oscillate perpendicular to the direction of energy transfer (wave travel).

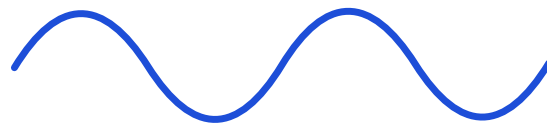
Longitudinal wave: a wave in which the particles oscillate parallel to the direction of energy transfer (wave travel).

Compression / rarefaction: a region of a longitudinal wave where particles are closer together / further apart than normal (high / low pressure).

Key points

- ✓ **Transverse:** all EM waves, waves on strings, water ripples, S-waves.
- ✓ **Longitudinal:** sound, ultrasound, P-waves, compression pulses on a slinky.
- ✓ Longitudinal waves need a **medium**; EM waves can travel through a vacuum.
- ✓ Longitudinal wave: λ = distance between successive **compressions**.
- ✓ Only transverse waves can be **polarised**: the test that tells them apart.
- ✓ Displacement-distance graphs look sinusoidal for **both** types.

transverse



oscillation



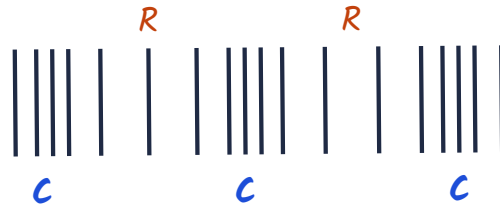
travel



oscillation



longitudinal



Transverse: oscillation perpendicular to travel. Longitudinal: oscillation parallel, forming compressions (C) and rarefactions (R).

Watch out!

- ! A sine-shaped displacement graph does not prove a wave is transverse.
- ! Saying sound particles travel with the wave: they only **oscillate** about fixed positions.

7.3 Doppler effect for sound waves

Definitions

Doppler effect: the change in the observed frequency (and wavelength) of a wave when the source moves relative to the observer.

Key points

- ✓ Moving source: wavefronts **bunch up ahead** and **spread out behind**; each is centred where the source was when emitted.
- ✓ The wave **speed** in air is unchanged; only the observed wavelength and frequency change.
- ✓ Source approaching: observed frequency **higher** (shorter λ).
- ✓ Source receding: observed frequency **lower** (longer λ).
- ✓ As a source passes, the heard pitch drops suddenly from high to low.
- ✓ The equation is for a **stationary observer** and a moving source.

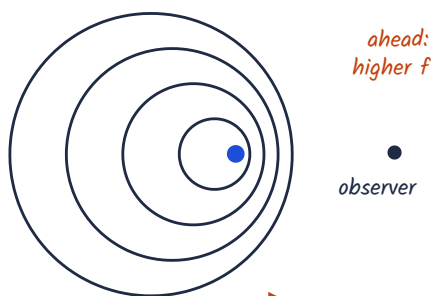
Equations

$$f_o = f_s v / (v - v_s)$$

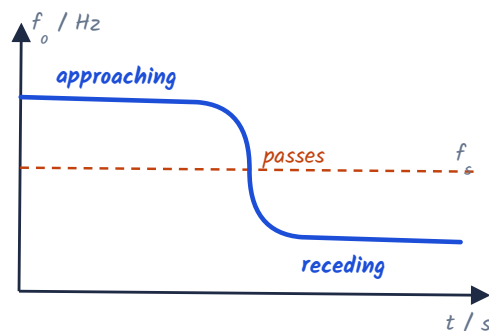
source approaching (higher f_o)
Hz

$$f_o = f_s v / (v + v_s)$$

source receding (lower f_o)
Hz



ahead: higher f
behind: lower f
Wavefronts from a source moving right: compressed ahead (higher f), stretched behind (lower f).



Frequency heard by a stationary observer as a source passes at constant speed.

Watch out!

- ! Sign error: approaching means $v - v_s$ in the denominator (answer larger than f_s).
- ! Saying the wave speed changes. It is the **wavelength** that changes.

7.4 Electromagnetic spectrum

Definitions

Electromagnetic wave: a transverse wave of oscillating electric and magnetic fields that can travel through a vacuum at speed c .

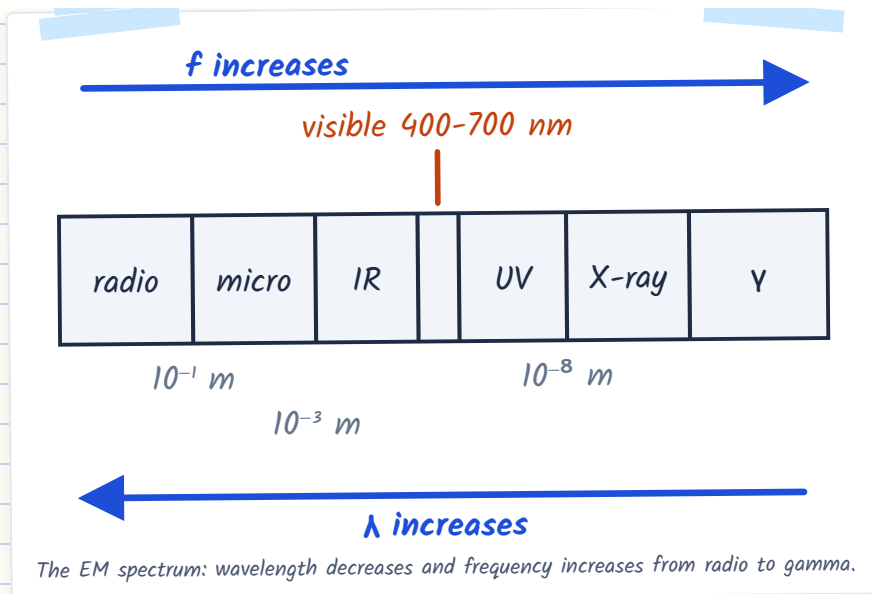
Equations

$$c = f\lambda$$

speed of light = frequency $\times$ wavelength
 m s^{-1}

Key points

- ✓ Increasing frequency (decreasing λ): **radio, microwave, infrared, visible, ultraviolet, X-ray, gamma.**
- ✓ All EM waves travel at $c = 3.00 \times 10^8 \text{ m s}^{-1}$ in free space (almost the same in air).
- ✓ All are **transverse** and can be polarised.
- ✓ Visible light: **400 nm (violet) to 700 nm (red).**
- ✓ Approximate λ : radio $> 10^{-1} \text{ m}$; microwave 10^{-3} – 10^{-1} m ; infrared 7×10^{-7} – 10^{-3} m .
- ✓ UV 10^{-8} – $4 \times 10^{-7} \text{ m}$; X-ray 10^{-13} – 10^{-8} m ; gamma 10^{-16} – 10^{-10} m (X and gamma overlap: named by origin).



Watch out!

- ! Converting nm: $400 \text{ nm} = 4 \times 10^{-7} \text{ m}$, not $4 \times 10^{-9} \text{ m}$.
- ! Getting the order reversed: gamma has the **highest** frequency and **shortest** wavelength.

7.5 Polarisation

Definitions

Plane-polarised wave: a transverse wave in which the oscillations occur in one plane only (containing the direction of travel).

Unpolarised wave: a transverse wave in which the oscillations occur in all planes perpendicular to the direction of travel.

Malus's law: the intensity transmitted by an analyser is $I = I_0 \cos^2 \theta$, where θ is the angle between the plane of polarisation and the transmission axis.

Equations

$$I = I_0 \cos^2 \theta$$

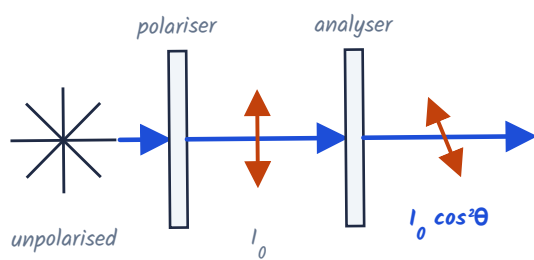
Malus's law: intensity through the analyser
 W m^{-2}

$$A = A_0 \cos \theta$$

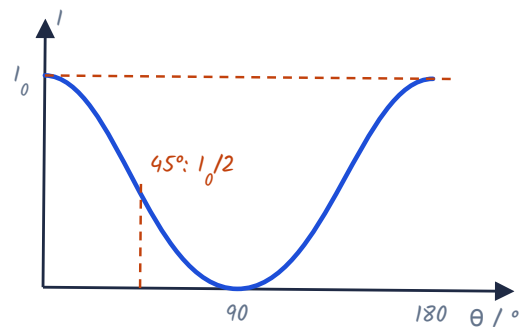
transmitted amplitude
 m

Key points

- ✓ Only **transverse** waves can be polarised; sound (longitudinal) cannot.
- ✓ A polariser passes only the component of oscillation along its **transmission axis**.
- ✓ Unpolarised light through one ideal polaroid: intensity **halves**.
- ✓ Amplitude transmitted = $A_0 \cos \theta$, so intensity ($\propto A^2$) = $I_0 \cos^2 \theta$.
- ✓ Crossed polaroids ($\theta = 90^\circ$): **no** light transmitted.
- ✓ Examples: light reflected from water or glass is partly polarised; microwaves from a transmitter are polarised (metal grille test).



Polariser then analyser at θ : vertical plane selected, then only the component along the analyser axis passes.



Malus's law: transmitted intensity against analyser angle; zero at 90° , full at 0° and 180° .

Watch out!

! $\cos^2 \theta$ is for **intensity**; amplitude uses $\cos \theta$.

! Using I_0 as the unpolarised intensity: after the first polariser it is already **half** that.