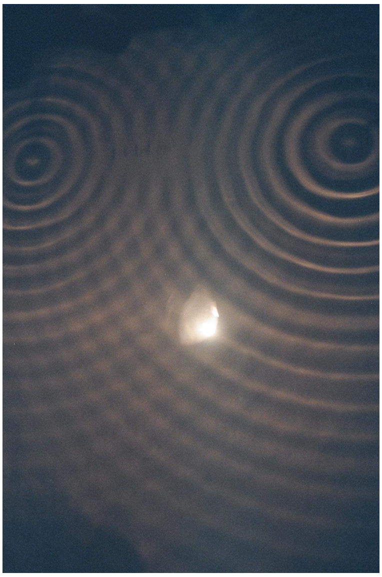
Waves, Sound, and Physical Optics

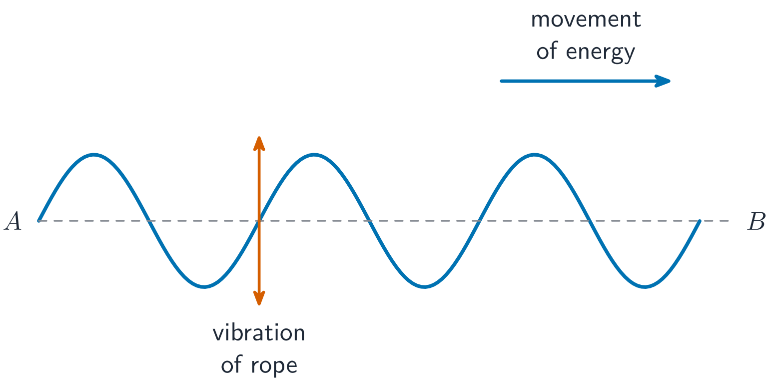
AP Physics 2

Properties of Wave Pulses and Waves



Ripple-tank interference: wave paths add constructively and destructively

A **wave** 波 carries **energy** through a medium (or space) without carrying the matter along. A single disturbance is a **pulse**; a repeating one is a wave. Two types:



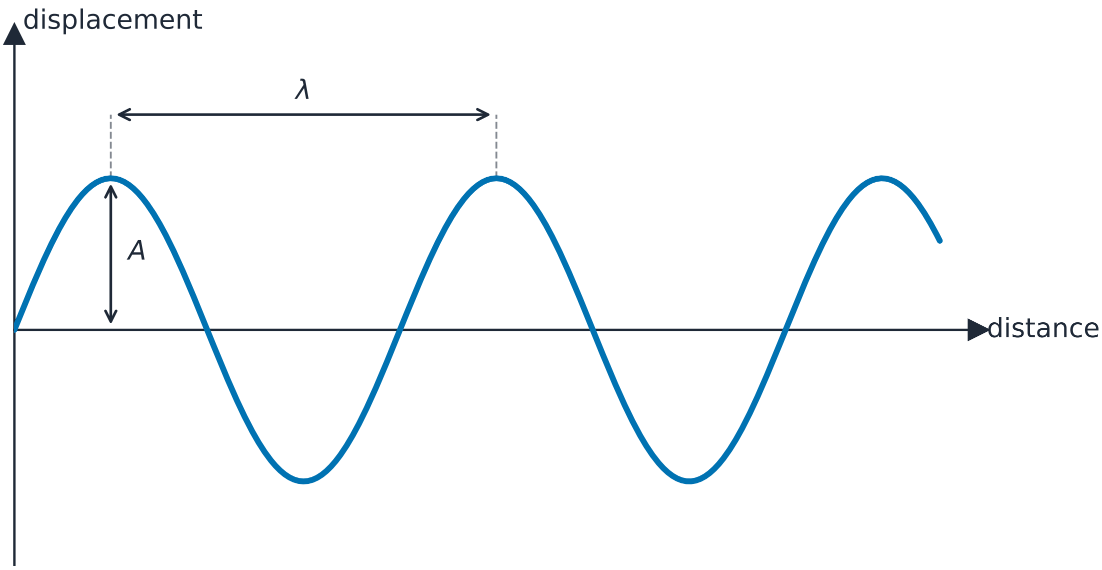
A transverse wave: the medium moves at right angles to the wave's travel

- **Transverse** 横波: the medium moves perpendicular to the wave's travel (a wave on a rope, light).

- **Longitudinal 纵波**: the medium moves along the direction of travel (sound).

Periodic Waves

A repeating wave is described by:



A displacement-distance graph shows the amplitude and wavelength

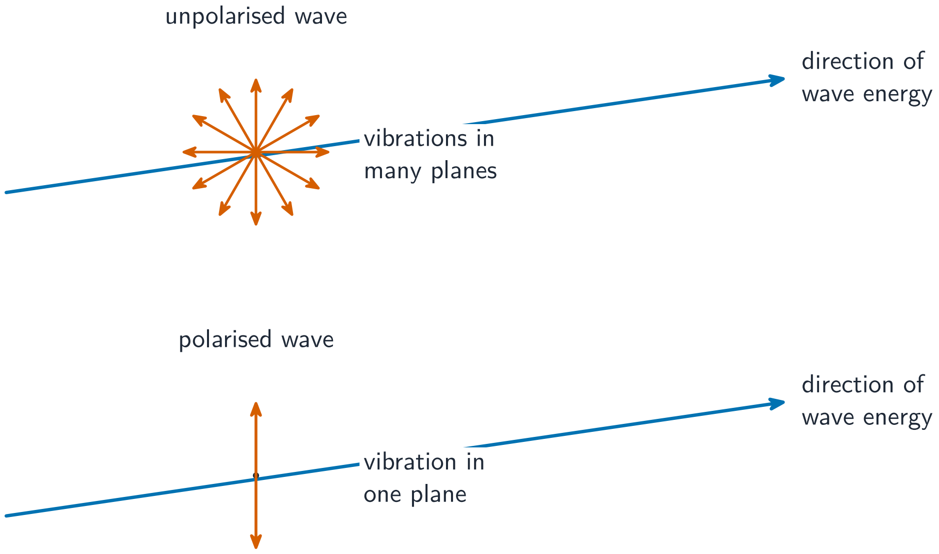
- **wavelength 波长** λ (distance between repeats),
- **frequency 频率** f (cycles per second) and **period** $T = 1/f$,
- **amplitude 振幅** A (maximum displacement – related to energy),
- **wave speed 波速** $v = f\lambda$, set by the **medium**, not the source.

Worked example. A musical note has frequency 340 Hz and the speed of sound is 340 m/s. Its wavelength is $\lambda = v/f = 340/340 = 1.0$ m. If the same note travels into water (where sound moves at ≈ 1500 m/s) the **frequency stays** 340 **Hz** but the wavelength stretches to $1500/340 \approx 4.4$ m – the source sets the frequency, the medium sets the speed and hence the wavelength.

Boundary Behavior and Polarization

At a boundary a wave partly **reflects** and partly **transmits**. Reflecting off a denser medium **inverts** the wave; off a less-dense medium it does not. **Polarization 偏振** applies to transverse waves only: a polarizer passes just one direction of oscillation, which is why polarized sunglasses cut glare.

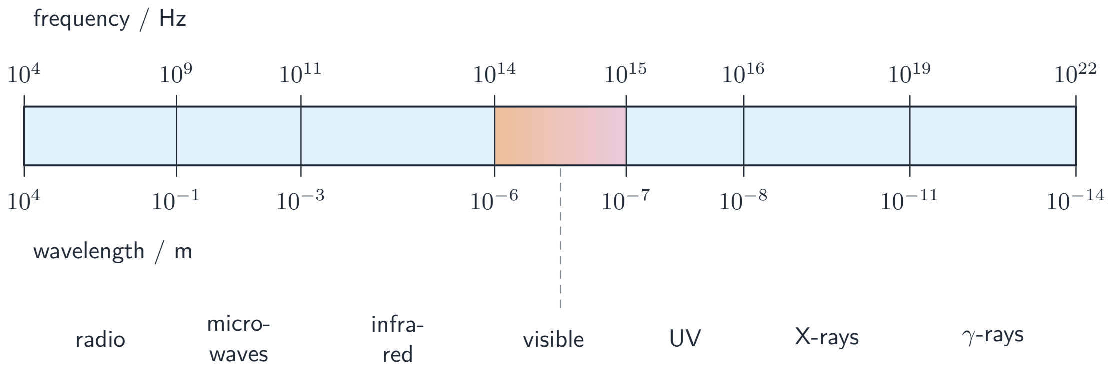
The effect of a polarizer is measured through **intensity** 强度 - the average power a wave delivers **per unit area** over one period, in W m^{-2}. Because a polarizer removes the components of the oscillation that are not aligned with it, it **reduces the wave's intensity**: unpolarized light passing a single ideal polarizer drops to **half** its intensity, and a second polarizer at an angle cuts it further. Intensity also falls with distance from a source, since the same power spreads over a larger area.



Unpolarised waves vibrate in many planes; a polarised wave vibrates in one

Electromagnetic Waves

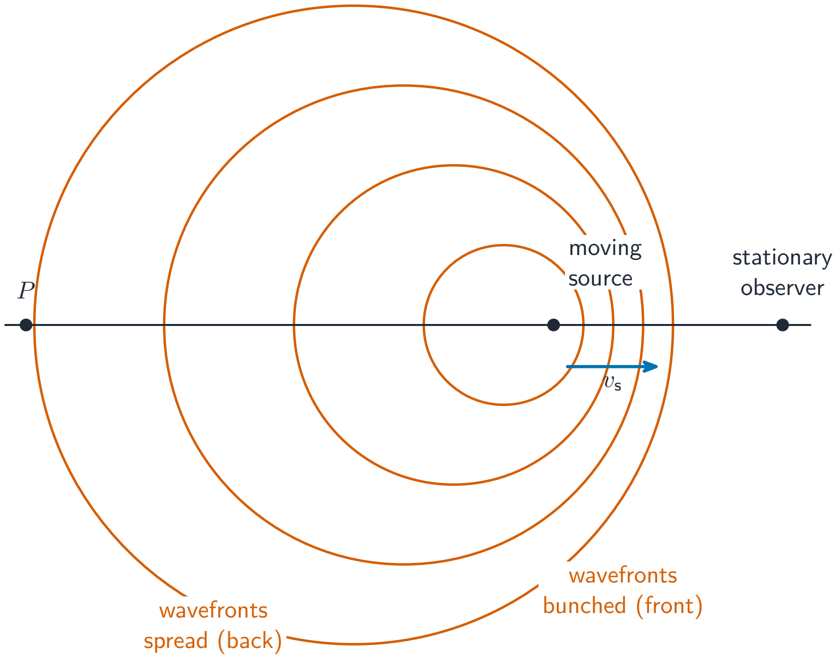
Electromagnetic waves 电磁波 are oscillating electric and magnetic fields that travel through vacuum at the speed of light c, needing no medium. They span the spectrum from radio to gamma rays; higher frequency means shorter wavelength and higher photon energy.



The electromagnetic spectrum, from radio waves to gamma rays

The Doppler Effect

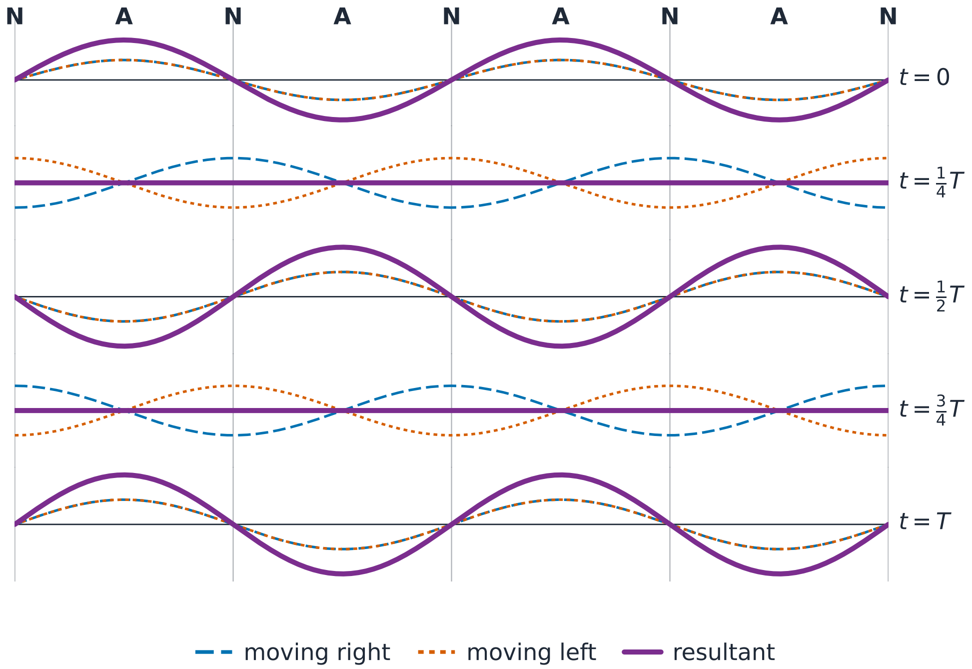
The **Doppler effect** 多普勒效应 is the change in observed frequency when a wave source and observer move relative to each other. Approaching $\Rightarrow$ higher frequency (shorter wavelength); receding $\Rightarrow$ lower frequency. It explains a passing siren's drop in pitch and the redshift of receding galaxies.



A moving source squashes the wavefronts ahead of it, raising the observed frequency

Wave Interference and Standing Waves

When waves overlap they **superpose** (add). **Constructive interference** 相长干涉 (crests aligned) gives a bigger wave; **destructive interference** 相消干涉 (crest on trough) cancels. Two waves travelling opposite ways in a bounded medium form a **standing wave** 驻波 with fixed **nodes** 波节 (no motion) and **antinodes** 波腹 (maximum motion) – the basis of resonance on strings and in pipes.



A standing wave forms where two waves travelling in opposite directions overlap

Worked example. A guitar string 0.65 m long is fixed at both ends. Its **fundamental** (first harmonic) fits half a wavelength between the ends, so $\lambda = 2L = 1.30$ m. If waves travel along the string at 260 m/s, the note's frequency is $f = v/\lambda = 260/1.30 = 200$ Hz. Shortening the string (a fret) raises the pitch.

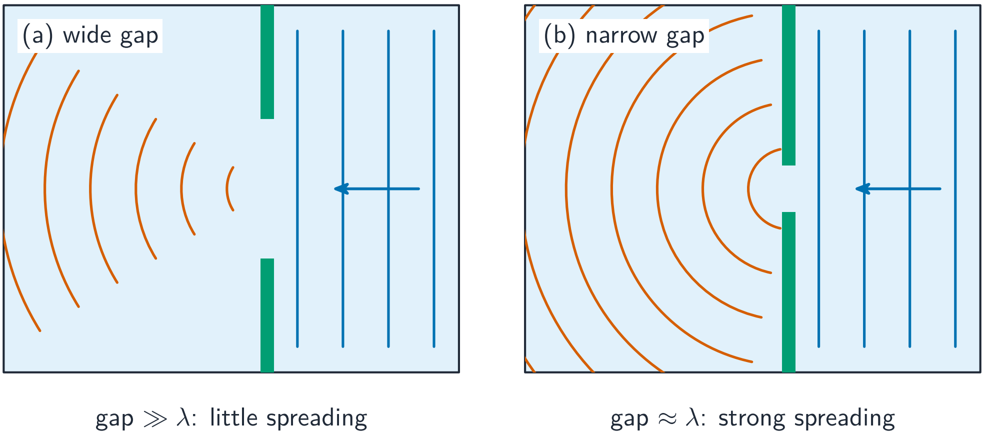
When two waves of **slightly different** frequency overlap, they drift in and out of step, so the combined sound swells loud and soft in a slow throb called **beats** 拍. The **beat frequency** 拍频 is simply the difference of the two frequencies:

$$f_{\text{beat}} = |f_1 - f_2|.$$

Two tuning forks of 256 Hz and 260 Hz sounded together give $|260 - 256| = 4$ beats each second; a musician tunes an instrument by slowing these beats towards zero against a reference note.

Diffraction

Diffraction 衍射 is the bending and spreading of waves around edges or through openings. The spreading is significant when the opening is comparable to the wavelength – so sound (long wavelength) bends around doorways easily, while light (tiny wavelength) needs a very narrow slit.



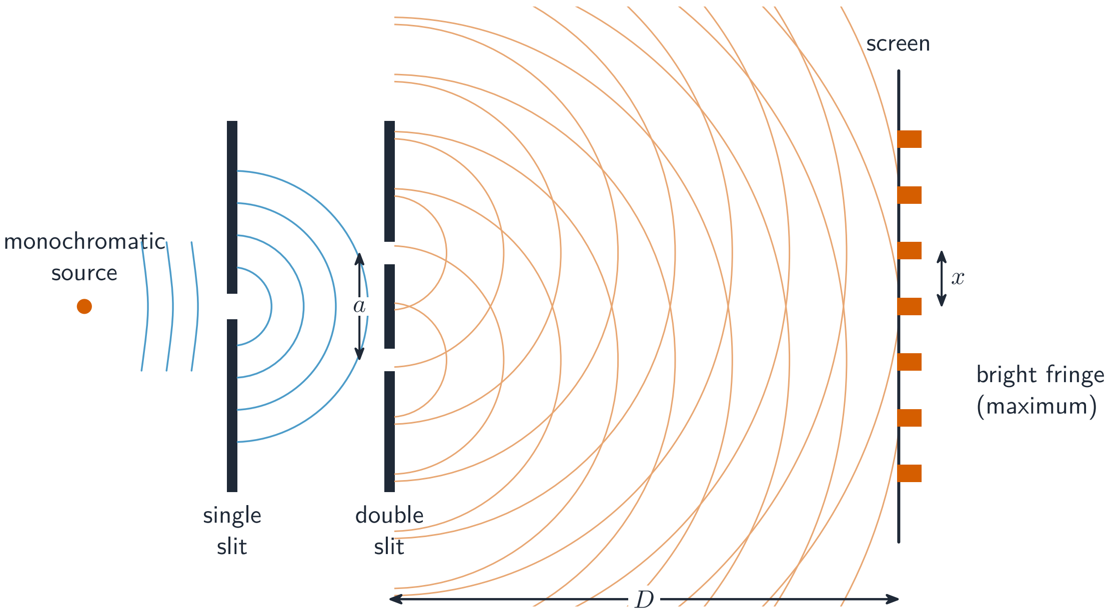
Waves spread out (diffract) as they pass through a gap

Double-Slit Interference and Diffraction Gratings

Coherent 相干 light through two closely spaced slits produces a pattern of bright and dark fringes. Bright fringes occur where the path difference is a whole number of wavelengths:

$$d \sin\theta = m\lambda.$$

A **diffraction grating** 衍射光栅 has many slits, giving sharp, widely spaced bright lines – useful for separating light into its wavelengths.

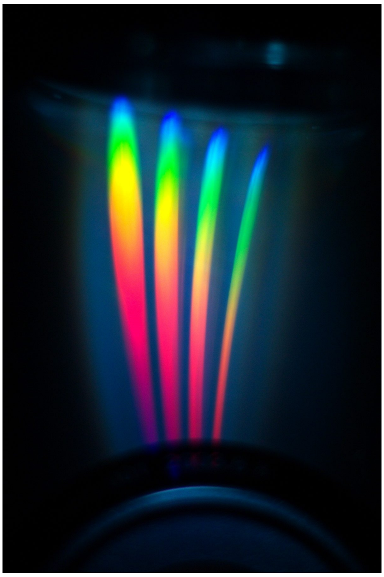


Young's double slits give an interference pattern of bright and dark fringes

Worked example. Light of wavelength 600 nm passes through two slits 0.20 mm apart. The first bright fringe ($m = 1$) sits at

$$\sin\theta = \frac{m\lambda}{d} = \frac{1 \times 600 \times 10^{-9}}{0.20 \times 10^{-3}} = 3.0 \times 10^{-3} \;\Rightarrow\; \theta = 0.17^\circ.$$

The tiny angle is why the slits must be very close together and the screen far away to see the fringes clearly.



The fine tracks on a CD act as a diffraction grating, splitting white light into a spectrum

Thin-Film Interference

Light reflecting off the top and bottom of a **thin film** 薄膜 (soap bubble, oil slick) interferes with itself. Depending on the film's thickness and a possible half-wavelength phase flip on reflection off a denser medium, particular wavelengths interfere constructively – producing the shifting colours you see.

The same physics is put to work in an **antireflection coating** 增透膜 on camera lenses, glasses, and solar cells: a thin transparent layer whose two reflected waves interfere **destructively**, so almost no light reflects and more is transmitted. The simplest coating is one **quarter of a wavelength** thick (measured in the coating), and its refractive index sits **between** that of air and the glass beneath, so the reflected light cancels itself out.

Exam tips

- Use $v = f\lambda$; the **source sets the frequency**, and when a wave enters a new medium the frequency stays fixed while the speed and wavelength change.
- Distinguish **transverse** (vibration perpendicular, can be polarised) from **longitudinal** (vibration along the travel, e.g. sound).
- **Constructive** interference needs a path difference of a whole number of wavelengths; **destructive** needs a half-odd number.
- On a string fixed at both ends the fundamental fits **half a wavelength** ($\lambda = 2L$).

- **Diffraction** is significant only when the gap is comparable to the wavelength — sound bends round doorways, light needs a very narrow slit.
- **Beats**: two waves of *slightly different* frequency throb at $f_{\text{beat}} = |f_1 - f_2|$ (e.g. two tuning forks; tuning to zero beats).
- An **antireflection coating** is a quarter-wavelength-thick layer (index between air and glass) whose two reflections cancel, cutting the reflected light.