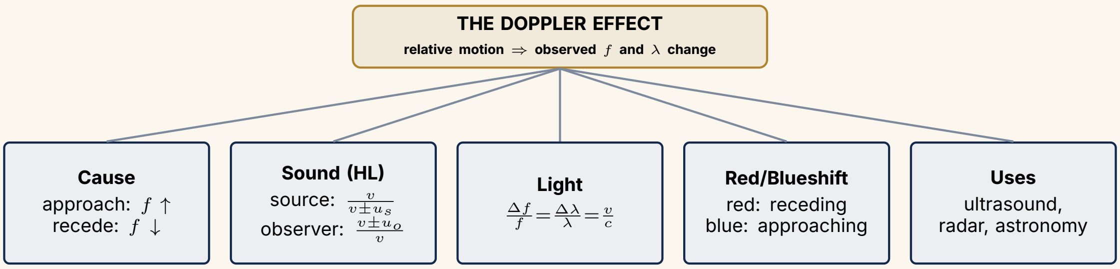
Topic C.5

THE DOPPLER EFFECT

Every Formula, Trick & Trap on a Page
& IB-Style Quick Reference

Topics Covered	Exam Relevance
The Doppler effect	P1 & P2 (SL + HL)
Doppler for sound (HL)	$f' = fv/(v \mp u_s)$
Doppler for EM waves	$\Delta f/f \approx v/c$
Red & blueshift	Spectral-line shifts
Radar, ultrasound, Hubble	$\Delta f = 2vf/c$

The Big Picture — How C.5 Fits Together



§1 — The Doppler Effect

C.5 (SL–HL)

Definition

The **Doppler effect**: observed frequency changes when source and observer move *relative to each other.*

- Approaching ⇒ $f' > f$ (higher frequency, shorter λ)
- Receding ⇒ $f' < f$ (lower frequency, longer λ)
- Speed of sound in medium: **unchanged** by source or observer motion

Wavefront Summary

	In front of source	**Behind source**
Wavelength	Compressed ($\lambda' < \lambda$)	Stretched ($\lambda' > \lambda$)
Frequency	Higher ($f' > f$)	Lower ($f' < f$)
Speed of sound	Same as stationary	Same as stationary

NOTE For a moving source: the medium has compressed wavefronts in front, stretched behind. For a moving observer: wavefront spacing is unchanged — only the rate of interception differs.

TRICK **Two ways to see the shift:** (1) *geometry* — crests bunch in front, spread behind; (2) *timing* — crests arrive more/less often than sent. Same result, pick whichever the question gives.

§2 — Doppler Formulae for Sound

C.5 (HL Additional)

Moving Source Formula (HL)

Source towards observer: $f' = f\cdot\dfrac{v}{v-u_s}$

Source away from observer: $f' = f\cdot\dfrac{v}{v+u_s}$

Emitted wavelength (source towards): $\lambda' = \dfrac{v-u_s}{f}$

Emitted wavelength (source away): $\lambda' = \dfrac{v+u_s}{f}$

Moving Observer Formula (HL)

Observer towards source: $f' = f\cdot\dfrac{v+u_o}{v}$

Observer away from source: $f' = f\cdot\dfrac{v-u_o}{v}$

v = speed of sound in medium; u_s = source speed; u_o = observer speed

TRICK TOWARDS = f goes UP. Moving source towards: *subtract* u_s from denominator. Moving observer towards: *add* u_o to numerator. Always check: approach ⇒ answer $> f$; recede ⇒ answer $< f$.

FROM THE PHOTON QUESTION BANK

Fix the sign *first*, then substitute. Speeds often come as a fraction of v (e.g. $u_s = v/4$) — stay algebraic. Reflection off a cliff/wall/car applies the formula **twice**: reflector as observer, then as source.

TRICK **Source vs. observer:** moving *source* changes λ in the medium (denominator moves); moving *observer* leaves λ alone, just samples faster (numerator moves). Ask: is the wavelength in the air actually changed?

TRAP IB problems will NEVER have both source AND observer moving simultaneously. It is always one or the other. The two formulas give *different* numerical answers for the same u — do not mix them up.

NOTE To find speed from observed frequency: rearrange the formula. E.g. moving observer away: $u_o = v\left(1 - \frac{f'}{f}\right)$.

§3 — Doppler Effect for Electromagnetic Waves

C.5 (SL–HL)

Light Doppler Formulae (non-relativistic: $v \ll c$)

Fractional frequency shift: $\dfrac{\Delta f}{f} \approx \dfrac{v}{c}$

Fractional wavelength shift: $\dfrac{\Delta\lambda}{\lambda} \approx \dfrac{v}{c}$

Recession velocity: $v = c \cdot \dfrac{\Delta\lambda}{\lambda}$

Radar (double shift): $\Delta f \approx \dfrac{2vf}{c}$

Redshift and Blueshift

	Blueshift	**Redshift**
Relative motion	Approaching	Receding
$\Delta\lambda$	Negative ($\lambda_{\text{obs}} < \lambda_{\text{rest}}$)	Positive ($\lambda_{\text{obs}} > \lambda_{\text{rest}}$)
Δf	Positive ($f_{\text{obs}} > f_{\text{rest}}$)	Negative ($f_{\text{obs}} < f_{\text{rest}}$)
Astronomical example	Andromeda galaxy (approaching)	Distant galaxies (Hubble)

TRICK Spectral line shift: compare observed line position with rest wavelength. If line shifted RIGHT (longer λ) $\Rightarrow$ redshift $\Rightarrow$ receding. If shifted LEFT $\Rightarrow$ blueshift $\Rightarrow$ approaching.

FROM THE PHOTON QUESTION BANK

Every line shifts by the *same fractional* amount — that is how you spot a genuine Doppler shift on a spectrum. Longer λ_{obs} than λ_{rest} = redshift = receding.

TRAP The fractional shift formula $\Delta f/f = v/c$ applies to *both* frequency and wavelength, and gives the same v. But $\Delta f/f \neq \Delta\lambda/\lambda$ in absolute values — they are related by $\Delta f/f = \Delta\lambda/\lambda$ because $f\lambda = c$ gives $\Delta f/f + \Delta\lambda/\lambda = 0$ to first order, so $|\Delta f|/f = |\Delta\lambda|/\lambda$.

§4 — Applications

C.5 (SL–HL)

Key Applications

- **Train through station:** constant high f' approaching, sharp drop as it passes, constant low f' receding.
- **Radar speed gun:** microwaves reflect off moving car (double shift); $\Delta f = 2vf/c$ gives speed.
- **Medical ultrasound:** sound reflects off moving blood cells; shift gives blood flow speed.
- **Stellar/galactic motion:** spectral line shift gives recession/approach velocity.
- **Hubble expansion:** all distant galaxies redshifted $\Rightarrow$ universe is expanding (evidence for the Big Bang).

Astronomy — Three More Effects

- **Cosmological redshift:** model space itself as expanding — the light's wavelength is *stretched* in transit, giving the redshift.
- **Rotating star/Sun:** one limb approaches (blueshift), the opposite limb recedes (redshift); the split fixes the rotation speed.
- **Doppler broadening:** thermal motion gives a *range* of atomic speeds, smearing each spectral line; higher temperature $\Rightarrow$ wider line.

NOTE For medical ultrasound, the probe is both source and detector. The formula for the frequency shift is $\Delta f = 2vf\cos\theta/c_{\text{tissue}}$, where θ is the angle between beam and flow direction. At $\theta = 0$, maximum shift.

FROM THE PHOTON QUESTION BANK

Name the wave type (sound/ultrasound vs microwave/light) — it decides the formula. For a rotating body the split between the two limbs is *twice* the single-limb shift.