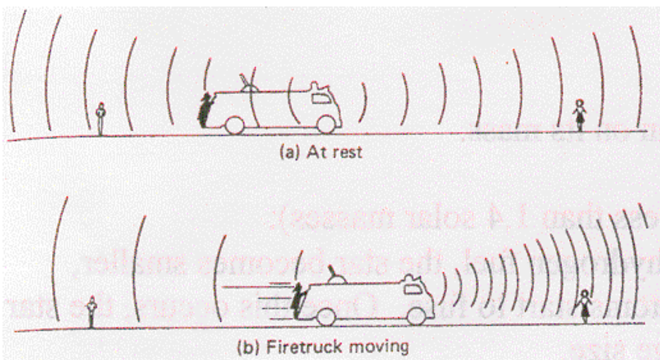
Physics 20 Lesson 32 The Doppler Effect

I. The Doppler Effect

Refer to Pearson pages 429 to 434 for a discussion of the Doppler Effect and the sound barrier.

Christian Johann Doppler (1803 - 1853), an Austrian, published a paper in 1842 where he called attention to the fact that if a luminous body, such as a star, is moving toward or away from an observer, the colour (frequency) of the star will appear different than a stationary star. This **Doppler Effect** applies to all waves including light and sound.

When a listener is in motion toward the source of a sound, the pitch (frequency) of the sound is higher than when the listener is at rest. In fact, if there is **relative** motion between the **source** of the sound and the **receiver** of the sound, the frequency which is heard by the receiver will be different than the frequency emitted by the source.



(a) Both observers on the sidewalk hear the same frequency from the fire truck at rest.

(b) Doppler Effect: observer toward whom the fire truck moves hears a higher-frequency sound, while the other observer hears a lower frequency sound.

There are two equations which are used to calculate the frequency of the wave which is detected by a receiver. One equation applies if the source is moving, and the other equation is used if the receiver is moving.

When the **source is at rest** and the **observer is moving**, the equation is:

$$f_o = f_s\left(\frac{v \pm v_o}{v}\right)$$

where f_s frequency from the source (Hz)
f_o frequency received by observer (Hz)
v speed of the wave (m/s)
v_o speed of observer

and
v_o is (+) when moving toward the source
v_o is (–) when moving away from the source

When the **source is moving** and the **observer is at rest**, the equation is:

$$f_o = f_s\left(\frac{v}{v \mp v_s}\right)$$

where v_s speed of source

and
v_s is (–) when moving toward the observer
v_s is (+) when moving away from the observer

If both the source and the observer are moving relative to one another, we can combine the equations into one:

$$f_o = f_s\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

Check out the video clip called P20 L32 Doppler effect on D2L.

Example 1

A fire engine is roaring past you at 15.0 m/s while its 900 Hz siren is on. If the speed of sound in air is 340 m/s, what frequency do you hear as the engine

a. comes toward you?
b. goes away from you?

for both situations we use the equation for a moving source

$$f_o = f_s\left(\frac{v}{v \mp v_s}\right)$$

a. since the engine is coming toward you v_s is (–)

$$f_o = f_s\left(\frac{v}{v - v_s}\right) = 900\text{ Hz}\left(\frac{340\text{m/s}}{340\text{m/s} - 15.0\text{m/s}}\right) = \mathbf{942\text{ Hz}}$$

b. since the engine is going away from you v_s is (+)

$$f_o = f_s\left(\frac{v}{v + v_s}\right) = 900\text{ Hz}\left(\frac{340\text{m/s}}{340\text{m/s} + 15.0\text{m/s}}\right) = \mathbf{862\text{ Hz}}$$

Example 2

A car is travelling at 29 m/s toward a stationary whistle with a frequency of 625 Hz. If the speed of sound is 337 m/s, what is the apparent frequency of the whistle as heard by the driver of the car?

For this situation we use the equation for a moving observer. Since the observer is travelling toward the source v_o is (+)

$$f_o = f_s\left(\frac{v + v_o}{v}\right) = 625\text{Hz}\left(\frac{337\text{m/s} + 29\text{m/s}}{337\text{m/s}}\right) = \mathbf{679\text{ Hz}}$$

Example 3

A whistle with a frequency of 2500 Hz is travelling south at 27 m/s. You are travelling north toward the whistle at 15 m/s. If the speed of sound is 341 m/s, what frequency do you hear?

For this situation where both the source and the observer are moving, we use the combined equation. Since the observer is travelling toward the source v_o is (+) and since the source is moving toward the observer v_s is (–).

$$f_o = f_s\left(\frac{v + v_o}{v - v_s}\right)$$

$$f_o = 2500\,\text{Hz}\left(\frac{341\,\text{m/s} + 15\,\text{m/s}}{341\,\text{m/s} - 27\,\text{m/s}}\right)$$

$f_o =$ **2834 Hz**

II. Practice problems

1. A fire engine is sitting beside the road with its 900 Hz siren on. You drive past the fire engine at 15.0 m/s. If the speed of sound in air is 340 m/s, what frequency do you hear as you
   a. go toward the engine? (940 Hz)
   b. go away from the engine? (860 Hz)

2. A distant star is being observed by an astronomer on Earth. The frequency for sodium light as measured on Earth is 5.17×10^{14} Hz. The measured frequency for sodium light from the star is 6.10×10^{14} Hz. If the speed of light is 3.00×10^{8} m/s, what is the speed of the star relative to us? Is it moving toward or away from us? (4.57×10^{7} m/s toward us)

III. Hand-in assignment

1. You are standing at a railway crossing. A train approaching at 100 km/h sounds its whistle. If the frequency of the whistle is 400 Hz and the speed of sound in air is 344 m/s, what is the frequency you hear (a) when the train approaches you and (b) when the train has passed you? (435 Hz, 370 Hz)

2. A factory whistle emits a sound with a wavelength of 38 cm. If the speed of sound is 340 m/s, what frequency will be heard by you if you are driving at 20 m/s (a) away from the whistle and (b) toward the whistle? (842 Hz, 948 Hz)

3. The whistle on a train has a frequency of 2150 Hz. If the speed of sound is 339 m/s, what is the apparent frequency you would hear if the train was travelling toward you at 25 m/s? (2321 Hz)

4. A whistle with a frequency of 1200 Hz is travelling south at a velocity of 30.0 m/s. You are travelling north away from the whistle at a speed of 18.0 m/s. If the speed of sound is 340 m/s, what is the apparent frequency of the whistle as heard by you? (1044 Hz)

5. A distant galaxy is being observed by an astronomer on Earth. The frequency for sodium light is 5.17×10^{14} Hz. The measured frequency for sodium light from the galaxy is 4.70×10^{14} Hz. If the speed of light is 3.00×10^{8} m/s, what is the speed of the galaxy relative to us? Is it moving toward or away from us? (3.0×10^{7} m/s away from us)