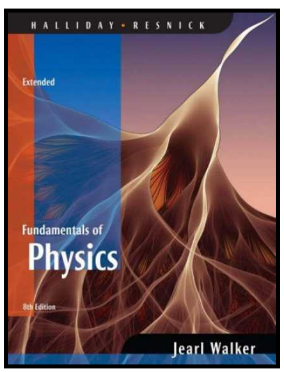
Workshop Physics 1017 - 312

University Physics II

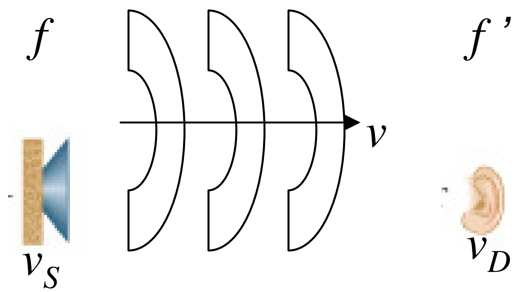


Week 8, Day 1

Outline

- **The Doppler Effect**
  - Moving source of sound
  - Moving source and detector/observer
  - The Sonic "Boom"
  - Wind effects
  - Doppler uses - RADAR
- **Activities**
  - Doppler Effect
  - Sound problems

The Doppler Effect



Consider the source and the detector of sound waves shown in the figure. We assume that the frequency of the source is equal to f.

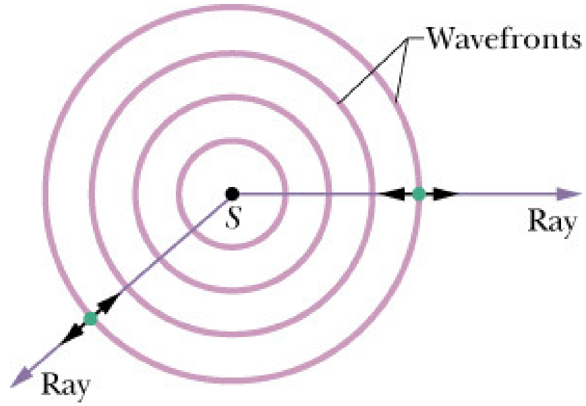
Originally discovered by the Austrian mathematician and physicist, Christian Doppler (1803-53), this change in pitch results from a shift in the frequency of the sound waves

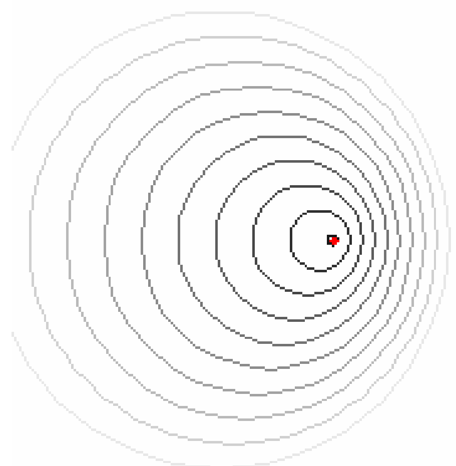
We take as the reference frame that surrounding air through which the sound waves propagate. If there is relative motion between the source and the detector then the detector perceives the frequency of the sound as $f' \neq f$. If the source or the detector move toward each other, $f' > f$. If on the other hand the source or the detector move away from each other, $f' < f$. This is known as the "***Doppler***" effect. The frequency f' is given by the equation $f' = f\,\dfrac{v \pm v_D}{v \pm v_S}$. Here v_S and v_D

A Moving Source of Sound

View Doppler Physlet online: http://webphysics.davidson.edu/Applets/Examples_From_Others/doppler.html

- **Waves and wavefronts**
  - Stationary sound source
    - *Equally spaced wavefronts*
    - *Symmetric in all directions*
  - Moving sound source
    - *Wavefronts are distorted*
    - *Distortion depends on speed*



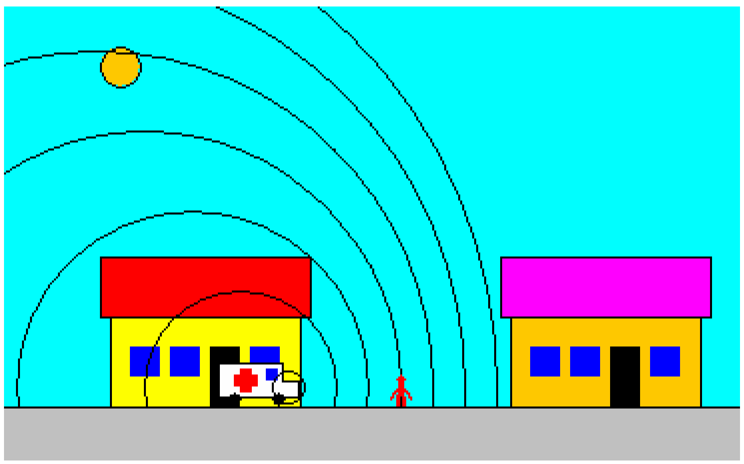


$$\lambda' = \lambda \pm v_s T = \lambda \pm \frac{v_s}{f} = \frac{v \pm v_s}{f}$$

$$\Rightarrow f' = \frac{v}{\lambda'} = f\,\frac{v}{v \pm v_S}$$

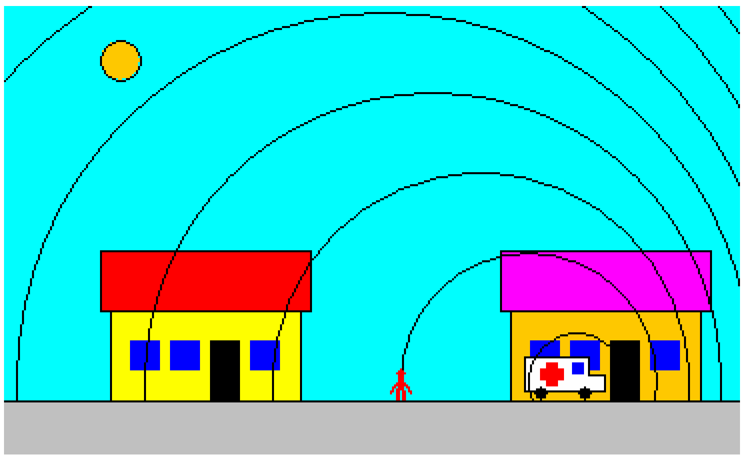
Doppler Effect - Example

- **Source Approaching**
  - As sources approaches the intervals between wavefronts shortens
  - The resulting frequency is shifted upward (more)



$$f' = f \frac{v}{v - v_S}$$

- **Source Leaving**
  - As source leaves the wavefronts reach person in longer intervals
  - The resulting frequency is shifted downward (less)



$$f' = f \frac{v}{v + v_S}$$

Image/applet credits: http://www.walter-fendt.de/ph14e/dopplereff.htm

Moving Source & Observer

When the motion of the detector or source is **toward** each other, the sign of the speed must give an **upward** shift in frequency. If on the other hand the motion is **away** from each other, the sign of the speed must give a **downward** shift in frequency.

$$f' = f\,\frac{v+v_D}{v-v_S} \qquad f' > f$$

$$f' = f\,\frac{v-v_D}{v+v_S} \qquad f' < f$$

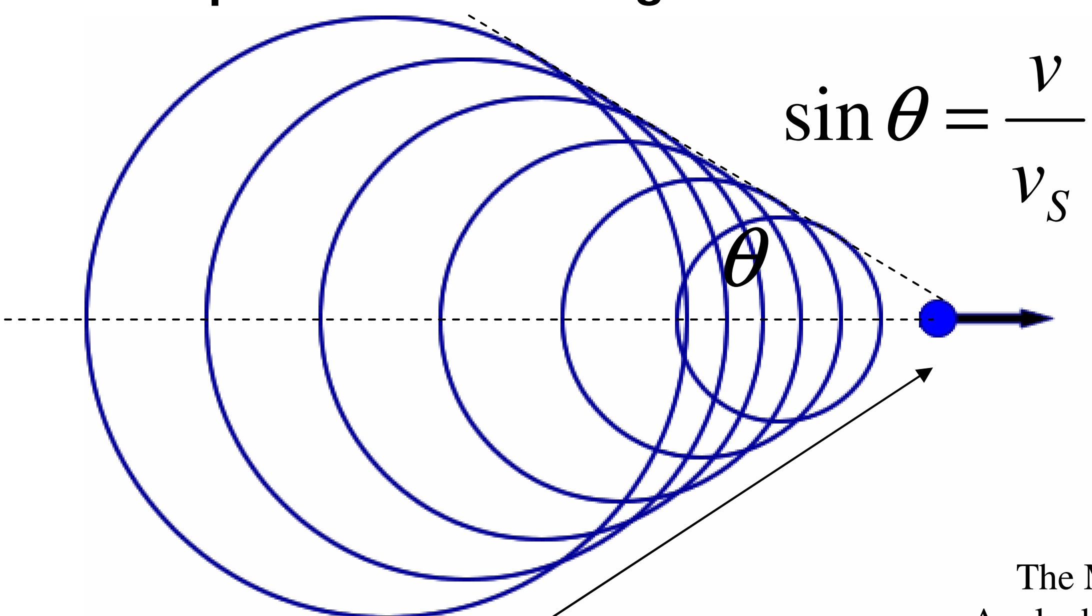
$$f' = f\,\frac{v-v_D}{v-v_S}$$

$$f' = f\,\frac{v+v_D}{v+v_S}$$

$$f' = f\,\frac{v\pm v_D}{v\pm v_S}$$

Sonic "Boom"

- For speeds equal or greater than the speed of sound the general Doppler Equations are no longer valid



$$\sin\theta = \frac{v}{v_S}$$

Air pressure first suddenly increases then suddenly decreases below normal in a sonic boom

The Mach Angle decreases with speed…

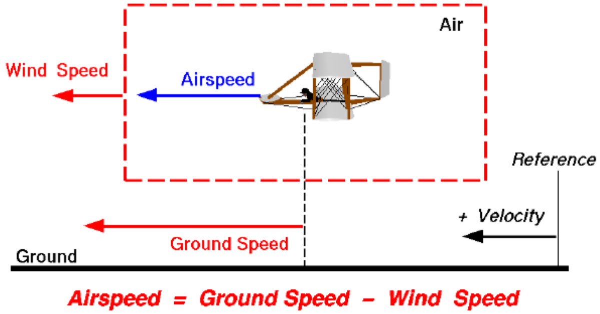
$$\theta_{1.1} = 56.4^\circ$$
$$\theta_{2.3} = 25.8^\circ$$
$$\theta_{4.2} = 13.8^\circ$$

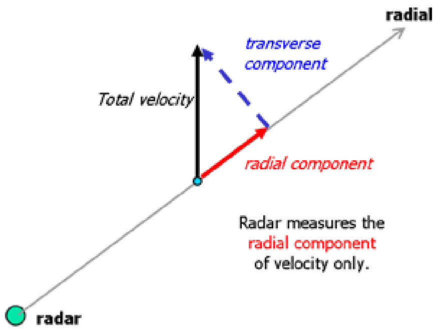
Wind Effects

Material adapted from: http://www.bom.gov.au/weather/radar/about/doppler_wind_images_intro.shtml#measure

- **Weather radar sends out electromagnetic waves**
  - short pulses which may be reflected by objects (rain drops, hail or snow) in their path
  - from the intensity of the returned signal one can estimate how heavy the rainfall, etc. is and where it is located

Velocities measured with respect to air that is stationary with respect to the ground…





$$f' = f\,\frac{v - v_D}{v + v_S} \quad \Longrightarrow \quad f' = f\,\frac{v - v_w - v_D}{v - v_w + v_S}$$

Source Moving Away from Moving Detector (w/o wind)

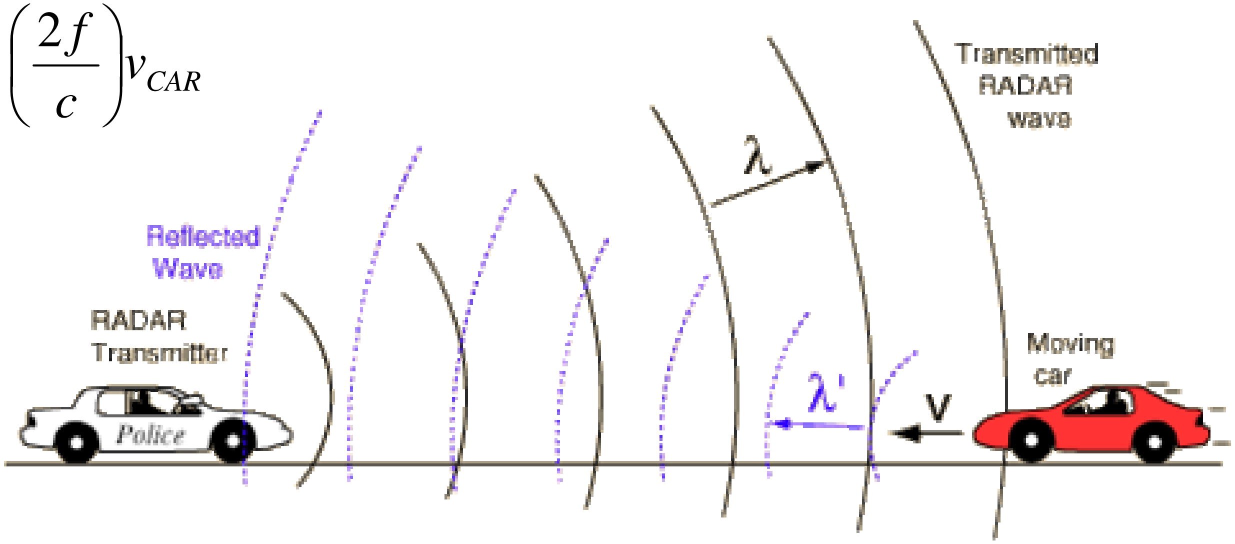
Source Moving Away from Moving Detector (w/ wind)

Doppler Uses – Police Radar

Material adapted from Hyperphysics at: http://hyperphysics.phy-astr.gsu.edu/Hbase/Sound/radar.html#c1

- **Radar Detectors**
  - RADAR speed detectors bounce microwave radiation off of moving vehicles and detect the reflected waves.
  - These waves are shifted in frequency by the Doppler effect
  - The *beat frequency* between the directed and reflected waves provides a measure of the vehicle speed.

$$f' - f = \left(\frac{2f}{c}\right) v_{CAR}$$



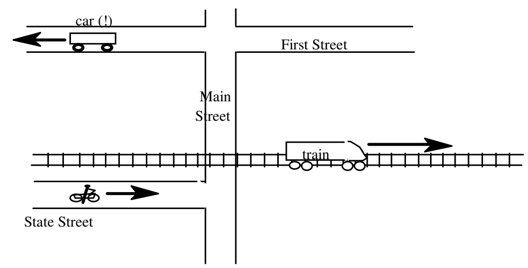
Activity – Test Your Understanding…

- **The Doppler Effect**
  - Pedestrian noise
    - *Moving person*
    - *Moving car*
    - *Moving train*
  - Wind effects

Your Name (**Print**): ____________________ Date: ________
Group Members: ____________________
____________________ Group: ________

Doppler Effect

The train traveling east on the tracks at 50 mph (22.2 m/s) is blowing its whistle which emits a frequency of 400 Hz. The speed of sound in air is 343 m/s. Assume all motion is along a straight line.



For each part, first write the equation you used to determine an answer, substitute numerical values, then write the numerical answer to four significant figures.

1. a) A pedestrian is waiting at Main Street to cross the tracks. What is the whistle frequency heard by the pedestrian?

   b) A bicyclist is riding east on State Street at 3.00 m/s. What is the whistle frequency heard by the bicyclist?

   c) The person in the car is driving west at 13.0 m/s. What is the whistle frequency heard by the motorist?

Activity – Sound Problems

- Sound Problems
  - Concept questions
    - *Questions 1, 3, 5*
  - Exercises
    - *Questions 4, 7, 9*

Your Name (**Print**): ______________________ Date: ________
Group Members: ______________________
______________________ Group: ________

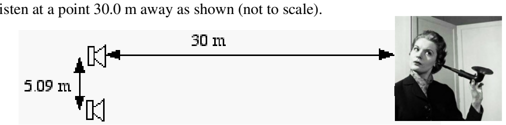
Sound Wave Problems

1. Sound from a speaker has an amplitude equal to the amplitude of the SHM of the speaker. You have two speakers, one high frequency and the other low frequency. You hear equal intensity sound waves, with the frequency of the second wave is 9 times the frequency of the first.
   a) Which speaker will have larger amplitude?
   b) What is the ratio of amplitudes?

2. A 3.00 kHz sound wave travels through air at 20.0 °C. The intensity of the sound wave is equal to the threshold of hearing (10^{-12} W/m^2). What are the pressure amplitude and displacement amplitude of the sound wave?

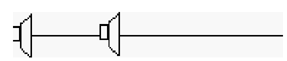
3. I produce sound with the same frequency, first in a pure oxygen atmosphere, then in a pure helium atmosphere. The bulk modulus is the same for the two gases.
   a) In which gas is the speed larger?
   b) What is the ratio of speeds?

4. Suppose I have two speakers, separated by 5.09 m, each emitting an 800 Hz sound in air at 20.0 °C, and I listen at a point 30.0 m away as shown (not to scale).



   a) Assume that the speakers are in phase–that is they both emit a peak at the same time. What will I hear, constructive or destructive interference?
   b) Now I move the bottom speaker vertically. At what speaker separation will I hear the other type of interference from part (a)?
   c) Suppose I double the frequency of the speakers, what will I hear for the two separations in a) and b) above?

5. Two identical sources emit sound of frequency 2 kHz. They are separated by 25.7 cm.



   a) What type of interference is heard at a distance of 5 m away along the axis joining the speakers?
   b) You now increase the frequency of both speakers. Find the next frequency for which you will hear destructive interference.
   c) Now return to 2 kHz. What, if anything, can you do to get the opposite type of interference as in part (a)?