

Interference, resonance and the Doppler shift

AP Physics 2 (algebra-based) · Lesson

Quick answer: Physical optics explains light and sound as waves that add together. Where two waves arrive in phase they reinforce, and where they arrive half a cycle apart they cancel. The path difference decides the result: whole wavelengths give bright or loud, half wavelengths give dark or quiet. This explains double-slit fringes, thin-film colours, pipe resonance and the Doppler shift.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 14

What is interference of waves?

When two waves overlap, their displacements add. This is the principle of superposition. Where crest meets crest the wave is stronger, and where crest meets trough it is weaker. For two sources that vibrate in phase, the outcome at a point depends only on the *path difference*, the extra distance one wave travels compared with the other.

Definition

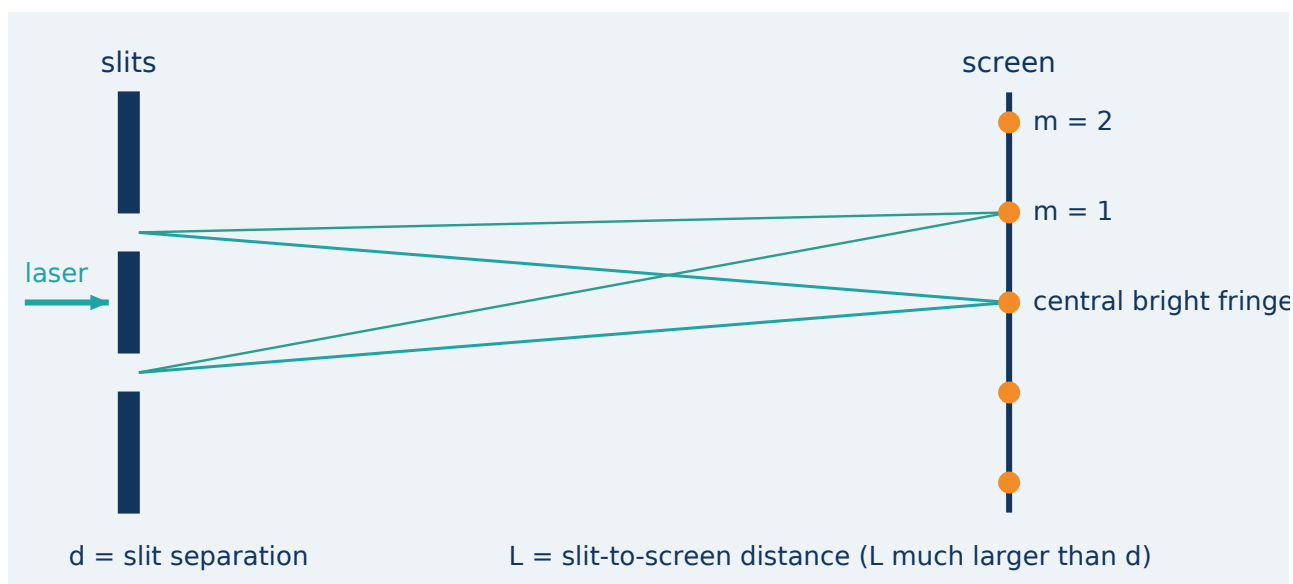
Interference is the combination of two coherent waves, which have the same frequency and a fixed phase relationship, into a pattern of strong and weak regions.

Key law

Constructive interference: path difference = $m\lambda$, with $m = 0, 1, 2...$ Destructive interference: path difference = $(m + \frac{1}{2})\lambda$. Each extra half wavelength flips the outcome.

How does a double slit make bright and dark fringes?

A laser lights two narrow slits. Each slit acts as a new source, and the two beams overlap on a distant screen. Waves reaching the central point travel equal distances, so they arrive in phase and the centre is bright. Moving sideways, the path difference grows until it equals one wavelength, giving the first-order bright fringe.



Double-slit set-up: bright fringes appear where the path difference is a whole number of wavelengths.

Formula

$$d \sin \theta = m\lambda \quad \Delta y \approx \lambda L / d$$

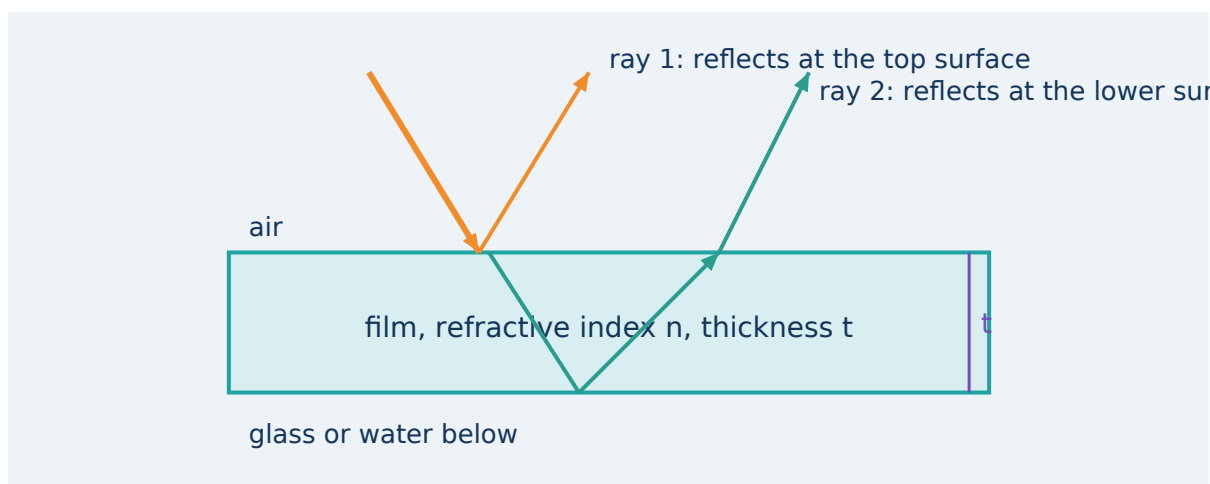
d is the slit separation (m), θ the angle to the fringe, m the order, λ the wavelength (m), L the slit-to-screen distance (m) and Δy the spacing between neighbouring bright fringes (m). The small-angle form needs L much larger than d .

Worked example

Aarav in Pune shines a laser of wavelength 600 nm through slits 0.20 mm apart onto a wall 2.0 m away. Data: $\lambda = 6.00 \times 10^{-7}$ m, $d = 2.0 \times 10^{-4}$ m, $L = 2.0$ m. Method: $\Delta y = \lambda L / d = (6.00 \times 10^{-7} \times 2.0) / (2.0 \times 10^{-4})$. Answer: $\Delta y = \mathbf{6.0 \times 10^{-3} \text{ m} = 6.0 \text{ mm}}$.

Why do thin films show colours?

A soap film or an oil slick reflects light from its top and bottom surfaces. The two reflected rays interfere. Ray 2 travels about $2t$ further, where t is the film thickness, and its wavelength inside the film is λ/n . A reflection off a medium of higher refractive index also flips the wave by half a cycle, like a pulse bouncing off a fixed end of a rope. Count these flips before you decide which condition applies.



Two reflected rays: ray 2 travels an extra distance of about $2t$ inside the film.

Common mistake

Students forget the phase flip. For a soap film in air, only the top reflection flips, so constructive reflection needs $2nt = (m + \frac{1}{2})\lambda$, not $2nt = m\lambda$. If both or neither reflections flip, the conditions swap back.

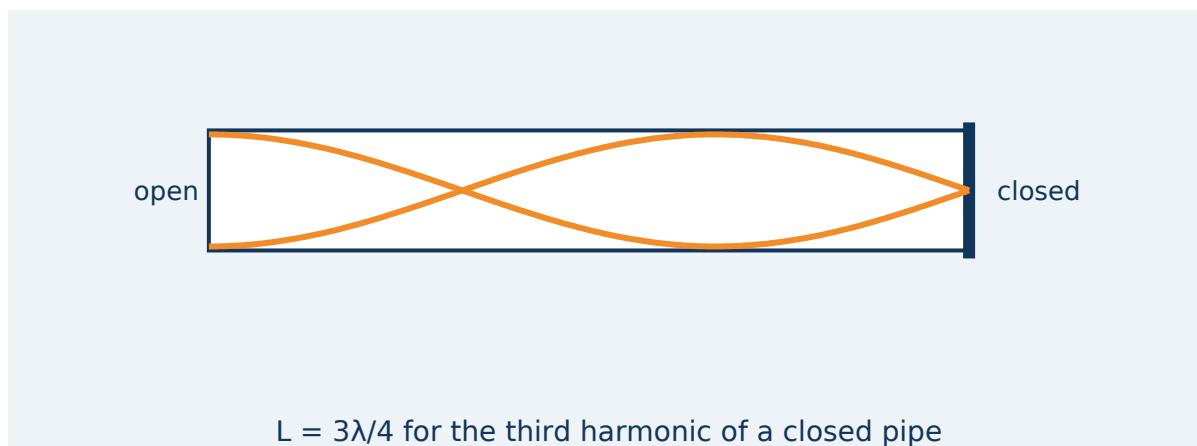
Worked example

A soap film ($n = 1.33$) in air is lit by green light of wavelength 550 nm. Data: only the top reflection flips, so the thinnest film that reflects strongly has $2nt = \lambda/2$. Method: $t = \lambda / (4n) = 550 / (4 \times 1.33)$. Answer: $t = \mathbf{103 \text{ nm}}$.

How do standing waves form in strings and pipes?

A wave reflected from the ends of a string or pipe overlaps with itself and forms a standing wave with fixed nodes and antinodes. Only wavelengths that fit the boundaries survive, so the instrument has a set of resonant frequencies.

System	Allowed wavelengths	Frequencies
String fixed at both ends	$\lambda = 2L / n$	$f = nv / 2L, n = 1, 2, 3...$
Pipe open at both ends	$\lambda = 2L / n$	$f = nv / 2L, n = 1, 2, 3...$
Pipe closed at one end	$\lambda = 4L / n, n \text{ odd}$	$f = nv / 4L, n = 1, 3, 5...$



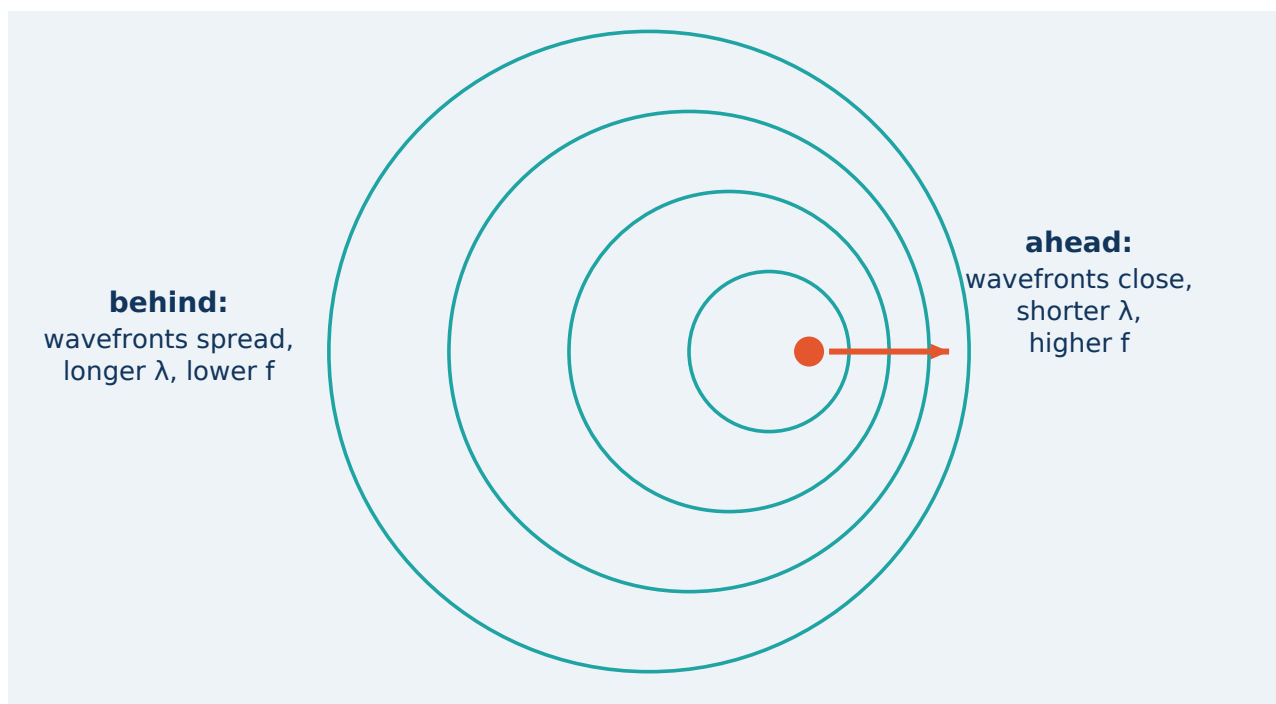
Third harmonic of a pipe closed at one end: three quarters of a wavelength fit in the length L .

Worked example

Kofi in Accra blows across a tube of length 0.40 m closed at one end; sound travels at 343 m/s. Method: $f_1 = v / 4L = 343 / (4 \times 0.40)$. Answer: $f_1 = \mathbf{214 \text{ Hz}}$. The next resonance is the third harmonic, $3f_1 = 643 \text{ Hz}$, because even harmonics are missing.

What does the Doppler effect do to frequency?

When a source moves through the medium, the wavefronts bunch up ahead of it and spread out behind it. A listener ahead hears a higher frequency and one behind hears a lower frequency. For a moving source and a stationary listener, $f' = f \cdot v / (v \mp v_s)$, with the minus sign for an approaching source.



Wavefronts from a moving source: compressed in front, stretched behind.

Worked example

An ambulance siren of 700 Hz moves toward a listener at 25 m/s. Sound travels at 343 m/s. Method: $f' = 700 \times 343 / (343 - 25) = 240\,100 / 318$. Answer: $\mathbf{755 \text{ Hz}}$. After it

passes, the denominator is $343 + 25 = 368$ and the pitch drops to 652 Hz.

Lina's tip

Before using any formula, sketch the two rays or the wavefronts. A quick drawing tells you whether the answer should be larger or smaller, which catches most sign errors.

Key points to remember

- Constructive interference: path difference = $m\lambda$; destructive: $(m + \frac{1}{2})\lambda$.
- Double slit: $d \sin \theta = m\lambda$ and fringe spacing $\Delta y \approx \lambda L / d$.
- Thin film: count phase flips, then use $2nt = m\lambda$ or $(m + \frac{1}{2})\lambda$.
- Closed pipe: $f = nv / 4L$ with odd n only; open pipe: $f = nv / 2L$.
- Moving source: $f' = f \cdot v / (v \mp v_s)$, higher when approaching.

Interference, resonance and the Doppler shift: frequently asked questions

What is the difference between constructive and destructive interference?

In constructive interference the waves arrive in phase and the amplitude grows. In destructive interference they arrive half a cycle apart and partly or fully cancel. The path difference decides which one occurs.

Why does the double-slit pattern get wider with red light than with blue light?

Fringe spacing is $\Delta y = \lambda L / d$, so it is proportional to wavelength. Red light has a longer wavelength than blue, so its fringes are further apart for the same slits and screen distance.

Why does a closed pipe have only odd harmonics?

A closed end must be a displacement node and an open end an antinode. Only an odd number of quarter wavelengths fits between the two, so the allowed frequencies are f , $3f$, $5f$ and so on.

When does a reflection flip the phase of a light wave?

A reflection flips the phase by half a cycle when light in a medium of lower refractive index hits a medium of higher refractive index. Reflection from a lower index medium causes no flip.

Does the Doppler effect change the speed of sound?

No. The speed of sound depends on the medium. Motion of the source changes the spacing of wavefronts, so the wavelength and frequency heard by the listener change while the speed stays the same.