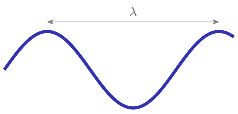
# Waves, Sound, and Physical Optics

AP Physics 2 ▪ Unit 14

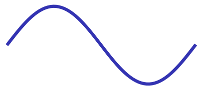
AP Physics 2






## What we will cover





# 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**

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

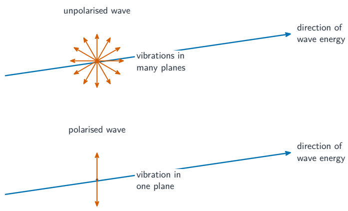
Speed is set by the medium: raise $f$ and $\lambda$ shrinks.

$170\,\mathrm{Hz}$ 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



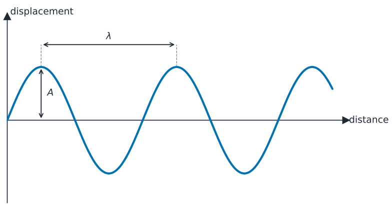
## Intensity, beats, and thin films

| | |
|---|---|
| **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 $\lambda$** | 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 $\lambda$, 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.

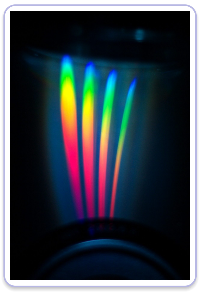
# 3 EM spectrum



## 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

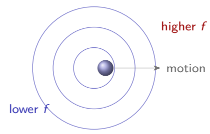


## The Doppler effect

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

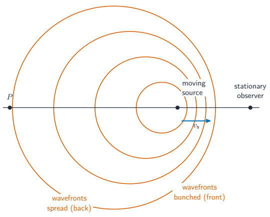
- approaching ⇒ bunched up, higher pitch
- receding ⇒ stretched, lower pitch

> 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

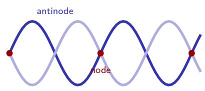


## Interference and standing waves

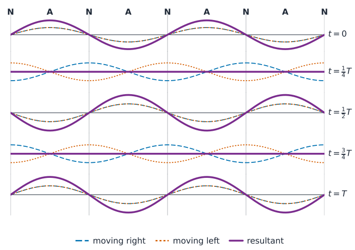
Overlapping waves add point by point (**superposition** 叠加原理):

- **constructive** 相长干涉: crest + crest ⇒ bigger
- **destructive** 相消干涉: crest + trough ⇒ cancel

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

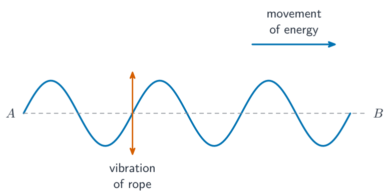



## Wave Interference and Standing Waves




> 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

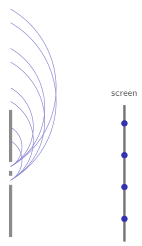
**Diffraction** 衍射: waves spread through gaps and around obstacles – most when the gap $\approx \lambda$.

**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.

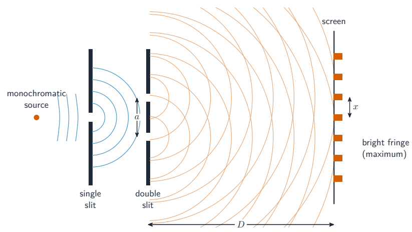


## Describing a periodic wave, and how two waves add

| | |
|---|---|
| **the quantities** | wavelength $\lambda$, 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 $\lambda$ |

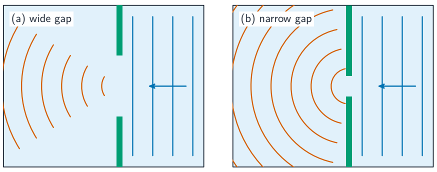
> Every interference question reduces to a path difference in wavelengths. Work that out first and the constructive/destructive answer follows.

## Double-Slit Interference and Diffraction Gratings




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

## Diffraction

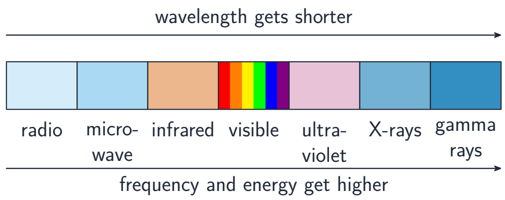



gap $\gg \lambda$: little spreading    gap $\approx \lambda$: strong spreading

> 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 $f_{beat} = |f_1 - f_2|$ (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

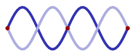
**2 EM spectrum**
all travel at $c$; differ only in frequency

**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 $\lambda$?
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