IB DP PHYSICS · THEME C WAVE BEHAVIOUR · C.5 · ~5 MIN READ

C.5 Doppler effect

The Doppler effect for sound and light, wavefront diagrams for a moving source, redshift and blueshift of spectral lines as evidence for moving stars and galaxies, and (HL) the moving-source and moving-observer equations for sound.

Doppler effect | Wavefront diagrams | Redshift & blueshift | Δf/f ≈ v/c | Moving source (HL) | Moving observer (HL)

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No tag = **SL and HL** HL ONLY HL students only DATA BOOKLET given in the exam

M1 A1 how marks are awarded highlight = comes up again and again Test yourself at the end

IN 30 SECONDS

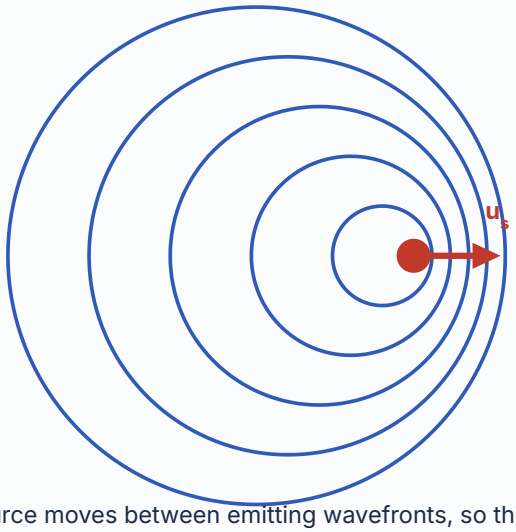
- The **Doppler effect** is the change in observed frequency and wavelength when the source and observer move relative to each other.
- Approaching: higher frequency, shorter wavelength. Moving apart: lower frequency, longer wavelength.
- For light ($v \ll c$): **$\Delta f/f = \Delta\lambda/\lambda \approx v/c$**. Spectral lines from receding galaxies are **redshifted**, the key evidence for the expanding universe.
- **HL:** for sound, $f' = f\, v/(v \pm u_s)$ for a moving source and $f' = f(v \pm u_o)/v$ for a moving observer.

BY THE END YOU CAN

- Describe the Doppler effect for sound and EM waves with wavefront diagrams.
- Use $\Delta f/f = \Delta\lambda/\lambda \approx v/c$ for light.
- Explain redshift and blueshift as evidence for the motion of stars and galaxies.
- Use the Doppler equations for a moving source and a moving observer of sound. HL

1 What the Doppler effect is

behind:
λ longer,
f lower



in front:
λ shorter,
f higher

The source moves between emitting wavefronts, so they bunch up ahead of it.

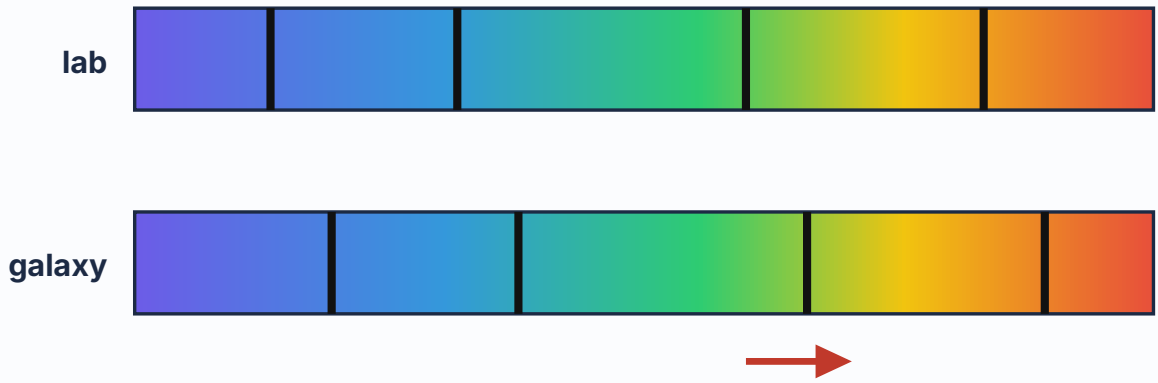
Each circle was emitted from where the source was at that moment.

- **Why:** the wave speed through the medium does not change, but a moving source emits each wavefront from a new position, so the wavefronts are closer together ahead of it. A moving observer meets wavefronts more often (or less often).
- **Everyday examples:** the falling pitch of a passing siren or racing car; police radar; ultrasound measuring blood flow.

2 Light: redshift and blueshift

$$\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$$ DATA BOOKLET

for EM waves when v is much less than c; v is the relative speed



Lines shifted to longer wavelength: the galaxy is moving away (redshift).

The pattern of lines is the same, just shifted. That proves it is the same element, moving.

WORKED EXAMPLE

The hydrogen line at 656.3 nm is observed at 662.0 nm in a galaxy's spectrum. Find the galaxy's speed and direction.

1. $\Delta\lambda = 662.0 - 656.3 = 5.7$ nm A1
2. $v = c\Delta\lambda/\lambda = 3.00 \times 10^8 \times 5.7/656.3$ M1
3. **$= 2.6 \times 10^6$ m s^{-1}, moving away (redshift)** A1

- **Evidence from astronomy:** distant galaxies are redshifted, and more distant ones more strongly: the universe is expanding. Binary stars show lines that shift back and forth as the stars orbit each other.

COMMON MISTAKE

Mixing up $\Delta\lambda$ and λ. $\Delta\lambda$ is the **change** (observed − emitted); λ is the emitted (lab) wavelength.

3 Sound: the Doppler equations HL

$$f' = f\frac{v}{v \pm u_s}$$ DATA BOOKLET

moving source: − when approaching, + when receding

$$f' = f\frac{v \pm u_o}{v}$$ DATA BOOKLET

moving observer: + when approaching, − when receding

WORKED EXAMPLE

A siren of 500 Hz moves at 30 m s^{-1} (v = 340 m s^{-1}). Find the frequency heard as it approaches and as it moves away.

1. approaching: f′ = 500 × 340/(340 − 30) = **548 Hz** M1 A1
2. **receding: f′ = 500 × 340/(340 + 30) = 460 Hz** A1

WORKED EXAMPLE

A cyclist rides at 20 m s^{-1} towards a stationary 500 Hz source. What frequency does she hear?

1. $f' = f(v + u_o)/v = 500 \times 360/340$ M1
2. **= 529 Hz** A1

MEMORY TRICK

Sign check: approaching must always give a **higher** frequency. Pick the sign that does that, and you never need to memorise the table.

EXAM TIP

In a "sketch how the frequency heard changes" question for a passing source: a constant high frequency while approaching, a sudden drop as it passes, then a constant low frequency (if the source moves in a straight line through you).

LINKING QUESTION

Redshift data feed into E.5 (stars and the universe). The relativistic Doppler effect and time dilation in A.5 are linked, but only the $v \ll c$ approximation is needed here.

IDEA FOR YOUR IA / EXPLORATION

Record a moving sound source (a buzzer on a rotating arm or a passing car) with a phone app, measure the frequency shift and deduce the speed, then compare with a direct measurement.

Test yourself — cover the answers first

QUICK CHECK

1. Does the speed of sound change when the source moves?
2. What is redshift?
3. Why do spectral lines give strong evidence for galaxy motion?
4. A star's line shifts to a shorter wavelength. Is it approaching or receding?
5. HL Which gives the bigger frequency change: source or observer moving at the same speed towards each other?

EXAM-STYLE

6. A star's spectral line at 500.0 nm (lab) is observed at 499.5 nm. Find its speed.
7. HL A train horn is heard at 520 Hz as the train approaches and 480 Hz as it leaves (v = 340 m s^{-1}). Find the train's speed.

Show answers

1. No: frequency and wavelength change, not the wave speed in the medium.
2. an increase in the observed wavelength because the source is moving away
3. the same pattern of lines is shifted, so it is the same element moving
4. approaching (blueshift)
5. the moving source (slightly larger)
6. $\Delta\lambda = -0.5$ nm
   $v = c \times 0.5/500$
   $= \mathbf{3.0 \times 10^5\ m\ s^{-1}}$ **towards us**
7. $520(340 - u) = 480(340 + u)$
   $176\,800 - 520u = 163\,200 + 480u$
   $u = 13\,600/1000 = \mathbf{13.6\ m\ s^{-1}}$

Stuck on a question?

Send it to me on WhatsApp. I read every message.

Want regular help? Send this to your parent →

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Ask Riyaz Sir