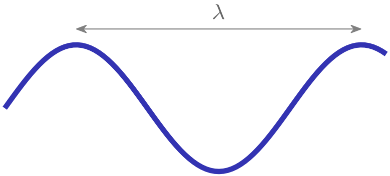
Waves, Sound, and Physical Optics

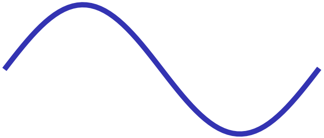
AP Physics 2 ▪ Unit 14

AP Physics 2



What we will cover

1. Wave types and properties
2. Periodic waves
3. Polarization
4. The electromagnetic spectrum
5. The Doppler effect
6. Interference and standing waves
7. Diffraction and the double slit

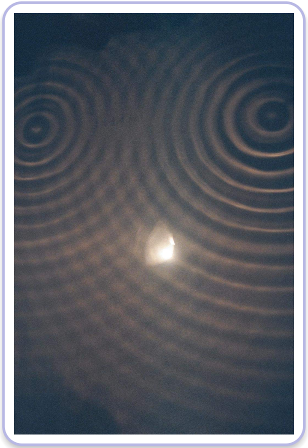


1 Wave types

Wave types

A **wave** 波 carries energy, not matter – the medium jiggles in place.

- **transverse** 横波: medium moves across the travel (string, light)
- **longitudinal** 纵波: medium moves along it, in compressions (sound)



Waves superpose to reinforce or cancel

2 Periodic waves

Periodic waves and polarization

The wave equation

$$v = f\lambda, \qquad f = \frac{1}{T}$$

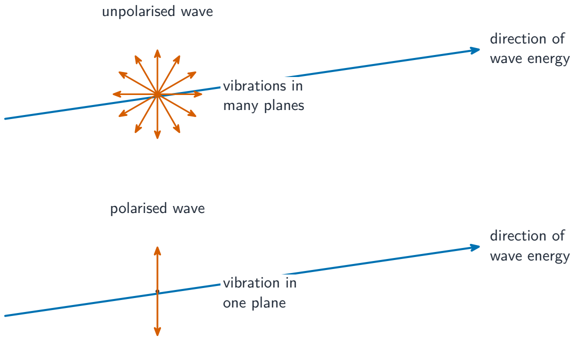
Speed is set by the medium: raise f and λ shrinks.

$170\,\mathrm{Hz}$ at $340\,\mathrm{m/s}$: $\lambda = 2\,\mathrm{m}$.

Polarization 偏振 works only on transverse waves – a filter passes one plane of vibration. Sound cannot be polarized.

Reflecting off a denser medium flips a wave over (inverted).

Boundary Behavior and Polarization



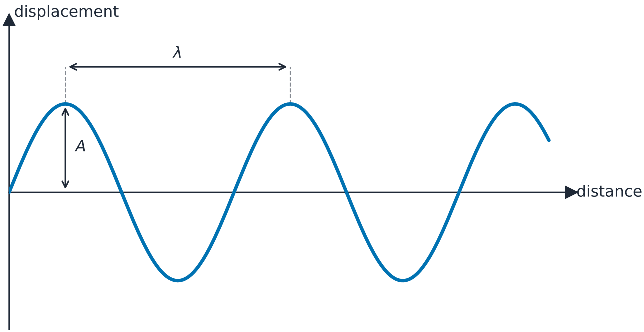
> Unpolarised waves vibrate in many planes; a polarised wave vibrates in one

Intensity, beats, and thin films

intensity 强度	the average power a wave delivers per unit area over one period, in $\mathrm{W/m^2}$
through a polarizer	$I = I_0 \cos^2\theta$ – unpolarised light loses half its intensity at the first polarizer
beats	two waves of slightly different frequency drift in and out of step, so the sound swells loud and soft at $\lvert f_1 - f_2 \rvert$
a thin film 薄膜	light reflecting off the top and bottom of a soap bubble or oil slick interferes with itself
what decides the colour	the film's thickness and the wavelength – which is why the colours shift as the film thins
an antireflection coating 增透膜	the same physics used deliberately: a layer that makes the two reflections cancel

A reflection off a denser medium adds a half-wavelength shift. Counting that extra half is what turns a thin-film question from guesswork into arithmetic.

Periodic Waves



A displacement-distance graph shows the amplitude and wavelength

The quantities that describe a periodic wave

wavelength λ	the distance between two successive identical points
period T	the time for one complete oscillation
frequency f	$1/T$ – oscillations per second, in hertz
amplitude A	the maximum displacement from equilibrium – it sets the energy, not the speed
the wave equation	$v = f\lambda$
what sets v	the medium, not the source – so changing f changes λ, and never v

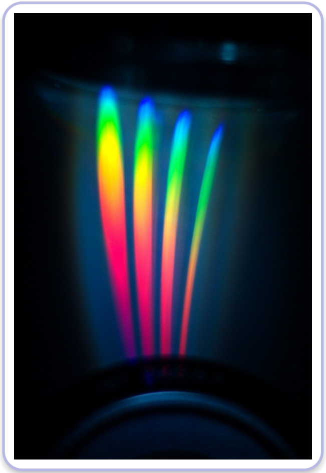
> When a wave crosses into a new medium, frequency is conserved and wavelength changes. Getting that the wrong way round inverts every refraction answer.

3 EM spectrum

The electromagnetic spectrum

An **electromagnetic wave** 电磁波 is oscillating E and B fields – no medium needed.

> All travel at $c = 3 \times 10^8\,\mathrm{m/s}$; they differ only in frequency.



Diffraction reveals the wave nature of

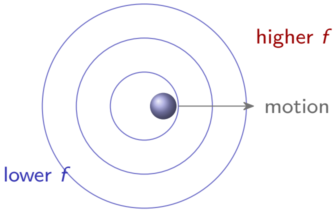
4 Doppler

The Doppler effect

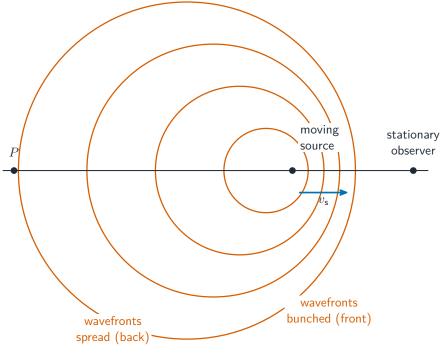
The **Doppler effect** 多普勒效应: the observed frequency shifts when source and observer move relatively.

- approaching $\Rightarrow$ bunched up, higher pitch
- receding $\Rightarrow$ stretched, lower pitch

> The **redshift** 红移 of galaxies is Doppler proof the universe expands.



A moving source squashes the wavefronts ahead of it



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

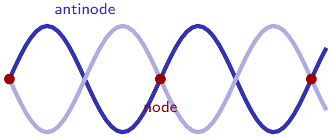
5 Interference

Interference and standing waves

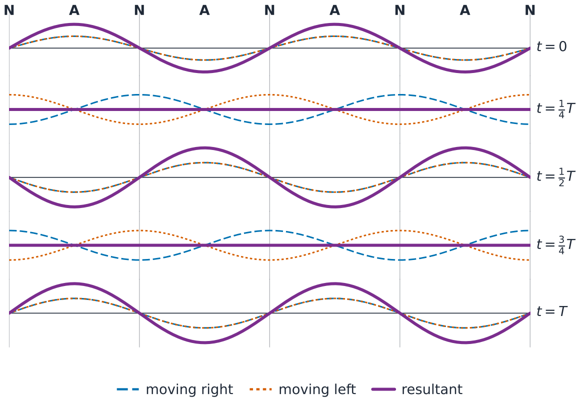
Overlapping waves add point by point (**superposition** 叠加原理):

- **constructive** 相长干涉: crest + crest $\Rightarrow$ bigger
- **destructive** 相消干涉: crest + trough $\Rightarrow$ cancel

> A **standing wave** 驻波 has fixed **nodes** 波节 and **antinodes** 波腹 – only certain wavelengths fit (musical notes).

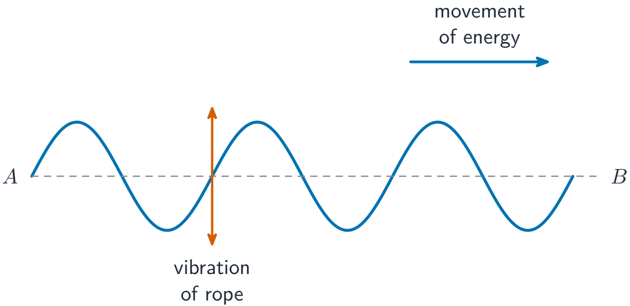


Wave Interference and Standing Waves



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

A transverse wave



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

6 Diffraction

Diffraction and the double slit

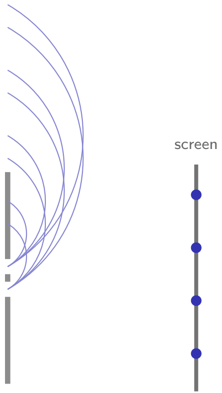
Diffraction 衍射: waves spread through gaps and around obstacles – most when the gap $\approx \lambda$.

Young's double slit – bright fringes

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

A **grating** 衍射光栅 (many slits) sharpens them into thin lines.

Thin-film 薄膜干涉 interference colours soap bubbles and oil slicks.



Intensity, and the antireflection coating

intensity 强度	the average power a wave delivers per unit area over one period, in W/m^2
through a polarizer	unpolarised light loses half; after that, $I = I_0 \cos^2 \theta$
a thin film	light reflecting off its top and bottom surfaces interferes with itself
what decides the colour	the film's thickness and the wavelength – which is why a soap bubble's colours shift as it thins
an antireflection coating 增透膜	the same physics used deliberately, on camera lenses, glasses and solar cells
how it works	a layer of chosen thickness makes the two reflections cancel, so more light is transmitted

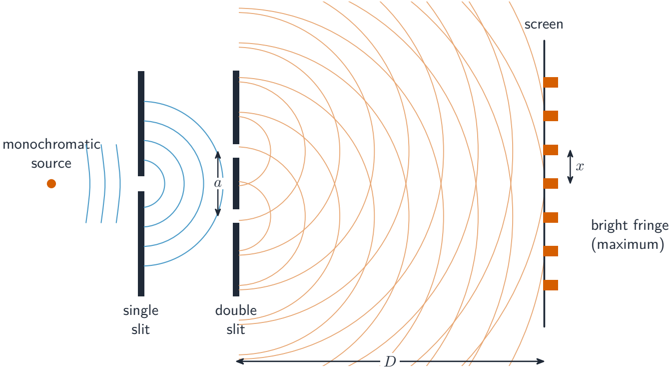
A reflection off a denser medium adds a half-wavelength shift. Counting that extra half turns a thin-film question from guesswork into arithmetic.

Describing a periodic wave, and how two waves add

the quantities	wavelength λ, period T, frequency $f = 1/T$, amplitude, and speed $v = f\lambda$
coherent 相干 sources	same frequency and a constant phase relationship – the condition for a stable interference pattern
constructive interference 相长干涉	path difference is a whole number of wavelengths; the amplitudes add
destructive interference 相消干涉	path difference is an odd number of half wavelengths; they cancel
beat frequency 拍频	$\lvert f_1 - f_2 \rvert$ – the slow swell when two close frequencies overlap
what sets v	the medium, not the source – so changing f changes λ

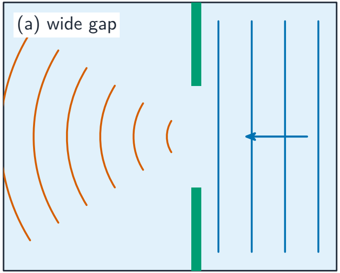
Every interference question reduces to a path difference in wavelengths. Work that out first and the constructive/destructive answer follows.

Double-Slit Interference and Diffraction Gratings

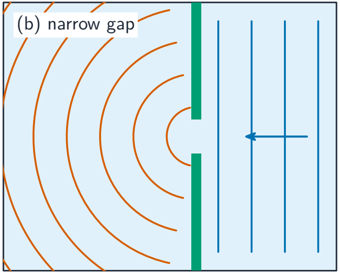


Young's double slits give an interference pattern of bright and dark fringes

Diffraction



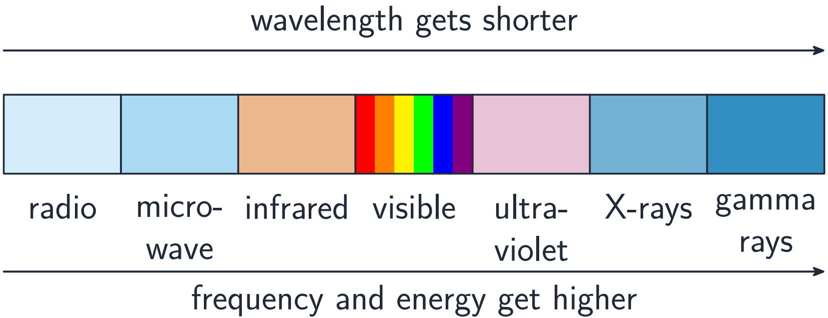
gap $\gg \lambda$: little spreading



gap $\approx \lambda$: strong spreading

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

Electromagnetic Waves



> The electromagnetic spectrum, from radio waves to gamma rays

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** ($\lambda = 2L$).

Exam tips (continued)

- **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.

7 Recap

Unit 14 – key takeaways

1 **Waves**

$v = f\lambda$; transverse vs longitudinal; only transverse polarize

2 **EM spectrum**

all travel at c; differ only in frequency

3 **Doppler**

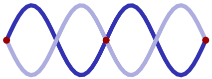
approach raises pitch; redshift shows expansion

4 **Interference**

standing-wave nodes; $d \sin\theta = m\lambda$ for the double slit

Check yourself

1. Double a wave's frequency in the same medium – what happens to λ?
2. Can sound be polarized?
3. A siren speeds toward you – higher or lower pitch?
4. What is a point that never moves on a standing wave called?



Answers **1.** it halves **2.** no **3.** higher **4.** a node