Section 9.5: The Doppler Effect

Tutorial 1 Practice, page 435

1. Given: \( v_{\text{source}} = 20.0 \text{ m/s}; f_0 = 1.0 \text{ kHz}; \) 
\( v_{\text{detector}} = 0 \text{ m/s}; v_{\text{sound}} = 330 \text{ m/s} \)

Required: \( f_{\text{obs}} \)

Analysis:

\[
\frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}}} f_0
\]

Solution:

\[
\frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}}} = f_0
\]

\[
\begin{align*}
\text{Given:} & \\
\text{v_{sound} + v_{detector} =} & 330 \text{ m/s + 0 m/s} \\
\text{v_{source} =} & \frac{330 \text{ m/s} + (-20.0 \text{ m/s})}{(1.0 \text{ kHz})} \\
\text{=} & \frac{330 \text{ m/s}}{310 \text{ m/s}} (1.0 \text{ kHz}) \\
\text{=} & 1100 \text{ Hz}
\end{align*}
\]

\( f_{\text{obs}} = 1.1 \text{ kHz} \)

Statement: The detected frequency of the approaching police car is 1100 Hz, or 1.1 kHz.

2. Given: \( f_{\text{obs}} = 900.0 \text{ Hz}; v_{\text{detector}} = 0 \text{ m/s}; \) 
\( f_0 = 950.0 \text{ Hz}; v_{\text{sound}} = 335 \text{ m/s} \)

Required: \( v_{\text{source}} \)

Analysis:

\[
\frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}}} = f_0
\]

\[
\begin{align*}
\text{v_{source} + v_{detector} =} & \frac{f_0}{f_{\text{obs}} (v_{\text{sound}} + v_{\text{detector}})} \\
\text{v_{source} =} & \frac{f_0}{f_{\text{obs}} (v_{\text{sound}} + v_{\text{detector}})} - v_{\text{sound}}
\end{align*}
\]

Solution:

\[
\begin{align*}
v_{\text{source}} &= \frac{f_0}{f_{\text{obs}}} (v_{\text{sound}} + v_{\text{detector}}) - v_{\text{sound}} \\
&= 950.0 \text{ Hz} (335 \text{ m/s} + 0 \text{ m/s}) - (335 \text{ m/s}) \\
&= 95 \text{ m/s} (335 \text{ m/s} - 335 \text{ m/s})
\end{align*}
\]

\( v_{\text{source}} = 18.6 \text{ m/s} \)

Statement: The speed of the ambulance is 18.6 m/s.

(b) Answers may vary. Sample answer:

Two examples of the Doppler effect are the noise of a jet at an air show and the sound of a racecar to someone near the track.

2. A sound wave has a higher frequency when the source is approaching a stationary observer because the sound waves are compressed as the source gets closer to the observer. Compressed sound waves mean a higher frequency.

3. Given: \( f_0 = 300.0 \text{ Hz}; T = 15 \text{ °C}; \) 
\( v_{\text{detector}} = 0 \text{ m/s}; v_{\text{source}} = 25 \text{ m/s} \)

Required: \( f_{\text{obs}} \)

Analysis: \( v_{\text{sound}} = 331.4 \text{ m/s} + (0.606 \text{ m/s}°\text{C})T; \)

\[
f_{\text{obs}} = \frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}} + v_{\text{detector}}} f_0
\]

Solution: Determine the speed of sound at 15 °C:

\[
\begin{align*}
\text{v_{sound} =} & 331.4 \text{ m/s} + (0.606 \text{ m/s}°\text{C})T \\
&= 331.4 \text{ m/s} + \left(0.606 \frac{\text{m/s}}{\text{°C}}\right) (15°\text{C})
\end{align*}
\]

\( v_{\text{sound}} = 340.5 \text{ m/s} \)

Determine the frequency detected by the observer:

\[
\begin{align*}
f_{\text{obs}} &= \frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}} + v_{\text{detector}}} f_0 \\
&= \frac{340.5 \text{ m/s} + 0 \text{ m/s}}{340.5 \text{ m/s} + (-25 \text{ m/s})} (300.0 \text{ Hz}) \\
&= \frac{340.5 \text{ m/s}}{315.5 \text{ m/s}} (300.0 \text{ Hz})
\end{align*}
\]

\( f_{\text{obs}} = 320 \text{ Hz} \)

Statement: The detected frequency of the object is 320 Hz.

4. Given: \( f_0 = 850 \text{ Hz}; \Delta f = 58 \text{ Hz}; v_{\text{detector}} = 0 \text{ m/s}; \) 
\( v_{\text{sound}} = 345 \text{ m/s} \)

Required: \( v_{\text{source}} \)

Analysis: \( f_{\text{obs}} = f_0 + \Delta f; \)

\[
f_{\text{obs}} = \frac{v_{\text{sound}} + v_{\text{detector}}}{v_{\text{source}} + v_{\text{detector}}} f_0
\]

\[
\begin{align*}
\frac{v_{\text{sound}} + v_{\text{source}}}{v_{\text{source}} + v_{\text{detector}}} &= \frac{f_0}{f_{\text{obs}} (v_{\text{source}} + v_{\text{detector}})} \\
\frac{v_{\text{source}}}{v_{\text{source}} + v_{\text{detector}}} &= \frac{f_0}{f_{\text{obs}} (v_{\text{source}} + v_{\text{detector}})} - v_{\text{source}}
\end{align*}
\]

Solution: Determine the observed frequency:

\[
\begin{align*}
f_{\text{obs}} &= f_0 + \Delta f \\
&= 850 \text{ Hz} + 58 \text{ Hz} \\
&= 908 \text{ Hz}
\end{align*}
\]

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1. (a) The Doppler effect describes the changing frequency of sound as the source is in motion relative to an observer.
Determine the speed of the fire truck:

\[ v_{source} = \frac{f_{obs}}{f_{obs}} \left( v_{sound} + v_{detector} \right) - v_{sound} \]

\[ = \frac{850 \ Hz}{908 \ Hz} \left( 345 \ m/s + 0 \ m/s \right) - \left( 345 \ m/s \right) \]

\[ v_{source} = -22 \ m/s \]

**Statement:** The speed of the fire truck is 22 m/s.

5. **Given:** \( v_{source} = 0 \ m/s; f_0 = 440.0 \ Hz; \)
\( v_{detector} = 90 \ km/h; T = 0 \ ^\circ C \)

**Required:** \( f_{obs} \)

**Analysis:**

\[ f_{obs} = \frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}} \cdot f_0 \]

**Solution:** Since the temperature is 0 °C, the speed of sound is 331.4 m/s.

Convert \( v_{source} \) to metres per second:

\[ v_{source} = 90 \ km/h \]
\[ = 90 \ \frac{km}{h} \left( \frac{1000 \ m}{1 \ km} \right) \left( \frac{1 \ h}{60 \ min} \right) \left( \frac{1 \ min}{60 \ s} \right) \]

\[ v_{source} = 25 \ m/s \]

Determine the observed frequency of the horn as I approach the observer:

\[ f_{obs} = \frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}} \cdot f_0 \]

\[ = \left( \frac{331.4 \ m/s + 0 \ m/s}{331.4 \ m/s + (-25 \ m/s)} \right) [440 \ Hz] \]

\[ = \left( \frac{331.4 \ m/s}{306.4 \ m/s} \right) [440 \ Hz] \]

\[ f_{obs} = 480 \ Hz \]

As I pass the observer, the person will detect the exact frequency of the horn.

**Statement:** The person will detect a frequency of 480 Hz as I approach, and a frequency of 440 Hz as I pass.

6. **Given:** \( v_{detector} = 0 \ m/s; f_{obs} = 560 \ Hz; \)
\( v_{sound} = 345 \ m/s; f_0 = 480 \ Hz \)

**Required:** \( v_{source} \)

**Analysis:**

\[ f_{obs} = \frac{f_0}{f_{obs}} \left( v_{sound} + v_{detector} \right) \]

\[ = \frac{f_0}{f_{obs}} \left( v_{sound} + v_{source} \right) \]

\[ v_{source} = \frac{f_0}{f_{obs}} \left( v_{sound} + v_{detector} \right) - v_{sound} \]

**Solution:**

\[ v_{source} = \frac{f_0}{f_{obs}} \left( v_{sound} + v_{observer} \right) - v_{sound} \]

\[ = \frac{560 \ Hz}{480 \ Hz} \left( 345 \ m/s + 0 \ m/s \right) - \left( 345 \ m/s \right) \]

\[ = \frac{56 \ Hz}{48 \ Hz} \left( 345 \ m/s \right) - 345 \ m/s \]

\[ v_{source} = 58 \ m/s \]

**Statement:** The speed of the source is 58 m/s.

7. The frequency reduces. The effect is not instantaneous as it depends on the speed of the source and how far the source is from the observer.