15.3 Doppler effect (full C.5, HL)

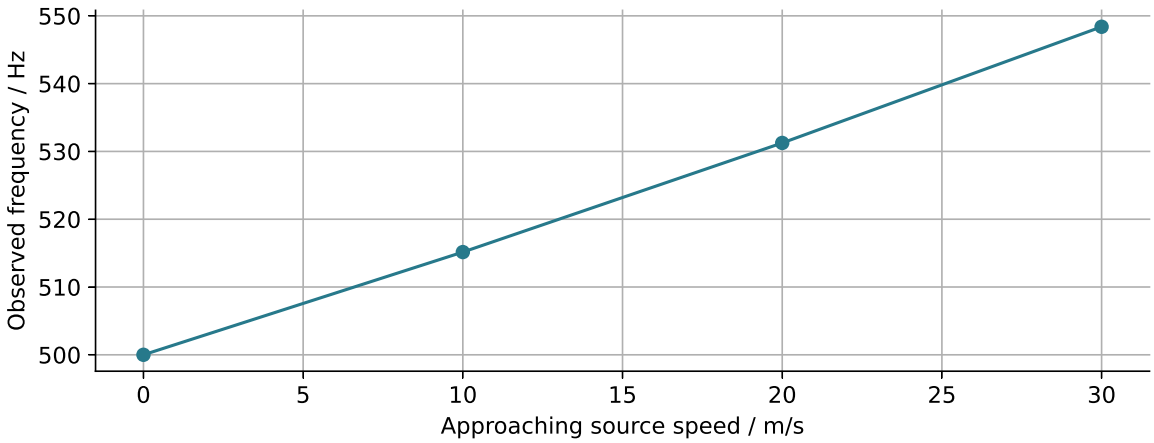
Name: _____ Class: _____ Date: _____ **Total: 29 marks**

KEY WORDS Doppler effect • redshift • blueshift • rest wavelength

Objective

Practise the full guide C.5 toolkit including AHL: the Doppler effect for sound and electromagnetic waves, wavefront diagrams for a moving source or observer, the low-speed light shift $\Delta f/f = \Delta\lambda/\lambda \approx v/c$, spectral-line shifts as evidence of stellar and galactic motion, the radar and medical applications; at higher level also the sound Doppler equations $f' = f\,v/(v \mp u_s)$ for a moving source and $f' = f\,(v \pm u_o)/v$ for a moving observer. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The C.5 rule set (HL)**

$$\frac{\Delta f}{f} = \frac{\Delta\lambda}{\lambda} \approx \frac{v}{c} \quad (v \ll c) \qquad f' = f\,\frac{v}{v \mp u_s} \qquad f' = f\,\frac{v \pm u_o}{v}$$

Wavefronts bunch ahead of a moving source (observed frequency rises) and stretch behind it (frequency falls). For light: blueshift on approach, redshift on recession; the shift of a known spectral line from its rest wavelength gives the radial speed of a star or galaxy.

■ **Worked example: reading a galaxy spectrum**

A hydrogen line with rest wavelength 656 nm appears at 659 nm. $\Delta\lambda = 3$ nm, so $\Delta\lambda/\lambda = 3/656 = 4.6 \times 10^{-3}$ and $v = 0.0046c = 1.4 \times 10^{6}$ m/s – redshift, so the galaxy recedes. Two habits: always compare with the rest wavelength of a known line, and check the direction of the shift before naming the motion.

2 Practice

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]

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 Exam-style questions

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]

3.2 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]

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]