2021-Ph-H2-Q2

Section: Our Dynamic Universe

Topic: Forces, Energy and Power

Summary:

A train consists of a steam engine and a carriage.

- The engine provides a driving force $F = 1.15 \times 10^5\,\text{N}$.
- Mass of engine: $m_E = 9.75 \times 10^4\,\text{kg}$.
- Mass of carriage: $m_C = 3.56 \times 10^4\,\text{kg}$.

Friction is negligible.

We must find:

(a) the tension in the coupling,

(b)(i) the speed of the train using Doppler effect,

(b)(ii) if a passenger hears a different frequency.

(a) Tension in coupling:

Total mass of the train:

$$m_{\text{total}} = m_E + m_C = 9.75 \times 10^4 + 3.56 \times 10^4 = 1.33 \times 10^5\,\text{kg}.$$

Acceleration:

$$a = \frac{F}{m_{\text{total}}} = \frac{1.15 \times 10^5}{1.33 \times 10^5} \approx 0.865\,\text{m s}^{-2}.$$

Tension in coupling (only the carriage mass):

$$T = m_C a = 3.56 \times 10^4 \times 0.865 \approx 3.08 \times 10^4\,\text{N}.$$

Answer: $T \approx 3.1 \times 10^4\,\text{N}$.

(b)(i) Speed of the train:

Using Doppler effect:

$$f_{\text{obs}} = f\frac{v}{v - v_S},$$

where $v = 340\,\text{m s}^{-1}$ and $f_{\text{obs}} = 531\,\text{Hz},\ f = 511\,\text{Hz}.$

Rearrange:

$$\frac{f_{\text{obs}}}{f} = \frac{v}{v - v_S} \Rightarrow v - v_S = \frac{vf}{f_{\text{obs}}}.$$

$$v_S = v - \frac{vf}{f_{\text{obs}}} = 340 - \frac{340 \times 511}{531}.$$

$$v_S \approx 340 - 327 \approx 13\,\text{m s}^{-1}.$$

Answer: $v_S \approx 13\,\text{m s}^{-1}$.

(b)(ii) Frequency heard by a passenger:

The passenger is **travelling with the whistle** (same velocity and direction).

- **No relative motion** between the source and passenger.
- Thus, the frequency heard by the passenger is **the same as the whistle's frequency (511 Hz).**

Answer: The student is **incorrect** because the passenger hears **511 Hz**, the same as emitted.

Guidance for Students:

- Use total mass for acceleration, then consider only the carriage for coupling tension.
- For Doppler questions, note who is moving relative to whom.
- Same velocity between source and observer means no frequency change.

Revision Tips:

- $F = ma$ (Newton's second law).
- Doppler formula (for source moving towards observer):

$$f_{\text{obs}} = \frac{fv}{v - v_S}.$$

- Always check if **relative motion** exists between source and observer.