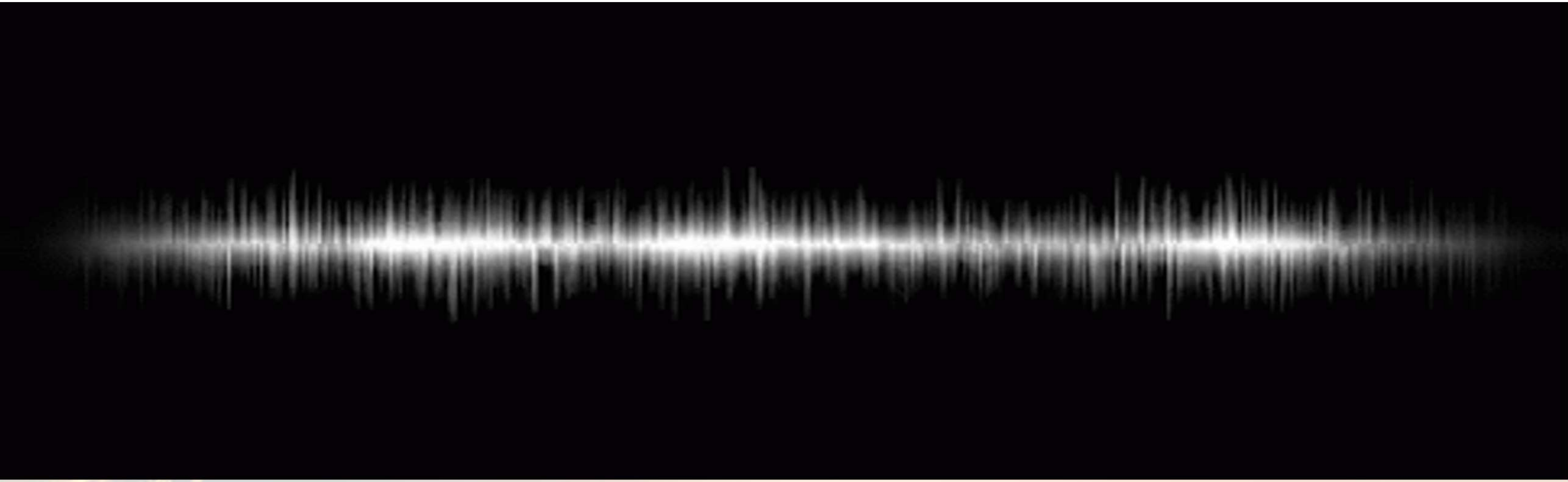


CPP1113
Sound waves

CHAPTER 5

PART 2

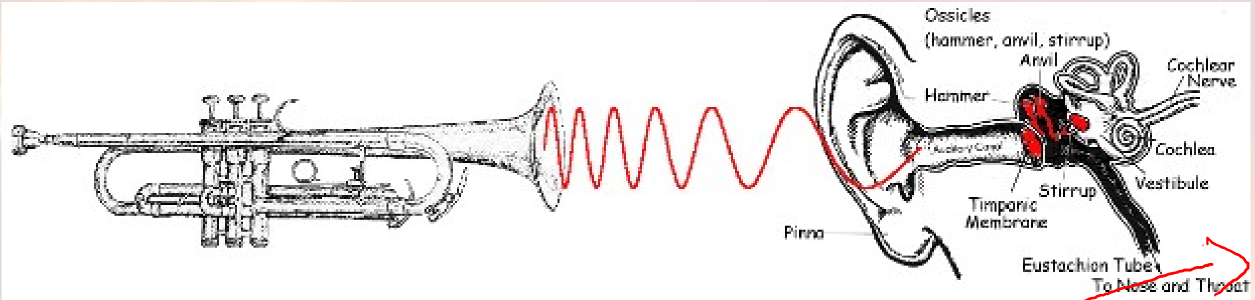
Contents

Objectives

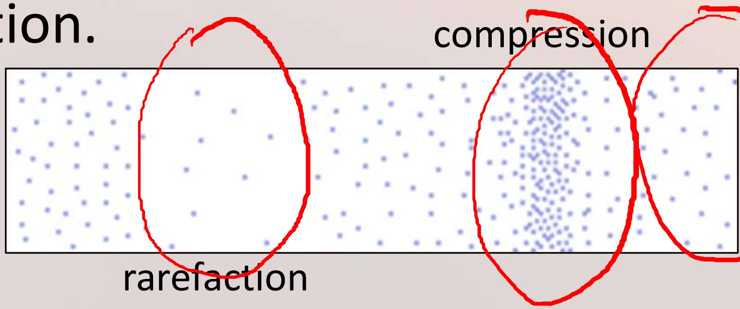
- Describe what is sound and how it is produced.
- Differentiate the three categories of sound.
- Explain what is interference of sound waves and beat phenomena.
- Define intensity and intensity level.
- Explain what is Doppler effect.
- Use the formula derived for Doppler effect in different cases.

5.1 Introduction

- Sound waves are longitudinal waves produced by variations in air pressure.

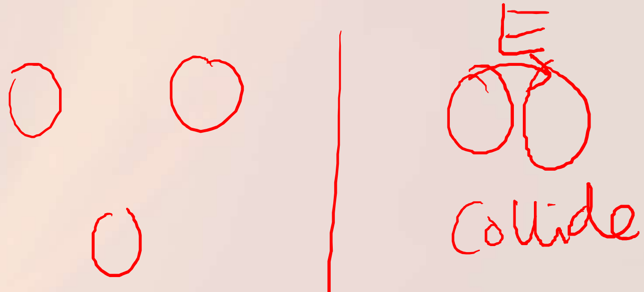


- A vibrating source pushes molecules in air back and forth, creating areas of compression and rarefaction.



collide

5.1 Introduction

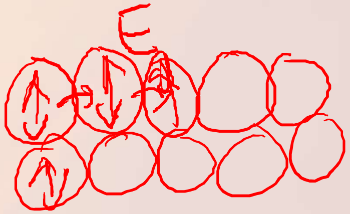


- When a molecule moves, it collides with the next one and makes it move too.

- The energy of a sound wave travels away from the source trough a series of molecule collisions parallel to the direction of the wave.

- Sound cannot travel through a vacuum.

5.1 Introduction



- Sound waves can also travel trough liquids and solids.
- The velocity of a sound wave depends on the temperature of the medium and its elasticity (more elasticity means that molecules will move easily).

5.1 Introduction

- Three aspects of sound :

There must be a source for a sound

- The source of a sound wave is vibrating object.

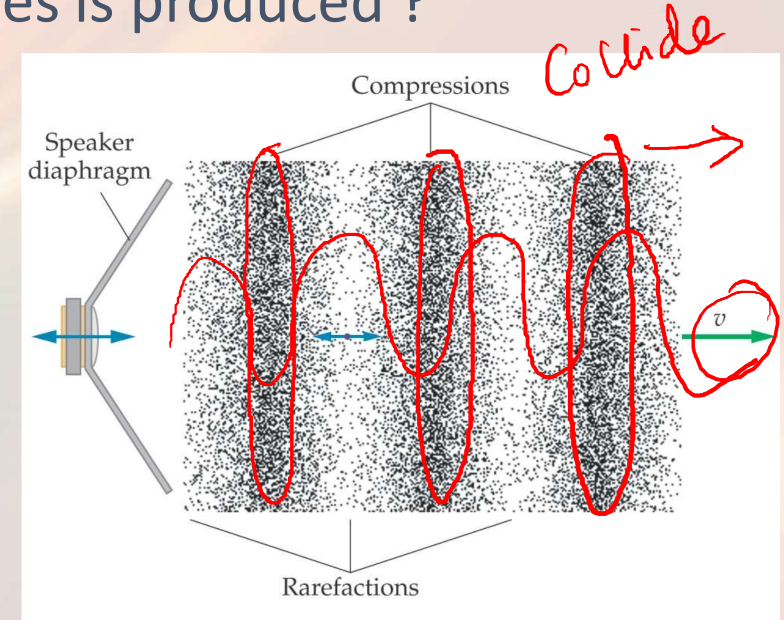
Energy Transformation

- The energy is transferred from the source in form of longitudinal sound waves.

The sound is detected by an ear or an instrument.

5.1 Introduction

How sound waves is produced ?

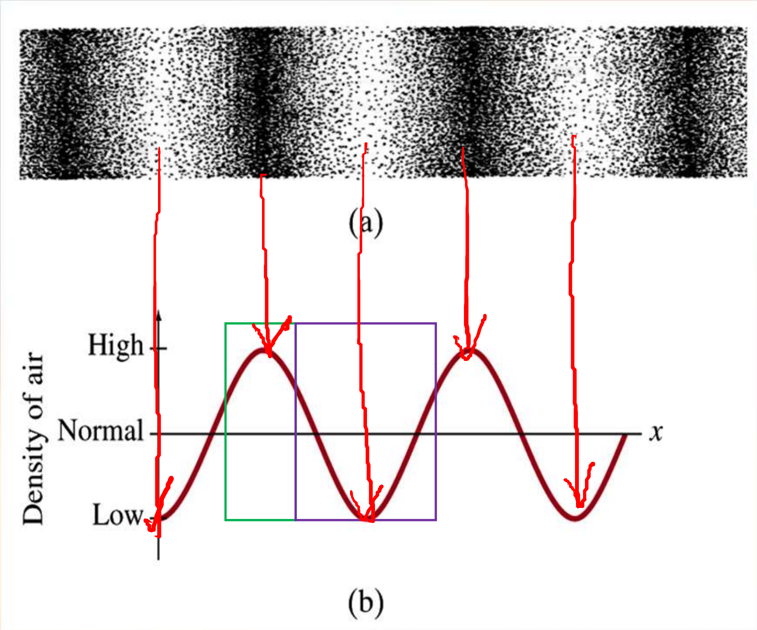


As the diaphragm of a speaker vibrates back and forth, it alternately compresses and rarefies the surrounding air. These regions of high and low density propagate away from the speaker with the speed of sound. Individual particles in the air oscillate back and forth about a given position, as indicated by the blue arrow.

5.1 Introduction

How sound waves is produced ?

As the waves travel, the particles in the medium vibrate to produce density and pressure changes along the direction of motion of the wave.



These changes result in a series of high pressure and low pressure regions

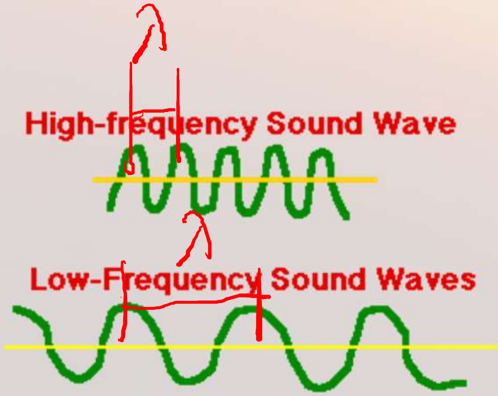
- high pressure regions
  - condensation (compression)
- low pressure regions
  - rarefaction (expansion)

5.2 Characteristics of Sound

$V = f\lambda$

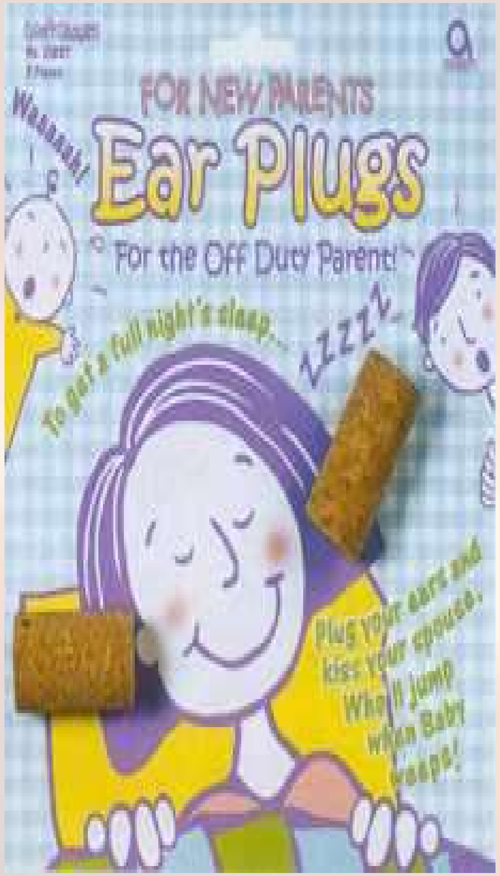
$\uparrow f \propto \frac{1}{\lambda}\downarrow$

- Pitch
  - The pitch of a note is determined solely by its frequency.
  - The lower the frequency, the lower the pitch and the higher the frequency, the higher the pitch.
  - Pitch also show how high or low a sound seems



5.2 Characteristics of Sound

- Loudness
  - Subjective quantity
  - A sensation in the consciousness of a human being
  - Loudness is related to the energy in the sound wave
  - It is related to a physically measurable quantity, the intensity of the wave



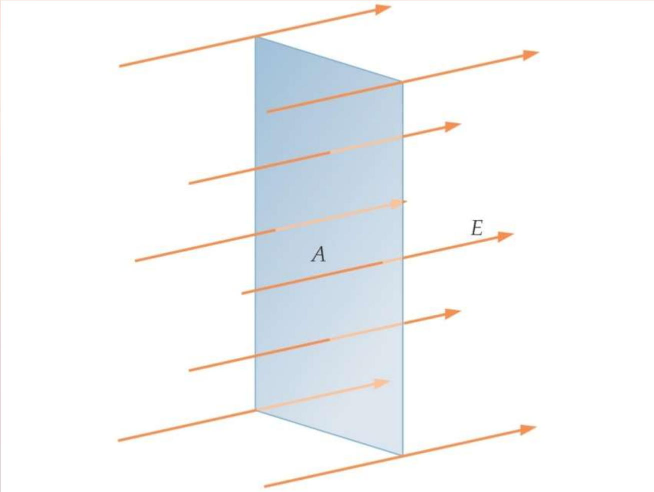
5.3 The Intensity of Sound Waves

$\downarrow I \propto \frac{1}{A\uparrow}$

- The idea on intensity
  - If a wave carries an energy, E through an area, A in the time, t, the corresponding intensity is

$$I = \frac{E}{At} = \frac{P}{A}$$

where P = E/t is the power.



5.3 The Intensity of Sound Waves

- The *intensity* of a wave is the rate at which the energy flows through a unit area, A, oriented perpendicular to the direction of travel of the wave

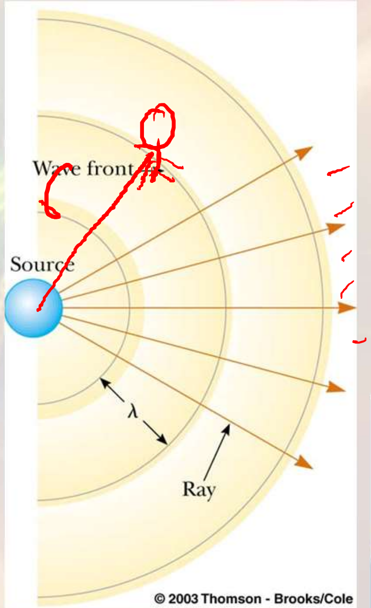
$$\boxed{I = \frac{\Delta E}{A\,\Delta t} = \frac{P}{A}} \quad \frac{(W)}{(m^2)}$$

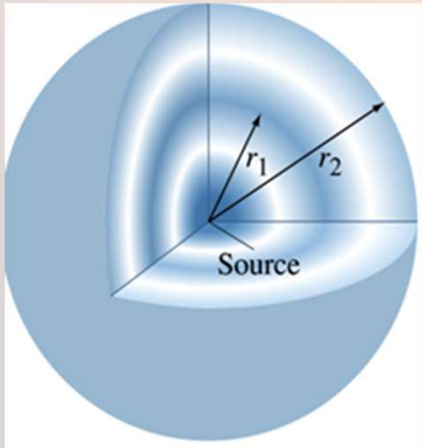
- P is the power, the rate of energy transfer
- Units are W/m^2

5.3 The Intensity of Sound Waves

$I = \frac{P}{A} = \frac{P}{4\pi r^2}$

- Intensity of Spherical Waves





r_1 r_2

- A spherical wave propagates radically outward from the oscillating sphere
- The energy propagates equally in all directions
- The intensity is

$$I = \frac{P}{4\pi r^2}$$

SI Unit: Wm^{-2}

5.3 The Intensity of Sound Waves

- The average power is the same through any spherical surface centered on the source
- The intensities at distances r_1 and r_2 are

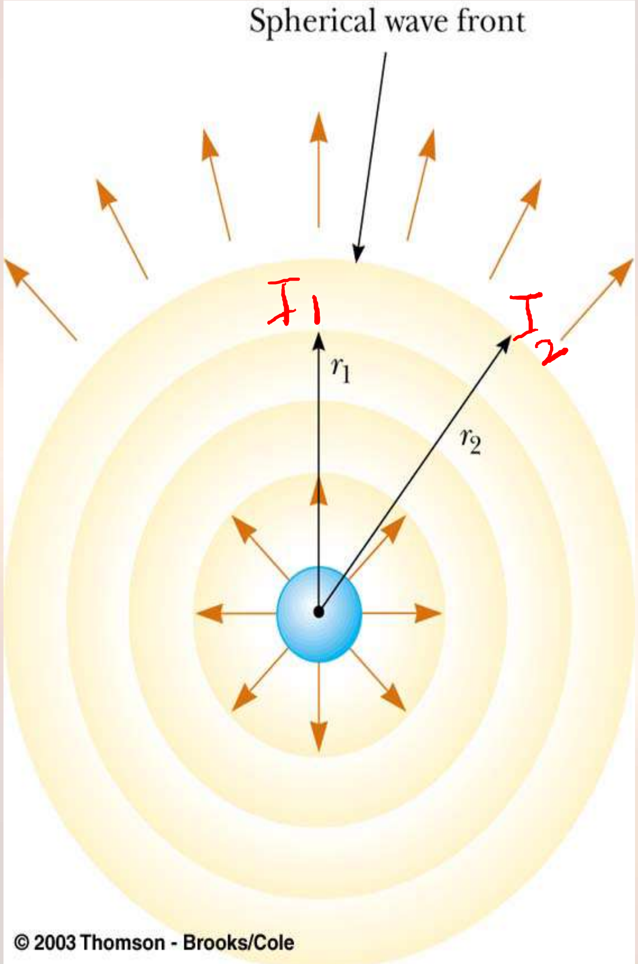
$$I_1 = \frac{P}{4\pi r_1^2} \qquad I_2 = \frac{P}{4\pi r_2^2}$$

$$P = P$$

$$I_1 \cancel{4\pi} r_1^2 = I_2 \cancel{4\pi} r_2^2$$

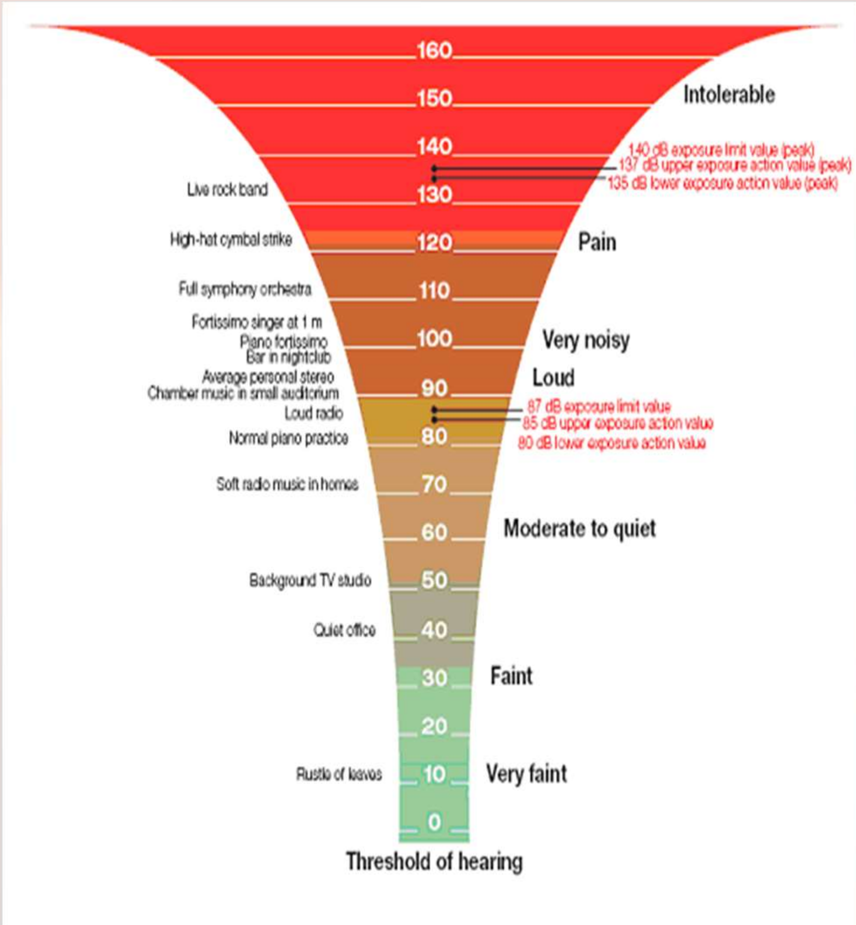
The ratio: $\boxed{\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}}$

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$$



5.3 The Intensity of Sound Waves

- Various Intensities of Sound
  - Threshold of hearing
    - Faintest sound most humans can hear
    - About 1 x 10^{-12} Wm^{-2}
  - Threshold of pain
    - Loudest sound most humans can tolerate
    - About 1 W/m^2



5.3 The Intensity of Sound Waves

$P = I_1 4\pi r_1^2$

$P = 2.8\times10^{-6}(4\pi)(1)^2$

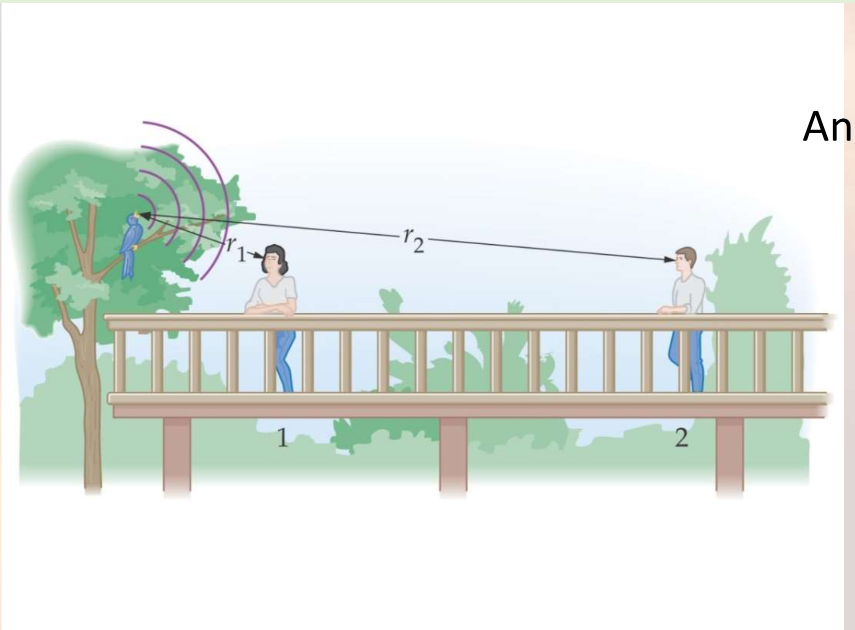
$P = 3.52\times10^{-5}\ W$

- Example

Two people relaxing on a deck listen to a songbird sing. One person, only 1.00 m from the bird, hears the sound with an intensity of 2.80 x 10–6 W/m2.

a) What intensity is heard by the second person, who is 4.25 m from the bird? Assume that no reflected sound is heard by either person.

b) What is the power output of the bird's song?



$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$

Answer: a) $1.55x10^{-7}\ W/m^2$

b) $3.52x10^{-5}\ W$

$\frac{2.8\times10^{-6}}{I_2} = \frac{4.25^2}{1^2}$

$I_2 = 1.55\times10^{-7}\ W/m^2$

5.4 Sound Level in Decibels (dB)

Intensity of sound wave (I)

- The decibel, dB, is a unit of gain or loss in power on a logarithmic basis, using base 10 logarithms
- β is the intensity level or the decibel level of the sound
- It is widely used in telecommunications and acoustics

Intensity of sound level (β)

$$\beta = 10 \log \frac{I}{I_o} dB$$

Where,

I_0= intensity of some reference level. Usually, the threshold of human hearing is chosen as reference, 1.00×10^{-12} Wm^{-2}

I = intensity of a sound in Wm^{-2} at the sound level, β

5.4 Sound Level in Decibels (dB)

$\beta = 10 \log \frac{I}{I_0} = 10 \log \frac{1\times10^{-8}}{1\times10^{-12}} = 40\ dB.$

- Example

40dB corresponds to an intensity that is times the standard reference level.

$I = 1\times10^{-8}\ W/m^2$

$$\beta = 10\log\frac{I}{I_o}\,dB$$

$$= 10\log(\frac{10^{-8}}{10^{-12}}) = 10\log(10^{4}) = 40dB$$

5.4 Sound Level in Decibels (dB)

- The threshold of pain (sound which makes a painful sensation to the ear , I = 1.00 Wm^{-2}) corresponds to a sound level of

$$\beta \equiv 10 \log\left(\frac{I}{I_O}\right) = 10 \log\left(\frac{1.00}{1.00 \times 10^{-12}}\right) = 120 \text{ dB}$$

- The threshold of hearing , I = 1.00×10^{-12} Wm^{-2} corresponds to a sound level of

$$\beta \equiv 10 \log\left(\frac{I}{I_O}\right) = 10 \log\left(\frac{1.00 \times 10^{-12}}{1.00 \times 10^{-12}}\right) = 0 \text{ dB}$$

5.4 Sound Level in Decibels (dB)

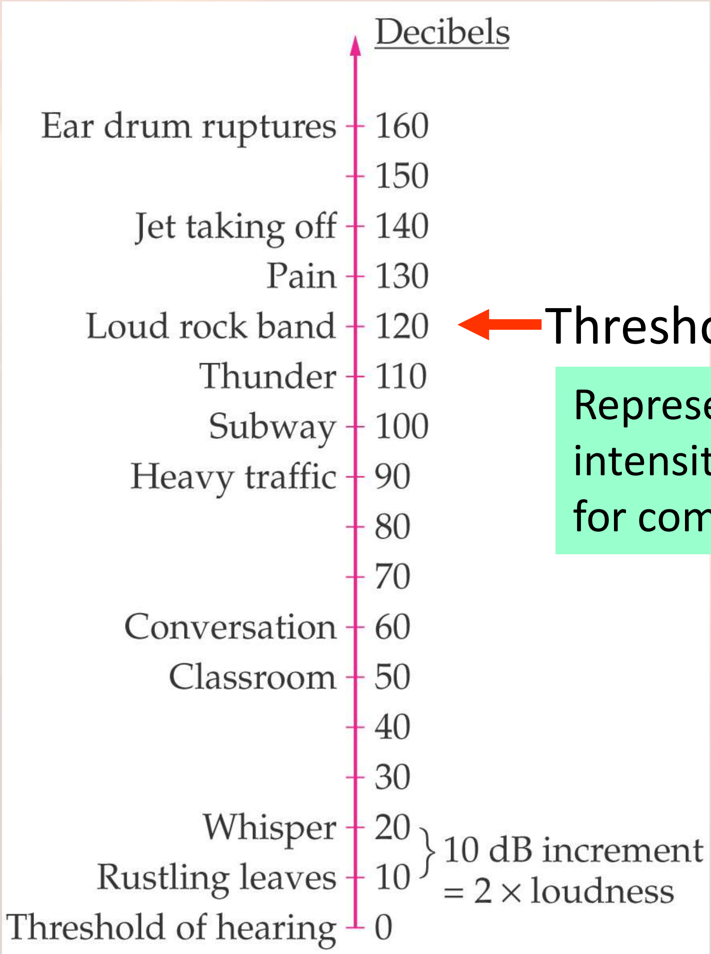
- Older people serious loss of hearing may occur at a level of -20 dB
- Exposure to sound over 90 dB for long period may effect hearing…deaf!

5.4 Sound Level in Decibels (dB)

TABLE 14.2 **Intensity Levels in Decibels for Different Sources**

Source of Sound	β (dB)
Nearby jet airplane	150
Jackhammer, machine gun	130
Siren, rock concert	120
Subway, power mower	100
Busy traffic	80
Vacuum cleaner	70
Normal conversation	50
Mosquito buzzing	40
Whisper	30
Rustling leaves	10
Threshold of hearing	0

5.4 Sound Level in Decibels (dB)



Threshold of painful

Representative intensity levels for common sounds.

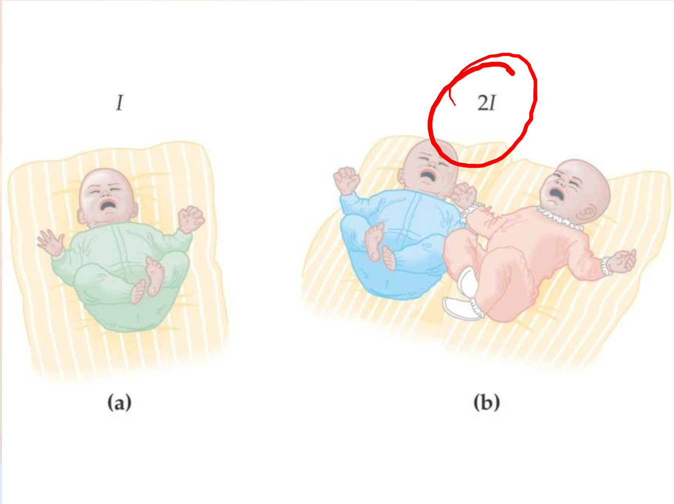
5.4 Sound Level in Decibels (dB)

$$\beta = 10 \log \frac{I}{I_0}$$

$$\beta = 10 \log \frac{8 \times 10^{-6}}{1 \times 10^{-12}}$$

$$\beta = 69 \text{ dB}$$

$$\begin{array}{r} 69 \\ \times\ 2 \\ \hline 138 \end{array}$$



(a) (b)

$$\beta = 10 \log \frac{2I}{I_0}$$

$$\beta = 10 \log \frac{2(8 \times 10^{-6})}{1 \times 10^{-12}}$$

$$\beta = 72 \text{ dB}$$

- Example

A crying child emits sound with an intensity of 8.0×10^{-6} Wm^{-2}. Find

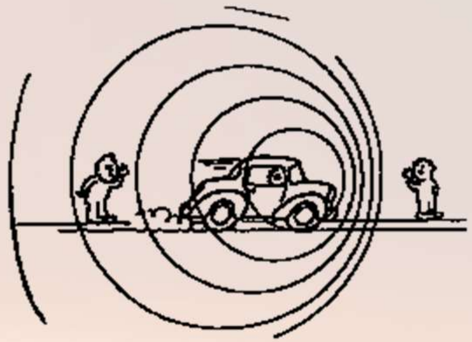
(a) the intensity level in decibels for the child's sounds

(b) the intensity level for this child and its twin, both crying with identical intensities.

Answer: a) 69 dB b) 72 dB

5.5 Doppler Effect

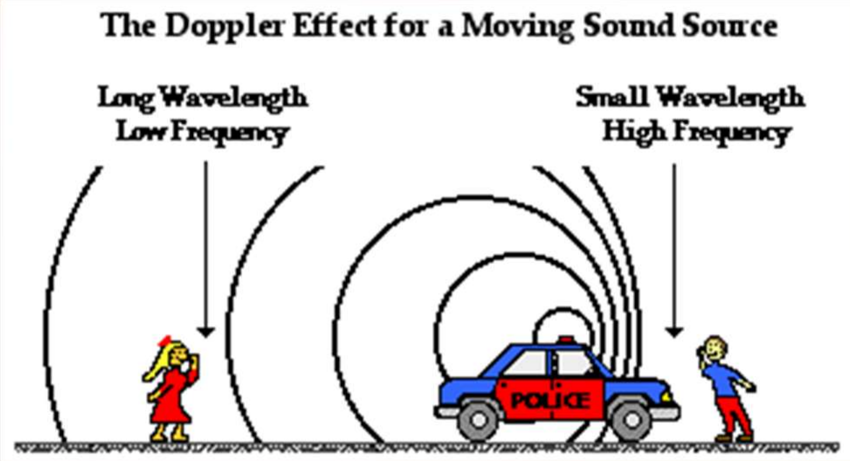
- Doppler Effect



- A change in frequency of the wave motion should be observed when a source of sound or light was moving.
- Change in pitch / frequency of the sound detected by an observer because the sound source and the observer have different velocities with respect to the medium of sound propagation.
- The apparent in frequency was first predicted by Doppler in 1845

5.5 Doppler Effect

- A Doppler effect is experienced whenever there is relative motion between a source of waves and an observer.
  - When the source and the observer are moving toward each other, the observer hears a higher frequency
  - When the source and the observer are moving away from each other, the observer hears a lower frequency



5.5 Doppler Effect

- 5 cases in Doppler effect

Source moving toward a stationary observer

Source moving away a stationary observer

Observer moving towards a stationary source

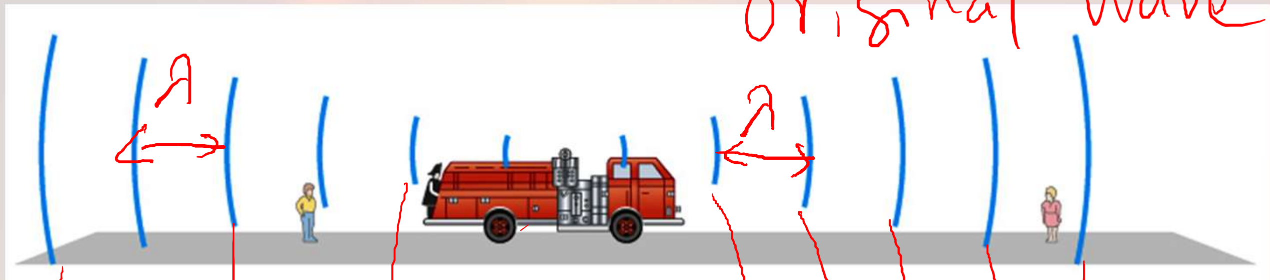
Observer moving away from stationary source

Both source and observer are in motion

- Source and observer moving towards each other
- Source and observer moving away from each other.
- Chasing

5.5 Doppler Effect

original wave pattern

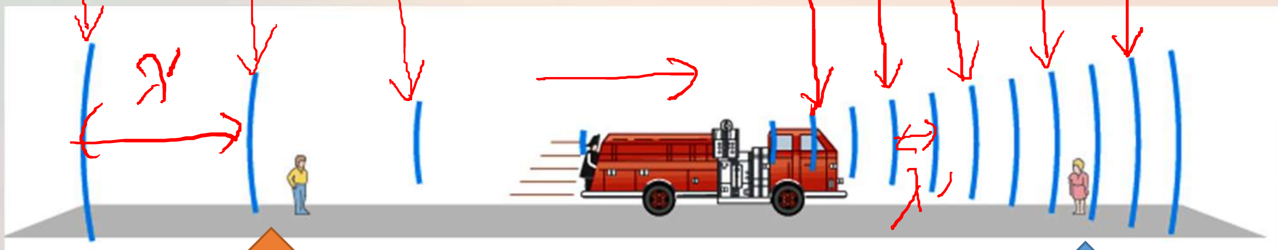


(a) At rest

- As the source at rest, the wavelength are in constant to both observer

$V = f\lambda$

$\uparrow f \propto \frac{1}{\lambda}\downarrow$



(b) Firetruck moving

$\downarrow f \propto \frac{1}{\lambda}\uparrow$

As the source moves away from the observer, the wavelength appears longer and the frequency appears to be lower

As the source moves toward the observer, the wavelength appears shorter and the frequency increases

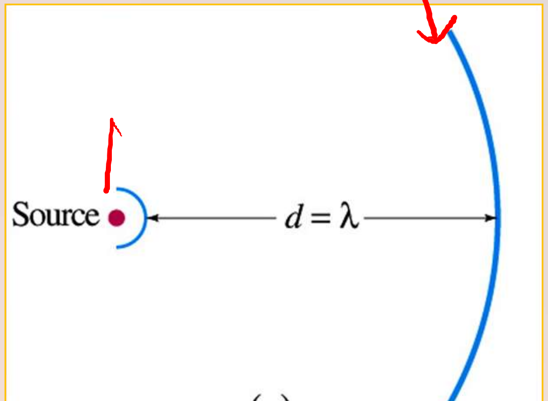
5.5 Doppler Effect

Source moving toward a stationary observer

The source is at rest

In a time T, the first crest has moved a distance,

$$d = vt$$



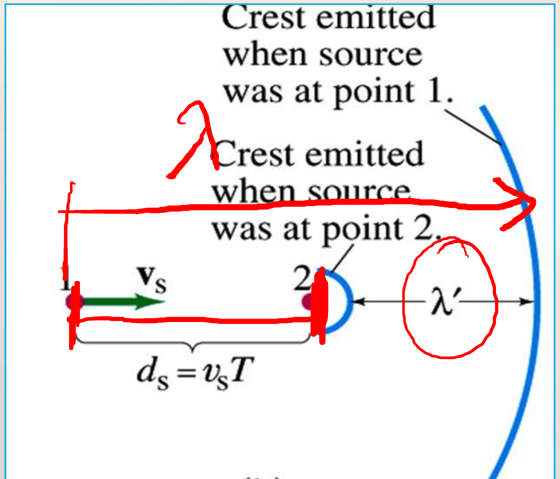
(a)

The source is moving toward the stationary observer with a velocity v_s.

-In this same time, the source has moved a distance

-The wavelength is shortened by this amount

$$d_s = v_s t$$



(b)

$\lambda' = \lambda - d_s$

5.5 Doppler Effect

- When the source is at the rest, the wavelength is λ.
- When the source is moving toward the observer, the wavelength is λ' and the formula is as following.

$$f' = f\left(\frac{v}{v - v_s}\right)$$

$$\lambda' = d - d_s$$

$$\lambda' = \lambda - d_s$$

$$\lambda' = \lambda - v_s T$$

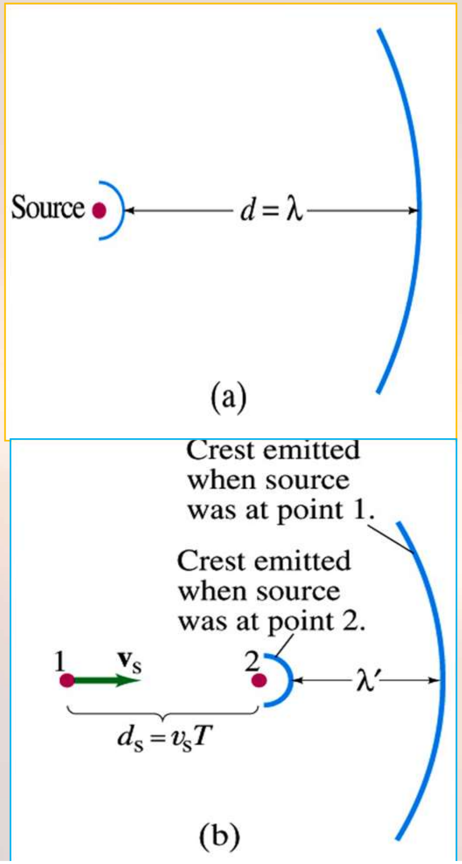
$$\lambda' = \lambda - v_s\left(\frac{\lambda}{v}\right)$$

$$\lambda' = \lambda\left(1 - \frac{v_s}{v}\right)$$

$$f' = \frac{v}{\lambda'}$$

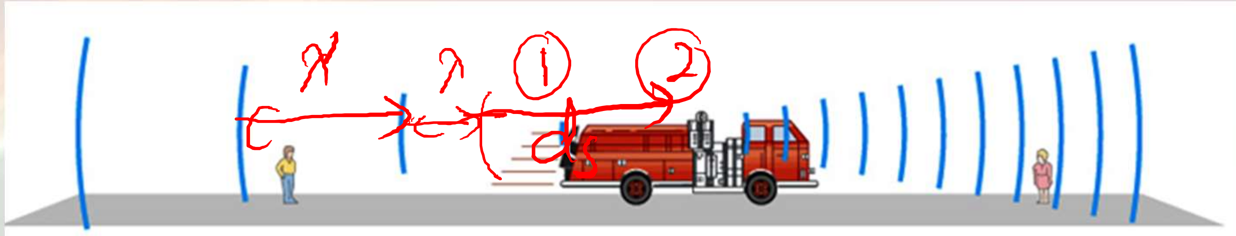
$$= \frac{v}{\lambda\left(1 - \frac{v_s}{v}\right)}$$

$$= f\left(\frac{1}{1 - \frac{v_s}{v}}\right) \times \frac{v}{v}$$



5.5 Doppler Effect

Source moving away a stationary observer



(b) Firetruck moving

The new wavelength will be longer:

$$\lambda' = d + d_s \quad ; \quad \lambda' = \lambda + v_s T$$

$$\lambda' = \lambda + v_s\left[\lambda/v\right] \quad ; \quad \lambda' = \lambda\left[1 + \frac{v_s}{v}\right]$$

The new frequency will be lower

$$f' = \frac{v}{\lambda'} = \frac{v}{\lambda\left(1 + v_s/v\right)} = f\left(\frac{1}{1 + v_s/v}\right) \times \frac{v}{v} = f\left(\frac{v}{v + v_s}\right)$$

5.5 Doppler Effect

Summary: Source Moving

$$\boxed{f' = f\left(\frac{v}{v \mp v_s}\right)}$$

Use the

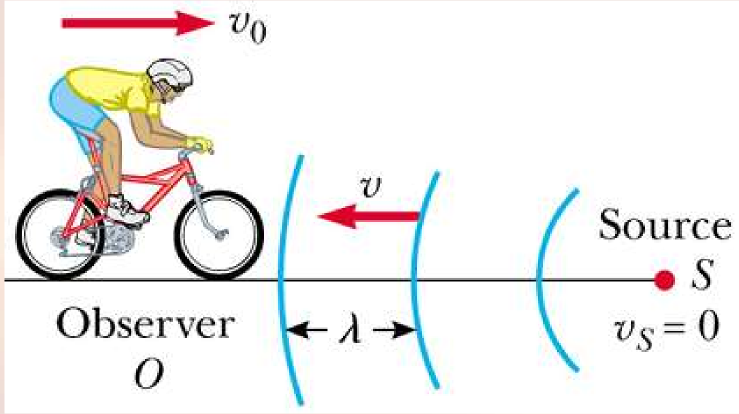
: $-v_s$ when the source is moving toward the observer

: $+v_s$ when the source is moving away from the observer

5.5 Doppler Effect

Observer moving towards a stationary source

- The frequency heard is increased
- The speed of the waves relative to the observer is $v' = v + v_o$

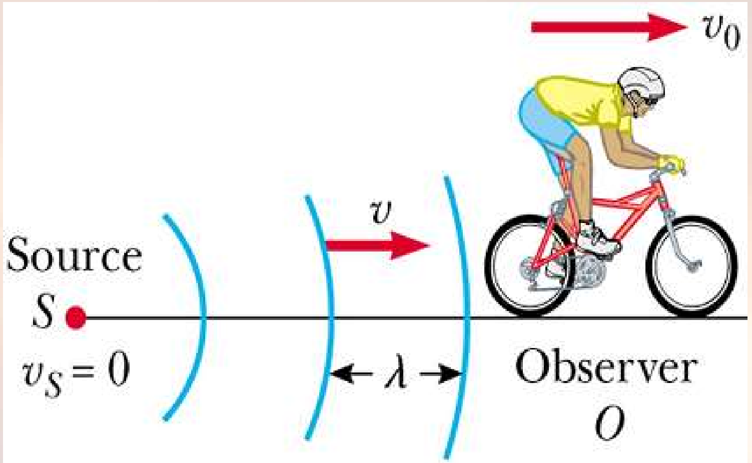


$$f' = \frac{v'}{\lambda} = \frac{v + v_o}{\lambda} = \frac{v\left(1 + \frac{v_o}{v}\right)}{\lambda} = f\left(1 + \frac{v_o}{v}\right) = f\left(\frac{v + v_o}{v}\right)$$

5.5 Doppler Effect

Observer moving away from stationary source

- The frequency appears lower
- The speed of the waves relative to the observer is v' = v - v_o



$$f' = \frac{v'}{\lambda} = \frac{v - v_o}{\lambda} = \frac{v\left(1 - {v_o}/{v}\right)}{\lambda} = f\left(1 - {v_o}/{v}\right) = f\left(\frac{v - v_o}{v}\right)$$

5.5 Doppler Effect

Summary : Observer Moving

- The apparent frequency, f', depends on the actual frequency of the sound and the speeds

$$\boxed{f' = f\left(\frac{v \pm v_o}{v}\right)}$$

- v_o is positive if the observer is moving toward the source
- v_o negative if the observer is moving away from the source

5.5 Doppler Effect

Both source and observer are in motion

- If both the source and the observer are in motion, we find the following general relationship for the observed frequency :

moving away

$$f' = f\left(\frac{v \pm v_o}{v \mp v_s}\right)$$

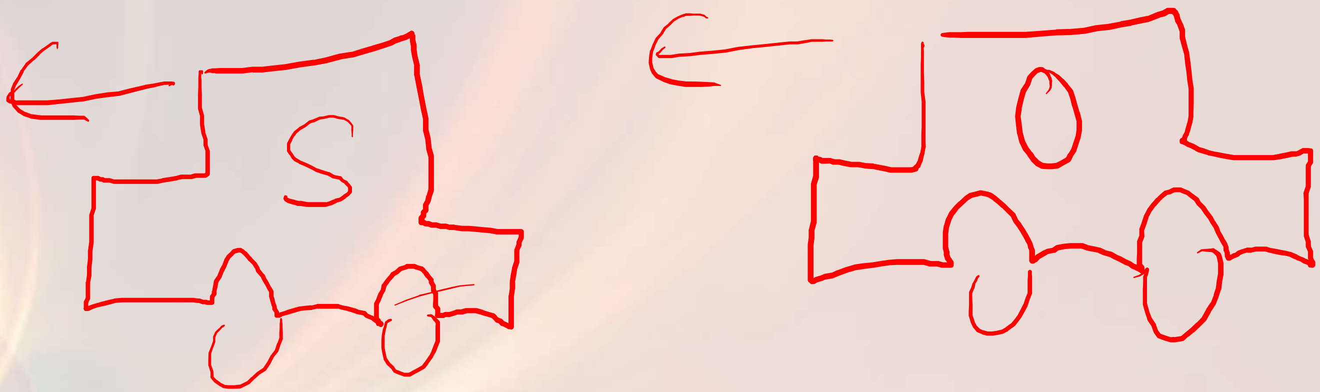
moving towards/ approaching

Both the source and observer moved toward each other

$$f' = f\left(\frac{v + v_o}{v - v_s}\right)$$

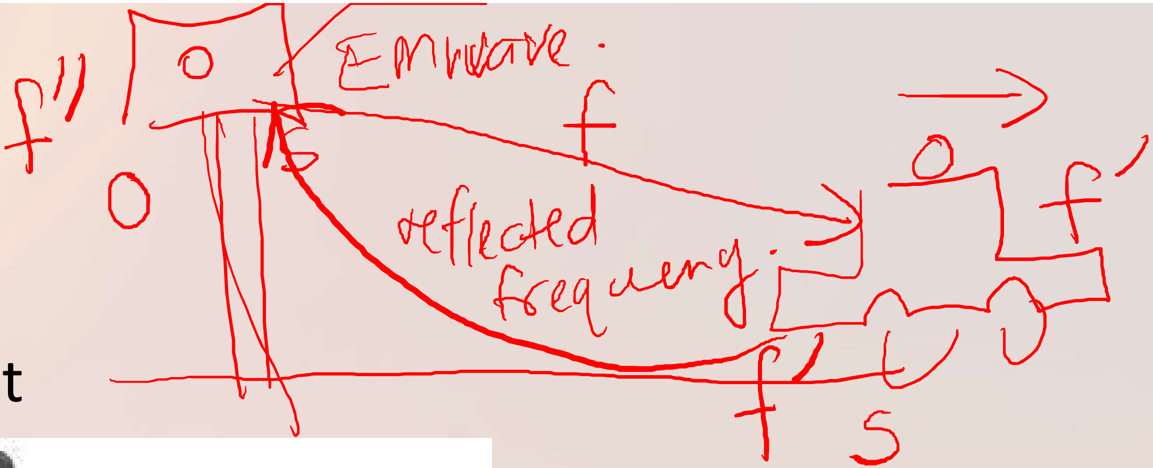
Both the source and observer moved away from each other

$$f' = f\left(\frac{v - v_o}{v + v_s}\right)$$



$$f' = f\left(\frac{v + v_0}{v + v_s}\right)$$

5.5 Doppler Effect



- Application of Doppler effect

92 km/h.

91 ~ 95 km/h.

90 km/h.

$$f'' = f'\left(\frac{V \overset{0}{\cancel{v_o}}}{V + \boxed{V_s}}\right)$$

Example

$V_s = 0$

The predominant frequency of a certain police car's siren is 1800 Hz when at rest. What frequency do you detect if you move with a speed of 30 m/s

(a) toward the car, and

(b) away from the car.

$$f' = f\left(\frac{V+V_o}{V}\right) = 1800\left(\frac{343+30}{343}\right)$$

$$f' = 1957.4 \text{ Hz}.$$

$$f' = f\left(\frac{V-V_o}{V}\right) = 1800\left(\frac{343-30}{343}\right)$$

$$f' = 1642.6 \text{ Hz}$$