Doppler Effect

\[ f_L = \frac{v + v_s}{v + v_s} f_s \]

- \( f_s \) — frequency at source
- \( f_L \) — frequency at listener
- \( v \) — speed of sound relative to air (344 m/s nominal)
- Coordinate system at rest relative to the air
- Coordinate direction from Listener to Source
- \( v_L \) — velocity of listener
- \( v_s \) — velocity of source
- Both \( v_L \) and \( v_s \) signed per above coordinate sys.

- When sound is reflected is a special case
  - worked in two parts:
    1st step — Reflecting surface is the listener
    2nd step — Reflecting surface treated as a source with frequency determined in the first step.

- Effect on wavelength
  - Only motion of source, \( v_s \), affects wavelength
  - Treat \( v \) and \( v_s \) as always positive
  - Wave length ahead of moving source is shortened
    \[ \lambda = \frac{v - v_s}{f_s} \]
  - Wave length behind moving source is lengthened
    \[ \lambda = \frac{v + v_s}{f_s} \]
56. Two train whistles, A and B, each have a frequency of 392 Hz. A is stationary and B is moving toward the right (away from A) at a speed of 35.0 m/s. A listener is between the two whistles and is moving toward the right with a speed of 15.0 m/s. (See Figure 12.45.) (a) What is the frequency from A as heard by the listener? (b) What is the frequency from B as heard by the listener? (c) What is the beat frequency detected by the listener?

\[ v_A = 0 \quad v_L = 15 \quad v_B = 35 \]

(a) \( \nu = \frac{344 - 15}{344 + 0} \times 392 \text{ Hz} = 375 \text{ Hz} \)

(b) \( \nu = \frac{344 + 15}{344 + 35} \times 392 \text{ Hz} = 371 \text{ Hz} \)

(c) \( f_{\text{beat}} = |f_1 - f_2| = |371 - 375| = 4 \text{ Hz} \)

What is \( \lambda \) due to A?

\[ \lambda = \frac{v}{f_A} = \frac{344 \text{ m/s}}{392 \text{ Hz}} = 0.878 \text{ m, any direction} \]

What is \( \lambda \) due to B?

In front of B, \( \lambda = \frac{v - v_B}{f_B} = \frac{344 - 35 \text{ m/s}}{392 \text{ Hz}} = 0.788 \text{ m} \)

Behind B, \( \lambda = \frac{v + v_B}{f_B} = \frac{344 + 35 \text{ m/s}}{392 \text{ Hz}} = 0.967 \text{ m} \)
The Beat Heard by a Bat

A bat flies toward a wall, emitting a steady sound with a frequency of 25.0 kHz. This bat hears its own sound plus the sound reflected by the wall. If the bat hears a beat frequency of 225 Hz, how fast is the bat flying toward the wall?

This is a two step problem. First the frequency of sound reaching the wall is shifted, and then the sound reflected back to the bat is shifted again.

1st Step. The wall is the listener.

\[
\frac{V_B}{V_{n-w}} \quad \text{wall}
\]

Source \quad \longleftrightarrow \quad \text{Listener} \quad V = \text{Speed of sound} = 343 m/s

\[V_s = -V_B \quad V_s = 0\]

\[
f_L = \frac{V + V_s}{V + V_s} f_s = \frac{V}{V - V_B} f_s
\]

with \( f_s = 25.0 \text{ kHz} \)

2nd Step. The wall reflects the sound so becomes the source and the bat is the listener. Now \( f_s \) will be the above \( f_L \).

\[
\frac{V_B}{V_{n-w}} \quad \text{wall}
\]

Listener \quad \longleftrightarrow \quad \text{Source}

\[V_L = +V_B \quad V_s = 0\]

\[
f_L = \frac{V + V_L}{V + V_s} f_s = \frac{V + V_B}{V} f_s = \frac{V + V_B}{V} \left( \frac{V}{V - V_B} f_s \right)
\]

\[
f_L = \frac{V + V_B}{V - V_B} f_s
\]
\[ f_s = 25.0 \text{ kHz}, \text{ the frequency sent out by bat} \]
\[ f_L = \text{frequency that bat hears coming back} \]

\[ f_{\text{Beats}} = | f_L - f_s | = f_L - f_s = \frac{V + V_B}{V - V_B} f_s - f_s \]

Common denominator \[ \frac{(V + V_B)f_s - (V - V_B)f_s}{V - V_B} = (V - V_B) f_{\text{Beats}} \]

Thus \[ 2V_B f_s = (V - V_B) f_{\text{Beats}} \]
\[ V_B (2f_s + f_{\text{Beats}}) = V f_{\text{Beats}} \]

\[ V_B = \frac{V f_{\text{Beats}}}{2f_s + f_{\text{Beats}}} \]

\[ V_B = \frac{343 \text{ m/s} \times 225 \text{ Hz}}{2 \times 25.0 \times 10^3 \text{ Hz} + 225 \text{ Hz}} \]

\[ V_B = 1.54 \text{ m/s} \]