A LEVEL PHYSICS 9702 · AS LEVEL · TOPIC 7 · ~8 MIN READ

Waves

Progressive waves and the words to describe them, reading an oscilloscope, deriving v = fλ, intensity and amplitude, transverse and longitudinal waves, the Doppler effect for a moving source, the electromagnetic spectrum and polarisation with Malus's law.

Progressive waves | Amplitude, phase, period | Oscilloscope | v = fλ | Intensity ∝ amplitude² | Transverse & longitudinal | Doppler effect | EM spectrum

RS by Riyaz Sir
mentorriyaz.in

Paper tag = **where it is examined** DATA & FORMULAE given in the exam C1 A1 B1 how marks are awarded

highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

- **A progressive wave transfers energy** without transferring matter. The particles of the medium oscillate about fixed positions.
- **v = fλ**: in one period the wave moves one wavelength.
- **Intensity = power per unit area,** and intensity ∝ (amplitude)². Halve the amplitude and the intensity falls to a quarter.
- **Doppler effect:** a source moving towards you sounds higher, $f_o = f_s\, v/(v - v_s)$; moving away, $f_o = f_s\, v/(v + v_s)$.
- **Only transverse waves can be polarised.** For plane-polarised light through a filter at θ: $I = I_o\cos^2\theta$ (Malus's law).

BY THE END YOU CAN

- Describe progressive waves using displacement, amplitude, phase difference, period, frequency, wavelength and speed.
- Use an oscilloscope's time-base and y-gain to find frequency and amplitude.
- Derive and use v = fλ, and use intensity ∝ amplitude².
- Compare transverse and longitudinal waves and interpret their graphs.
- Use the Doppler equation for a moving source.
- Recall the regions and wavelengths of the electromagnetic spectrum, and use Malus's law.

1 Describing progressive waves

Key terms

Displacement — distance of a point on the wave from its equilibrium (rest) position, in a given direction.

Amplitude — the maximum displacement from the equilibrium position.

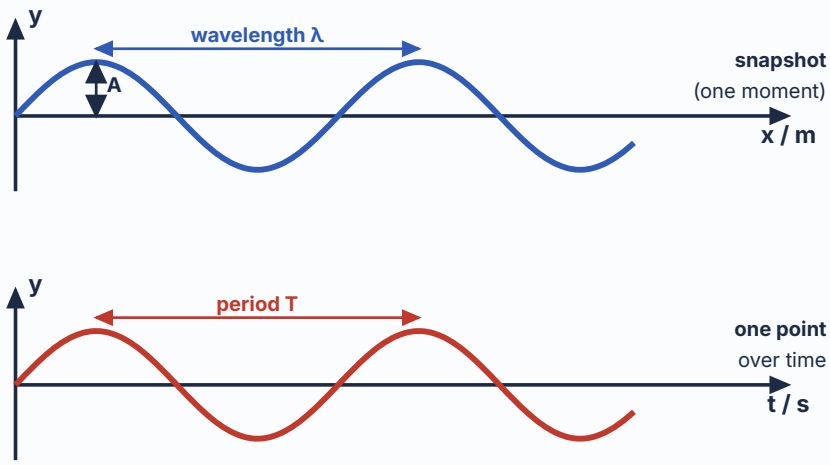
Wavelength (λ) — the distance between two adjacent points on the wave that are in phase (e.g. crest to crest).

Period (T) — the time for one complete oscillation of a point on the wave.

Frequency (f) — the number of oscillations per unit time; f = 1/T.

Phase difference — how far one oscillation is ahead of another, as a fraction of a cycle, in degrees or radians: φ = (Δx/λ) × 360°.

Wave speed — the distance travelled by the wave (a wavefront) per unit time.



Same shape, different axes: read λ from a distance graph, T from a time graph.

Displacement–distance (a snapshot) shows λ; displacement–time (one point) shows T.

- **Deriving v = fλ:** in one period T the wave travels one wavelength λ. Speed = distance/time = λ/T = fλ.

$$v = f\lambda$$ LEARN IT

$$f = 1/T$$

WORKED EXAMPLE

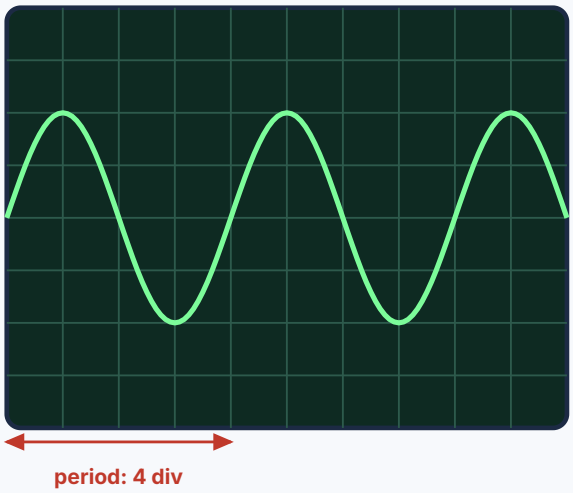
Two points on a progressive wave of wavelength 0.60 m are 0.15 m apart along the direction of travel. Find their phase difference.

1. **φ = (0.15/0.60) × 360° = 90° (π/2 rad)** C1 A1

COMMON MISTAKE

Confusing the speed of a point on the wave with the wave speed. Points on a transverse wave move up and down, with changing speed; the wave moves along at constant speed. The 2024 Paper 1 report noted this confusion.

Using an oscilloscope



time-base:
2 ms per div
period = 4 × 2
= 8 ms
f = 1/T = 125 Hz
y-gain: 0.5 V per div
amplitude = 2 div
= 1.0 V

Count divisions, then multiply by the time-base (horizontal) or y-gain (vertical).

- **Period** = (number of horizontal divisions for one cycle) × time-base. **Amplitude** = (vertical divisions from centre to peak) × y-gain.

2 Energy and intensity

Intensity

Intensity — power transmitted per unit area, normal to the direction of travel (W m^{-2}).

$$I = P/A \; ; \; I \propto A^2$$ LEARN IT

A in the second relation is amplitude

- **From a point source** spreading equally in all directions: $I = P/(4\pi r^2)$, an inverse-square law.

WORKED EXAMPLE

A small lamp emits 60 W of light uniformly. Find the intensity 3.0 m away, and the new intensity if the amplitude of the wave is doubled.

1. $I = 60/(4\pi \times 3.0^2)$ = **0.53 W m^{-2}** C1 A1
2. **$I \propto A^2$, so doubling A multiplies I by 4: 2.1 W m^{-2}** A1

COMMON MISTAKE

Not combining $I = P/A$ with $I \propto A^2$. The 2024 Paper 1 report flagged items that needed both together.

3 Transverse and longitudinal waves

Comparison

	Transverse	Longitudinal
Oscillation direction	perpendicular to the direction of energy transfer	parallel to the direction of energy transfer
Examples	light and all EM waves, waves on strings, water ripples	sound, ultrasound, compression waves on a slinky
Features	crests and troughs	compressions and rarefactions
Polarisation	possible	not possible

- **Graphs of longitudinal waves:** a displacement–distance graph still looks like a sine curve; displacement is along the direction of travel. Compressions are where neighbouring particles move towards each other.

4 The Doppler effect for sound

Moving source, stationary observer

- **Why it happens:** the source moves between emitting successive wavefronts, so the wavefronts are bunched up in front of it (shorter λ, higher observed frequency) and spread out behind it (longer λ, lower frequency).

$$f_o = f_s \, v/(v \pm v_s)$$ DATA & FORMULAE

minus when the source approaches, plus when it moves away; v = speed of sound

WORKED EXAMPLE

An ambulance siren emits 800 Hz and moves at 25 m s^{-1}. The speed of sound is 340 m s^{-1}. Find the frequency heard as it approaches and as it moves away.

1. approaching: 800 × 340/(340 − 25) = **864 Hz** C1 A1
2. **receding: 800 × 340/(340 + 25) = 745 Hz** A1

COMMON MISTAKE

Confusing frequency with loudness. A higher observed frequency means a higher pitch, not a louder sound (2024 Paper 1).

Riyaz Sir

5 The electromagnetic spectrum

Regions

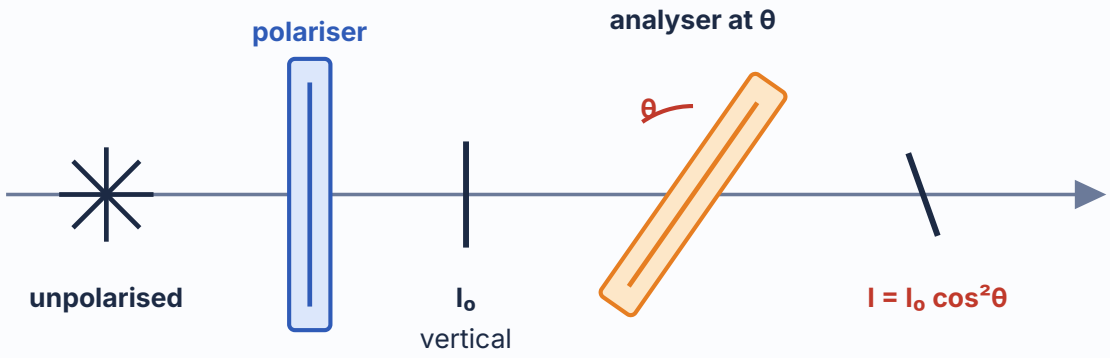
Region	Approximate wavelength in free space
radio waves	$> 10^{-1}$ m
microwaves	10^{-3} m to 10^{-1} m
infrared	7×10^{-7} m to 10^{-3} m
visible light	4×10^{-7} m to 7×10^{-7} m (400–700 nm)
ultraviolet	10^{-8} m to 4×10^{-7} m
X-rays	10^{-13} m to 10^{-8} m
gamma rays	$< 10^{-11}$ m (overlaps X-rays)

- **All EM waves** are transverse and travel at $c = 3.00 \times 10^{8}$ m s^{-1} in free space. Only the order of magnitude of each range is expected.

6 Polarisation

Plane-polarised waves

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



The analyser passes amplitude × cos θ, so intensity × $\cos^2\theta$.

The analyser transmits the component of the oscillation along its axis.

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

Malus's law; θ = angle between the plane of polarisation and the filter's transmission axis

- **Why cos²:** the filter passes the amplitude component $A_o \cos\theta$, and intensity ∝ amplitude², so $I = I_o \cos^2\theta$.
- **The syllabus doesn't require** the effect of a filter on unpolarised light.

WORKED EXAMPLE

Plane-polarised light of intensity 12 W m^{-2} passes through a polarising filter whose axis is at 60° to the plane of polarisation. Find the transmitted intensity.

1. $I = 12 \times \cos^2 60° = 12 \times 0.25 = 3.0$ W m^{-2} C1 A1

COMMON MISTAKE

Using cos θ, sin θ or $\sin^2\theta$ instead of $\cos^2\theta$ (2024 Paper 1). The angle is between the polarisation plane and the filter axis.

LINKING QUESTION

Superposition of waves gives stationary waves, diffraction and interference in Superposition; the Doppler shift of light is redshift in Astronomy and cosmology; and ultrasound is a longitudinal wave used in Medical physics.

Test yourself — cover the answers first

QUICK CHECK

1. Define wavelength.
2. A wave has frequency 50 Hz and wavelength 6.8 m. Find its speed.
3. What happens to intensity if amplitude is halved?
4. Which type of wave can be polarised?
5. State the wavelength range of visible light.

EXAM-STYLE

6. Plane-polarised light passes through two filters: the first at 30° to the plane of polarisation, the second at 30° to the first. What fraction of the intensity is transmitted?
7. A source moving away from an observer is heard at 0.90 of its emitted frequency. The speed of sound is 340 m s^{-1}. Find the source speed.
8. On an oscilloscope the time-base is 0.5 ms div^{-1} and one cycle spans 5.0 divisions. The y-gain is 2 V div^{-1} and the peak-to-peak height is 6.0 divisions. Find the frequency and amplitude.

Show answers

1. distance between adjacent points in phase
2. 340 m s^{-1}
3. it falls to a quarter
4. transverse
5. 400 nm to 700 nm
6. $\cos^2 30° \times \cos^2 30° = 0.56$
7. $0.90 = 340/(340 + v_s) \Rightarrow v_s = 38$ m s^{-1}
8. T = 2.5 ms ⇒ f = 400 Hz; amplitude = 3.0 div × 2 V = 6.0 V

Stuck on a question?

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