Lecture 9
(Interference, Beats, and Doppler Effect)

Physics 262-01 Spring 2019

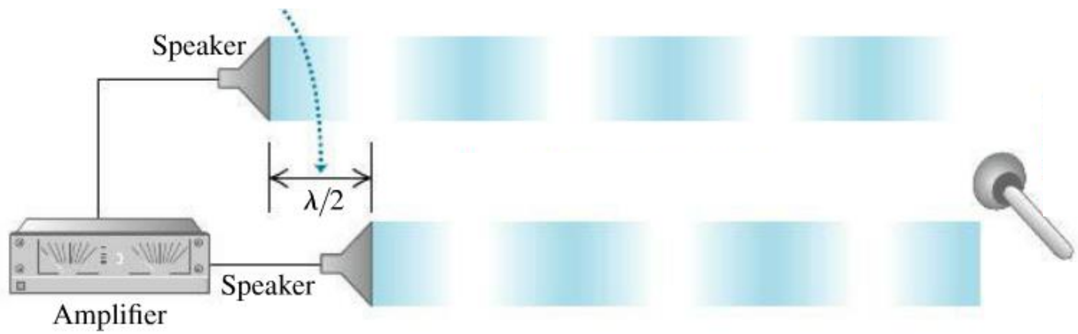
Douglas Fields

- https://phet.colorado.edu/en/simulation/legacy/wave-interference

- http://www.cabrillo.edu/~jmccullough/Applets/OSP/Oscillations_and_Waves/waves_interference.jar

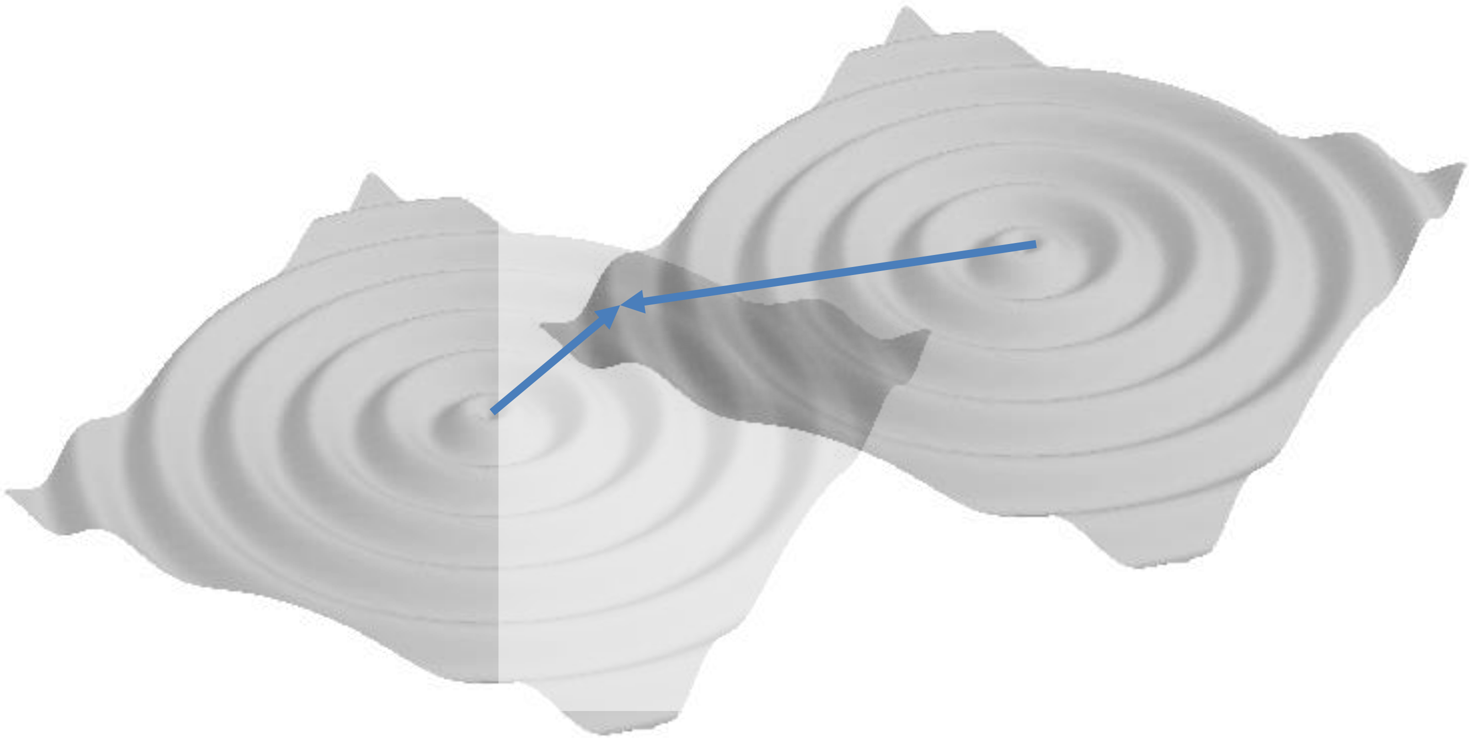
Reading Quiz

- If the two speakers below are in phase and both driven at frequency f, but are located one in front of the other as shown, what would the microphone detect?

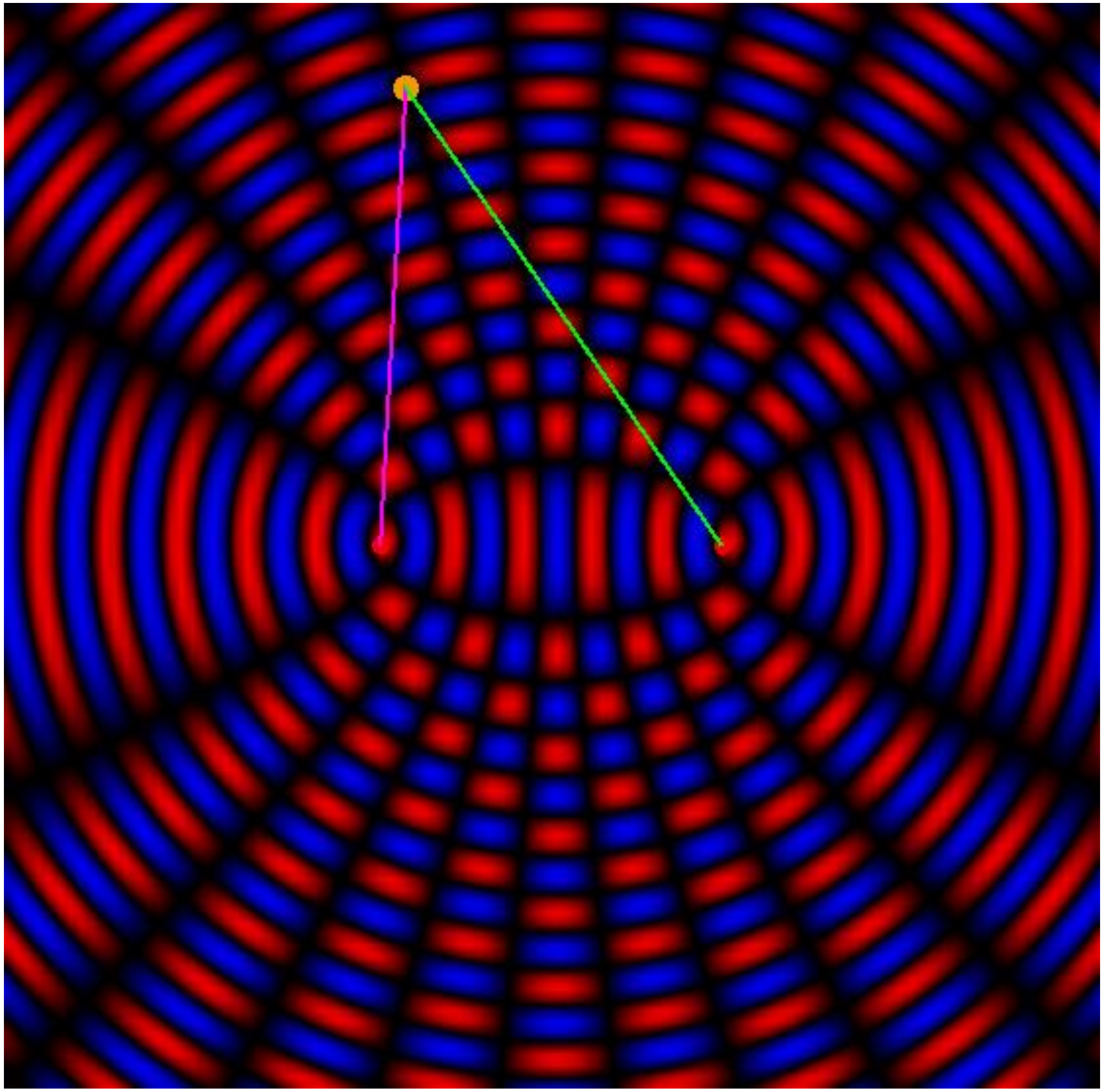


A) Twice the loudness of one speaker
B) The same loudness but at a different frequency
C) No sound
D) The Grateful Dead playing Sugar Magnolia

2D Waves



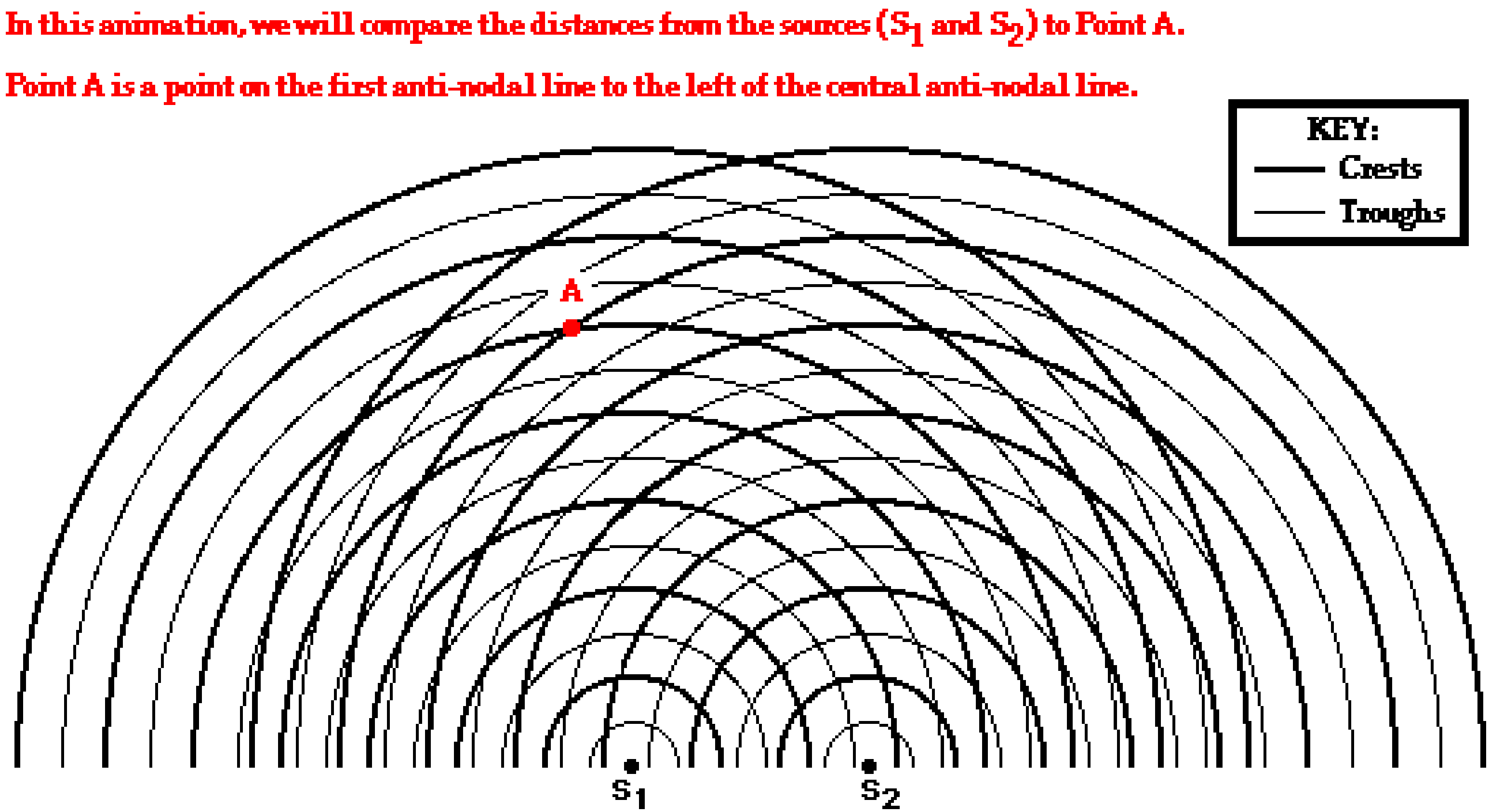
Interference



Interference

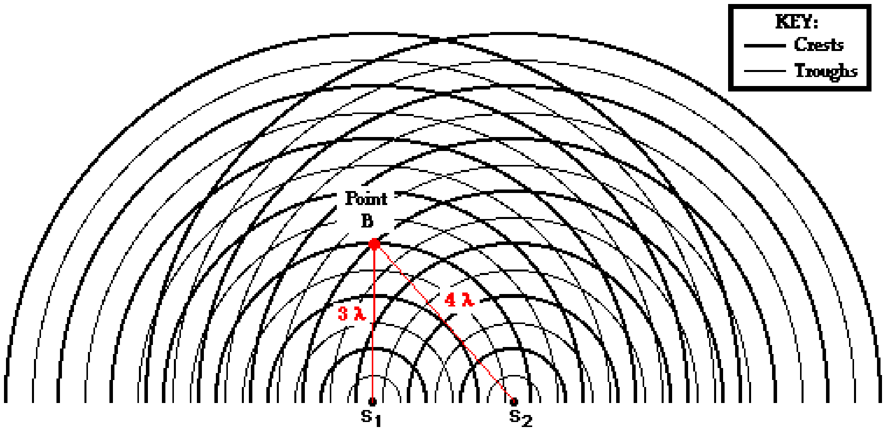
- Let’s look at two source interference:

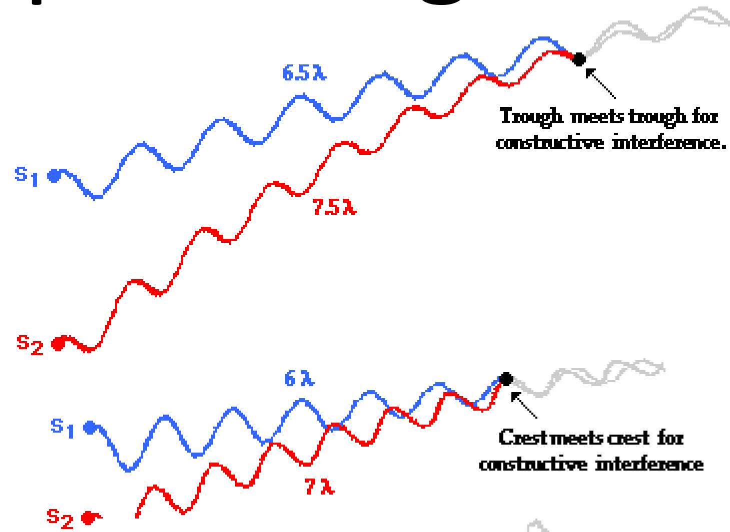
Interference and path length



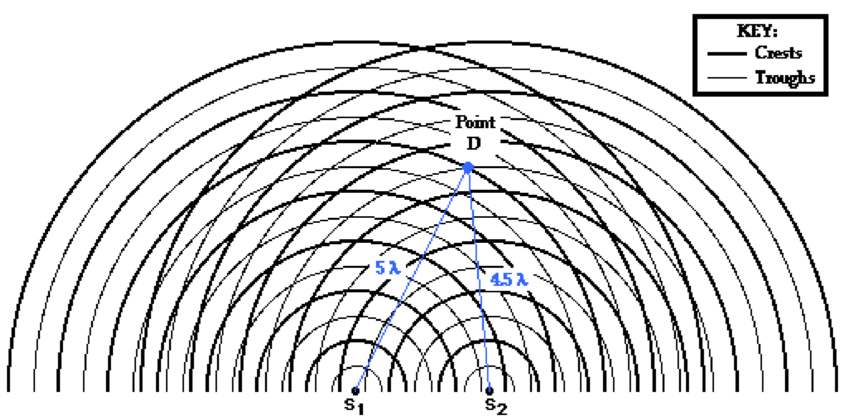
Interference and path length

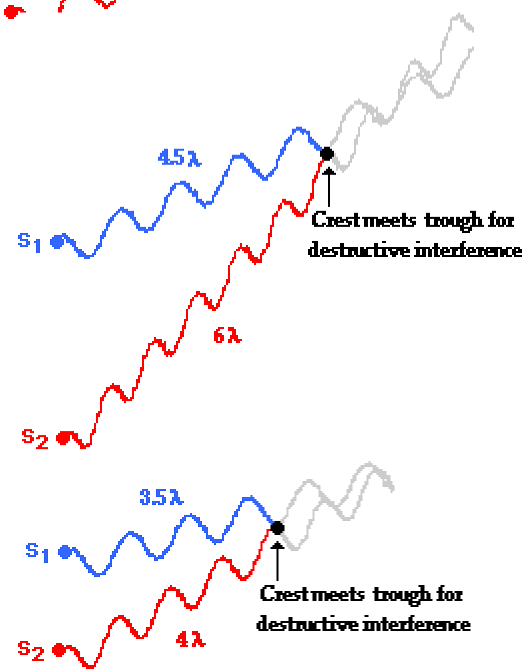
- Constructive



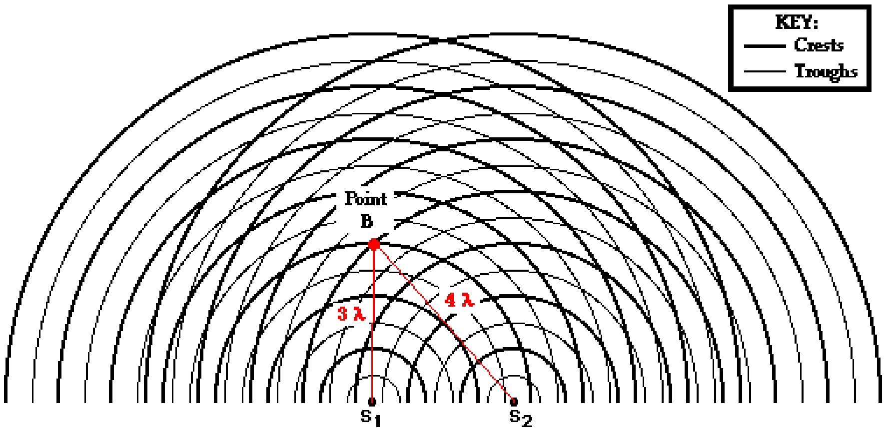


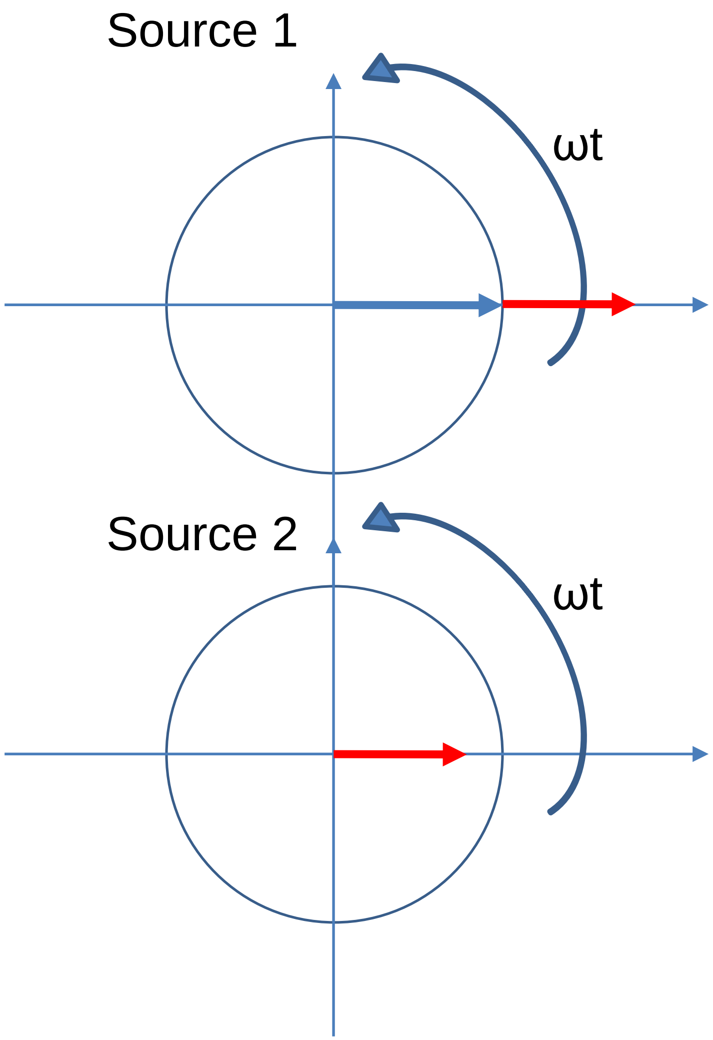
- Destructive



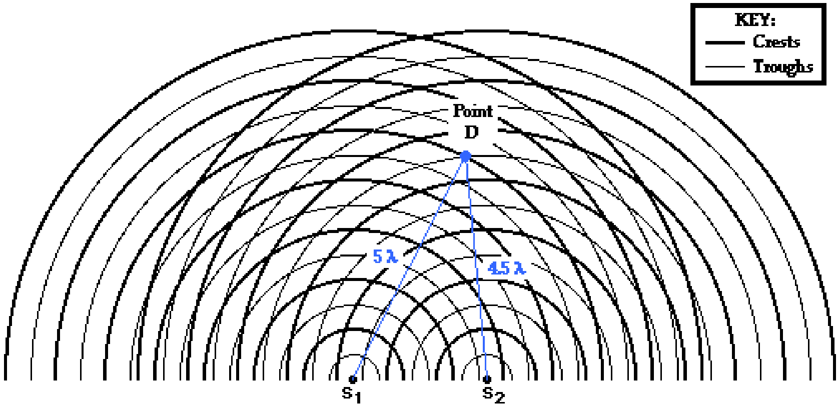


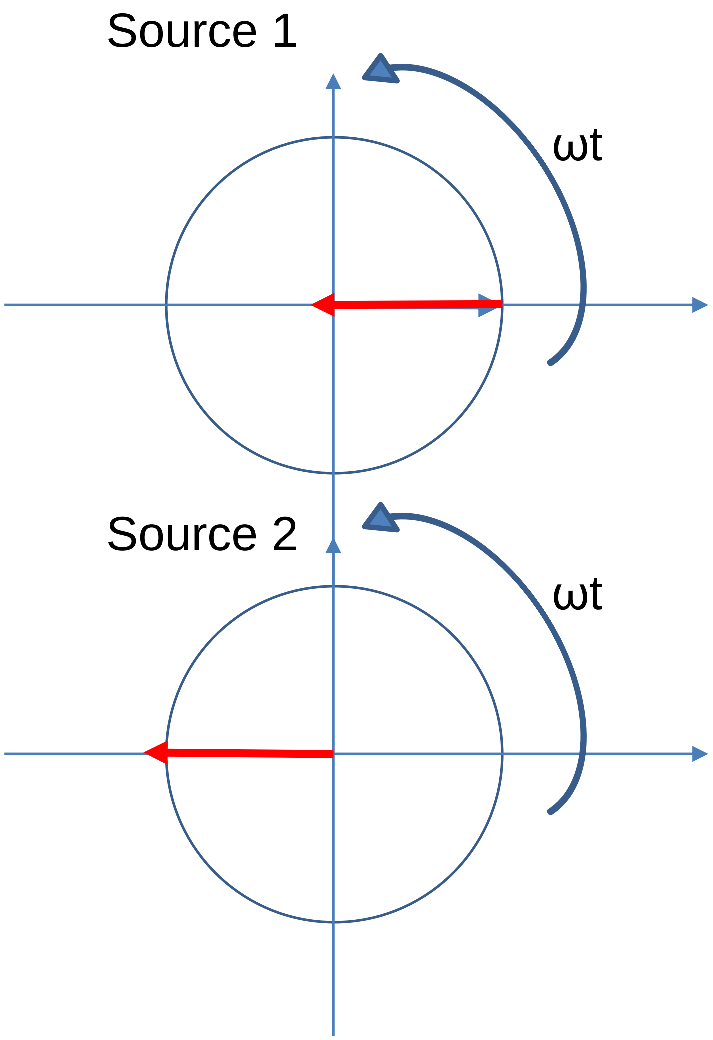
Phasor Analysis





Phasor Analysis





What else can cause a phase difference???

- Even if the distance between two sources and a detector are the same, you can still get destructive interference…
  - The sources can be out of phase.
  - The waves might travel through media with different wave speeds.
  - One wave might undergo a reflection (flipping the phase).

Beats

- What if the two sources don't have the same frequency?

$$y_1(x,t) = \sin(kx - \omega t)$$

$$y_2(x,t) = \sin((k + dk)x - (\omega + d\omega)t)$$

- Using sinA + sinB = 2cos[(A-B)/2]sin[(A+B)/2]

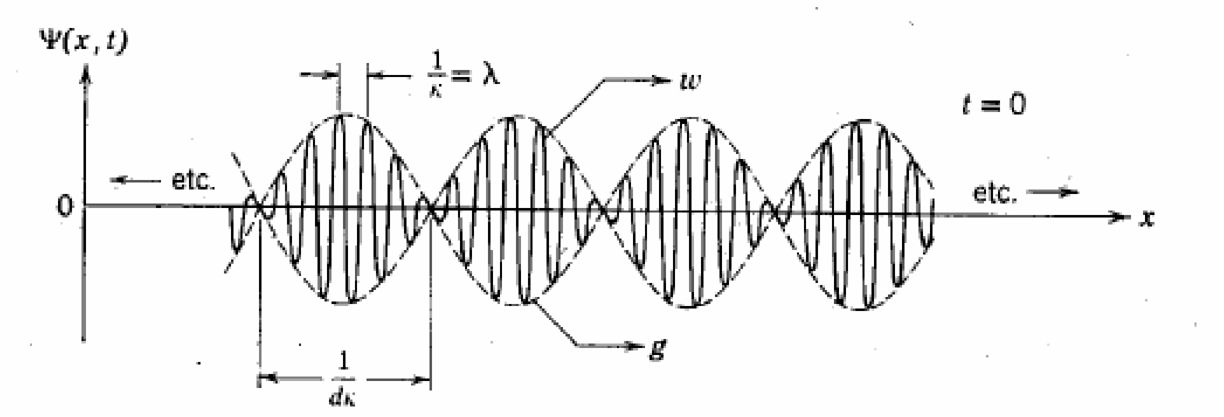
$$y(x,t) = 2\cos\left(\frac{dk}{2}x - \frac{d\omega}{2}t\right)\sin\left(\frac{2k + dk}{2}x - \frac{2\omega + d\omega}{2}t\right)$$

$$= 2\cos\left(\frac{dk}{2}x - \frac{d\omega}{2}t\right)\sin(kx - \omega t)$$

Since dk < k and dω < ω

Wave Pulses (Beats)

- $$y(x,t) = 2\cos\left(\frac{dk}{2}x - \frac{d\omega}{2}t\right)\sin(kx - \omega t)$$

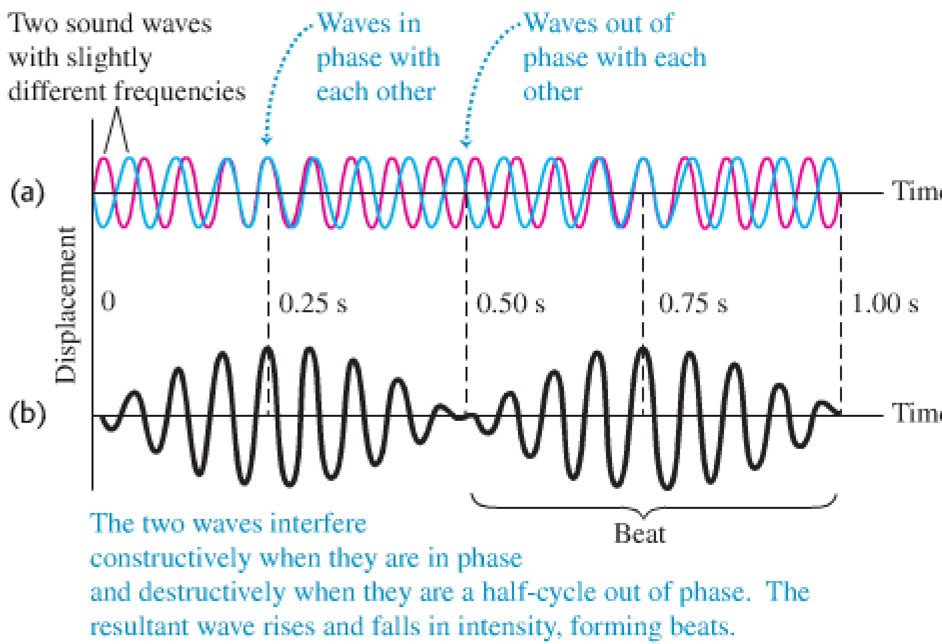


Beats

- If the two waves have slightly different wavelengths, they can interfere with a time dependence:

$$f_a = 16Hz, \quad f_b = 18Hz$$

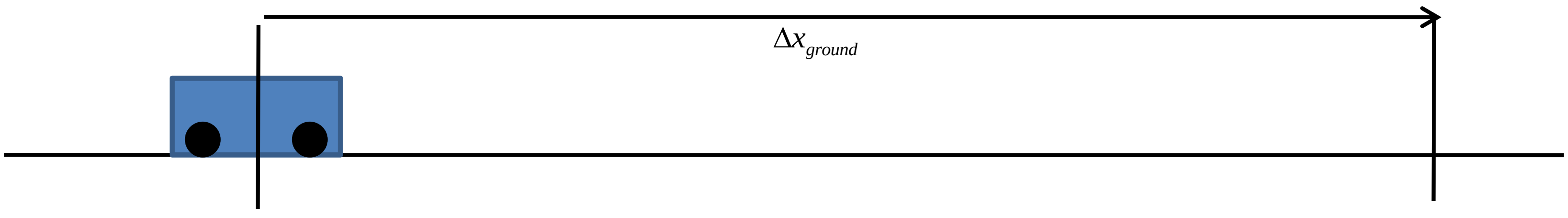
$$f_{beat} = f_a - f_b$$



Relative Velocities

- We need to review what we know about relative velocities:

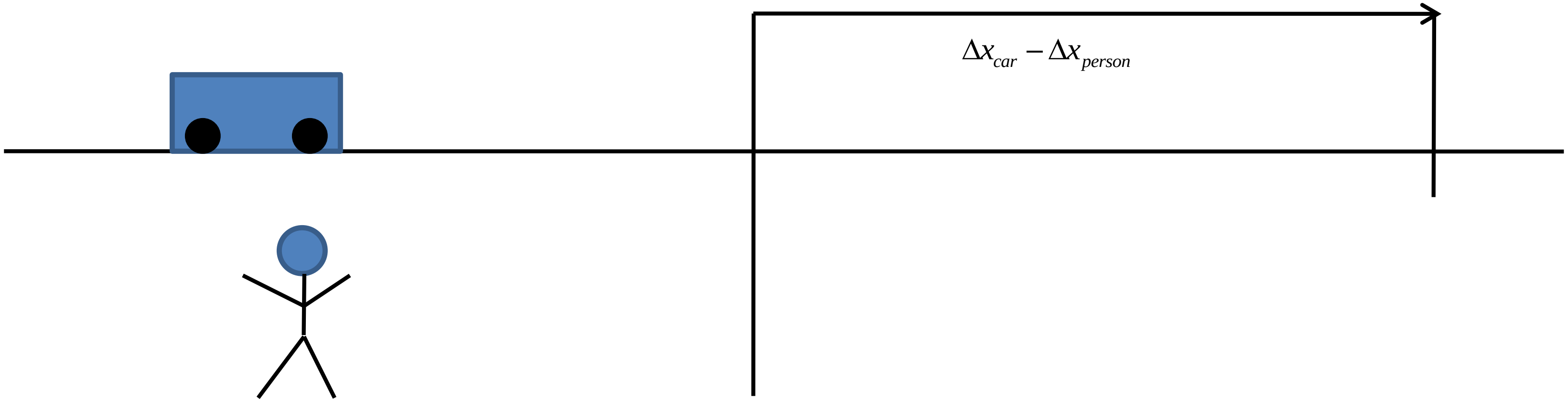
$$v_{car-ground} = \frac{\Delta x_{car-ground}}{\Delta t}$$



Relative Velocities

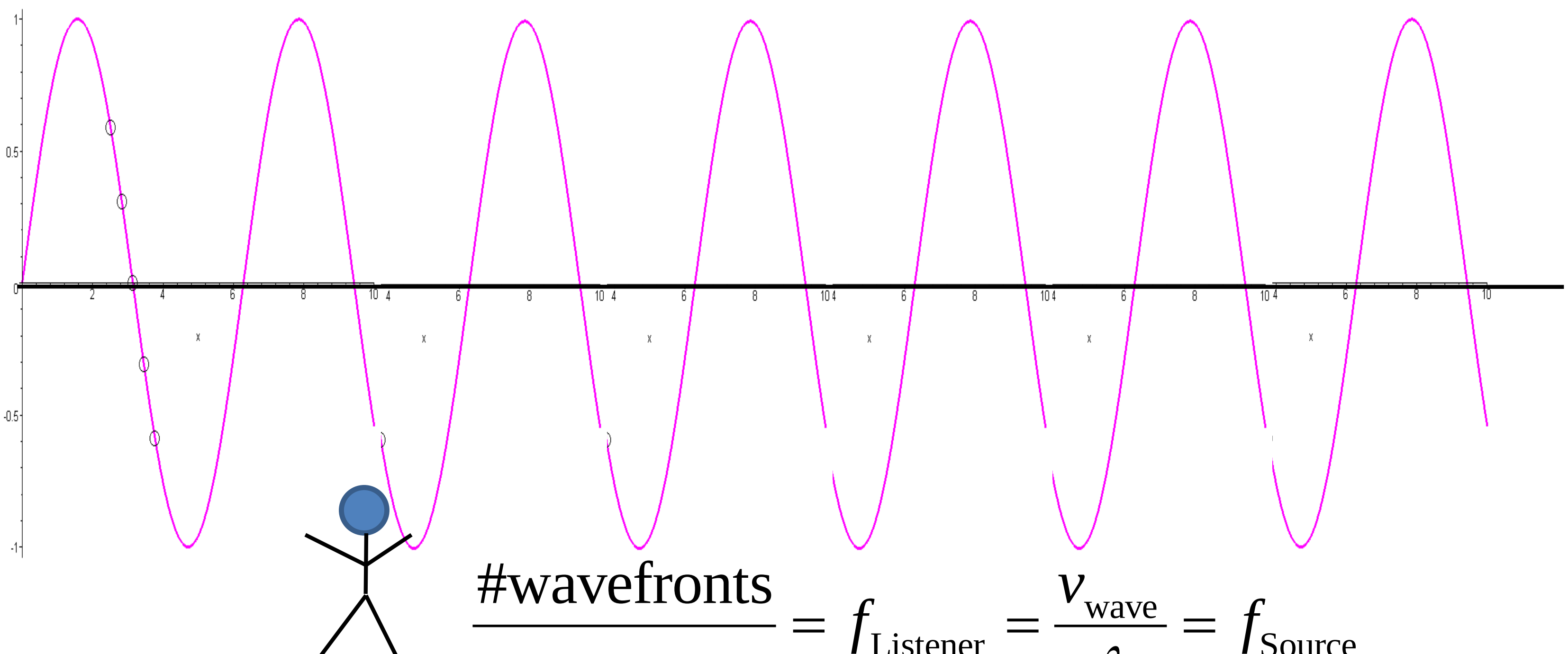
- We need to review what we know about relative velocities:

$$v_{car-person} = \frac{\Delta x_{car-ground} - \Delta x_{person-ground}}{\Delta t} = v_{car-ground} - v_{person-ground}$$



Relative Velocities & Waves

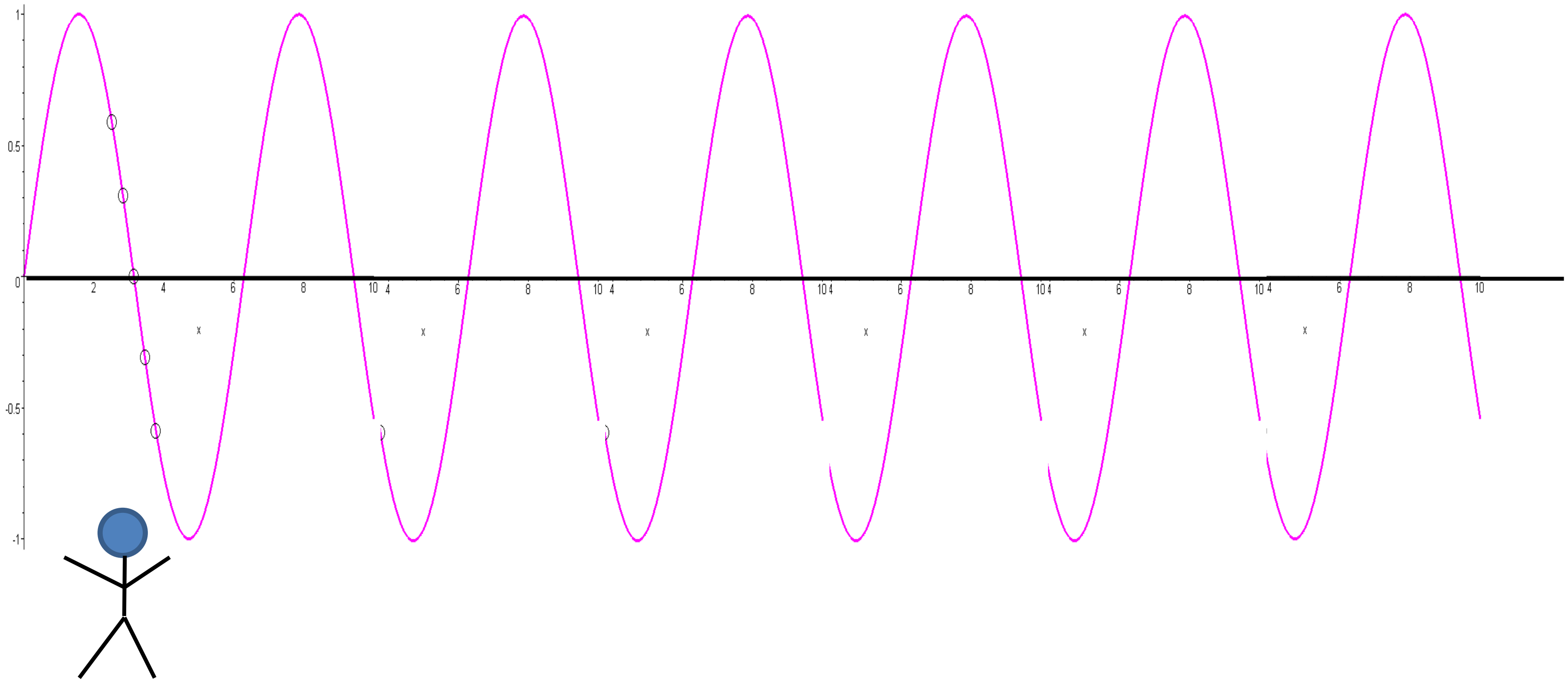
- Now, instead of the car, what if we are viewing a wave?
- We perceive the wave by measuring the number of wave-fronts that arrive at our location (we sense the changes in pressure in our ears, or detect the changes in electric field).



$$\frac{\#\text{wavefronts}}{\text{sec}} = f_{\text{Listener}} = \frac{v_{\text{wave}}}{\lambda} = f_{\text{Source}}$$

Relative Velocities & Waves

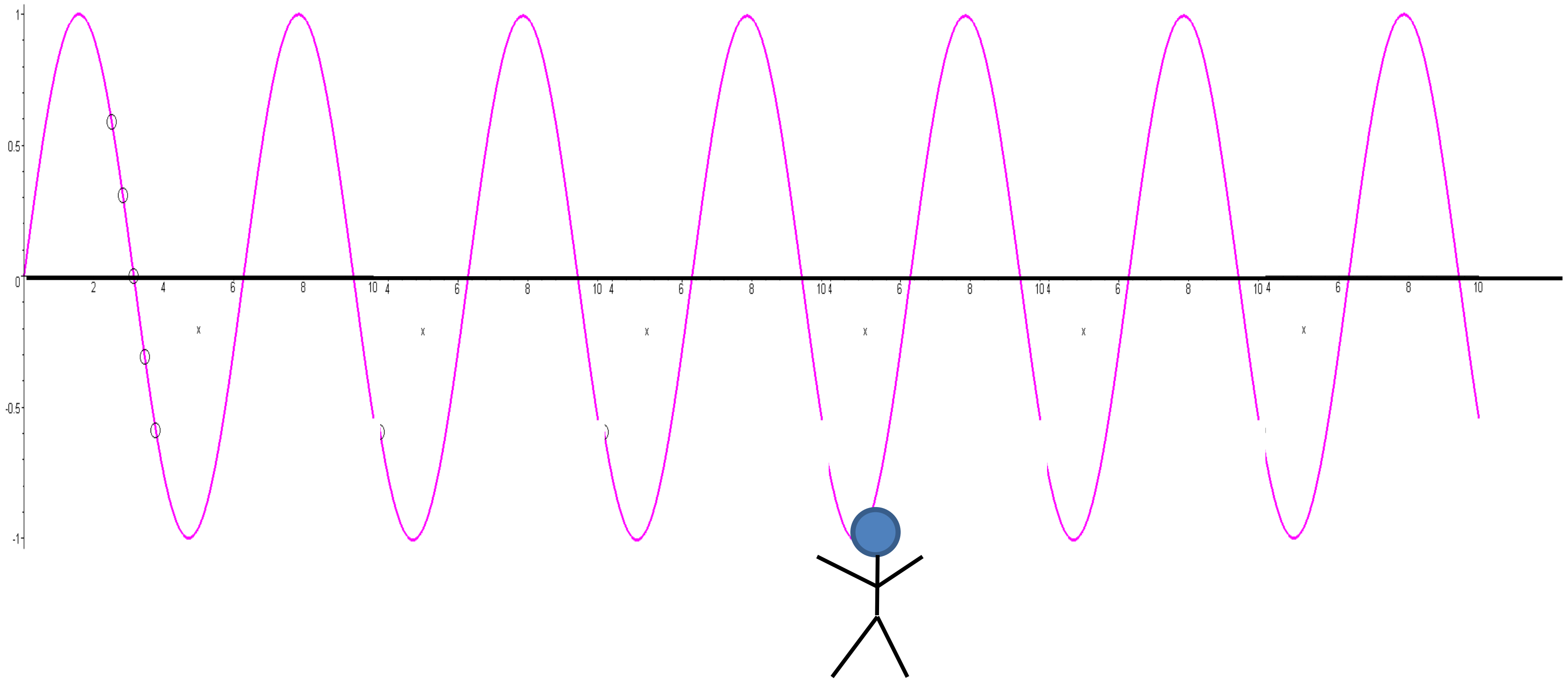
- What if we are moving too?



$$f_{\text{Listener}} = \frac{v_{\text{wave-person}}}{\lambda} = \frac{v_{\text{wave}} - v_{\text{person}}}{\lambda} = \frac{v_{\text{wave}} - v_{\text{person}}}{v_{\text{wave}} / f_{\text{Source}}} = \left(\frac{v_{\text{wave}} - v_{\text{person}}}{v_{\text{wave}}} \right) f_{\text{Source}}$$

Relative Velocities & Waves

- Notice that the directions matter:



Doppler Effect

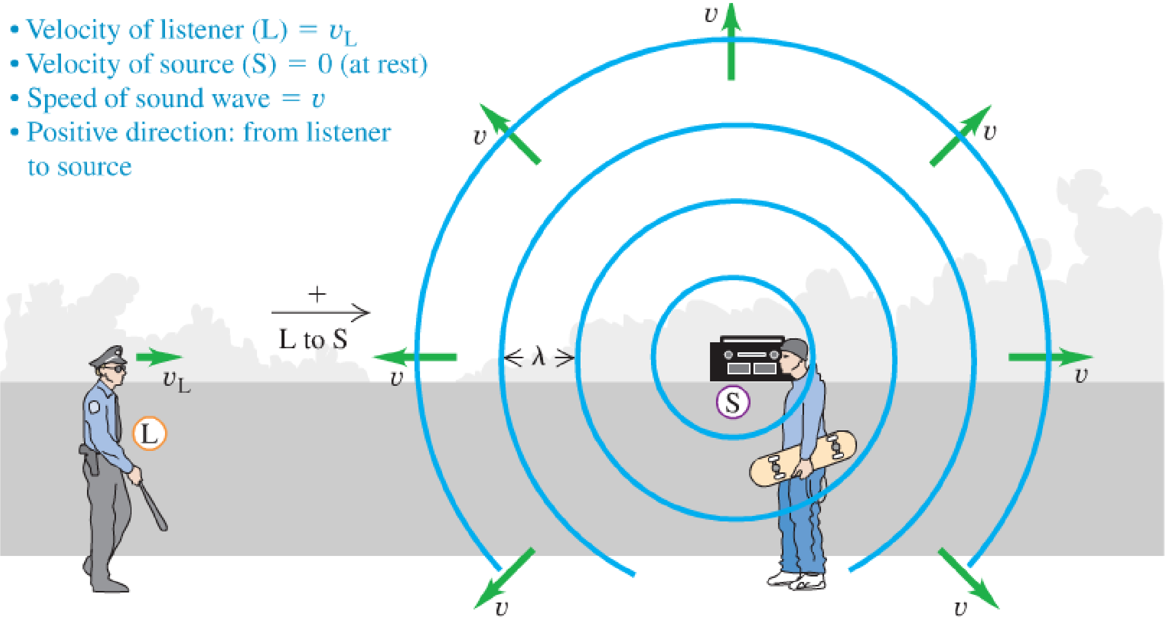
- This change in the perception of the frequency of sound (or light) emitted from a source is known as the Doppler effect.
- You have heard this in sound waves emitted from sirens, train whistles, etc.
- But the same principle is used to determine car speeds by a policeman with a radar gun, or the relative velocity and rotation speeds of galaxies as viewed by astronomers.

Book Definitions

- The book uses a little different formalism.
- They define Doppler shift as:

$$f_{\text{Listener}} = \left(\frac{v + v_{\text{Listener}}}{v} \right) f_{\text{Source}} = \left(1 + \frac{v_{\text{Listener}}}{v} \right) f_{\text{Source}}$$

- Where they have defined a positive listener velocity as in the direction *toward the source*.



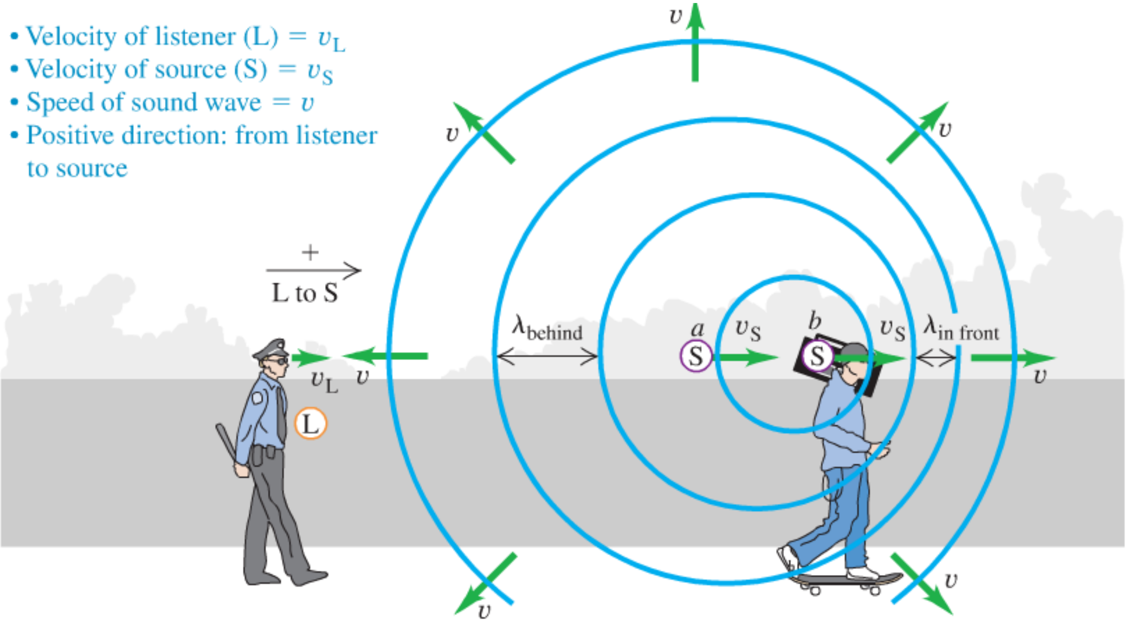
Moving Source

- If the source is moving, then the wavelength is also changed:

$$\lambda_{\text{Shifted}} = \left(\frac{v}{f_{\text{Source}}} + \frac{v_{\text{Source}}}{f_{\text{Source}}} \right) = \frac{v + v_{\text{Source}}}{f_{\text{Source}}}$$

- Then, the frequency heard by the listener is:

$$f_{\text{Listener}} = \left(\frac{v + v_{\text{Listener}}}{\lambda_{\text{Shifted}}} \right) = \left(\frac{v + v_{\text{Listener}}}{v + v_{\text{Source}}} \right) f_{\text{Source}}$$



Keeping track of signs…

- The only hard thing is to keep track of the signs of the velocities.
- Just put a listener where you need the information, and then the positive direction is towards the source