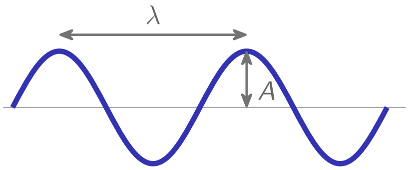
Waves

AS Physics ▪ Topic 7

A-Level Physics



What we will cover

1. Progressive waves
2. Transverse & longitudinal
3. Doppler effect
4. Electromagnetic spectrum
5. Polarisation
6. Recap

1 Progressive waves

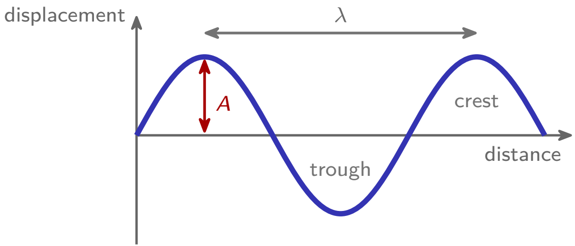
What a wave is

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

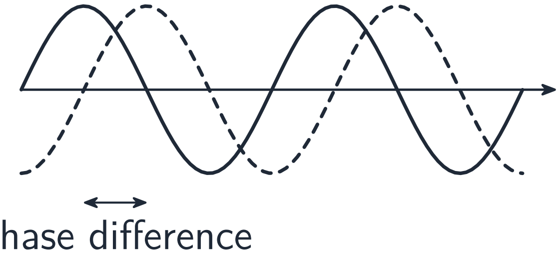
Oscilloscope

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

Phase, drawn



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).

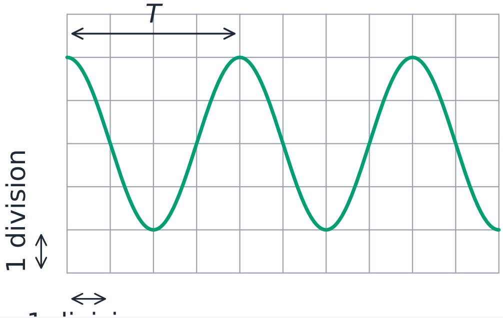
The wave equation

In one period the wave moves one wavelength:

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

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

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

$5\,\mathrm{ms/div}$, one cycle $= 4$ div

$T = 20\,\mathrm{ms} \Rightarrow f = 50\,\mathrm{Hz}$

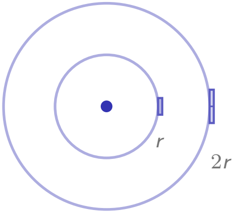
Intensity

Power through unit area:

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

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

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



same power,
$4\times$ the area
$\Rightarrow I/4$

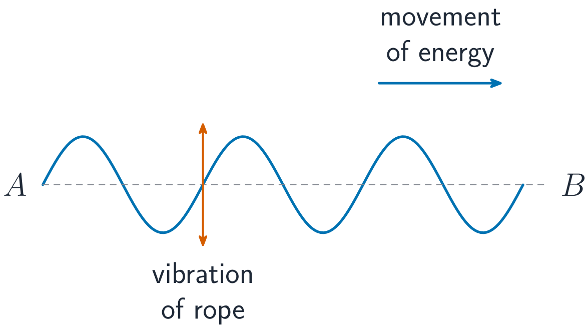
$60\,\mathrm{W}$ lamp, $r = 2.0\,\mathrm{m}$

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

Double the distance $\Rightarrow$ quarter the intensity.

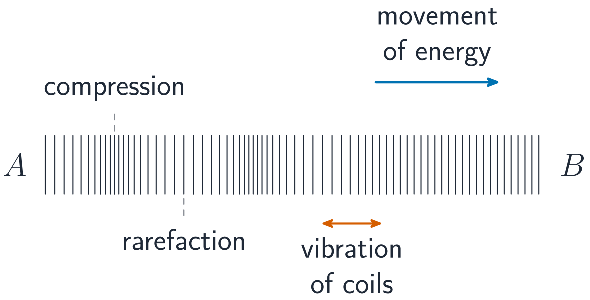
2 Wave types

Transverse waves



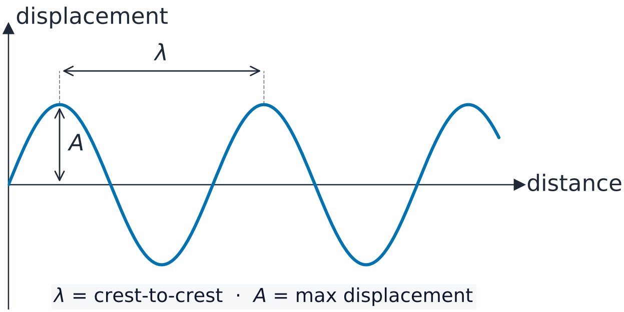
Particles **oscillate** 振动 perpendicular to the **energy** 能量 flow. Examples: a wave on a rope, all EM waves, S-waves.

Longitudinal waves



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

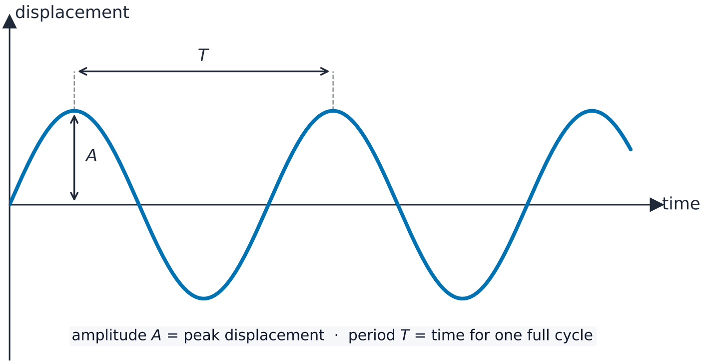
Displacement against *distance*: read A and λ



distance $\rightarrow$ *read* λ

A snapshot of the whole wave at one moment – a **sine curve** 正弦曲线 for both kinds. For a longitudinal wave the axis is the small back-and-forth displacement *along* the direction of travel.

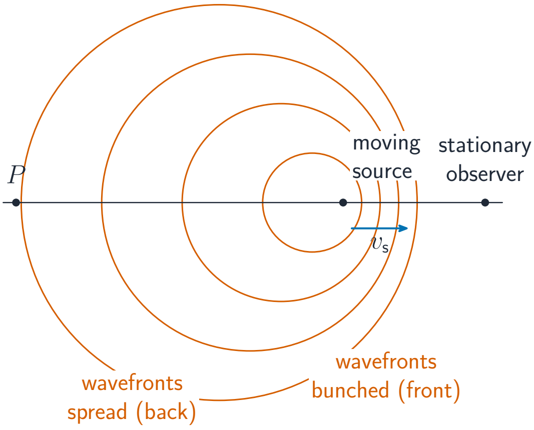
Displacement against *time*: read A and T



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

3 Doppler effect

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:

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

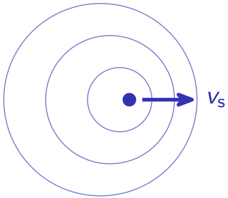
- towards $\rightarrow$ minus, wavefronts squashed, f_o higher
- away $\rightarrow$ plus, wavefronts spread out, f_o lower

Worked example – a car horn

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

$$f_o = \frac{340 \times 800}{340 - 30} = \frac{272\,000}{310} \approx 877\,\mathrm{Hz}.$$

Higher than $800\,\mathrm{Hz}$ – as expected for approach.



bunched ahead

4

EM spectrum

The electromagnetic spectrum

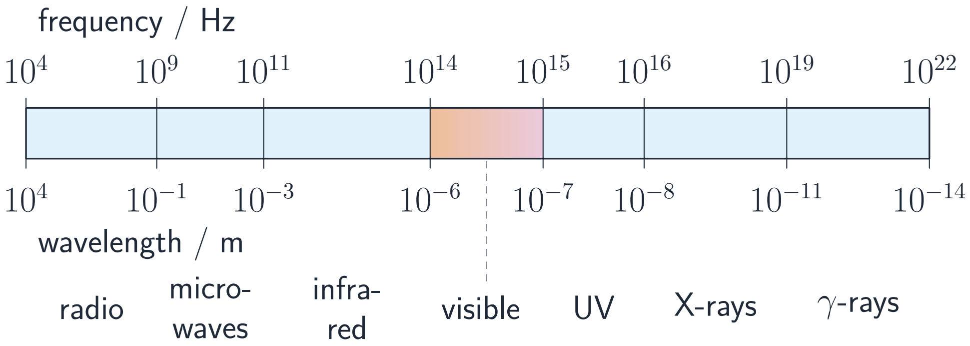
All **electromagnetic waves** 电磁波 are transverse and travel in a **vacuum** 真空 at $c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$. Use $c = f\lambda$.

radio	microwaves 微波	infrared 红外线	visible	ultraviolet 紫外线	X-rays	γ-rays
$> 10^{-1}$	10^{-3}–10^{-1}	7×10^{-7}–10^{-3}	400–$700\,\mathrm{nm}$	10^{-8}–4×10^{-7}	10^{-11}–10^{-8}	$< 10^{-11}$

longer λ → shorter λ

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

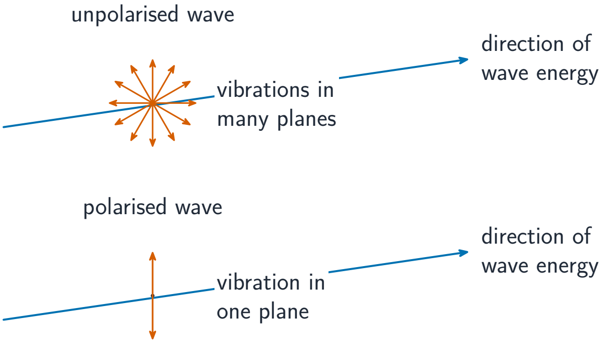
The electromagnetic spectrum, in detail



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

5 Polarisation

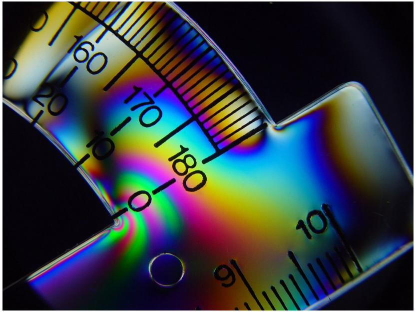
Polarisation



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.

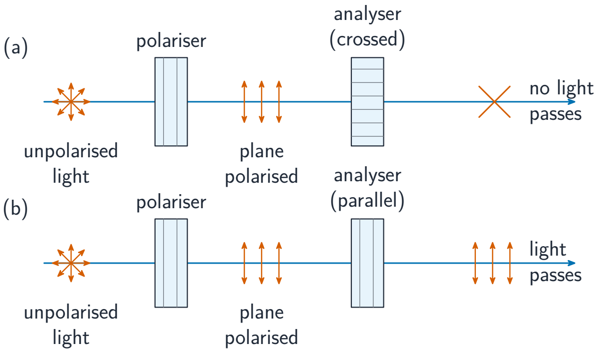
Malus's law

Through a filter at angle θ to the polarisation:

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

$I_0 = 12\,\mathrm{W\,m^{-2}}$, $\theta = 30°$

$I = 12\cos^2 30° = 12 \times 0.75 = 9.0\,\mathrm{W\,m^{-2}}$



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

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.

6 Recap

Topic 7 – key takeaways

1 Wave equation

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

2 Two types

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

3 Doppler

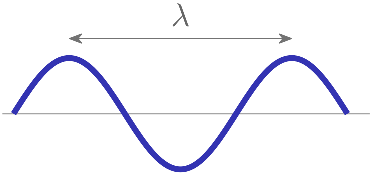
moving source shifts the heard frequency

4 Polarisation

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

Check yourself

1. A wave has $f = 50\,\mathrm{Hz}$, $\lambda = 6.0\,\mathrm{m}$ – 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.** $v = f\lambda = 300\,\mathrm{m\,s^{-1}}$ **2.** no (longitudinal) **3.** falls **4.** none $(\cos^2 90^\circ = 0)$