Problem of the week

The Doppler effect (HL only)

(a) A source moves away from a stationary observer with speed 52.0 m s^{-1}. The source emits sound of frequency 2650 Hz. The speed of sound is 338 m s^{-1}. Calculate

(i) the frequency measured by the observer,

(ii) the wavelength at the source,

(iii) the wavelength measured by the observer.

(b) An observer moving at 48.0 m s^{-1} approaches a stationary source that emits sound of frequency 2410 Hz. The speed of sound is 338 m s^{-1}.

(i) Calculate the frequency measured by the observer.

(ii) Calculate the wavelength at the source.

(iii) State the wavelength measured by the observer.

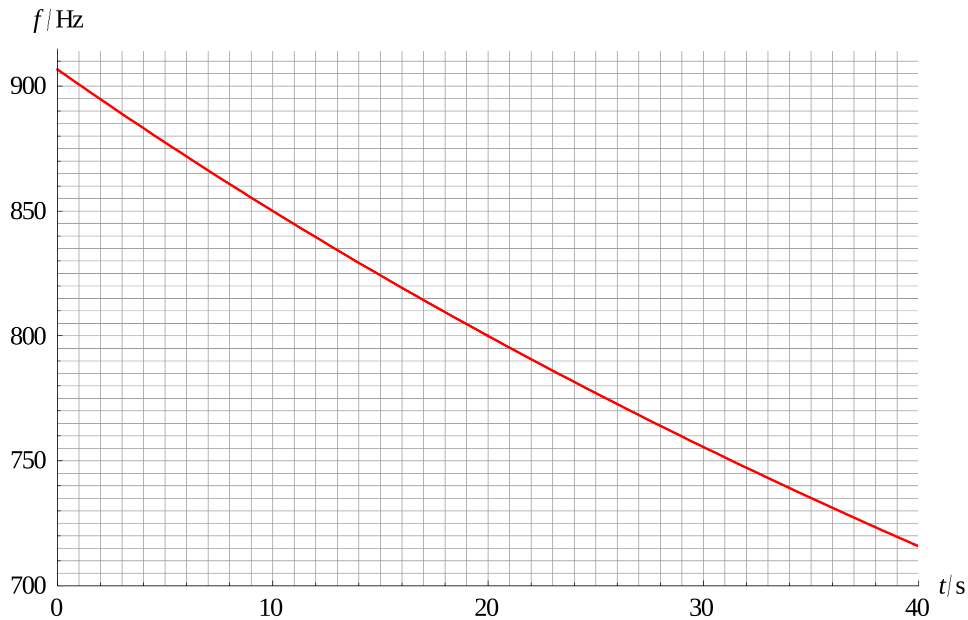
(iv) Verify, by explicit calculation, your answer to (iii).

(c) Ultrasound is directed from a stationary probe towards an approaching car. The emitted frequency is 35 kHz. The ultrasound is reflected by the car and is received back at the probe where the frequency is measured to be 48 kHz. The speed of ultrasound is 340 m s^{-1}.

(i) Determine the speed of the car.

(ii) The speed limit was 120 km/hour. The speeding fine is € 300 for every 10 km/hour above the speed limit. Estimate the fine.

(d) A train emitting sound of frequency 800 Hz approaches a platform, stops for an instant and then moves away. The graph shows how the frequency heard by a stationary observer on the platform varies with time.



(i) State the time at which the train stops at the platform.

(ii) Qualitatively describe the motion of the train.

(e) The speed of sound is 340 m s^{-1}. Estimate, to 1 s.f., the speed of the train

(i) at t = 0,

(ii) at t = 30 s.

Answers

(a)

(i) $f' = f\frac{c}{c+v} = 2650 \times \frac{338}{338+52.0} = 2296.7 \approx 2.30 \times 10^3 \text{ Hz}$.

(ii) $\lambda = \frac{c}{f} = \frac{338}{2650} = 0.126 \text{ m}$.

(iii) $\lambda' = \frac{c}{f'} = \frac{338}{2296.7} = 0.147 \text{ m}$.

(b)

(i) $f' = f\frac{c+v}{c} = 2410 \times \frac{338+48}{338} = 2752.2 \approx 2750 \text{ Hz}$.

(ii) The wavelength at the source is $\frac{338}{2410} = 0.140 \text{ m}$.

(iii) The observer will measure the same wavelength as the source i.e. 0.140 m.

(iv) The observer measures a speed of sound of 338 + 48.0 = 386 m s^{-1}. And so, a wavelength of $\frac{386}{2752.2} = 0.140 \text{ m}$.

(c)

(i) The car behaves as a moving observer approaching the source, so it receives a frequency $f' = 35 \times \frac{c+v}{c}$. This is reflected at the same frequency and the car now acts as a source approaching an observer. The observer then receives a frequency $f'' = f' \times \frac{c}{c-v} = 35 \times \frac{c+v}{c-v}$. Hence $48 = 35 \times \frac{340+v}{340-v}$. Solving (use your GDC), $v = 53.3 \approx 53 \text{ m s}^{-1}$.

(ii) The car's speed is about 190 km/hour so the fine will be € 2100.

(d)

(i) When the frequency is 800 Hz i.e., at t = 20 s.

(ii) The train decelerates approaching the station, stops instantaneously at t = 20 s and then accelerates away.

(e)

(i) At t = 0, the frequency is about 905 Hz. Hence $905 = 800 \times \frac{340}{340-v} \Rightarrow v \approx 40 \text{ m s}^{-1}$.

(ii) At t = 30 s, the frequency is about 755 Hz. Hence $755 = 800 \times \frac{340}{340+v} \Rightarrow v \approx 20 \text{ m s}^{-1}$.