2.3 Sound

Doppler Effect.

Shock Waves

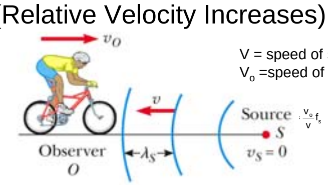
Doppler Effect

Doppler effect- the shift in frequency of a wave where the source and observer are moving relative to one another.

Two different cases for sound:

- Observer moving – source stationary
- Source moving- observer stationary.

Observer moving toward a Stationary source (Relative Velocity Increases)



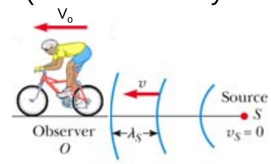
V = speed of sound

V_o =speed of observer

- Relative velocity of wave (v_o + v) increases.
- Frequency increases

$$f_o = \frac{v + v_o}{\lambda_s} = \frac{v + v_o}{v} f_s = (1 + \frac{v_o}{v}) f_s$$

Observer moving away from a stationary source (Relative velocity decreases)

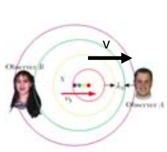


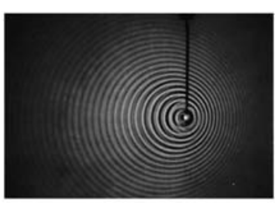
Relative velocity of wave (v-v_o) decreases.

Frequency decreases.

$$f_o = \frac{v - v_o}{\lambda_s} = \frac{v - v_o}{v} f_s = (1 - \frac{v_o}{v}) f_s$$

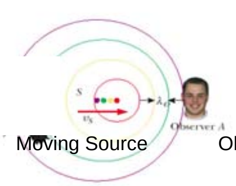
Source moving toward a stationary observer (wavelength in the medium decreases)





- When the source is moving the wavelength of the wave in the media is changed
  - source approaches observer A
    - Wavelength decreases and frequency heard by observer A increases
  - Source moves away from observer B.
    - Wavelength increases and frequency heard by observer B decreases.

Source Moving Toward observer A

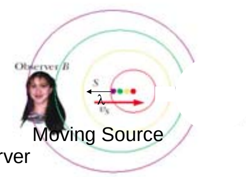


Distance traveled by source in one period

- Wavelength decreases $\lambda = \lambda_s - v_s T$
- Frequency increases $f_o = \frac{v}{\lambda_s - v_s T_s} = \frac{v}{v T_s - v_s T_s}$

$$f_o = \frac{v}{v - v_s} f_s$$

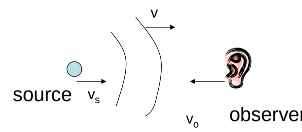
Source Moving Away from observer B



- Wavelength increases $\lambda = \lambda_s + v_s T$
- Frequency decreases $f_o = \frac{v}{\lambda_s + v_s T_s} = \frac{v}{vT_s + v_s T_s}$

$$f_o = \frac{v}{v + v_s} f_s$$

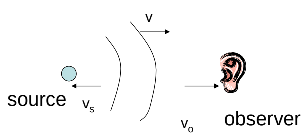
Observer and source moving



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

- The frequency increases when the source and observer are moving toward each other.

Observer and source moving



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

- The frequency decreases when the source and observer are moving away each other.

Question

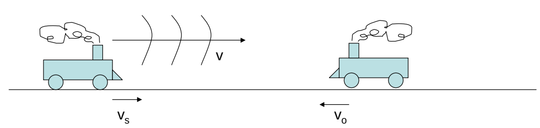
A fire truck is going down the street toward a stationary observer sounds an alarm with a frequency f_s. Which of these is true of the frequency heard by the observer.

A. The frequency is higher because the wavelength of the sound in air is lengthened.
B. The frequency is higher because the wavelength of the sound in air is shortened.
C. The frequency is higher but the wavelength of the sound in air is the same as for a stationary truck.
D. The frequency is higher because the speed of sound in air is faster.

Example

A fire truck is approaching an observer with a speed of 30 m/s. The siren has a frequency of 700 Hz. What frequency does the observer hear as the truck approaches? speed of sound 340 m/s

Two trains are approaching each other each moving at 34 m/s. One train sounds a whistle at a frequency of 1000 Hz. Find the frequency shift of sound heard by an observer on the other train.



Approximate solution at low speeds.

Source moving toward observer.

$$f_o = \frac{v}{v - v_s} f_s = \frac{v}{v(1-\frac{v_s}{v})} f_s = \frac{1}{1-\frac{v_s}{v}} f_s$$

At low speed v_s <<v

$$f_o \approx (1 + \frac{v_s}{v}) f_s$$

Using the relation

$$\frac{1}{1-x} \approx 1 + x \qquad \text{When } x<<1$$

Approximate solution for two trains approaching

$$f_o = \frac{v+v_o}{v-v_s} f_s = \left(\frac{v+v_o}{v}\right)\left(\frac{v}{v-v_s}\right) f_s \cong \left(1+\frac{v_o}{v}\right)\left(1+\frac{v_s}{v}\right) f_s$$

negligible

$$f_o = \left(1 + \frac{v_s}{v} + \frac{v_o}{v} + \frac{v_s v_o}{v^2}\right) f_s \cong \left(1 + \frac{v_s}{v} + \frac{v_o}{v}\right) f_s$$

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

- The shift in frequency is approximately proportional to the ratio of the train velocities to speed of sound as we found in the previous example.
- This is a good approximation when the train velocities are slow compared to the speed of sound.
- This is a good approximation for the Doppler shift of electromagnetic waves.

Doppler shift of Electromagnetic waves

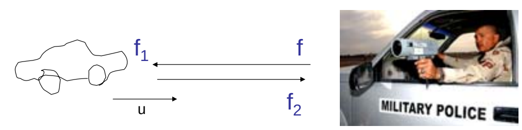
- Electromagnetic waves are also shifted by the Doppler effect.
- Since EM waves travel in a vacuum the equations governing the shift are different.
- The same shift is observed for moving source or moving observer.
- For motion with speeds less than the speed of light the relation is the same as for the approximate shift for sound waves when u<<v.

$$f = f_s(1 \pm \frac{u}{c})$$

u = relative velocities of source and observe.
c = speed of light
Positive sign when approaching
Negative sign when moving away.

Doppler Radar

Doppler radar is used to determine the speed of a car.



The beat frequency between the Doppler shifted frequency and the initial frequency is measured to determine the speed of the car.

$f_1 = f_s\,(1+u/c)$ negligible

$f_2 = f_1(1+u/c) = f_s\,(1+u/c)^2 = f_s\,(1+2u/c + (u/c)^2)$

beat frequency $= f_2 - f_s = 2\frac{u}{c} f_s$

Question

A Doppler shifted radar beam is reflected off a car going 30m/s coming directly toward a stationary police car. If the frequency of the radar is 1.00×10^{10} Hz. The beat frequency of the reflected beam with the stationary source is. (speed of light is 3.00×10^{8}m/s)

A. 1×10^{2} Hz

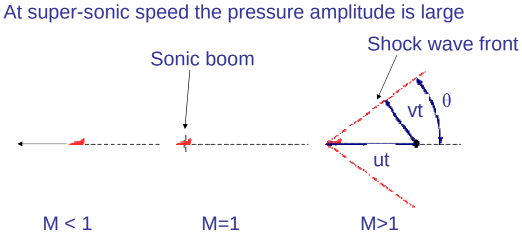
B. 2×10^{2} Hz

C. 1×10^{3} Hz

D. 2×10^{3} Hz

Shock wave

At super-sonic speed the pressure amplitude is large



Mach number $M = \frac{u}{v}$

Mach angle θ $\sin\theta = \frac{v}{u}$

Question

An observer feels a shock wave and sees that the supersonic jet is at an angle of 20^{O} above the horizon flying in the horizontal direction. What is the speed of the jet (take the speed of sound to be 340 m/s)