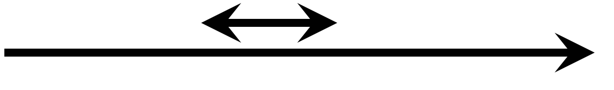
Ch18 Wave II

Sound Waves

Sound Waves

- Mechanical waves
  - Need medium to travel
    Can not travel in vacuum
- Longitudinal



Point source emits sound in all directions

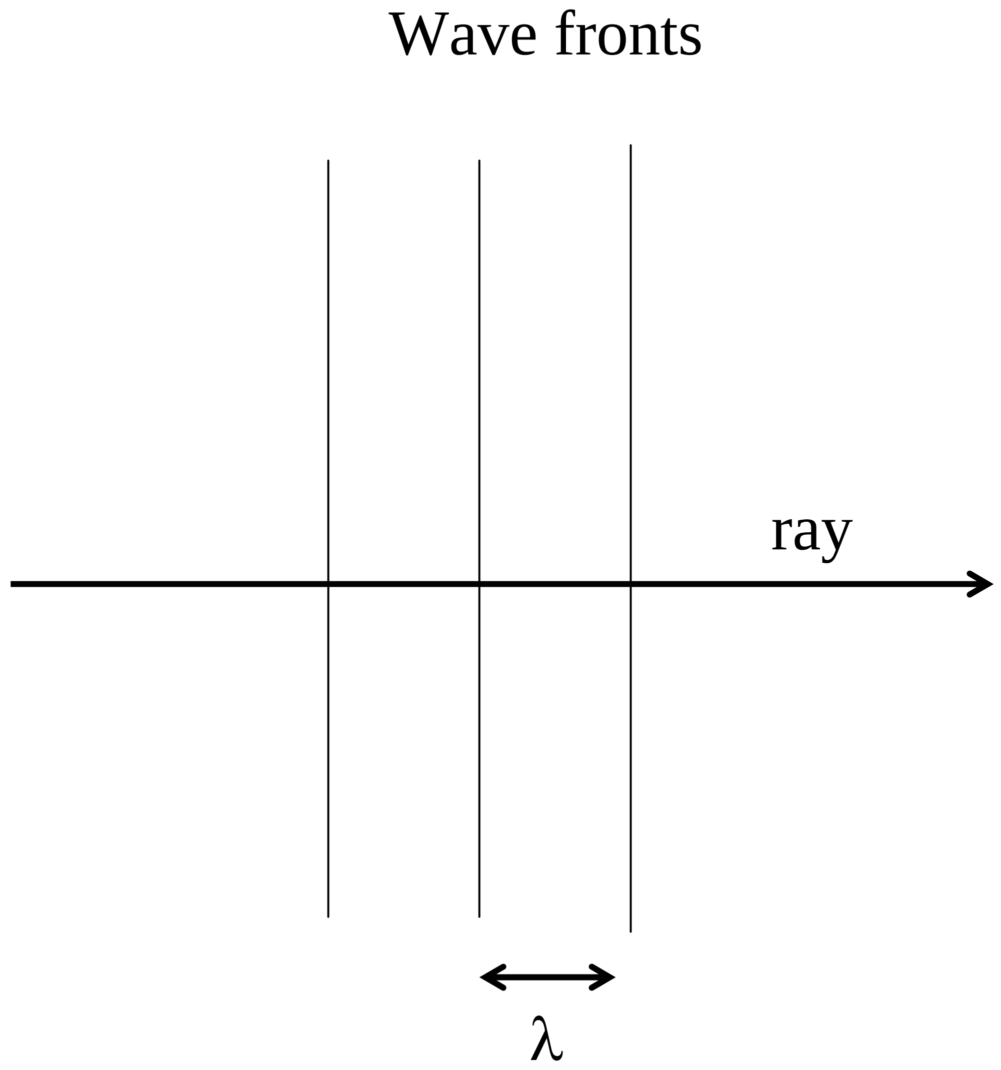
Wave front:

* imaginary surface over which displacement of particles are same

* Wave fronts of a point source are spheres

Rays

* indicates direction of propagation
* perpendicular to wave fronts


Wave fronts
ray
λ

Bulk modulus
of the medium

Speed of sound

$$V = \sqrt{\frac{B}{\rho}}$$

Density
of the medium

Bulk modulus

Change in pressure

$$B = -\frac{\Delta P}{\Delta V / V}$$

Change in volume

Original volume

B always positive quaintly

B measured in Pa (N/m^2)

B determines the change in volume due to a change in pressure

Speed of sound

Depends on

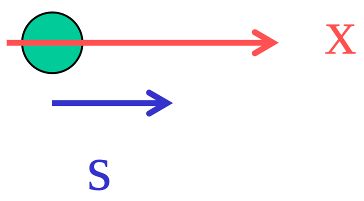
pressure and temperature

For air

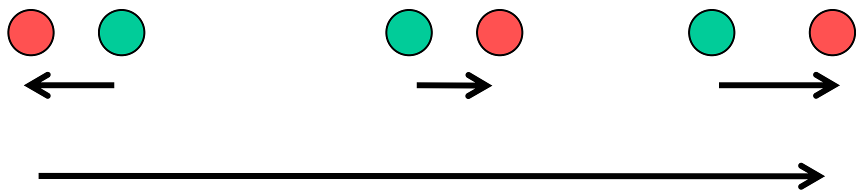
$v(20^0C) = 343$ m/s

$v(0^0C) = 331$ m/s

Displacement along x
plotted along y



Traveling sound waves



$$s(x,t) = s_m \cos(kx-\omega t)$$

Displacement

Displacement
Amplitude

$$s(x,t) = s_m \cos(kx-\omega t)$$

$$\Delta p(x,t) = \Delta p_m \sin(kx-\omega t)$$

Pressure variation

Pressure amplitude

s and Δp are $\frac{\pi}{2}$ out of phase

Pressure amplitude

Displacement amplitude

$$\Delta p_m = (v\ \rho\ \omega)\ s_m$$

Density

Velocity

Angular frequency

At f = 1000 Hz

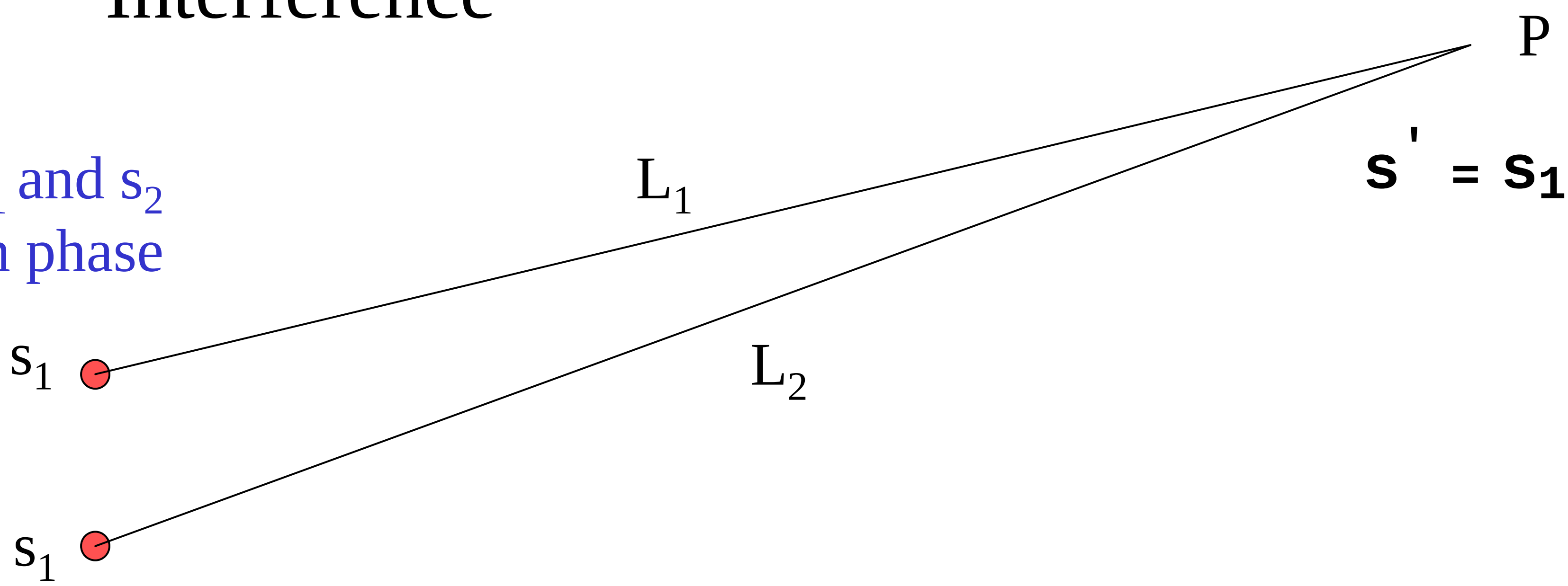
	Max you can hear	Min you can hear	
s_m	10 μm	10 pm	$\lambda = 0.34$ m
Δp_m	30 Pa	10 μPa	10^5 Pa Atmospheric

Interference

$$s_1 = s_m \sin(kL_1 - \omega t)$$

$$s_2 = s_m \sin(kL_2 - \omega t)$$

s_1 and s_2 in phase



$$s' = s_1 + s_2$$

$$s' = 2\, s_m \cos\left(\frac{kL_2 - kL_1}{2}\right) \sin\left(\frac{kL_2 + kL_1}{2} - \omega t\right)$$

Amplitude

$$\text{Amplidue} = 2\, s_m \cos\left(k\,\frac{L_2 - L_1}{2}\right)$$

$$k\,\frac{L_2 - L_1}{2} = \frac{2\pi}{\lambda}\,\frac{L_2 - L_1}{2} = \frac{\pi}{\lambda}\,(L_2 - L_1) = \frac{\pi}{\lambda}\,\Delta L$$

Max amplitude $2s_m$

Constructive interference

Min amplitude Zero

Destructive interference

$$\frac{\pi}{\lambda}\,\Delta L = n\pi$$

$\boxed{n = 1, 2, \ldots}$

$$\frac{\pi}{\lambda}\,\Delta L = \left(n + \frac{1}{2}\right)\pi$$

$$\boxed{\Delta L = n\lambda}$$

$$\boxed{\Delta L = \left(n + \frac{1}{2}\right)\lambda}$$

Power

rate of energy transfer

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

Intensity

Average rate per unit area at which energy is transferred though a surface

Area

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

Displacement amplitude

$$I = \frac{1}{2}\rho v \omega^2 s_m^2$$

Intensity

Velocity

Angular frequency

Density

Variation of intensity with distance

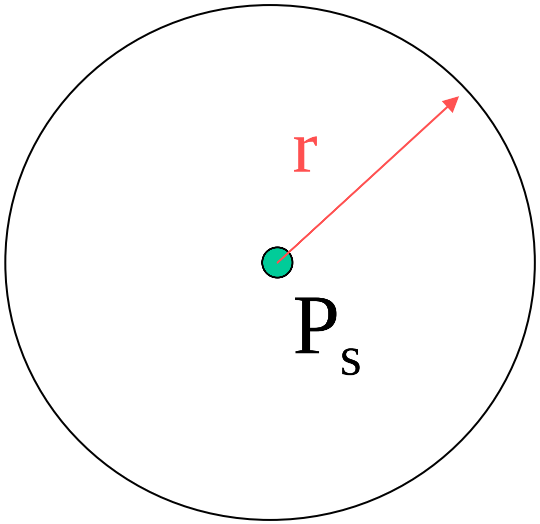
Depends on the nature of the sound source

Point source

emits sound isotropically

(equal intensity in all direction)

$$\mathbf{I} = \frac{\mathbf{P_s}}{\mathbf{A}} = \frac{\mathbf{P_s}}{\mathbf{4\,\pi\,r^2}}$$



For point source, intensity decreases with the square of the distance from the source

Checkpoint

At f = 1000 Hz

	Max you can hear	Min you can hear
Displacement amplitude s_m	10 μm	10 pm
Intensity I	1 W/m^2	10^{-12} W/m^2

Need simpler way to express intensity

Sound level

Intensity

$$\beta = (10\ \mathrm{dB}) \log\left[\frac{I}{I_0}\right]$$

Unit to measure sound level
dB = decibell
Deci related to 10 10
Bell Alexander Graham Bell

Reference intensity
$I_0 = 10^{-12}\ \mathrm{W/m^2}$

Lowest you can hear

$$\beta = (10\ \mathrm{dB}) \log\left[\frac{I}{I_0}\right]$$

	Max you can hear	Min you can hear
Sound level β	120 dB	0 dB
Intensity I	1 W/m^2	10^{-12} W/m^2

β is a simpler way to express intensity

Sample problem 18-4

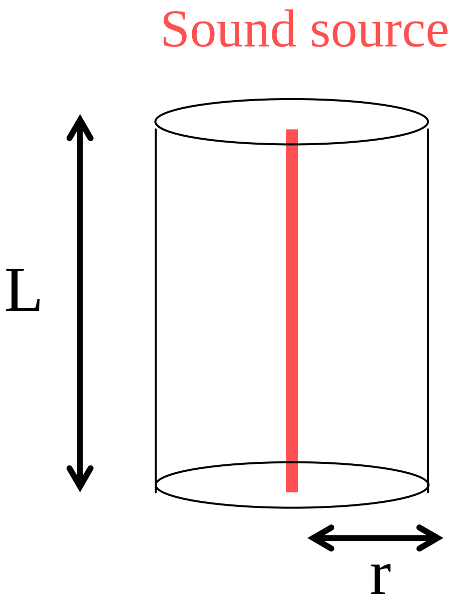
Intensity form linear source like electric spark

Given

$L = 10$ m

$P_s = 1.6 \times 10^4$ W/m^2

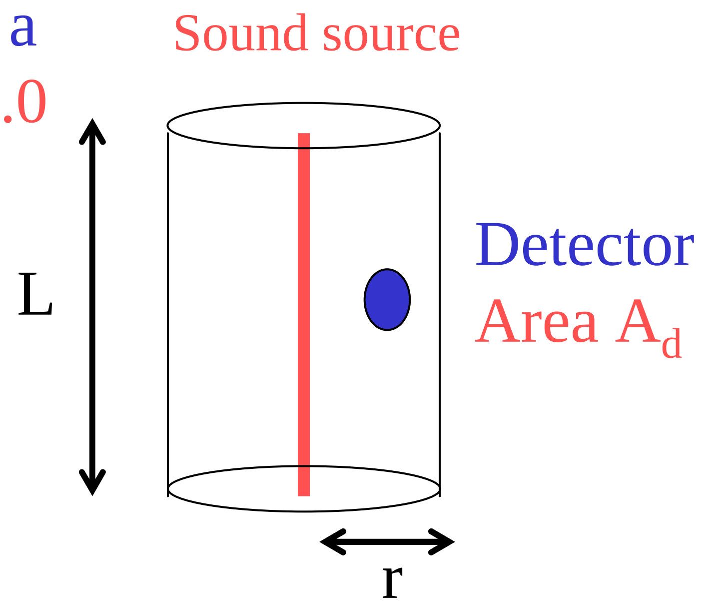
What is intensity 12 m form the source?



$$I = \frac{P_s}{A} = \frac{P_s}{2\pi r L} = \frac{1.6 \times 10^4}{2\pi (12)(4)}$$

Sample problem 18-4 continue

At what rate P_d is sound energy detected a detector located at r and has area $A_d = 2.0\ \text{cm}^2$?



$$I = \frac{P_d}{A_d}$$

$$P_d = I\,A_d = \left[\frac{1.6 \times 10^4}{2\pi\,(12)\,(4)}\right]\left[2.0 \times 10^{-4}\right]\ \text{W}$$

Sample problem 18-5

Two sources with sound levels β_1 = 92 dB and β_2 = 120 dB. What is the ratio of their intensities?

$$\boxed{\frac{\beta}{10} = \log\left[\frac{I}{I_0}\right]}$$

$$\frac{\beta}{10} = \log\left[\frac{I}{I_0}\right]$$

$$10^{\frac{\beta}{10}} = 10^{\log\left[\frac{I}{I_0}\right]} = \frac{I}{I_0}$$

$$I = I_0\, 10^{\frac{\beta}{10}}$$

$$\frac{I_2}{I_1} = \frac{I_0\, 10^{\frac{\beta_2}{10}}}{I_0\, 10^{\frac{\beta_1}{10}}} = \frac{10^{\frac{\beta_1}{10}}}{10^{\frac{\beta_2}{10}}} = 10^{\frac{\beta_2}{10} - \frac{\beta_1}{10}} = 10^{\frac{120}{10} - \frac{92}{10}}$$

Sources of musical sound (resonances)

Resonances

Higher amplitudes → Higher sound levels

How to produce resonances?

Standing waves

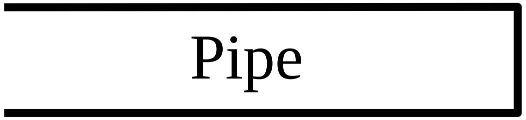
How to set standing waves?

Reflections

appropriate frequencies

Reflections from the ends of pipes

Open end



Closed end

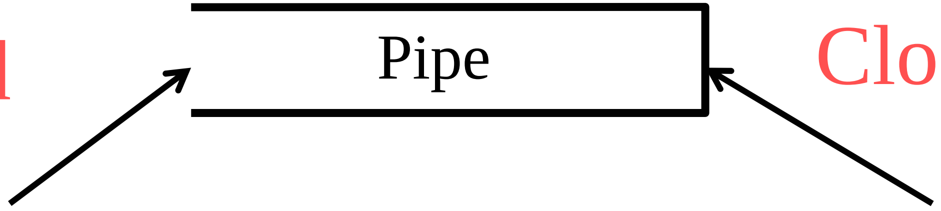
Reflections from the ends of pipes

Like reflections
from the ends of strings

Reflections from the ends of pipes

Open end

Closed end

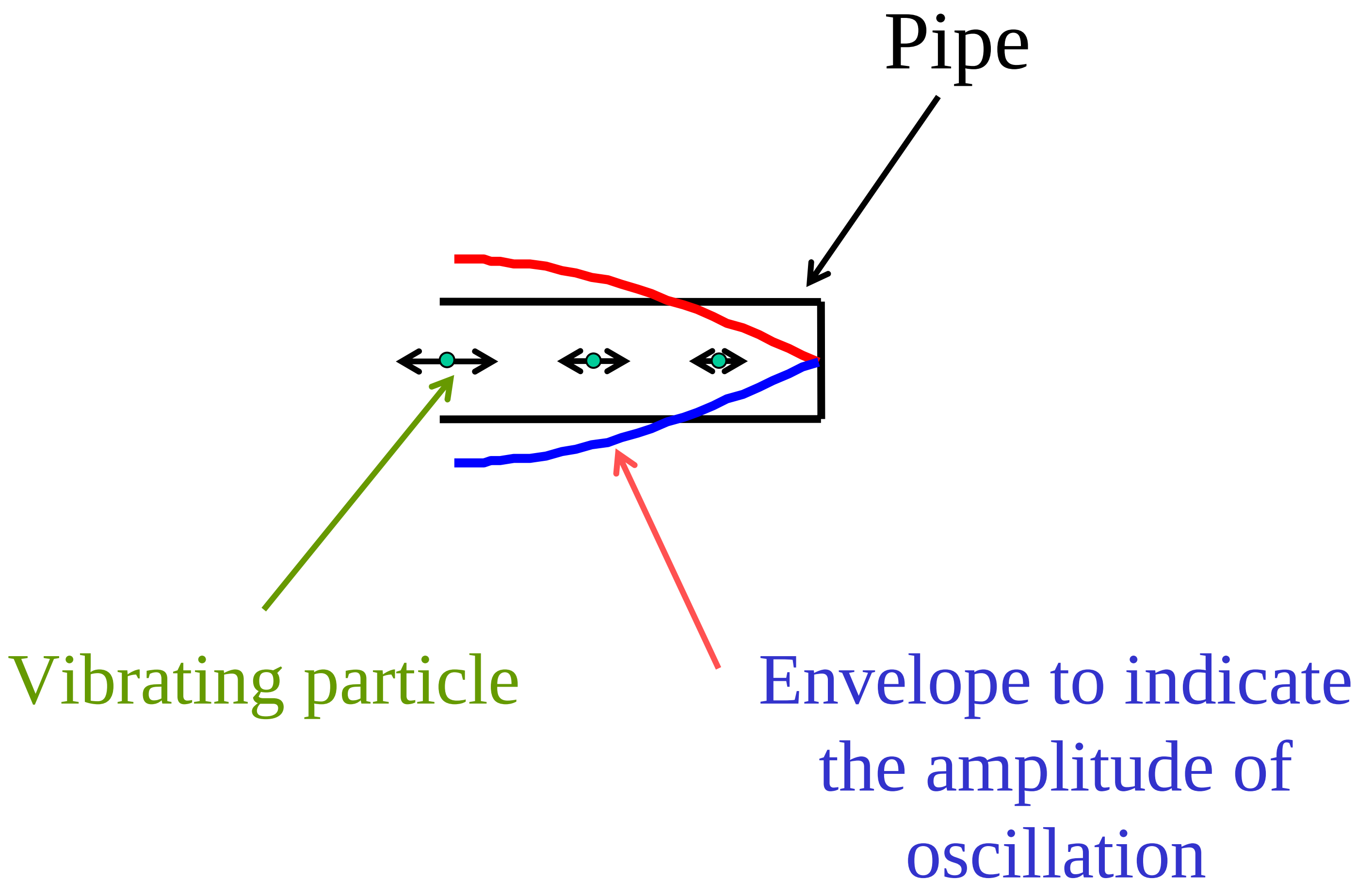


Max displacement

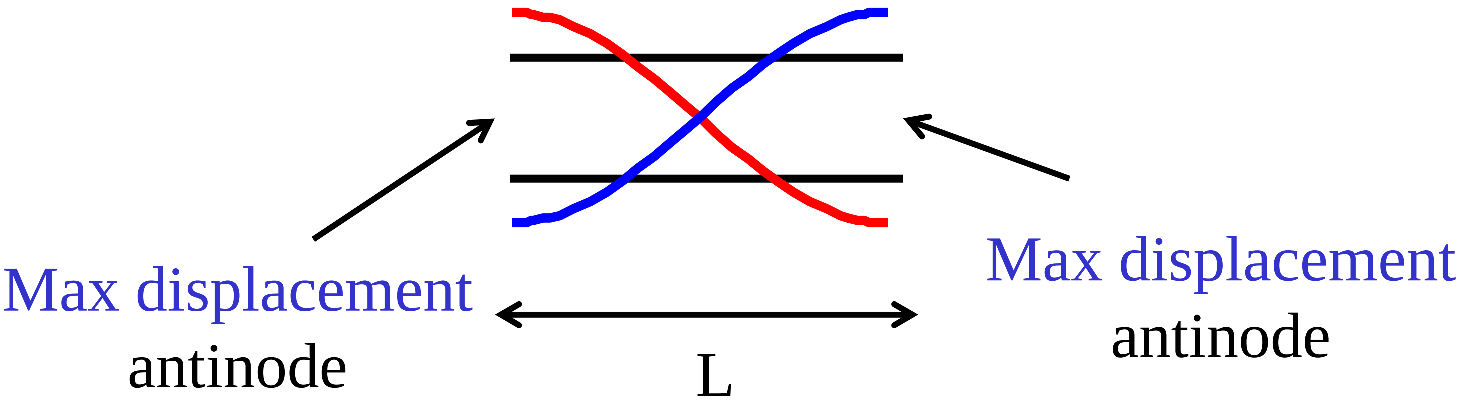
antinode

Zero displacement

node


Pipe
Vibrating particle
Envelope to indicate the amplitude of oscillation

Pipes with two open ends

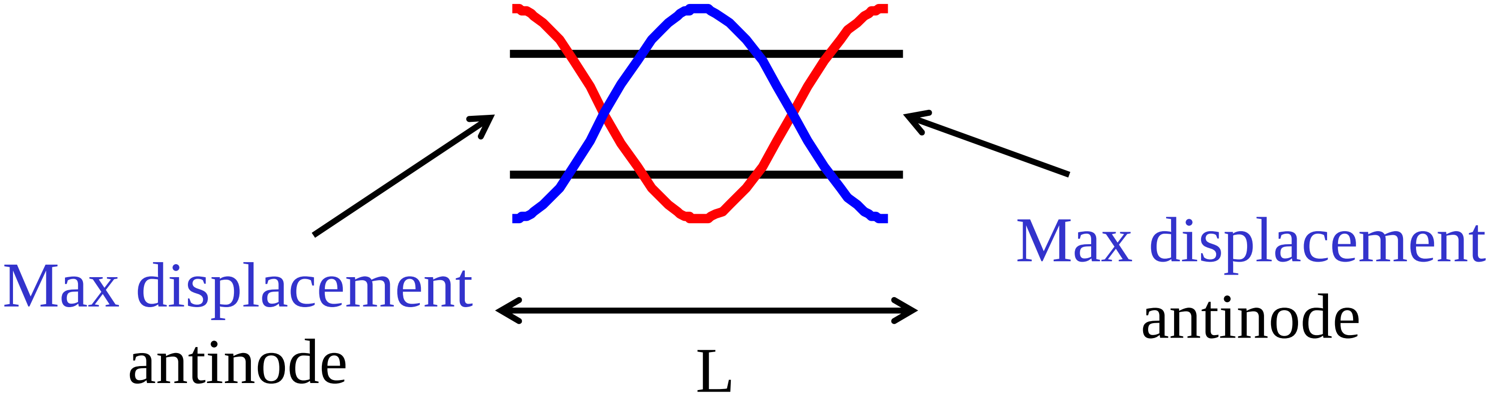


$$L = \mathbf{1}\,\frac{\lambda}{2}$$

First Harmonic

Fundamental

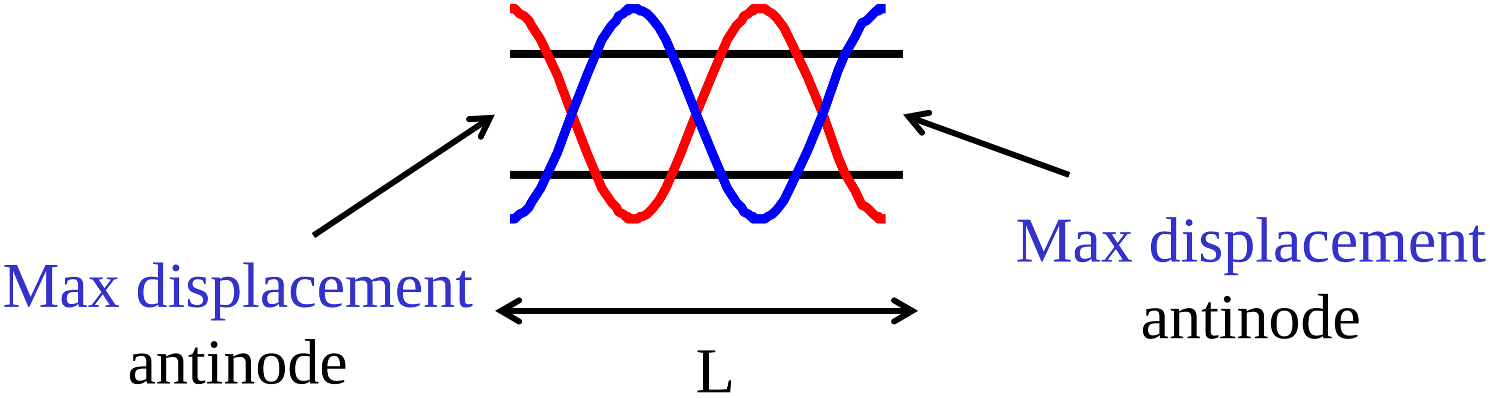
Pipes with two open ends



$$L = \color{red}{2}\,\frac{\lambda}{2}$$

Second Harmonic

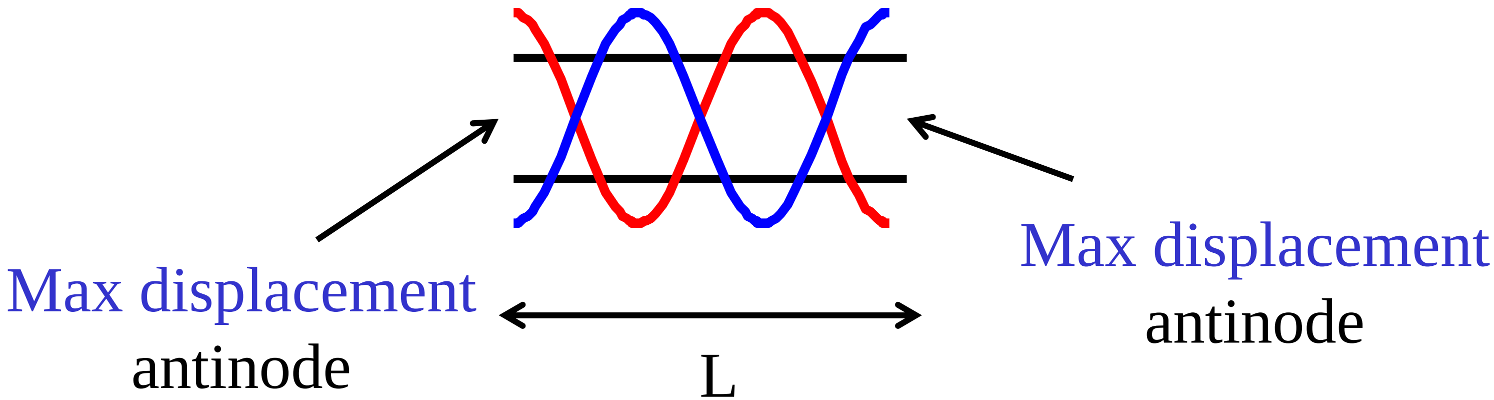
Pipes with two open ends



$$L = 3\,\frac{\lambda}{2}$$

Third Harmonic

Pipes with two open ends

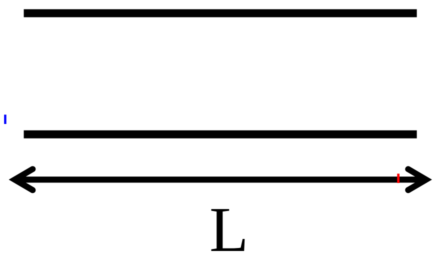


$$\boxed{L = n\,\frac{\lambda}{2}}$$

n^{th} Harmonic

$n = 1, 2, 3, ..$

Pipes with two open ends



$$L = n \frac{\lambda}{2} \Rightarrow \frac{1}{\lambda} = n \frac{1}{2L}$$

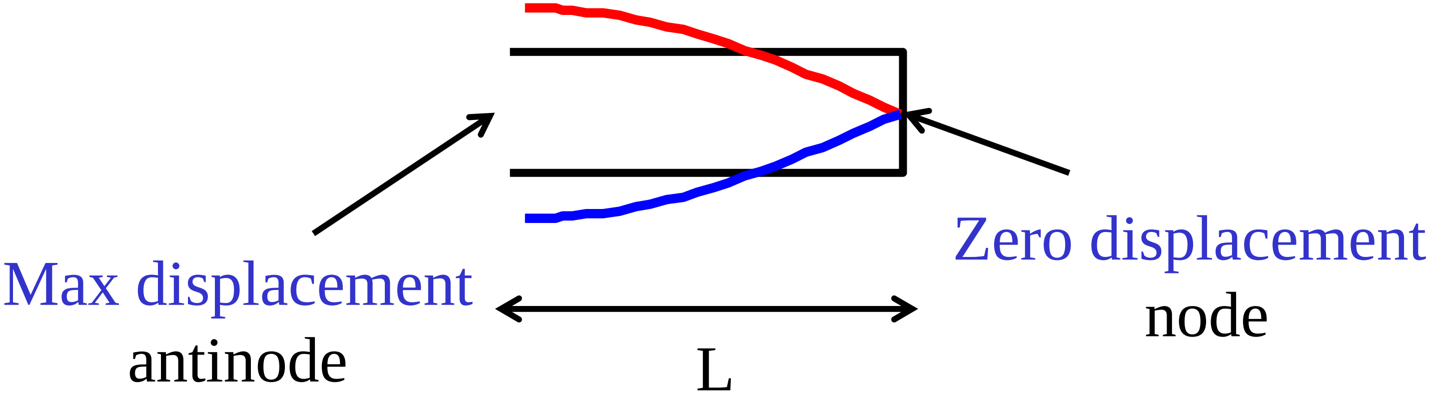
$$f = \frac{v}{\lambda} \Rightarrow f = n \frac{v}{2L}$$

Resonance frequency

$$\boxed{f_n = n \frac{v}{2L}}$$

$n = 1, 2, 3, ..$ n^{th} Harmonic

Pipes with one open end



$$L = 1\,\frac{\lambda}{4}$$

First Harmonic

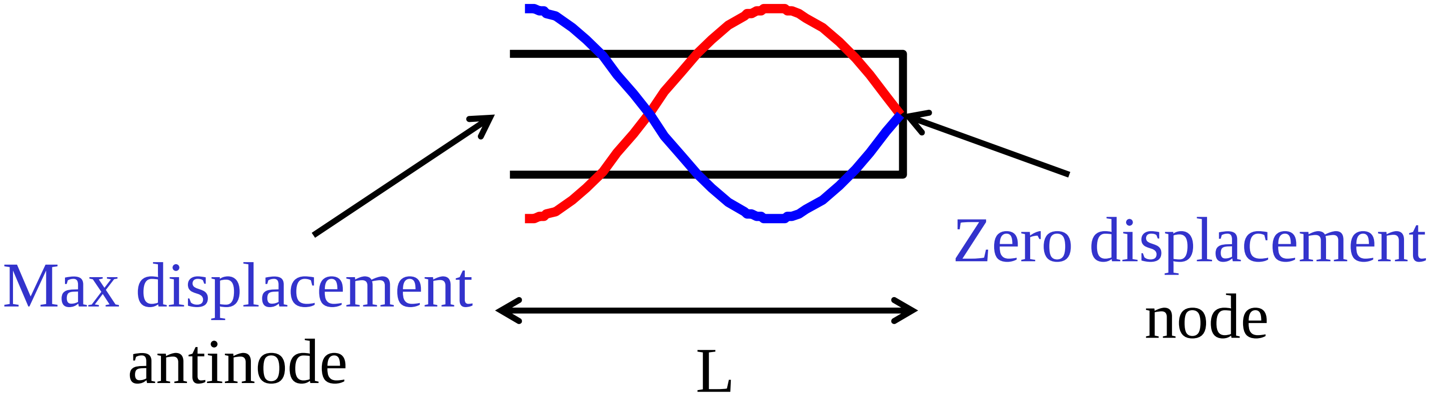
Fundamental

Pipes with one open end

Missing

Second Harmonic

Pipes with one open end



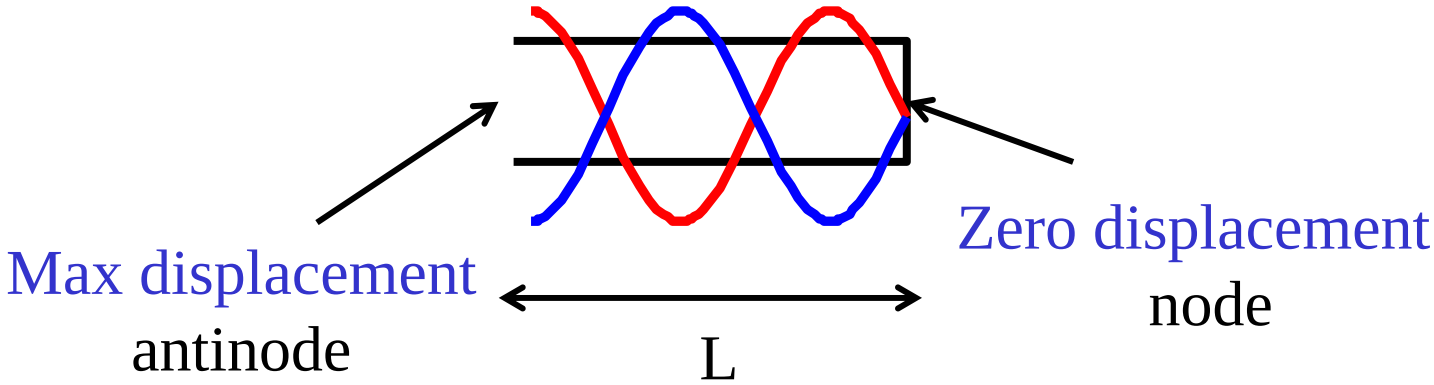
$$L = 3\,\frac{\lambda}{4}$$

Pipes with one open end

Missing

Fourth Harmonic

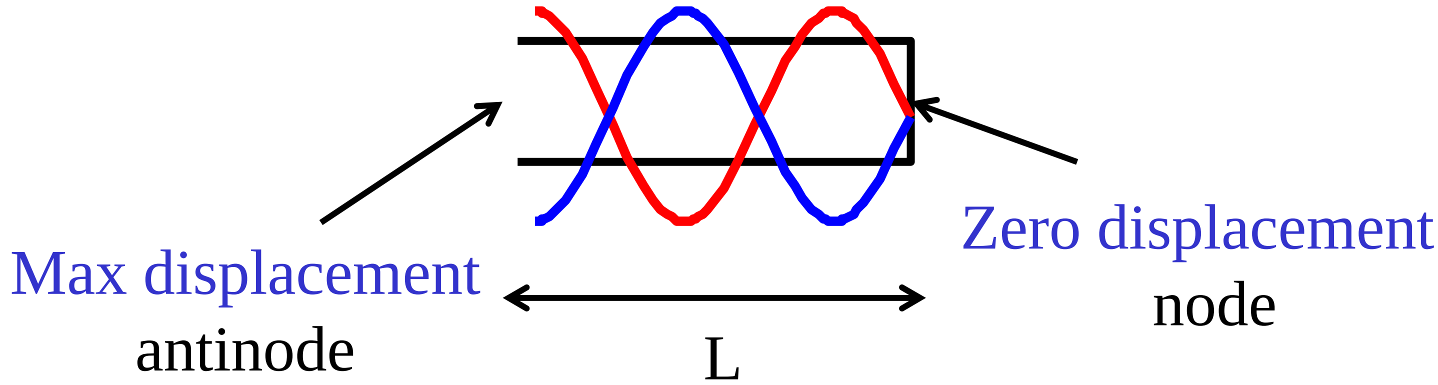
Pipes with one open end



$$L = 5\,\frac{\lambda}{4}$$

Fifth Harmonic

Pipes with one open end

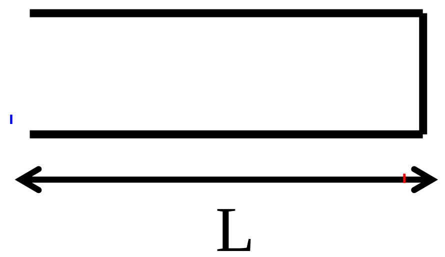


$$\boxed{L = n\,\frac{\lambda}{4}}$$

n = 1,3,5,..

Only odd integers

Pipes with one open end



$$L = n\frac{\lambda}{4} \Rightarrow \frac{1}{\lambda} = n\frac{1}{4L}$$

$$f = \frac{v}{\lambda} \Rightarrow f = n\frac{v}{4L}$$

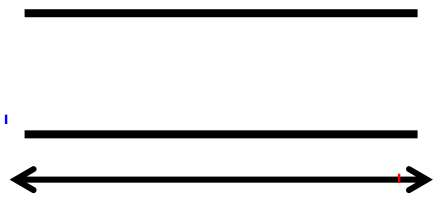
Resonance frequency

$$\boxed{f_n = n\frac{v}{4L}}$$

$n = 1,3,5,..$ n^{th} Harmonic

Only odd integers

Pipe



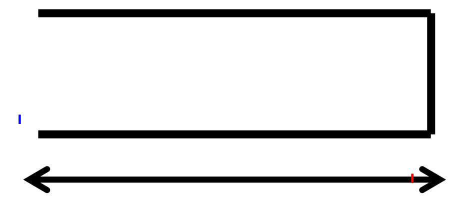
L

$$L = n \frac{\lambda}{2}$$

$$f_n = n \frac{v}{2L}$$

n = integer

Pipe



L

$$L = n \frac{\lambda}{4}$$

$$f_n = n \frac{v}{4L}$$

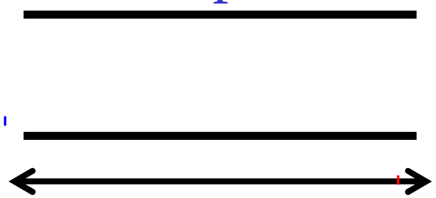
n = odd integer

Missing even harmonics

Checkpoint 4

Checkpoint 4

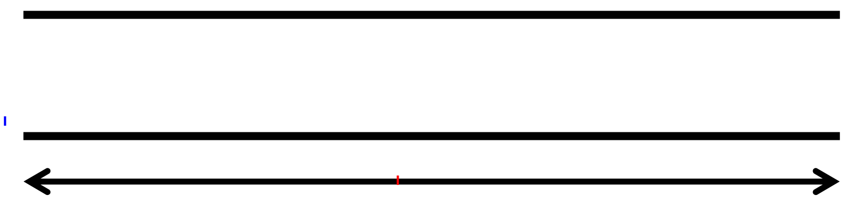
Pipe A



L_A

Fundamental

Pipe B



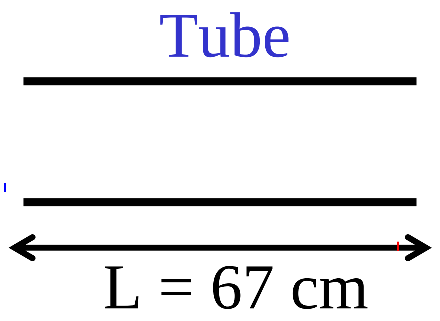
$2L_A$

Which Harmonic?

$$f_n = n \frac{v}{2\,L}$$

$$f = 1 \frac{v}{2\,(L_A)} = 2 \frac{v}{2\,(2\,L_A)}$$

Sample problem 18-6

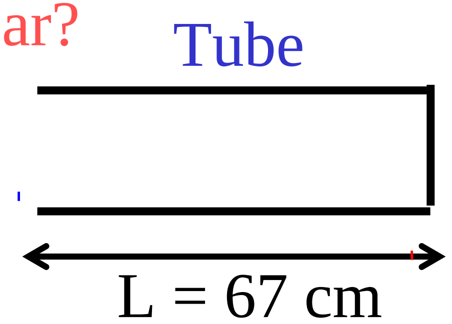


Background noises setup fundamental standing wave.
Use speed of sound 343 m/s.

What frequency do you hear?

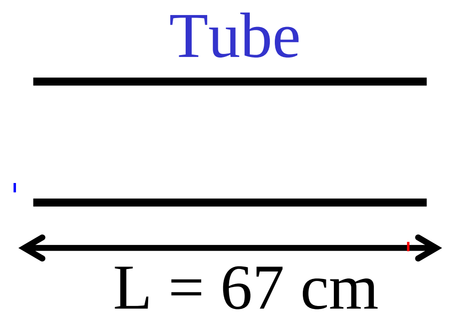
$$f_1 = 1 \frac{v}{2L} = \frac{343}{2(.67)} = 256 \text{ Hz}$$

If you close one end, what frequency do you hear?



$$f_1 = 1 \frac{v}{4L} = \frac{343}{4(.67)} = 128 \text{ Hz}$$

Sample problem 18-6

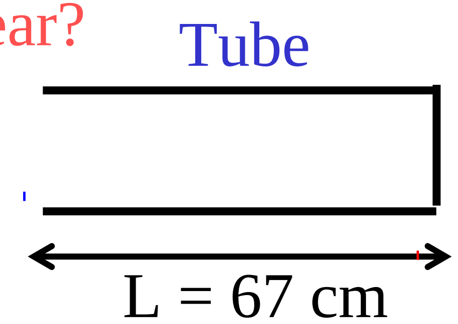


Background noises setup fundamental.
Use speed of sound 343 m/s.

What frequency do you hear?

$$f_1 = 1\ \frac{v}{2\,L} = \frac{343}{2\,(.67)} = 256\ \text{Hz}$$

If you close one end, what frequency do you hear?

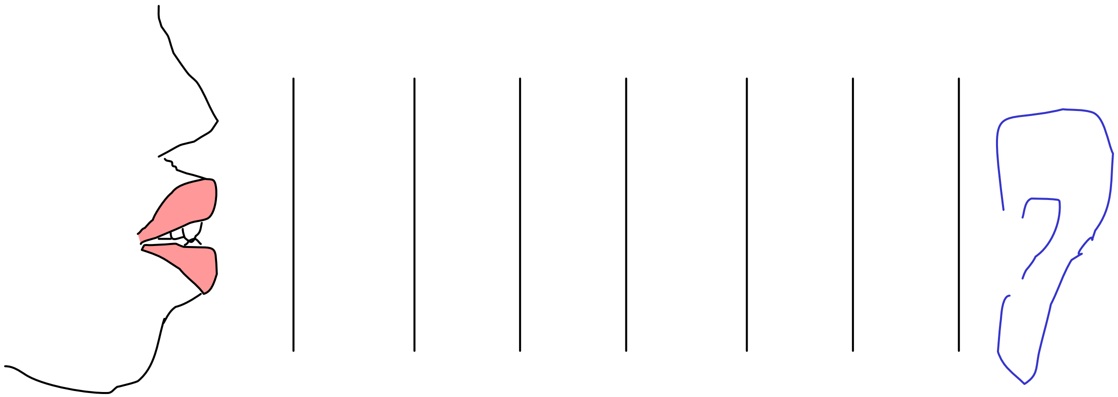


$$f_1 = 1\ \frac{v}{4\,L} = \frac{343}{4\,(.67)} = 128\ \text{Hz}$$

The Doppler Effect

Change in frequency because of motion

The Doppler Effect



Detector intercepts f Wavefronts per second

Source

$v_S = 0$

frequency f

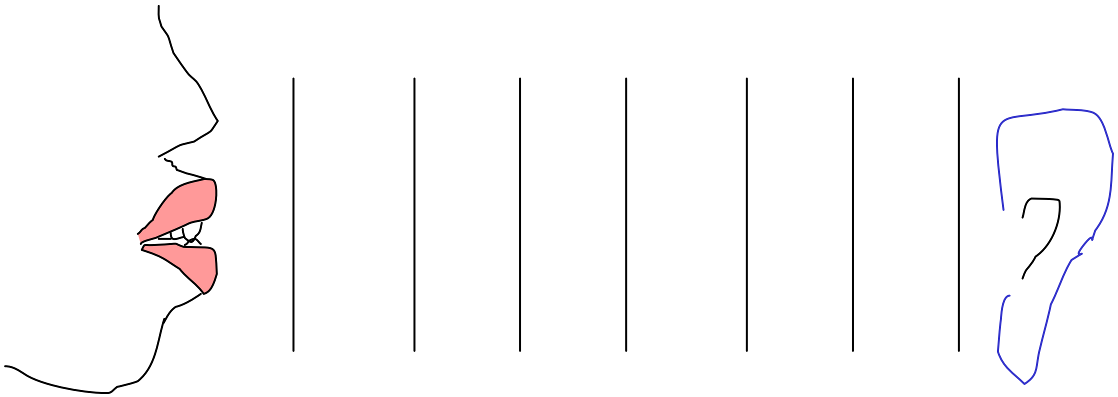
Detector

$v_D = 0$

frequency f'

$$f' = f$$

The Doppler Effect



Detector
intercepts
mote than f
Wavefronts
per second

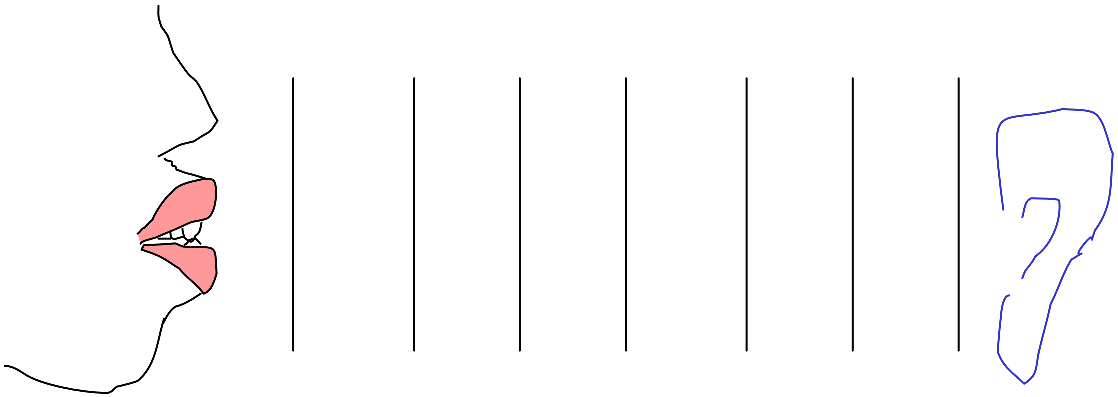
Source
$v_D = 0$
frequency f

Detector
frequency f'

v_D

$$f' > f$$

The Doppler Effect



Detector intercepts less than f Wavefronts per second

Source

$v_D = 0$

frequency f

Detector

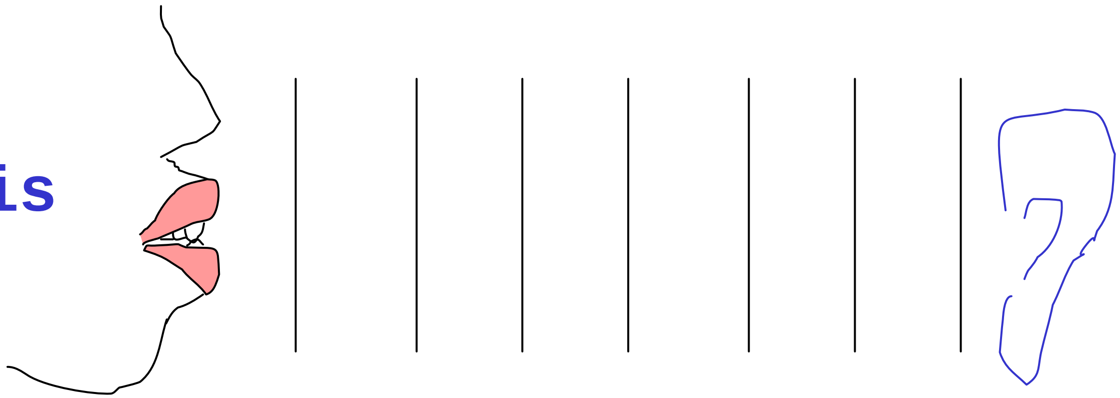
frequency f'

v_D

$$f' < f$$

The Doppler Effect

Distance between wavefronts is λ



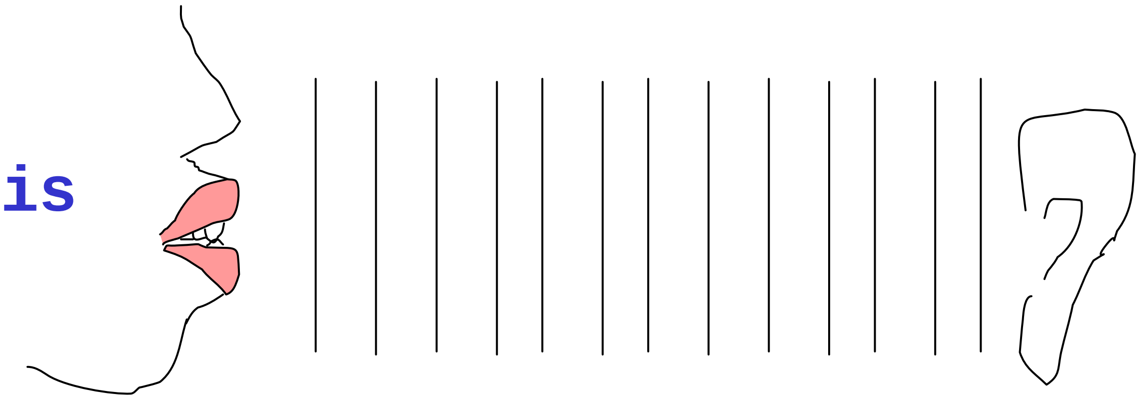
Source
$v_D = 0$
frequency f

Detector
$V_S = 0$
frequency f'

$$f' = f$$

The Doppler Effect

Distance between wavefronts is less than λ



Source

frequency **f**

v_s

Detector

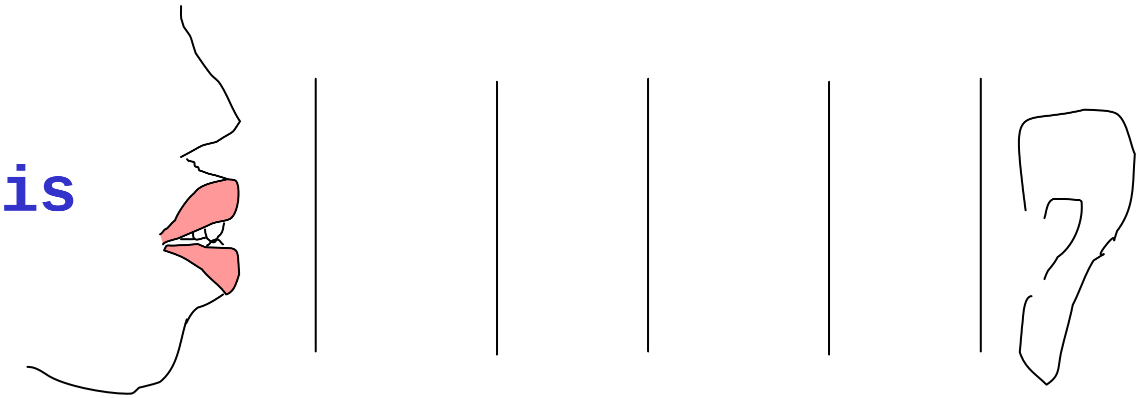
$v_s = 0$

frequency **f′**

$$f' > f$$

The Doppler Effect

Distance between wavefronts is more than λ



Source

frequency f

Detector

$V_s = 0$

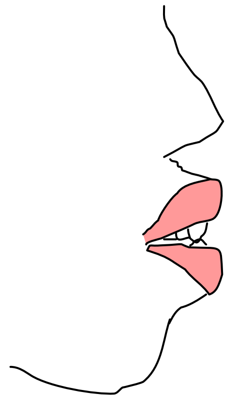
frequency f'

V_s

$$f' < f$$

The Doppler Effect

Source



Detector

Frequency at detector

Speed of sound

Speed of detector

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

frequency of source

Speed of source

The Doppler Effect

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

Choose the signs such that when source and detector move towards each other you get higher frequency, and when they move away from each other you get lower frequency

The Doppler Effect

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

Detector move opposite to sound direction

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

Detector move in the sound direction

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

Source move in the sound direction

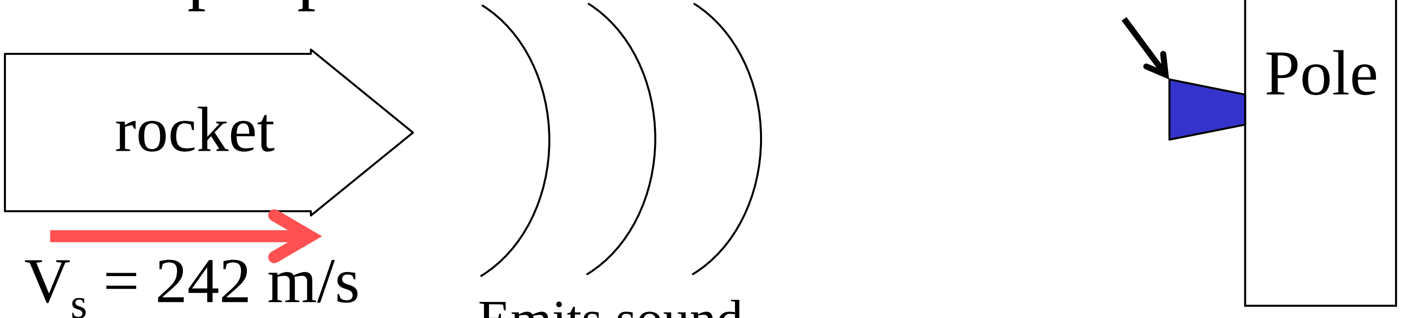
$$f' = f\,\frac{v \pm v_D}{v - v_S}$$

Source move opposite to the sound direction

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

Checkpoint 6

Sample problem 18-7



Emits sound
at frequency
at 1250 Hz

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

What frequency is sensed by a detector on the pole?

Detector stationary

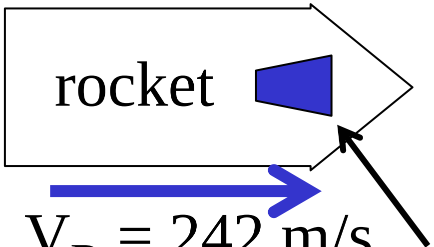
$$f' = f\,\frac{v \pm 0}{v \pm v_S}$$

Moving towards each other
frequency increases

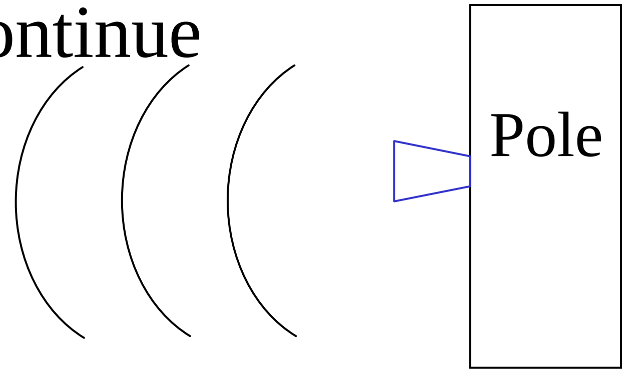
$$f' = f\,\frac{v}{v - v_S}$$

$$f' = 1250\,\frac{343}{343. - 242} = 4245\ \text{Hz}$$

Sample problem 18-7 continue



detector



Echo
Reflected back

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

What frequency is sensed by a detector on the rocket?

Source stationary

$$f' = f\,\frac{v \pm v_D}{v \pm 0}$$

Moving towards each other
frequency increases

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

$$f' = 4245\,\frac{343 + 242}{343.} = 7240\ \text{Hz}$$

Checkpoint 7

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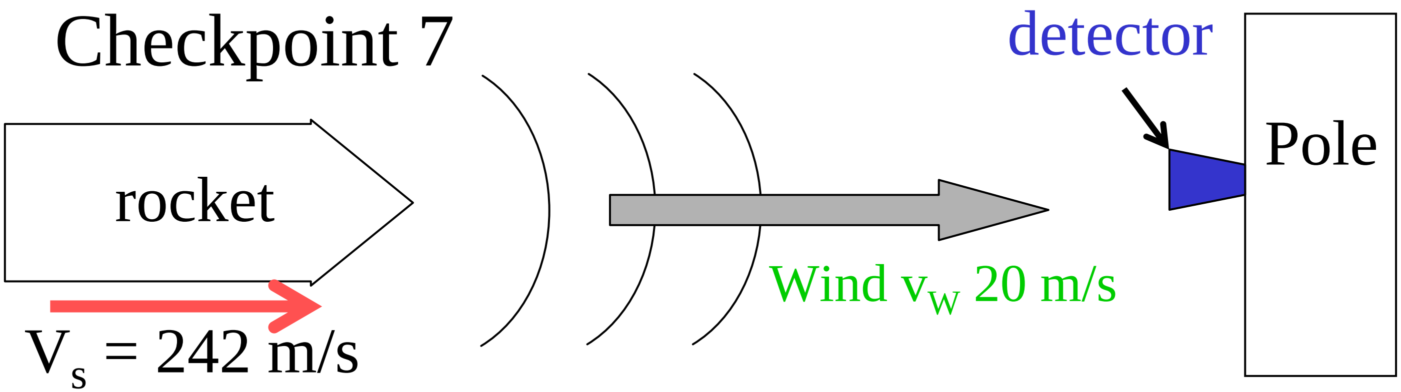
Checkpoint 7



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

What value for source speed you should use?

No wind

$$f' = f\,\frac{v \pm 0}{v \pm v_S}$$

wind

Imagine you move with wind

$$f' = f\,\frac{v + v_W}{v - (v_S - v_W)}$$

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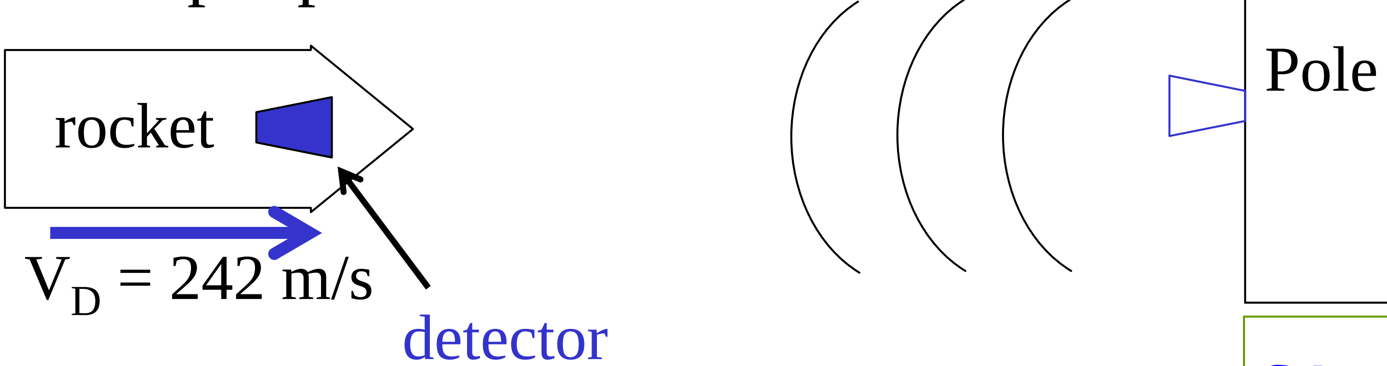
Sample problem 18-7 continue



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

What value for source speed you should use?

No wind

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

wind

Imagine you move with wind

$$f' = f\,\frac{v + v_W}{v - (v_S - v_W)}$$