Section 9.5: The Doppler Effect

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

Required: f_{obs}

Analysis:

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

Solution:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ &= \left(\frac{330 \text{ m/s} + 0 \text{ m/s}}{330 \text{ m/s} + (-20.0 \text{ m/s})}\right)(1.0 \text{ kHz}) \\ &= \left(\frac{330 \cancel{\text{m/s}}}{310 \cancel{\text{m/s}}}\right)(1.0 \text{ kHz}) \\ &= 1100 \text{ Hz} \\ f_{obs} &= 1.1 \text{ kHz} \end{aligned}$$

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

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

Required: v_{source}

Analysis:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ v_{sound} + v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) \\ v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) - v_{sound} \end{aligned}$$

Solution:

$$\begin{aligned} v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{observer}) - v_{sound} \\ &= \frac{950.0 \text{ Hz}}{900.0 \text{ Hz}}(335 \text{ m/s} + 0 \text{ m/s}) - (335 \text{ m/s}) \\ &= \frac{95 \cancel{\text{Hz}}}{90 \cancel{\text{Hz}}}(335 \text{ m/s}) - 335 \text{ m/s} \\ v_{source} &= 18.6 \text{ m/s} \end{aligned}$$

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

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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.

(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 Hz; T = 15 °C; $v_{detector}$ = 0 m/s; v_{source} = 25 m/s

Required: f_{obs}

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

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

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

$$\begin{aligned} v_{sound} &= 331.4 \text{ m/s} + (0.606 \text{ m/s/°C})T \\ &= 331.4 \text{ m/s} + \left(0.606 \frac{\text{m/s}}{\cancel{°\text{C}}}\right)(15 \cancel{°\text{C}}) \\ v_{sound} &= 340.5 \text{ m/s} \end{aligned}$$

Determine the frequency detected by the observer:

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ &= \left(\frac{340.5 \text{ m/s} + 0 \text{ m/s}}{340.5 \text{ m/s} + (-25 \text{ m/s})}\right)(300.0 \text{ Hz}) \\ &= \left(\frac{340.5 \cancel{\text{m/s}}}{315.5 \cancel{\text{m/s}}}\right)(300.0 \text{ Hz}) \\ f_{obs} &= 320 \text{ Hz} \end{aligned}$$

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

4. Given: f_0 = 850 Hz; Δf = 58 Hz; $v_{detector}$ = 0 m/s; v_{sound} = 345 m/s

Required: v_{source}

Analysis: $f_{obs} = f_0 + \Delta f$;

$$\begin{aligned} f_{obs} &= \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right) f_0 \\ v_{sound} + v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) \\ v_{source} &= \frac{f_0}{f_{obs}}(v_{sound} + v_{detector}) - v_{sound} \end{aligned}$$

Solution: Determine the observed frequency:

$$\begin{aligned} f_{obs} &= f_0 + \Delta f \\ &= 850 \text{ Hz} + 58 \text{ Hz} \\ f_{obs} &= 908 \text{ Hz} \end{aligned}$$

Determine the speed of the fire truck:

$$v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{detector}\right) - v_{sound}$$
$$= \frac{850\ \text{Hz}}{908\ \text{Hz}}\left(345\ \text{m/s} + 0\ \text{m/s}\right) - \left(345\ \text{m/s}\right)$$
$$v_{source} = -22\ \text{m/s}$$

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 °C

Required: f_{obs}

Analysis:

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

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

Convert v_{source} to metres per second:

$$v_{source} = 90\ \text{km/h}$$
$$= 90\ \frac{\text{km}}{\text{h}}\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{60\ \text{min}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)$$
$$v_{source} = 25\ \text{m/s}$$

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

$$f_{obs} = \left(\frac{v_{sound} + v_{detector}}{v_{sound} + v_{source}}\right)f_0$$
$$= \left(\frac{331.4\ \text{m/s} + 0\ \text{m/s}}{331.4\ \text{m/s} + \left(-25\ \text{m/s}\right)}\right)\left(440\ \text{Hz}\right)$$
$$= \left(\frac{331.4\ \text{m/s}}{306.4\ \text{m/s}}\right)\left(440\ \text{Hz}\right)$$
$$f_{obs} = 480\ \text{Hz}$$

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:

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

Solution:

$$v_{source} = \frac{f_0}{f_{obs}}\left(v_{sound} + v_{observer}\right) - v_{sound}$$
$$= \frac{560\ \text{Hz}}{480\ \text{Hz}}\left(345\ \text{m/s} + 0\ \text{m/s}\right) - \left(345\ \text{m/s}\right)$$
$$= \frac{56\ \text{Hz}}{48\ \text{Hz}}\left(345\ \text{m/s}\right) - 345\ \text{m/s}$$
$$v_{source} = 58\ \text{m/s}$$

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.