

Exercise walk-through

15.3

Doppler effect (full C.5, HL)

International Baccalaureate · IB Diploma · Physics · HL

Light Doppler · 3.1

Reasoning

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. 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.

Doppler · 2.1

Reasoning

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.

Read a spectral shift

- 1 Set the model** A line with rest wavelength 656 nm is observed at 659 nm. Use the low-speed radial-motion approximation.
- 2 Calculate** $z = (659 - 656)/656 = 0.00457$. Recession speed $v \approx cz = 1.37 \times 10^6$ m/s.

Decision

Longer wavelength means lower frequency. Signed fractional changes in frequency and wavelength have opposite signs.

Exercises 2.1·2.3

2.1 Describe, in terms of wavefronts, why the pitch of a siren rises as it approaches a stationary listener. [2]

2.2 State what is meant by a redshift, and what it indicates about the motion of the source. [2]

2.3 State the condition under which the relation $\Delta\lambda/\lambda \approx v/c$ may be used for light. [1]

Exercises 2.1·2.3

2.1 Describe, in terms of wavefronts, why the pitch of a siren rises as it approaches a stationary listener. [2]

2.1 The moving source chases the wavefronts it emits ahead of itself, so the fronts are bunched together ahead – more fronts reach the listener per second and the observed frequency (pitch) rises.

2.2 State what is meant by a redshift, and what it indicates about the motion of the source. [2]

2.2 A shift of spectral lines to longer wavelengths than the rest values; the source is moving away from the observer.

2.3 State the condition under which the relation $\Delta\lambda/\lambda \approx v/c$ may be used for light. [1]

2.3 The relative speed v must be much smaller than the speed of light.

Exercises 2.4·3.1

2.4 Name two applications of the Doppler effect, one in medicine and one outside it. [2]

2.5 A fire engine's 500 Hz siren travels at 34 m/s toward a stationary listener; the speed of sound is 340 m/s. Calculate the observed frequency approaching, and receding at the same speed. [3]

3.1 A distant star's hydrogen line, rest wavelength 486 nm, is observed at 484 nm. Calculate the fractional shift and the radial velocity, and state the direction of motion.[3]

Exercises 2.4-3.1

2.4 Name two applications of the Doppler effect, one in medicine and one outside it. [2]

2.4 Medical: Doppler ultrasound measuring blood-flow speed; any other: radar speed guns, weather radar, astronomy redshifts.

2.5 A fire engine's 500 Hz siren travels at 34 m/s toward a stationary listener; the speed of sound is 340 m/s. Calculate the observed frequency approaching, and receding at the same speed. [3]

2.5 Approaching: $f' = fv/(v - u_s) = 500 \times 340/306 = 556$ Hz; receding: $f' = 500 \times 340/374 = 455$ Hz.

3.1 A distant star's hydrogen line, rest wavelength 486 nm, is observed at 484 nm. Calculate the fractional shift and the radial velocity, and state the direction of motion.[3]

3.1 $\Delta\lambda/\lambda = (484 - 486)/486 = -4.1 \times 10^{-3}$; $v = 4.1 \times 10^{-3} \times 3.0 \times 10^8 = 1.2 \times 10^6$ m/s; the negative shift is a blueshift – the star approaches.

Exercises 3.2-3.3

3.2 Explain how comparing several spectral lines from a galaxy with laboratory rest wavelengths gives both the direction and the speed of its motion. [4]

3.3 A radar speed gun emits radio waves that reflect from a moving car and return with a shifted frequency. Explain why the reflected wave is shifted, and why the car's speed can be found from the size of the shift. [3]

Exercises 3.2-3.3

3.2 Explain how comparing several spectral lines from a galaxy with laboratory rest wavelengths gives both the direction and the speed of its motion. [4]

3.2 Each element emits at known rest wavelengths, so matching the observed pattern identifies the lines and the shift is measured line by line; all lines shifting together by the same fraction confirms real motion rather than an instrumental effect; shift to longer wavelengths = recession, shorter = approach; the fractional shift times c gives the radial speed.

3.3 A radar speed gun emits radio waves that reflect from a moving car and return with a shifted frequency. Explain why the reflected wave is shifted, and why the car's speed can be found from the size of the shift. [3]

3.3 The reflection from the moving car acts like a re-emitting moving source, so the returned wave's frequency differs from the emitted one; the shift grows with the car's speed – $\Delta f/f \approx v/c$; comparing returned and emitted frequencies therefore yields the speed.

Exercises 3.4·3.5

3.4 A police siren passes a stationary observer. Describe how the observed pitch changes as the siren approaches, passes and recedes, explaining the change at each stage in terms of wavefronts. [4]

3.5 A 400 Hz source and a listener can each move at 20 m/s ($v = 340$ m/s), one at a time. Calculate the observed frequency when the source moves toward the stationary listener, and when instead the listener moves toward the stationary source, and explain why the two answers differ. [5]

Exercises 3.4·3.5

3.4 A police siren passes a stationary observer. Describe how the observed pitch changes as the siren approaches, passes and recedes, explaining the change at each stage in terms of wavefronts. [4]

3.4 Approaching: fronts bunch at the listener – pitch high; at the moment of passing: relative radial speed passes through zero – the pitch slides down through its true value; receding: fronts stretch behind the siren – pitch low; the source frequency never changes; only the observed frequency does.

3.5 A 400 Hz source and a listener can each move at 20 m/s ($v = 340$ m/s), one at a time. Calculate the observed frequency when the source moves toward the stationary listener, and when instead the listener moves toward the stationary source, and explain why the two answers differ. [5]

3.5 Moving source: $f' = 400 \times 340/320 = 425$ Hz; moving observer: $f' = 400 \times 360/340 = 424$ Hz; the moving source changes the wavelength in the medium – fronts are physically crowded – while the moving observer only crosses the unchanged wavefronts faster, so the two shifts are not identical.