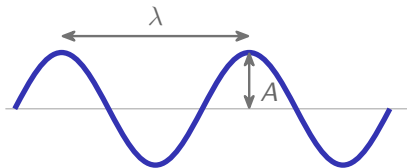


Waves

AS Physics ■ Topic 7

A-Level Physics



What we will cover

- 1 Progressive waves 7.1
- 2 Phase and the CRO 7.1.1
- 3 Transverse & longitudinal 7.2
- 4 Doppler effect 7.3
- 5 Electromagnetic spectrum 7.4
- 6 Polarisation 7.5
- 7 Recap



1

Progressive waves

Sheet 7.1 – what you need to know

You must be able to:

- describe a **progressive wave** and what it transfers
- use displacement, amplitude, wavelength, period, frequency and speed
- read λ , T and A off graphs against distance and against time
- derive $v = f\lambda$ and use it with kHz, MHz and ms

What the exam asks

“State what is meant by a progressive wave.” [1]

“Use the definitions of speed v , frequency f and wavelength λ to derive the wave equation $v = f\lambda$.” [2]

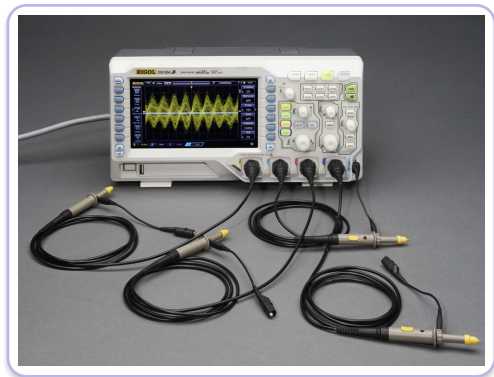
“Calculate the frequency, in GHz, of the microwaves.” [2]

Practise on exercise sheet 7.1, then try the real exam questions on past-paper sheet 7.1.

What a wave is

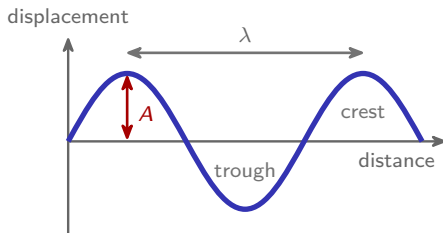
A **progressive wave** 行波 carries **energy** without moving matter overall.

- particles of the **medium** 介质 **oscillate** 振动 about rest positions
- only the disturbance **propagates** 传播



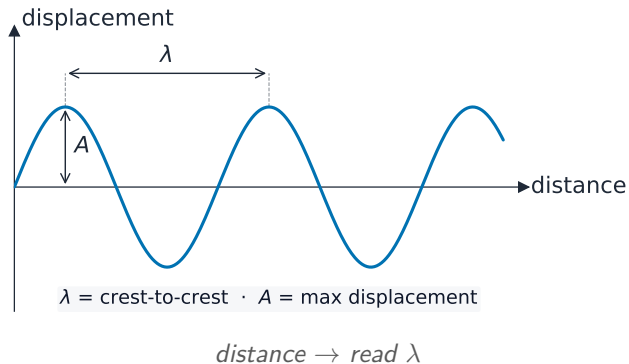
An oscilloscope traces a wave's shape against time

Key terms



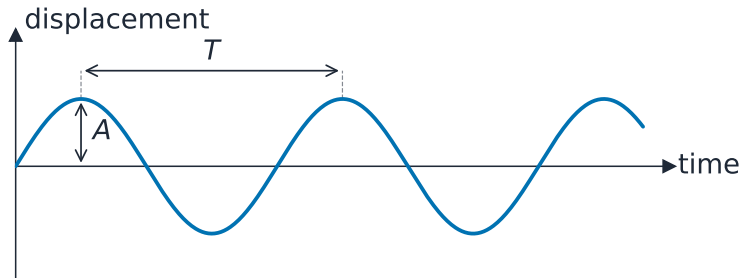
- **displacement** 位移 y – how far a particle has moved from rest *now*; a **vector** 矢量
- **amplitude** 振幅 A – the largest displacement
- **wavelength** 波长 λ – shortest distance between two points **in phase** 同相
- **period** 周期 T and **frequency** 频率 $f = 1/T$, in **hertz** 赫兹
- **speed** 速率 v – how fast a **crest** 波峰 travels
- **phase difference** 相位差 – the

Displacement against *distance*: read A and λ



A **snapshot** at one moment: a **sine curve** 正弦曲线 for both kinds. Longitudinal: displacement is *along* the travel.

Displacement against *time*: read A and T



amplitude A = peak displacement · period T = time
for one full cycle

One particle followed through time – also a sine curve. This is the graph that gives you T , and so $f = 1/T$.

Reading the two graphs

- against **distance**: crest to crest is λ
- against **time**: crest to crest is T
- on either: the amplitude is from the middle to a crest, **not** crest to trough

Read off: $\lambda = 0.80 \text{ m}$, $T = 0.40 \text{ s}$,
 $A = 3.0 \text{ cm}$

frequency: $f = \frac{1}{T} = \frac{1}{0.40 \text{ s}} = 2.5 \text{ Hz}$

speed, the wave equation:

$$v = f\lambda = (2.5 \text{ Hz})(0.80 \text{ m}) = 2.0 \text{ m s}^{-1}$$

6.0 cm crest to trough is **twice** the amplitude.

The wave equation

In one period the wave moves one wavelength:

$$v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} \xrightarrow{f = 1/T} v = f\lambda$$

$v = f\lambda$ holds for every progressive wave.

The wave equation with prefixes

Radio at 97.5 MHz

$$\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{97.5 \times 10^6 \text{ Hz}} = 3.08 \text{ m}$$

Ultrasound: 2.0 MHz in tissue at 1540 m s^{-1}

$$\lambda = \frac{v}{f} = \frac{1540 \text{ m s}^{-1}}{2.0 \times 10^6 \text{ Hz}} = 7.7 \times 10^{-4} \text{ m}$$

Sound: $T = 5.0 \text{ ms}$, $\lambda = 1.7 \text{ m}$

$$v = \frac{\lambda}{T} = \frac{1.7 \text{ m}}{5.0 \times 10^{-3} \text{ s}} = 340 \text{ m s}^{-1}$$

Convert the prefix first: $\text{M} = 10^6$, $\text{k} = 10^3$, $\text{m} = 10^{-3}$.

2

Phase, the CRO and intensity

Sheet 7.1.1 – what you need to know

You must be able to:

- find the **phase difference** of two points or two oscillations
- read the period, frequency and amplitude off an **oscilloscope** trace
- use $\text{intensity} = \frac{\text{power}}{\text{area}}$, including a point source
- use $\text{intensity} \propto \text{amplitude}^2$

What the exam asks

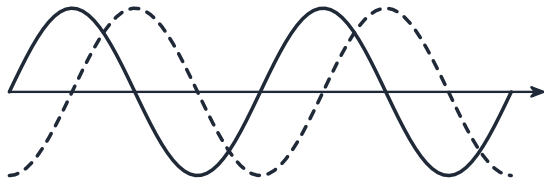
“State the phase difference between the oscillations of points R and T.” [1]

“Determine the time-base setting, in s cm^{-1} , of the CRO.” [2]

“Determine, in terms of I_0 , the final intensity of the wave.” [2]

Practise on exercise sheet 7.1.1, then try the real exam questions on past-paper sheet 7.1.1.

Phase, drawn



phase difference

Two points are **in phase** when they move together, and antiphase when one is exactly half a cycle behind.

Two points one wavelength apart are **in phase** (phase difference 0 or 2π); half a wavelength apart they are exactly **out of phase** (π).

Phase difference

$$\Delta\phi = \frac{x}{\lambda} \times 360^\circ$$

$$\Delta\phi = \frac{t}{T} \times 360^\circ$$

$360^\circ = 2\pi$ rad. Half a wavelength apart: **antiphase**, 180° .

A wave with $\lambda = 0.80$ m and $T = 0.40$ s

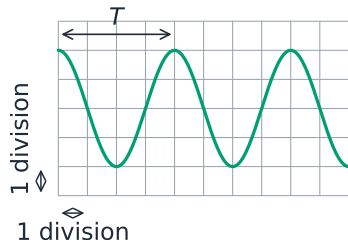
two points 0.30 m apart:

$$\Delta\phi = \frac{x}{\lambda} \times 360^\circ = \frac{0.30 \text{ m}}{0.80 \text{ m}} \times 360^\circ = 135^\circ, \text{ or } \frac{3}{4}\pi \text{ rad}$$

crests 0.10 s apart:

$$\Delta\phi = \frac{t}{T} \times 360^\circ = \frac{0.10 \text{ s}}{0.40 \text{ s}} \times 360^\circ = 90^\circ$$

Reading a CRO trace



period = $n \times$ timebase · peak voltage = $n \times$ Y-gain

- a **cathode-ray oscilloscope** 示波器 (CRO) plots voltage against time
- **time-base** 时基: seconds per division across $\rightarrow$ read T
- **y-gain** 垂直增益: volts per division up $\rightarrow$ read amplitude

5 ms/div, one cycle = 4 div

$$T = (4 \text{ div})(5 \text{ ms div}^{-1}) = 20 \text{ ms}$$

$$f = \frac{1}{T} = \frac{1}{0.020 \text{ s}} = 50 \text{ Hz}$$

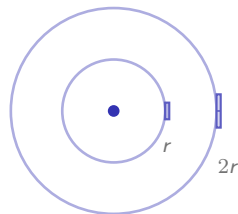
Intensity

Power through unit area:

$$I = \frac{P}{A}, \quad I \propto (\text{amplitude})^2$$

A **point source** 点源 spreads over a sphere $4\pi r^2$:

$$I = \frac{P}{4\pi r^2}, \quad I \propto \frac{1}{r^2}.$$



same power,
4 × the area
⇒ $I/4$

60 W lamp, $r = 2.0$ m

$$I = \frac{P}{4\pi r^2} = \frac{60 \text{ W}}{4\pi (2.0 \text{ m})^2} \approx 1.2 \text{ W m}^{-2}$$

3

Transverse and longitudinal

Sheet 7.2 – what you need to know

You must be able to:

- compare **transverse** and **longitudinal** waves, with examples
- find the compressions and rarefactions of a longitudinal wave
- read both kinds of wave off displacement graphs
- say which way a particle is moving at an instant

What the exam asks

“By reference to the direction of transfer of energy, state what is meant by a longitudinal wave.”

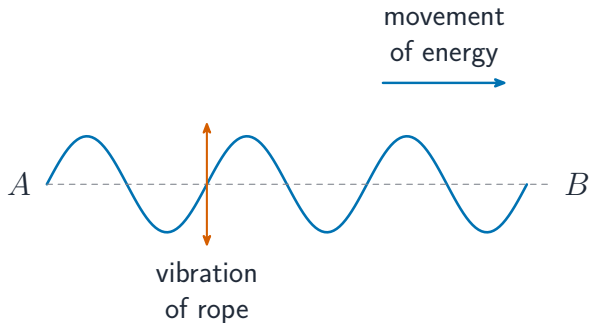
[1]

“Draw circles around two particles which are exactly one wavelength apart.” **[1]**

“State the direction of motion of particle Z at time $t_0 + \frac{T}{4}$.” **[1]**

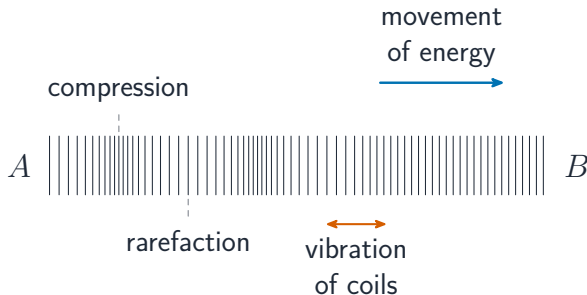
Practise on exercise sheet 7.2, then try the real exam questions on past-paper sheet 7.2.

Transverse waves



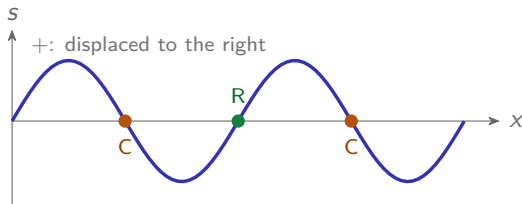
Particles **oscillate** 振动
perpendicular to the **energy** 能量
flow. Examples: a wave on a rope,
all EM waves, S-waves.

Longitudinal waves



Particles oscillate **parallel** to the energy flow. Made of **compressions** 压缩 and **rarefactions** 稀疏. Examples: sound, P-waves.

Compressions on a displacement graph



- **compression** C: the particles on its left move right, those on its right move left; the curve crosses zero going **down**
- **rarefaction** R: they move apart; the curve crosses zero going **up**
- at a crest or a trough the displacement is largest, but the air is at normal pressure

4

Doppler effect

Sheet 7.3 – what you need to know

You must be able to:

- explain why a moving source changes the **observed frequency**
- use $f_o = \frac{f_s v}{v \pm v_s}$ with the right sign
- find the source's speed from the frequencies heard

What the exam asks

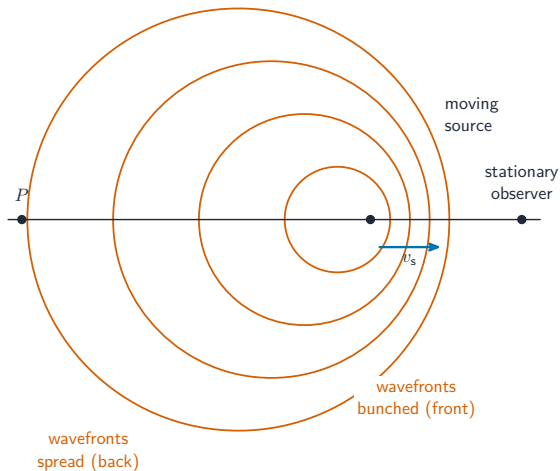
“Explain why the frequency of the sound detected by the observer is sometimes above and sometimes below 1.2 kHz.” [2]

“Determine the frequency, to three significant figures, of the sound heard by the child.” [2]

“Use Fig. 4.2 to determine the speed of the vehicle.” [3]

Practise on exercise sheet 7.3, then try the real exam questions on past-paper sheet 7.3.

Doppler effect



A moving **source** 波源 changes the frequency a **stationary** 静止 **observer** 观察者 hears, because the **wavefronts** 波前 ahead are squashed:

$$f_o = \frac{v f_s}{v \pm v_s}.$$

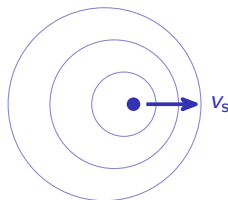
- towards → **minus**, wavefronts squashed, f_o higher
- away → **plus**, wavefronts spread out, f_o lower

Worked example – a car horn

$$f_s = 800 \text{ Hz}, v_s = 30 \text{ m s}^{-1} \text{ towards you,}$$
$$v = 340 \text{ m s}^{-1}$$

$$f_o = \frac{f_s v}{v - v_s} = \frac{(800 \text{ Hz})(340 \text{ m s}^{-1})}{340 \text{ m s}^{-1} - 30 \text{ m s}^{-1}} \approx 877 \text{ Hz}$$

Higher than 800 Hz – as expected for approach.



bunched ahead

5

Electromagnetic spectrum

Sheet 7.4 – what you need to know

You must be able to:

- state that all EM waves are **transverse** and travel at c
- order the regions from radio waves to γ -rays
- use $c = f\lambda$, and recall visible light is 400 to 700 nm

What the exam asks

“State the name of the principal region of the electromagnetic spectrum for the wave.” [1]

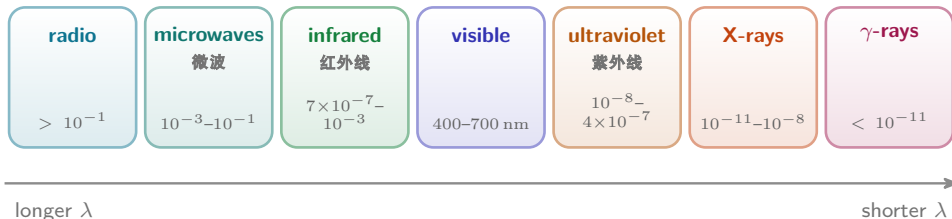
“Calculate the frequency, in THz, of the wave.” [2]

“State whether the frequency of the red light is greater than, less than or the same as the frequency of the original light.” [1]

Practise on exercise sheet 7.4, then try the real exam questions on past-paper sheet 7.4.

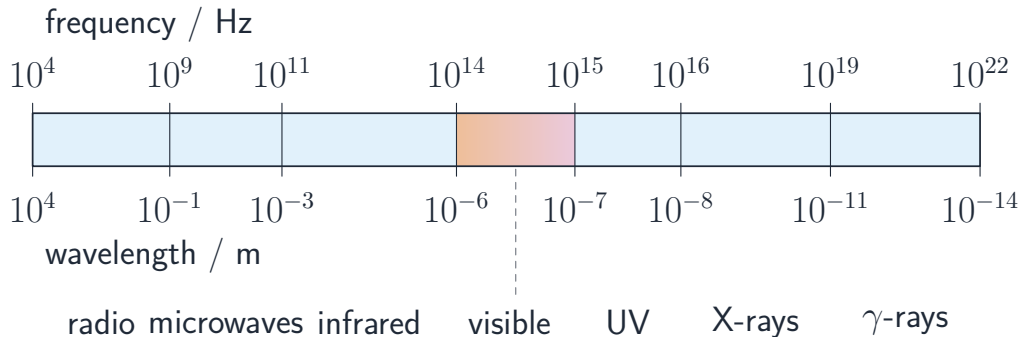
The electromagnetic spectrum

All **electromagnetic waves** 电磁波 are **transverse** and travel in a **vacuum** 真空 at $c = 3.00 \times 10^8 \text{ m s}^{-1}$. Use $c = f\lambda$.



The boundaries are **not sharp**. Learn the orders of magnitude, not the edges.

The electromagnetic spectrum, in detail



One family, one speed: only the wavelength changes across it.

Which region of the spectrum?

A wave of frequency 2.5×10^{14} Hz

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{2.5 \times 10^{14} \text{ Hz}} = 1.2 \times 10^{-6} \text{ m}$$

just longer than red light: **infrared**

A wave of wavelength 8.4×10^{-6} m

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m s}^{-1}}{8.4 \times 10^{-6} \text{ m}} = 3.6 \times 10^{13} \text{ Hz}$$

= **36 THz**, also infrared

Visible light is 400 to 700 nm, about 4×10^{14} to 7.5×10^{14} Hz: work from there.

6

Polarisation

Sheet 7.5 – what you need to know

You must be able to:

- explain why only **transverse** waves can be polarised
- use **Malus's law** $I = I_0 \cos^2 \theta$, forwards and backwards
- link the transmitted intensity to the amplitude, $I \propto A^2$
- apply Malus's law once for each filter

What the exam asks

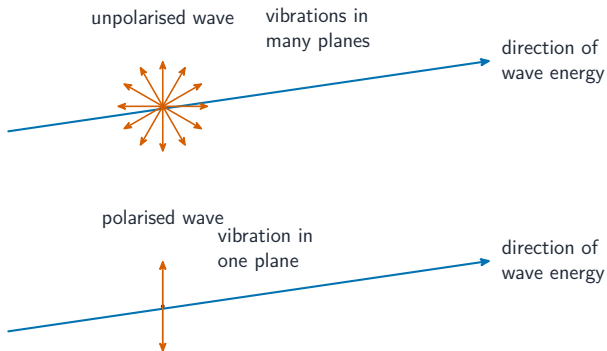
“State the meaning of polarisation.” [1]

“State why light waves can be plane polarised but sound waves cannot.” [1]

“Calculate the angle of rotation of filter B from its starting position.” [3]

Practise on exercise sheet 7.5, then try the real exam questions on past-paper sheet 7.5.

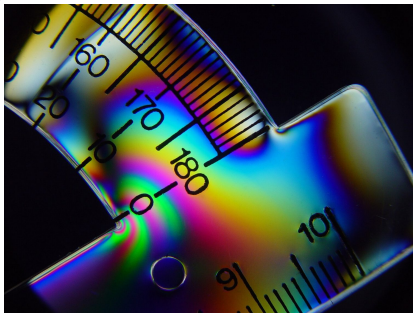
Polarisation



Polarisation 偏振: oscillation confined to **one plane**. Light that has been through a **polarising filter** 偏振片 is **plane-polarised** 平面偏振; the filter passes the part along its **transmission axis** 透光轴.

Only **transverse** waves polarise. Sound (longitudinal) cannot – a useful test.

Polarisation put to work



Stressed plastic between crossed polarisers: the plastic rotates the plane of polarisation by an amount that depends on the stress, so the colour fringes map where the material is loaded.

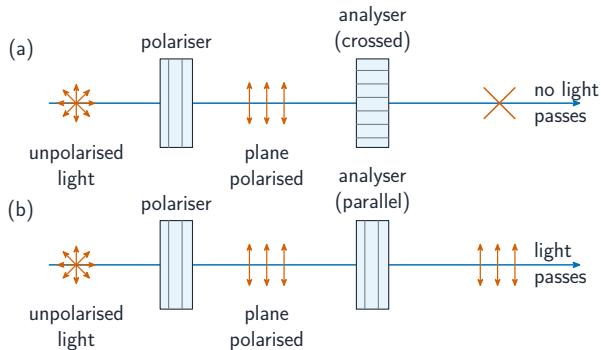
Malus's law

Through a filter at angle θ to the polarisation:

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

$$I_0 = 12 \text{ W m}^{-2}, \theta = 30^\circ$$

$$\begin{aligned} I &= I_0 \cos^2 \theta \\ &= (12 \text{ W m}^{-2}) \cos^2 30^\circ \\ &= 9.0 \text{ W m}^{-2} \end{aligned}$$



Crossed filters (a) block the light; parallel filters (b) let it pass

Malus's law backwards, and the amplitude

For what θ is the intensity halved?

$$\cos^2 \theta = \frac{I}{I_0} = 0.5, \text{ so } \cos \theta = \sqrt{0.5} \text{ and } \theta = 45^\circ$$

A filter passes $I = 0.25 I_0$: the amplitude?

$$I \propto A^2: \\ A = A_0 \sqrt{\frac{I}{I_0}} = A_0 \sqrt{0.25} = 0.50 A_0$$

Two filters: 30° , then 60° further

once per filter, each angle from the axis before it:

$$I_1 = I_0 \cos^2 30^\circ = 0.75 I_0$$

$$I_2 = I_1 \cos^2 60^\circ = 0.75 I_0 \times 0.25 = 0.19 I_0$$

Crossed filters, 90° apart, pass nothing.

7

Recap

Exam tips

- Define terms precisely (displacement, amplitude, wavelength, period, frequency) and use $v = f\lambda$.
- Distinguish **transverse** (vibration perpendicular to travel) from **longitudinal** (parallel); only transverse waves can be **polarised**.
- For the **Doppler effect**, the observed frequency **rises** as the source approaches and falls as it recedes.
- Learn the **electromagnetic spectrum** order; all its waves travel at c in a vacuum.

Topic 7 – key takeaways

1

Wave equation

$$v = f\lambda; \text{ intensity} \propto \text{amplitude}^2, \\ \propto 1/r^2$$

2

Two types

transverse $\perp$, longitudinal $\parallel$ to
energy

3

Doppler

moving source shifts the heard
frequency

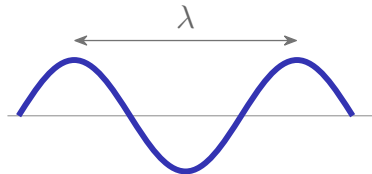
4

Polarisation

one plane; only transverse; $I = I_0 \cos^2 \theta$

Check yourself

- 1 A wave has $f = 50 \text{ Hz}$, $\lambda = 6.0 \text{ m}$ – find v .
- 2 Can a sound wave be polarised?
- 3 Source moves away – does the pitch rise or fall?
- 4 Light through a filter at 90° – how much passes?



Answers 1. $v = f\lambda = 300 \text{ m s}^{-1}$ 2. no (longitudinal) 3. falls
4. none ($\cos^2 90^\circ = 0$)