Wave phenomena: the seven types, with examples, rules and the equations

A wave carries energy without carrying the material it travels through. Transverse: the vibration is at right angles to the travel (string, water surface, light). Longitudinal: along it (sound, a slinky). Wavelength λ, frequency f, period T = 1/f, amplitude, and v = f λ.

Phenomenon	What happens	Everyday example	Rule or equation
Reflection	the wave bounces off a surface	a mirror; an echo; a sea wall	angle of incidence = angle of reflection, both from the normal
Refraction	the wave changes direction when its speed changes, usually at a new medium	a bent-looking straw; a lens; a pool looking shallow	Snell's law n1 sin θ1 = n2 sin θ2; slower in the denser medium, bends toward the normal
Diffraction	the wave spreads out after an edge or a gap	hearing round a corner; waves through a harbour mouth	greatest when the gap is about one wavelength
Interference	two waves meet and add or cancel	soap-bubble colours; noise-cancelling headphones; Young's slits	constructive at whole-wavelength path differences, destructive at half; λ = ax/D
Polarisation	the vibration is restricted to one plane	polarised sunglasses; 3D cinema; LCD screens	only transverse waves; the proof that light is transverse
Doppler effect	the observed frequency changes as source or observer moves	a passing siren; redshift; radar speed guns	approaching: higher f, shorter λ; receding: the reverse
Standing waves	a wave and its reflection make fixed nodes and antinodes	a guitar string; an organ pipe; microwave hot spots	a string fixed at both ends fits whole numbers of half-wavelengths

The key numbers and relations

Relation	Use
v = f λ	every wave calculation before university; v in m/s, f in Hz, λ in m
T = 1/f	period from frequency and back
Echo distance = v × t / 2	sound at about 340 m/s in air: a 1 s echo means a wall 170 m away
n = c / v, n1 sin θ1 = n2 sin θ2	refractive index and Snell's law; total internal reflection when sin θc = n2/n1
λ = a x / D	Young's double slit: slit separation a, fringe spacing x, screen distance D
f_n = n v / 2L	a string fixed at both ends: the nth harmonic; a pipe open at one end f_n = n v / 4L, odd n only

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Wave or particle, the exam questions on each phenomenon, and a practice set

Phenomenon	Particles can do it?	Waves can?
Reflection	yes	yes
Refraction	yes (a different reason)	yes
Diffraction	no	yes
Interference	no	yes
Polarisation	no	yes, if transverse

Diffraction and interference are the two behaviours only a wave shows, which is why Young's 1801 double-slit experiment settled that light is a wave, and why the photoelectric effect (light arriving in lumps) a century later meant it is also a particle.

The standard exam question on each

[ ] Reflection: draw the normal and measure both angles from it; an echo-timing calculation
[ ] Refraction: draw the ray bending toward the normal into glass and away out of it; a Snell's law calculation; explain why the pool looks shallow
[ ] Diffraction: explain why sound bends round a doorway and light does not (the gap-to-wavelength ratio)
[ ] Interference: explain bright and dark fringes with path difference; calculate λ from fringe spacing
[ ] Polarisation: explain how sunglasses cut glare; state why sound cannot be polarised
[ ] Doppler: explain the siren's change of pitch; redshift as evidence of expansion
[ ] Standing waves: draw the first three harmonics on a string and label nodes and antinodes; find the frequency from the length

Practice

1. A water wave has frequency 2 Hz and wavelength 0.75 m. Find its speed.
2. An echo returns 0.6 s after a shout. How far away is the cliff? (v = 340 m/s)
3. Light enters glass (n = 1.5) from air at 40° to the normal. Find the angle of refraction.
4. Why can you hear a conversation through an open door but not see the speakers?
5. In a double-slit experiment the slits are 0.5 mm apart, the screen 2.0 m away and the fringes 2.4 mm apart. Find the wavelength.
6. Explain why only transverse waves can be polarised.
7. A string 0.8 m long fixed at both ends carries waves at 320 m/s. Find the fundamental frequency.
8. An ambulance siren sounds higher as it approaches. Explain with wavelength.

Answers

1. 1.5 m/s. 2. 102 m. 3. sin r = sin 40° / 1.5 = 0.4285, r = 25.4°. 4. Sound's wavelength (about 1 m) is close to the door width, so it diffracts strongly; light's wavelength is a million times smaller, so it barely spreads. 5. λ = ax/D = 0.5 × 10^-3 × 2.4 × 10^-3 / 2.0 = 6.0 × 10^-7 m (600 nm). 6. Polarisation restricts the vibration to one plane across the direction of travel; a longitudinal wave vibrates along the travel and has no such plane. 7. λ = 2L = 1.6 m, f = v/λ = 200 Hz. 8. The waves ahead of the moving source are bunched: shorter wavelength, so higher frequency and pitch; behind, stretched and lower.