Doppler effect

Select LEARNING OBJECTIVES:

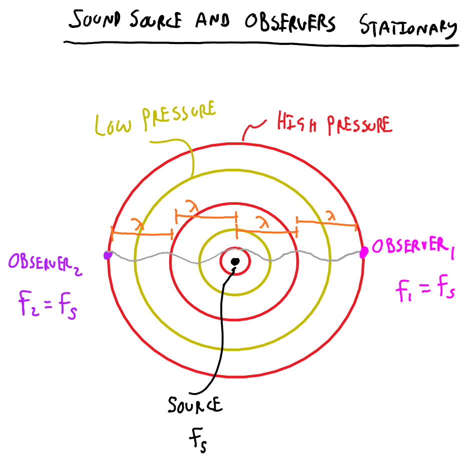
- Be able to draw a picture that describes the Doppler Effect.
- Be able to correctly solve for v from the Doppler equations.
- Be able to apply the Doppler shift to conceptual questions about changing relative speed.
- be able to draw a plot of the observed Doppler shifted frequency as a function of time for random situations.

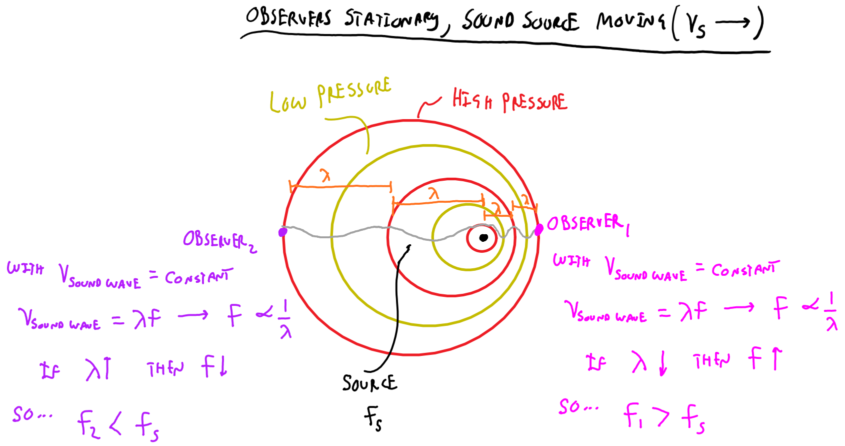
TEXTBOOK CHAPTERS:

- Boxsand :: Doppler shift

WARM UP: When singing or talking, how do we control the amplitude of the sound that we emit?

Consider a stationary source emitting a sound of frequency 440 Hz that is located a distance "d" away from your location. The sound wave that travels through space is a disturbance of high and low pressure that oscillate around atmospheric pressure. As the wave reaches your ear, the air pressure at your eardrum oscillates between a high and low pressure at a frequency of 440 Hz. This pressure oscillation causes your eardrum to vibrate at 440 Hz, the frequency of the source. Thus the pitch that we perceive is dependent on how many times the pressure at our eardrums oscillate per unit time (e.g. 440 pressure oscillations per second). However, this is not the end of the story. You are probably familiar with the apparent frequency change of a siren on a car as the car passes you. Remember that the frequency is determined by the source, in this case the siren at 440 Hz, however you observe the frequency changing as the car approaches and passes you. What is going on here? This is observation is known as the Doppler effect. *The Doppler effect describes how the observed frequency is shifted from the sources frequency as the observer and source move relative to each other.* Below is two figures showing a source of sound emitting at a frequency (f_s) and two observers. Note when there is no relative motion between the source and observers the frequency the observers perceive is the same frequency as the source (left picture).





Now look at the picture on the right, as the source produces a high pressure wave it then travels a bit to the right before it emits the next high pressure wave. Thus the high pressure waves seem to be stacked close to each other to the right of the source and spread apart left of the source. Thus the two observers will hear different apparent frequency not equal to the source frequency. This is a bit hard to visualize with a static image, luckily there are many great simulations available on this topic. One of my favorites is found here. Take some time to play around with this simulation, it will really help solidify a conceptual understanding of why we perceive a different pitch as we move relative to a source of sound. It should also be noted, there is nothing special about the source of sound moving, you can also keep the source stationary and move yourself and get similar Doppler shift effects. This can be done with the simulation as well. Finally, uncheck the "limit max speed" button and see what happens when you set the source in motion faster than the speed of the pressure waves. Think sonic booms!

The mathematical model which captures the features of the Doppler effect is shown below.

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

SPEED OF OBSERVER RELATIVE TO MEDIUM

OBSERVER FREQUENCY

SOURCE FREQUENCY

SPEED OF WAVE IN MEDIUM

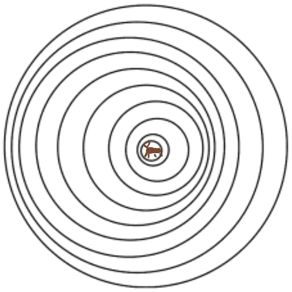
SPEED OF SOURCE RELATIVE TO MEDIUM

$$v_o \begin{cases} - & \text{IF } |\Delta \vec{r}_{so}| \uparrow \\ + & \text{IF } |\Delta \vec{r}_{so}| \downarrow \end{cases}$$

$$v_s \begin{cases} + & \text{IF } |\Delta \vec{r}_{so}| \uparrow \\ - & \text{IF } |\Delta \vec{r}_{so}| \downarrow \end{cases}$$

PRACTICE: The picture below is a top view of ripple waves made by a water bug on the surface of water. From the wave pattern, we can see that the bug has been moving

(a) continuously to the left.
(b) continuously to the right.
(c) back and forth, first left and then right.
(d) back and forth, first right and then left.
(e) in a circle.



PRACTICE: A bat emitting a sound with frequency of 50 kHz is traveling 11 m/s as seen in the figure below. Person "a" is running away from the bat at 11 m/s. Person "c" is running towards the bat at 20 m/s. What frequencies are heard by each person? Assume the bat is an ideal source of sound.

$$F_o = F_s\left(\frac{V \pm V_o}{V \mp V_s}\right)$$

c : $|\Delta \vec{r}| \downarrow$

$$F_c = F_b\left(\frac{V + V_c}{V - V_b}\right)$$

$$F_c = 50\text{ kHz}\left(\frac{343\text{ m/s} + 20\text{ m/s}}{343\text{ m/s} - 11\text{ m/s}}\right)$$

$$\boxed{F_c \approx 54.7\text{ kHz}}$$

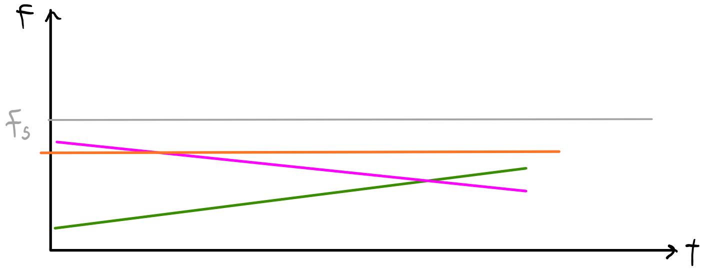
a : $|\Delta \vec{r}| = 0$

So $F_a = F_b$

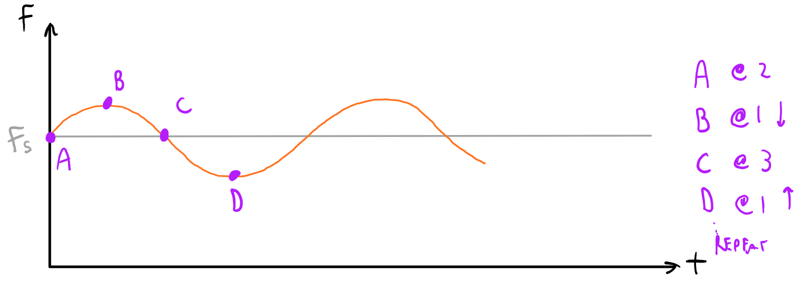
$$\boxed{F_a = 50\text{ kHz}}$$

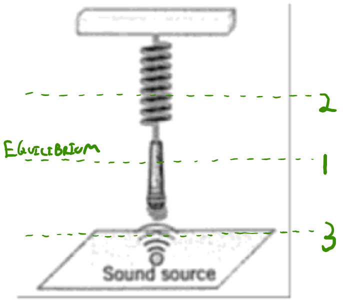
PRACTICE: A on the graph below, plot the frequency you hear as a function of time for

(a) A car receding form you at a constant speed.
(b) A car receding from you at an increasing speed.
(c) A car receding from you at a decreasing speed.



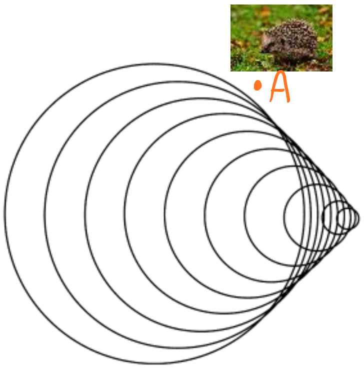
PRACTICE: A microphone is undergoing simple harmonic motion (SHM) above a 440-Hz (f_s) sound source as shown in the figure. Sketch the frequency the microphone records as a function of time if the microphone starts recording at position 2.





PRACTICE: The following figure shows the wave fronts generated by an airplane flying past an observer, A, at a speed greater than that of sound. After the airplane has passed, the observed reports hearing

(a) a sonic boom, then silence.
(b) a succession of sonic booms.
(c) a continuous sonic boom, gradually dying away.
[✓ (d)] first nothing, then a sonic boom, then sound of engines.
(e) no sonic boom because the airplane flew faster than sound all along.



QUESTIONS FOR DISCUSSION:

(1) If a source of sound and an observer are stationary with respect to each other on a windy day, will the wind affect the observed frequency that the observer perceives? Explain.