

# Doppler effect

International Baccalaureate · IB Diploma · Physics · HL

## Scope and prerequisites

This handout covers selected HL topics for the course first assessed in 2025; it is not the whole syllabus.

Prerequisites: read the stated quantities and units, and use arithmetic and the model conditions below.

The examples are original and fictional: they are not real measurements or real student investigations.

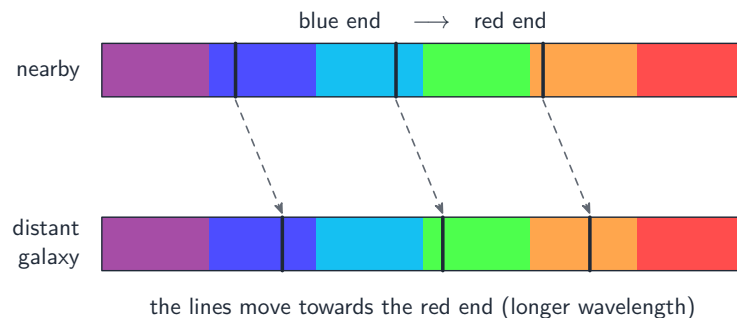
## Spectral shifts: a low-speed astronomical estimate

### ■ What would explain this observation?

- A recognizable spectral line appears at a longer wavelength in a distant source. Its shift can provide evidence of recession along the line of sight.

### ■ Build the model

- Relative source-observer motion changes observed frequency or wavelength.
- For light at a relative speed much smaller than  $c$ , the magnitude of the fractional wavelength shift is approximately  $v/c$ .
- Recession corresponds to longer wavelength, and approach to shorter wavelength.
- **redshift** : Shift of an identified line toward longer wavelength.
- **rest wavelength** : Wavelength of the line measured with no relative source motion.



*Every line shifts towards longer wavelength:  $z = \Delta\lambda/\lambda$ , and  $v \approx cz$  at low speed*

### ■ Choose evidence that can test it

- Compare a identified line with its laboratory rest wavelength.
- Use  $z = (\text{observed} - \text{rest})/\text{rest}$ , then  $v$  approximately  $cz$  in the stated low-speed model.
- Do not apply this approximation without checking the regime or treating a cosmological redshift as a simple exact velocity.

**In the lab:** Use attributed spectra with calibration and line identification. Compare several lines for a consistent shift. State uncertainty and distinguish relative line-of-sight motion from an unmeasured transverse component.

### ■ Work from known quantities

- Known: a 500 nm rest line is observed at 501 nm.  $z = (501 - 500)/500 = 0.002$ .
- With  $c = 3.0 \times 10^8$  m/s,  $v$  approximately  $6.0 \times 10^5$  m/s away.
- The sound-source denominator formula is not the required SL light approximation.

**Your turn:** A 600 nm rest line is observed at 601.2 nm. Find  $z = (\text{observed} - \text{rest})/\text{rest}$ .

### ■ Check the conclusion and its limits

- The approximate shift relation does not show that light travels faster from an approaching source.
- A single unidentified line cannot safely establish a redshift.

**Not true:** An observed redshift means light speed increased. Light speed in vacuum is the same for all observers. Redshift is a change in observed wavelength from relative motion (or expanding space), not light travelling faster or slower.

### Key:

- Relative source-observer motion changes observed frequency or wavelength.
- Compare a identified line with its laboratory rest wavelength.
- Watch for: the approximate shift relation does not show that light travels faster from an approaching source.

### ■ Write from a redshift of 0.004

- A 400 nm rest line is observed at 401.6 nm.
- Find  $z$ . Redshift does not mean the speed of light increased.

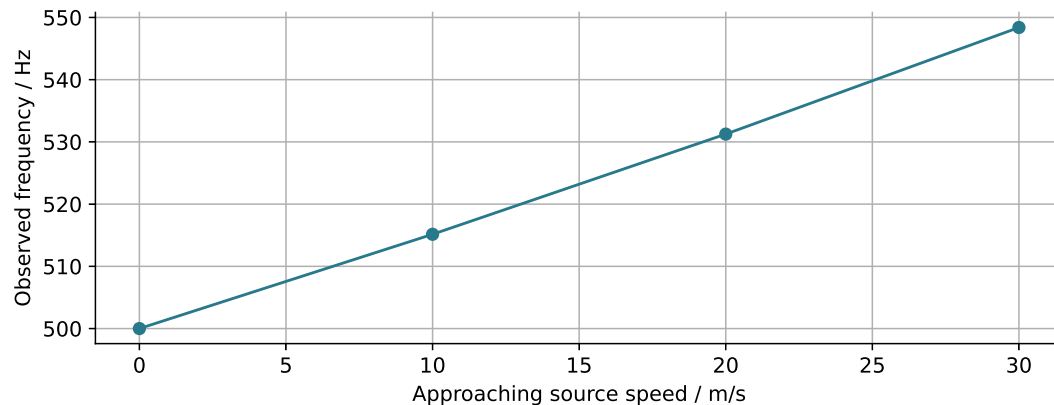
## Doppler effect: separate source motion from wave speed

### ■ What would explain this observation?

- An approaching sound source is heard at a higher pitch even when the source produces a constant frequency.

### ■ Build the model

- **Doppler shift** arises from relative source-observer motion.
- A moving source compresses **wavefront** spacing ahead and increases it behind.
- For sound in a stationary medium, the wave speed relative to that medium need not change.
- Doppler shift: Change of observed frequency due to relative motion.
- wavefront: A surface joining points with the same wave phase.



*An approaching source is heard higher:  $f = f \cdot v/(v - u) = 500 \times 340/330 \approx 515 \text{ Hz}$  at 10 m/s*

### ■ Choose evidence that can test it

- For a source approaching a stationary observer along the line of sight,  $f_{\text{observed}} = f_{\text{source}} \times v/(v - v_{\text{source}})$ .
- Recession uses  $v + v_{\text{source}}$  in the denominator.
- These are sound-wave models; light requires its appropriate relation.

**In the lab:** Use a simulation or recorded data with stated source and observer directions. Draw wavefronts before choosing signs. Avoid demonstrations near moving traffic or unsafe high-volume sources.

### ■ Work from known quantities

- Known: source frequency 500 Hz, sound speed 340 m/s, source approaches at 20 m/s.
- Observed frequency =  $500 \times 340/(340 - 20) = 531.25 \text{ Hz}$ .
- The increase is 31.25 Hz; it is not the source frequency changing.

**Your turn:** A 600 Hz source approaches a stationary observer at 20 m/s. Use  $v = 340 \text{ m/s}$ . Find observed frequency.

### ■ Check the conclusion and its limits

- A stationary source and moving observer require the observer-motion relation.
- Do not use the same denominator formula for every arrangement or import a sound formula into relativity.

**Not true:** The Doppler effect always means the wave speed in the medium changed. The wave speed in the medium is fixed by the medium. The Doppler shift comes from relative motion changing the spacing of wavefronts (moving source) or the rate they meet the observer (moving observer) - not from a change in wave speed.

### Key:

- Doppler shift arises from relative source-observer motion.
- For a source approaching a stationary observer along the line of sight,  $f_{\text{observed}} = f_{\text{source}} \times v/(v - v_{\text{source}})$ .
- Watch for: A stationary source and moving observer require the observer-motion relation.

### ■ Write from an observed frequency of 510 Hz

- A 450 Hz source approaches a stationary observer at 40 m/s. The wave speed is 340 m/s.
- Find the observed frequency. The wave speed in the medium does not change.

### ■ Write from a blue shift of 0.001

- A 600 nm rest line is observed at 599.4 nm.
- $z = (599.4 - 600) \div 600 = -0.001$ , so  $v \approx 0.001c = 3.0 \times 10^5 \text{ m s}^{-1}$  TOWARD the observer – the sign carries the direction.