C.5 Doppler effect

Practice Worksheet — name: ________________________ date: _____________

FORMULAS FOR THIS TOPIC

DOPPLER (LIGHT, V ≪ C) $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$ MOVING SOURCE (HL) $f' = f\left(\frac{v}{v \pm u_s}\right)$

MOVING OBSERVER (HL) $f' = f\left(\frac{v \pm u_o}{v}\right)$

SECTION A — MULTIPLE CHOICE

A1. An ambulance siren sounds higher-pitched as it approaches because:

- (A) The siren frequency actually increases
- (B) The sound travels faster towards the observer
- (C) Successive wavefronts are emitted from positions closer to the observer, compressing the wavelength
- (D) The amplitude of the sound increases

A2. A hydrogen line at 656.3 nm appears at 662.9 nm in a galaxy's spectrum. The galaxy is:

- (A) Approaching at about 1% of c
- (B) Receding at about 1% of c
- (C) Approaching at about 3% of c
- (D) Receding at about 3% of c

A3. For sound, a source approaching a stationary observer at speed u and an observer approaching a stationary source at the same speed give:

- (A) Exactly the same observed frequency
- (B) Slightly different frequencies, because the two situations are physically distinct
- (C) The same frequency only if $u > v$
- (D) Different frequencies for light but the same for sound

SECTION B — SHORT ANSWER

B1. A train sounding a 500 Hz horn approaches a stationary observer at 30 m s^{-1} (speed of sound 340 m s^{-1}). Calculate the observed frequency as it approaches and after it passes. [4 marks]

B2. Sketch the wavefront diagram for a source moving to the right at half the wave speed, and use it to explain the frequency change ahead of and behind the source. [3 marks]

B3. Explain how the Doppler effect allows astronomers to detect a planet orbiting a distant star. [3 marks]

ANSWER KEY

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Section A

A1: Successive wavefronts are emitted from positions closer to the observer, compressing the wavelength — The source frequency never changes; each wavefront is emitted a little nearer to you than the last, shortening the received wavelength and raising the observed frequency. Loudness (amplitude) is a separate effect.

A2: Receding at about 1% of c — The wavelength increased (redshift), so the galaxy recedes. $\frac{\Delta\lambda}{\lambda} = \frac{6.6}{656.3} \approx 0.010$, giving $v \approx 0.01c \approx 3 \times 10^6$ m s^{-1}.

A3: Slightly different frequencies, because the two situations are physically distinct — Sound travels in a medium, which breaks the symmetry: a moving source compresses the wavelength itself, a moving observer sweeps up unchanged wavefronts faster. The formulas $f\frac{v}{v-u}$ and $f\frac{v+u}{v}$ agree only in the limit $u \ll v$.

Section B

B1: Approaching: $f' = 500 \times \frac{340}{340-30} = 548$ Hz. Receding: $f' = 500 \times \frac{340}{340+30} = 459$ Hz. The listener hears a drop of nearly 90 Hz as it passes — the classic Doppler swoop.

B2: The diagram shows circles of increasing radius whose centres shift progressively to the right: wavefronts bunch ahead of the source (shorter λ, higher f) and spread behind it (longer λ, lower f). Each wavefront is centred on the point where the source was when it was emitted.

B3: The star and planet orbit their common centre of mass, so the star wobbles periodically towards and away from Earth. Its spectral lines shift alternately blue and red with the orbital period. The period and amplitude of this radial-velocity curve reveal the planet's orbit and minimum mass.