TOPIC C.5 · SL & HL · THEME C WAVE BEHAVIOUR

Doppler effect cheatsheet

Why a siren changes pitch as it passes, the HL sound formulas, redshift and the real-world uses. Red pen = what I'd tell you in class.

Paper 1 & Paper 2 | HL: sound formulas | 7 worked examples

approaching = higher, receding = lower ↓

Relative motion shifts the frequency
approach: f′ > f recede: f′ < f wave speed unchanged

① The effect	② Sound (HL)	③ Light	④ Uses
relative motion changes f and λ	moving source: $v/(v \mp u_s)$ moving observer: $(v \pm u_o)/v$	$\Delta f/f \approx \Delta\lambda/\lambda \approx v/c$ red and blue shift	radar, ultrasound galaxies, rotating stars

source or observer, never mix them

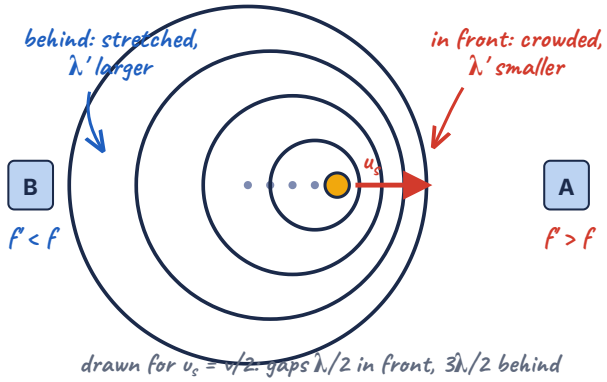
light: v ≪ c, one formula

1 The Doppler effect *relative motion changes f*

SL/HL · P1 & P2

wave speed never changes, only how the crests are spaced

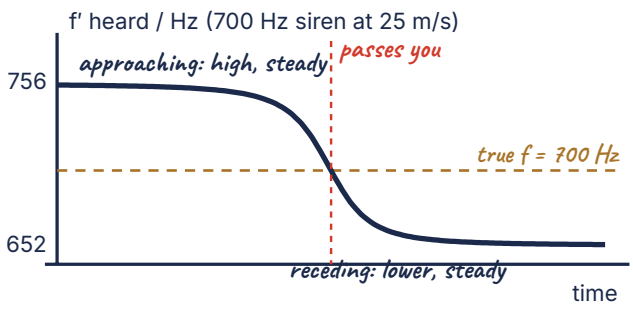
When a source and an observer move relative to each other, the observed frequency f′ is different from the emitted f. Closing in raises it; moving apart lowers it.



	in front of source	behind source
wavelength	compressed, λ′ < λ	stretched, λ′ > λ
frequency	higher, f′ > f	lower, f′ < f
wave speed	unchanged: set by the medium	

TWO WAYS TO SEE IT

Geometry: crests bunch up ahead of a moving source and spread out behind it. **Timing:** crests arrive more often than sent (approach) or less often (recede). Same result.



Train passing: constant high pitch, a sharp drop as it goes by, then constant low.

Trap. A moving **observer** does not change the wavelength in the air. They just meet the crests faster or slower. The siren driver hears no change.

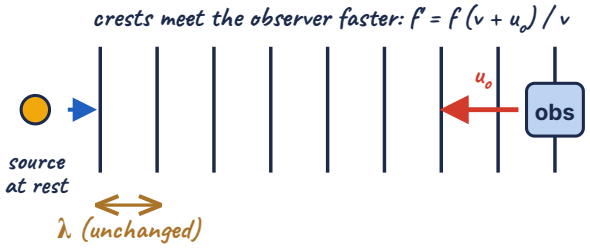
2 Doppler formulas for sound *HL only*

HL · P1 & P2

HL FORMULAS (IN BOOKLET)

	towards	away
moving source	$f' = f\dfrac{v}{v - u_s}$	$f' = f\dfrac{v}{v + u_s}$
moving observer	$f' = f\dfrac{v + u_o}{v}$	$f' = f\dfrac{v - u_o}{v}$

v = speed of sound in the medium, u_s = source speed, u_o = observer speed, both relative to the air. Moving source: $\lambda' = (v \mp u_s)/f$.



wavelength in the air is the same, only the catch rate changes

WORKED EXAMPLE · MOVING SOURCE

An ambulance siren of 700 Hz moves at 25 m s^{-1}. v = 340 m s^{-1}. Find f′ as it approaches and as it recedes.

1. Towards: f′ = 700 × 340 / (340 − 25) = **756 Hz**
2. Away: f′ = 700 × 340 / (340 + 25) = **652 Hz**

check: approach gives f′ > 700, recede f′ < 700

WORKED EXAMPLE · MOVING OBSERVER

A car moves at 20 m s^{-1} towards a fixed 600 Hz siren. Find f′, and f′ when it drives away.

1. Towards: f′ = 600 × (340 + 20)/340 = **635 Hz**
2. Away: f′ = 600 × (340 − 20)/340 = **565 Hz**

THE METHOD (EVERY TIME)

1. **Who moves?** The source or the observer, never both.
2. **Towards or away?** Towards means f′ must come out bigger.
3. **Pick the formula** from the table, then substitute.
4. **Sense-check** against step 2.

WORKED EXAMPLE · FIND THE SPEED

A cyclist moving away from a fixed 800 Hz siren hears 760 Hz. Find the cyclist's speed (v = 340 m s^{-1}).

1. Observer away: f′ = f (v − u_o)/v, so u_o = v (1 − f′/f)
2. u_o = 340 × (1 − 760/800) = **17 m s^{-1}**

Sign check. Towards means f′ goes **up**. Source towards: subtract u_s in the denominator. Observer towards: add u_o in the numerator. Then check f′ > f for approach.

Trap. The two formulas give **different** answers for the same speed. Treat a moving source and a moving observer separately and never mix them.

WORKED EXAMPLE · REFLECTION (DONE TWICE)

A 500 Hz sound reflects off a car moving at 10 m s^{-1} straight towards the source. What frequency returns?

1. Car as moving observer: f_1 = 500 × (340 + 10)/340 = 514.7 Hz.
2. Car as moving source of f_1: f_2 = 514.7 × 340/(340 − 10) = **530 Hz**

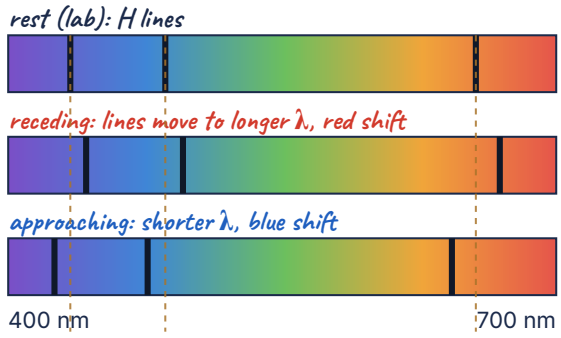
Fractions of v

Speeds often come as v/4 or v/10. Stay algebraic: u_s = v/4 towards gives f′ = f / (1 − ¼) = 4f/3. → *v cancels, so you don't need its value.*

3 Doppler effect for light *red shift and blue shift*

SL/HL · P1 & P2

For EM waves at speeds much less than c, there is no source-versus-observer difference and one formula covers both. Spectral lines from a receding source move to **longer** wavelength.



Hydrogen lines at 656, 486 and 434 nm. Every line moves by the same fraction.

FORMULAS (V ≪ C)

$$\frac{\Delta f}{f} \approx \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$$ in booklet

$v = c\,\Delta\lambda / \lambda$ recession speed

	Blue shift	Red shift
motion	approaching	receding
λ observed	shorter	longer
f observed	higher	lower
example	Andromeda	distant galaxies

WORKED EXAMPLE · A GALAXY

A hydrogen line of rest wavelength 656 nm is seen at 662 nm. How fast is the galaxy moving, and which way?

1. Δλ = 662 − 656 = 6 nm, and the line is at a **longer** wavelength: red shift, so it is **receding**.
2. $v = c\,\Delta\lambda/\lambda = 3.00 \times 10^8 \times 6/656 =$ **2.7×10^6 m s^{-1}**

Trap. The v/c formula is for light and v ≪ c only. For sound use the HL source and observer formulas. And since fλ = c, |Δf|/f = |Δλ|/λ to first order, so use either one.

Spot a real Doppler shift. All lines move by the same fraction. Line shifted right (longer λ) = red = receding.

4 Applications *name the wave, pick the formula*

SL/HL · P1 & P2

WHERE IT IS USED

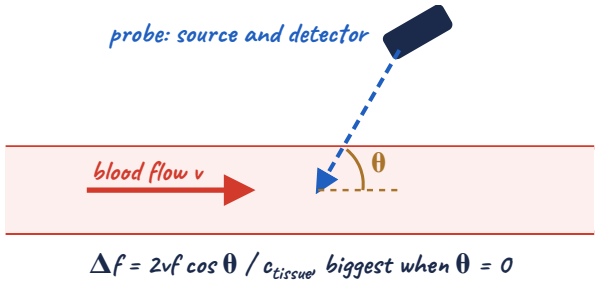
radar speed gun	microwaves reflect off a moving car, $\Delta f \approx 2vf/c$ (double shift)
medical ultrasound	sound off moving blood cells gives the flow speed
galaxies	red shift of distant galaxies: the universe is expanding (Big Bang evidence)

WORKED EXAMPLE · RADAR GUN

A 24 GHz radar gun measures a shift Δf for a car at 30 m s^{-1}. Find Δf.

1. $\Delta f = 2vf/c = 2 \times 30 \times 24 \times 10^9 / 3.00 \times 10^8$
2. Δf = **4.8 kHz**

the 2: the car receives, then re-emits



WORKED EXAMPLE · ULTRASOUND

A 5.0 MHz beam meets blood at 0.50 m s^{-1}, θ = 60° to the flow. c_{tissue} = 1540 m s^{-1}. Find Δf.

1. $\Delta f = 2vf \cos\theta / c = 2 \times 0.50 \times 5.0 \times 10^6 \times 0.50 / 1540$
2. Δf = **1.6 kHz**

THREE MORE ASTRONOMY EFFECTS

- **Cosmological red shift:** space itself stretches the light's wavelength in transit.
- **Rotating star:** one limb approaches (blue), the other recedes (red). The split gives the rotation speed, and is twice the single-limb shift.
- **Doppler broadening:** thermal motion smears each line. Hotter gives wider lines.

5 Which formula? Exam attack plan *match the trigger*

SL/HL · P1 & P2

When the question says	Reach for
moving **source**, find f′	$f' = f\, v/(v \mp u_s)$: minus when approaching
moving **observer**, find f′	$f' = f\,(v \pm u_o)/v$: plus when approaching
wavelength from a moving source	$\lambda' = (v \mp u_s)/f$
find a speed from f and f′	rearrange the matching formula
sound off a moving wall or car	use the formula twice (observer, then source)
light from a star or galaxy	$\Delta\lambda/\lambda \approx v/c$, so $v = c\,\Delta\lambda/\lambda$
red shift or blue shift?	compare λ observed with λ rest
radar speed gun	$\Delta f = 2vf/c$ (the factor of 2)
ultrasound blood flow	$\Delta f = 2vf\cos\theta / c_{tissue}$
"why are the lines shifted?"	relative motion, so the Doppler effect

Name the wave first

Sound or ultrasound? Microwave or light? The wave type decides the formula before you touch a calculator. → *sound: v/(v ± u). light: v/c.*

Never write "the speed of the wave changes". Only f and λ do.

Before you move on from a Doppler question

- ✓ Sound or light? Sound needs the source/observer formulas, light uses v/c.
- ✓ Fix the sign: towards must give f′ > f.
- ✓ Fractions of v: stay algebraic and let v cancel.
- ✓ Longer observed λ = red shift = receding.
- ✓ Source moving or observer moving? Never both at once.
- ✓ Speed of the wave is unchanged by the motion.
- ✓ Reflection off a moving object: apply the formula twice.
- ✓ Radar and ultrasound: do not forget the factor 2.