WAVES & OSCILLATIONS

Standing Waves
Doppler Effect

DR. SHYAMSUNDAR GHOSH

Assistant Professor,

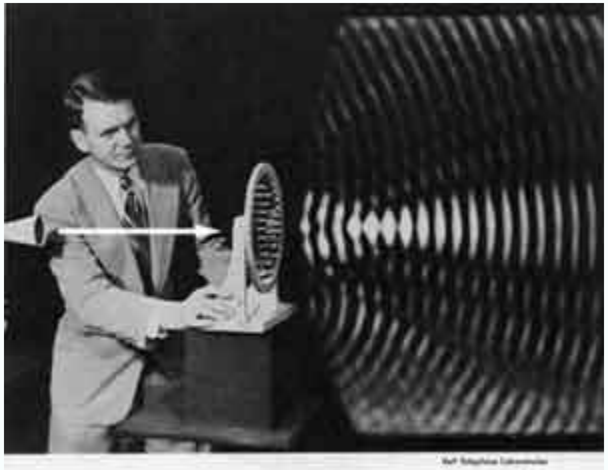
Department of Physics,

Bejoy Narayan Mahavidyalaya, Hooghly-712147

Objectives

- Define and give characteristics and examples of longitudinal, transverse and surface waves
- Apply the equation for wave velocity in terms of its frequency and wavelength
- Describe the relationship between wave energy and its amplitude
- Describe the behavior of waves at a boundary: fixed-end, free-end, boundary between different media
- Distinguish between constructive and destructive interference
- State and apply the principle of superposition
- Describe the formation and characteristics of standing waves
- Describe the characteristics of sound and distinguish between ultrasonic and infrasonic sound waves
- Calculate the speed of sound in air as a function of temperature
- Use boundary behavior characteristics to derive and apply relationships for calculating the characteristic frequencies for an open pipe and for a closed pipe

What is a wave?

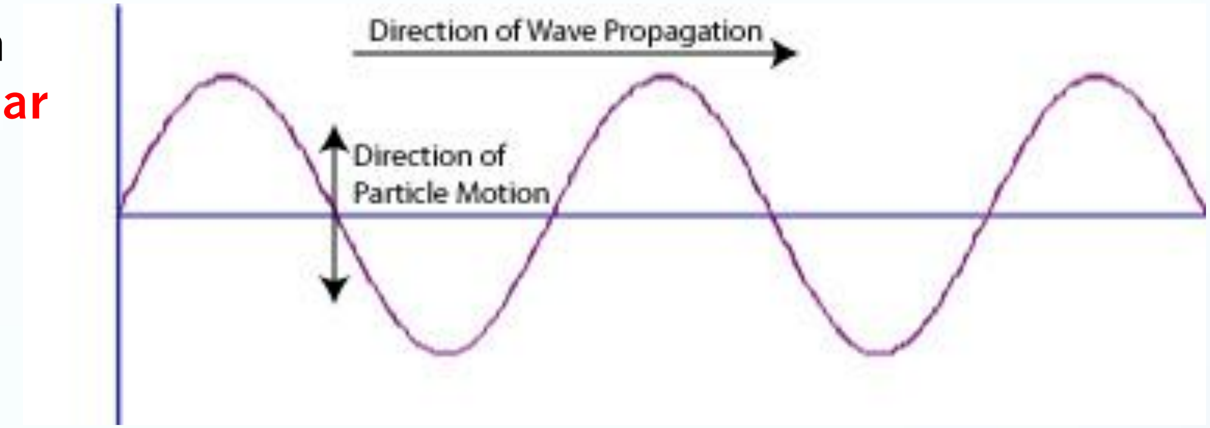


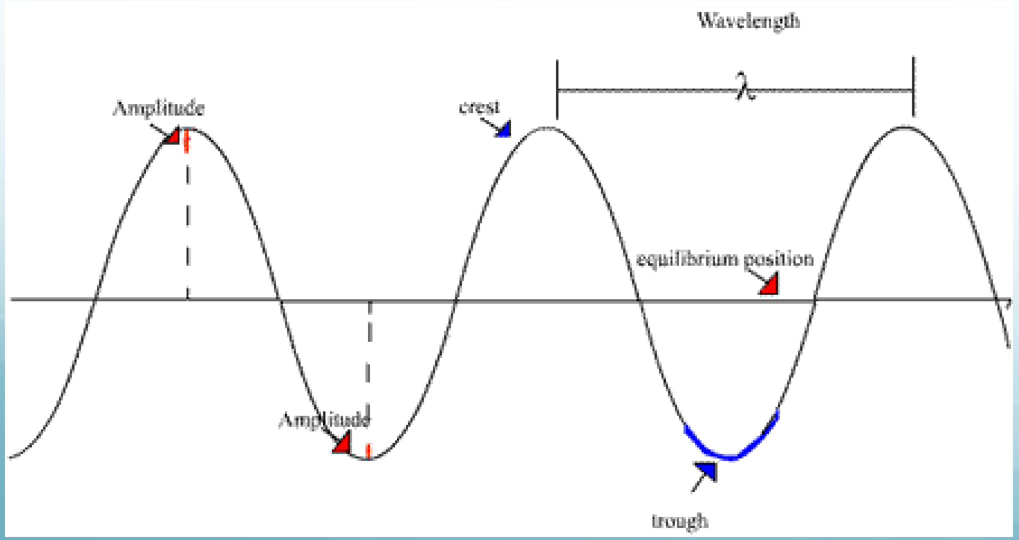
- Two features common to all waves
  - A wave is a traveling disturbance
  - A wave carries energy from place to place
    - A medium is the substance that all SOUND WAVES travel through and need to have in order to move.

Types of Waves

The first type of wave is called a transverse wave

The direction of the motion of a particle is **perpendicular** to the motion of the wave





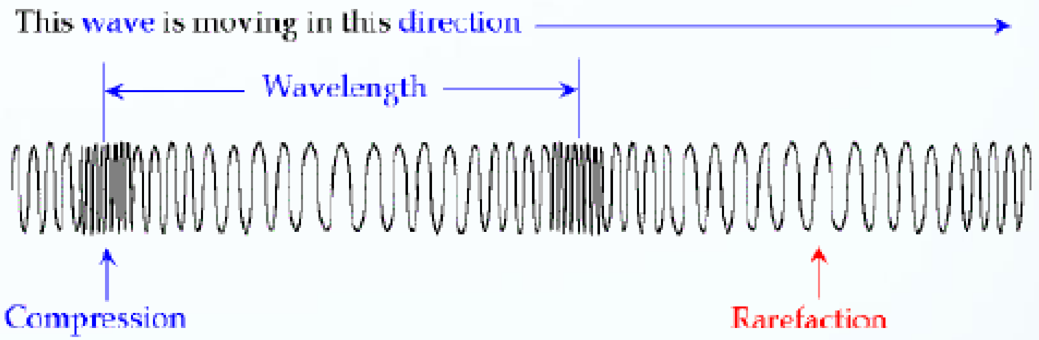
Parts of a Wave

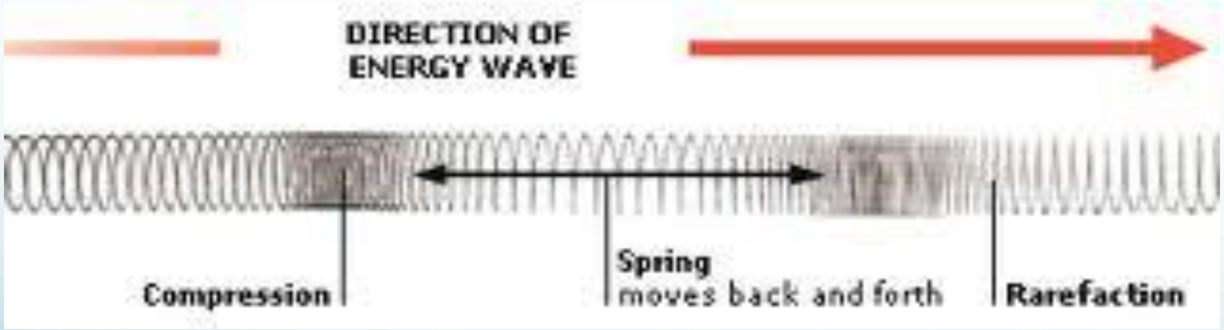
- **Amplitude**
- **Crest**
- **Trough**
- **Wavelength**
- **Equilibrium Position**

Types of Waves

Another type of wave is called a longitudinal wave

The direction of the motion of a particle is **parallel** to the motion of the wave





Parts of a Wave

- **Compression**
- **Rarefaction**

Wave Speed

What is the relationship between speed, period, and wavelength?

$$v = \frac{\Delta x}{\Delta t}$$

$$\Delta x = wavelength = \lambda$$

$$v = \frac{\lambda}{\mathrm{T}}; but\ \mathrm{T} = \frac{1}{f}\ therefore$$

$$v = f\lambda$$

You can find the speed of a wave by multiplying the wave's wavelength in meters by the frequency (cycles per second). Since a "cycle" is not a standard unit this gives you meters/second.

Example

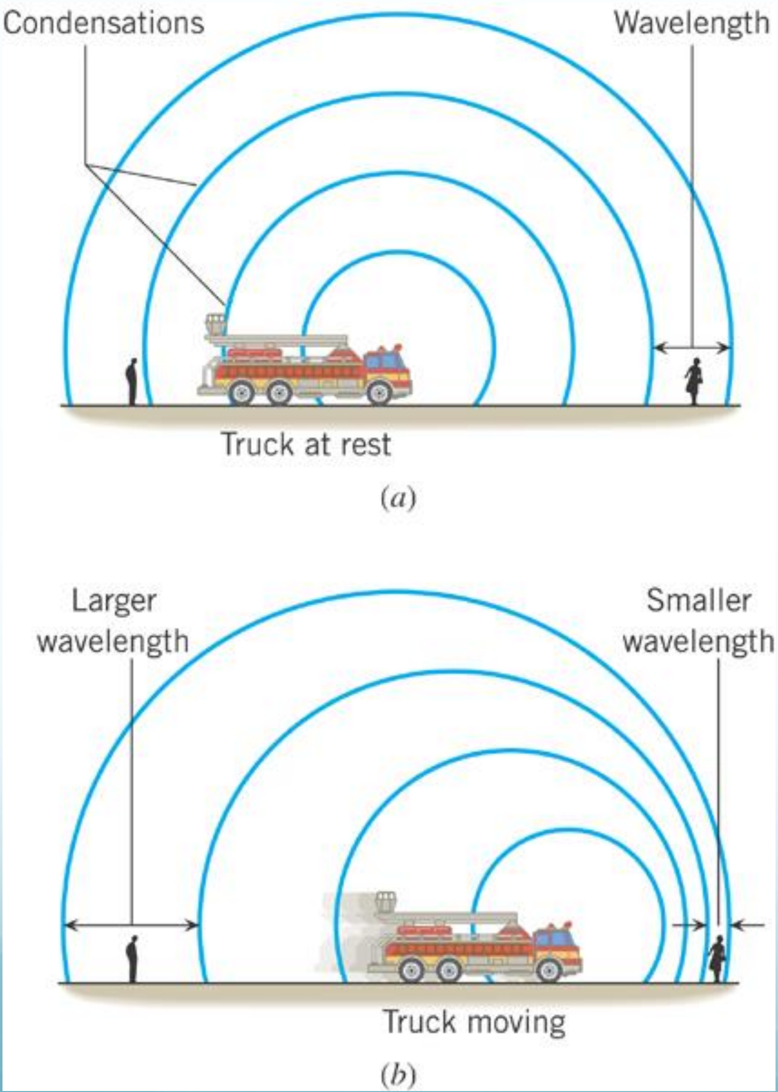
A harmonic wave is traveling along a rope. It is observed that the oscillator that generates the wave completes 40.0 vibrations in 30.0 s. Also, a given maximum travels 425 cm along a rope in 10.0 s . What is the wavelength?

$$f = \frac{cycles}{\sec} = \frac{40}{30} =$$ **1.33 Hz**

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{4.25}{10} =$$ **0.425 m/s**

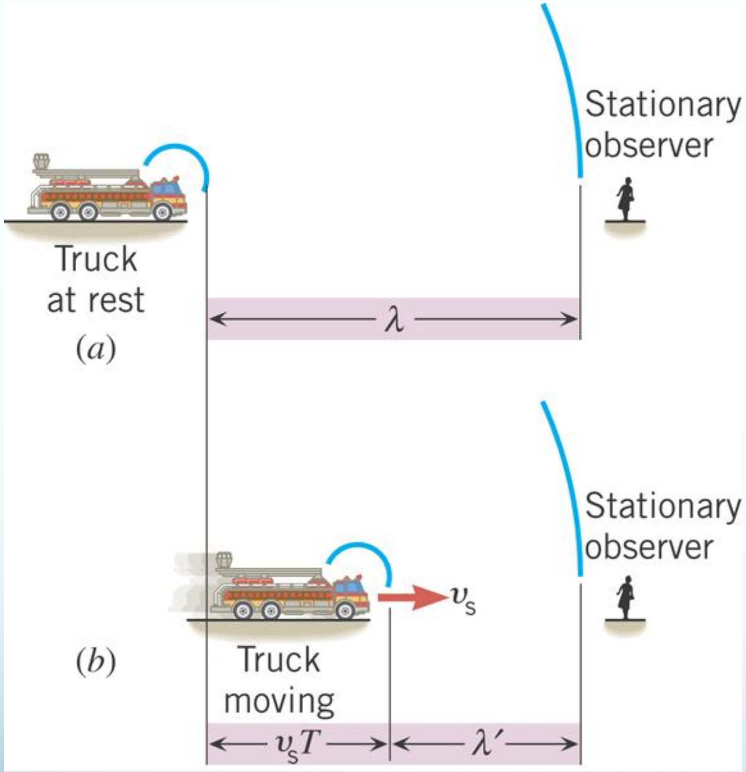
$$v_{wave} = \lambda f \rightarrow \lambda = \frac{v_{wave}}{f} =$$ **0.319 m**

DOPPLER EFFECT



The ***Doppler effect*** is the change in frequency or pitch 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.

MOVING SOURCE



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

$$f_o = \frac{v}{\lambda'} = \frac{v}{\lambda - v_s T} = \frac{v}{v/f_s - v_s/f_s}$$

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

source moving toward a stationary observer

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

source moving away from a stationary observer

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

***Example :* The Sound of a Passing Train**

A high-speed train is traveling at a speed of 44.7 m/s when the engineer sounds the 415-Hz warning horn. The speed of sound is 343 m/s. What are the frequency and wavelength of the sound, as perceived by a person standing at the crossing, when the train is (a) approaching and (b) leaving the crossing?

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

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

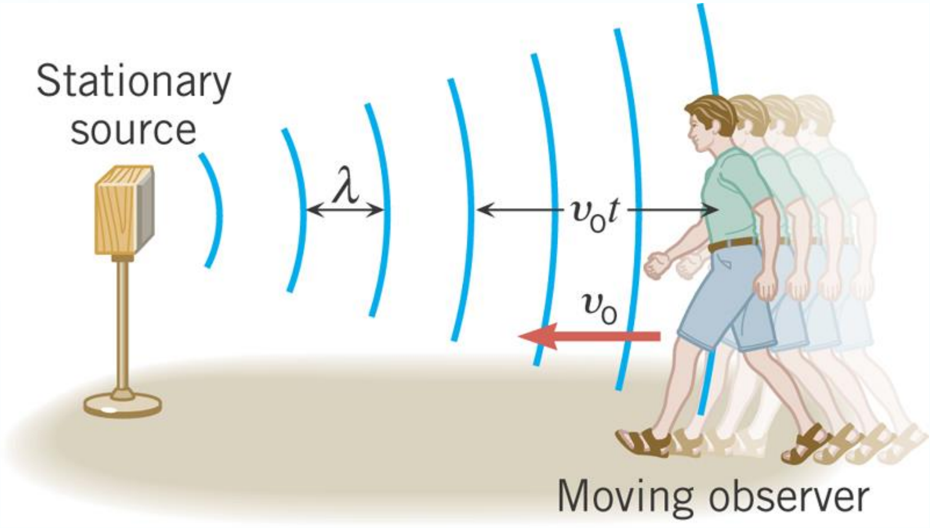
approaching

$$f_o = (415\,\text{Hz})\left(\frac{1}{1-\frac{44.7\text{m/s}}{343\text{m/s}}}\right) = 477\,\text{Hz}$$

leaving

$$f_o = (415\,\text{Hz})\left(\frac{1}{1+\frac{44.7\text{m/s}}{343\text{m/s}}}\right) = 367\,\text{Hz}$$

MOVING OBSERVER



$$f_o = f_s + \frac{v_o}{\lambda} = f_s\left(1 + \frac{v_o}{f_s \lambda}\right)$$

$$= f_s\left(1 + \frac{v_o}{v}\right)$$

Observer moving towards stationary source

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

Observer moving away from stationary source

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

GENERAL CASE

$$f_o = f_s\left(\frac{1 \pm \frac{v_o}{v}}{1 \mp \frac{v_s}{v}}\right)$$

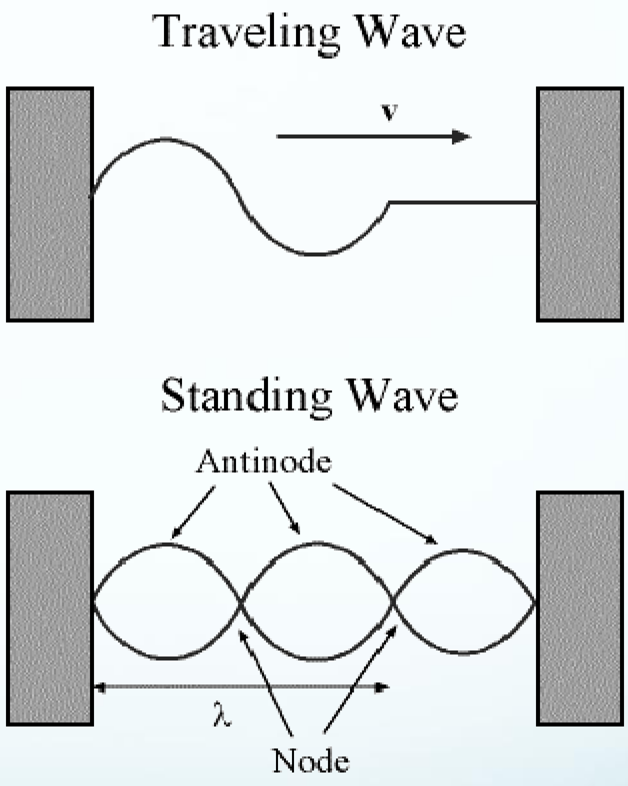
Numerator: plus sign applies when observer moves towards the source

Denominator: minus sign applies when source moves towards the observer

Standing Waves

A standing wave is produced when a wave that is traveling is reflected back upon itself. There are two main parts to a standing wave:

- **Antinodes** – Areas of MAXIMUM AMPLITUDE
- **Nodes** – Areas of ZERO AMPLITUDE.



Sound Waves

The production of sound involves setting up a wave in air. To set up a **CONTINUOUS** sound you will need to set a standing wave pattern.

Three LARGE CLASSES of instruments

- Stringed - standing wave is set up in a tightly stretched string
- Percussion - standing wave is produced by the vibration of solid objects
- Wind - standing wave is set up in a column of air that is either OPEN or CLOSED

Factors that influence the speed of sound are density of solids or liquid, and **TEMPERATURE**

$$v_{sound} = 331\, m/s \quad @\, 0^{\circ}\, Celsius$$

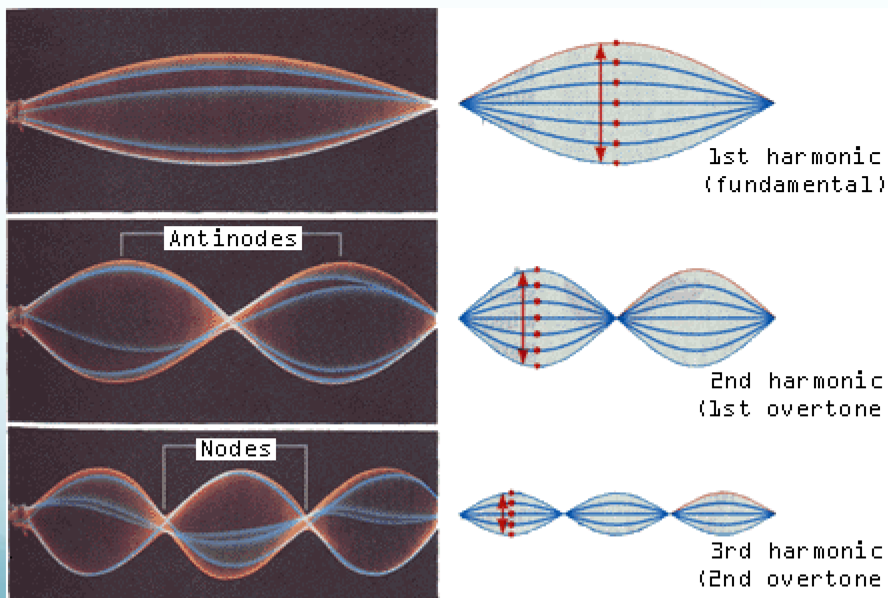
$$\uparrow or \downarrow by\ 0.6\, m/s\ for\ every\ 1^{\circ}C$$

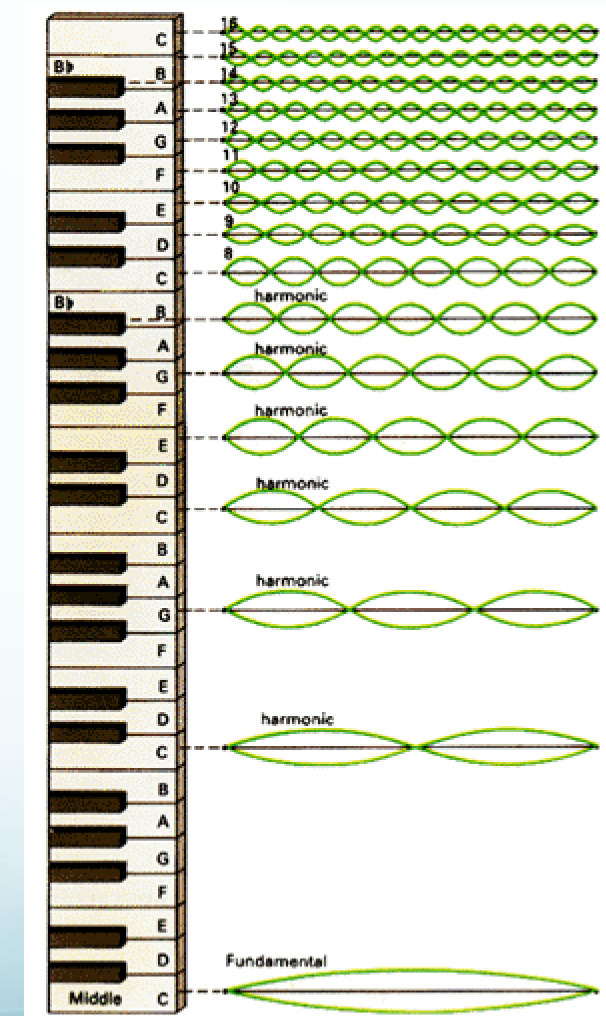
Standing waves occur under a special set of circumstances.

- Standing waves occur at frequencies that are multiples of the **Fundamental**.
  - The "*Fundamental*" is the natural frequency of the string.
- The fundamental and multiples of its frequency are called, "**Harmonics**."
- You can tell the harmonic number by counting the number of bumps that are found on the wave.
  - These bumps are separated by "collars" that seem to cut that bump off from the next.
    - These collars are called "**Nodes**."
      - The central portion of the bump where the most motion occurs is called the "**Antinode**."

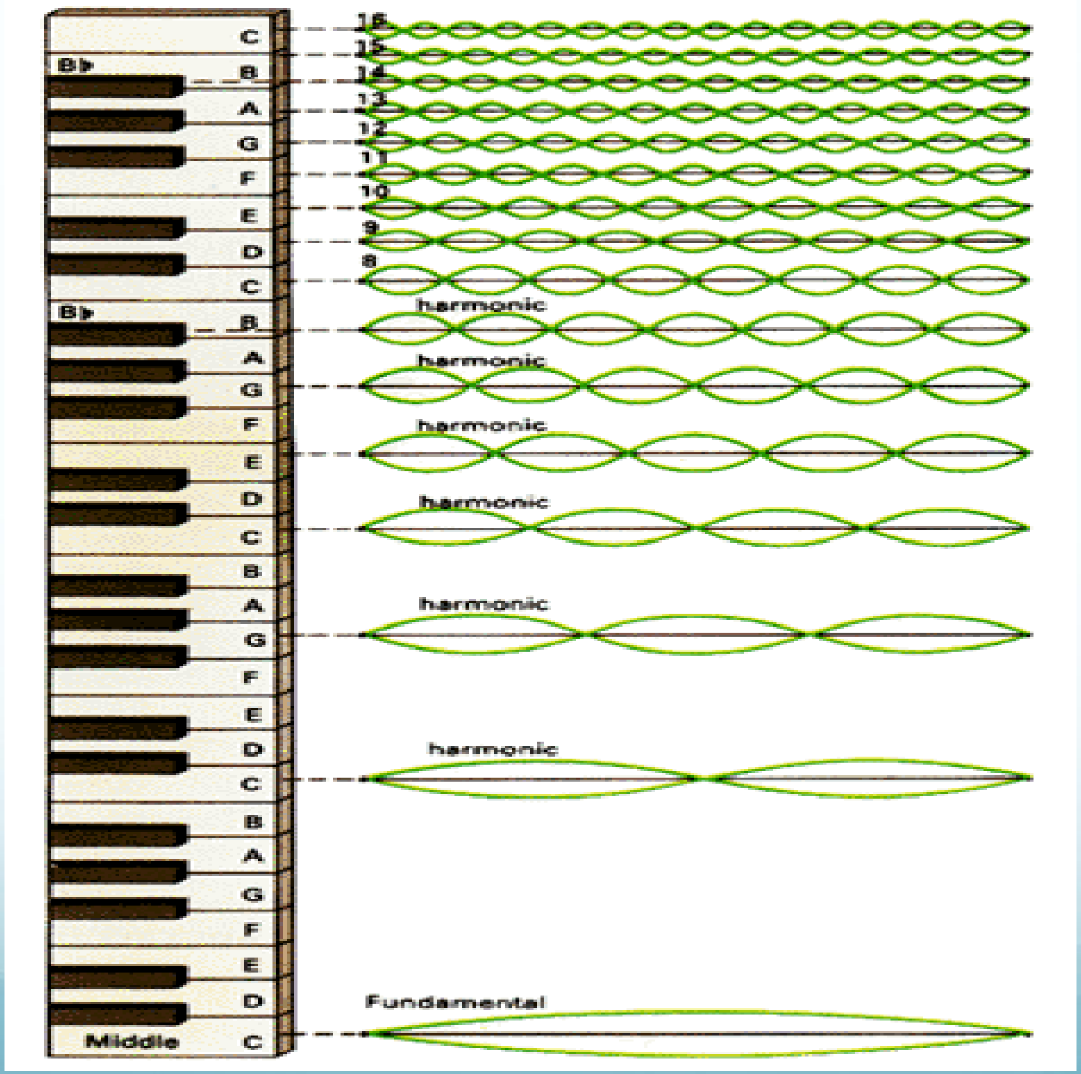
What do harmonics look like?

- Just look at the keys on a piano to see the different harmonics.



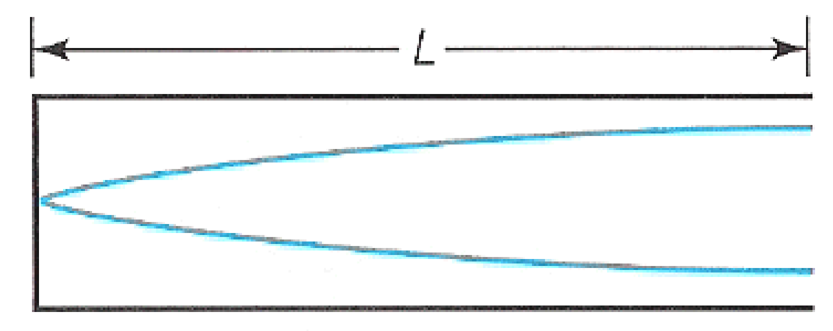


Looking at the same harmonics, describe to me the number of *nodes* and *antinodes* that you see in each harmonic.



Closed Pipes

Have an antinode at one end and a node at the other. Each sound you hear will occur when an ***antinode*** appears at the top of the pipe. **What is the SMALLEST length of pipe you can have to hear a sound?**



You get your first sound or encounter your first antinode when the length of the actual pipe is equal to a quarter of a wavelength.

$$length = \frac{1}{4}\lambda$$

$$4l = \lambda$$

$$v = \lambda f$$

$$v_{closed} = 4lf$$

This **FIRST SOUND** is called the **FUNDAMENTAL FREQUENCY or the FIRST HARMONIC.**

Closed Pipes - Harmonics

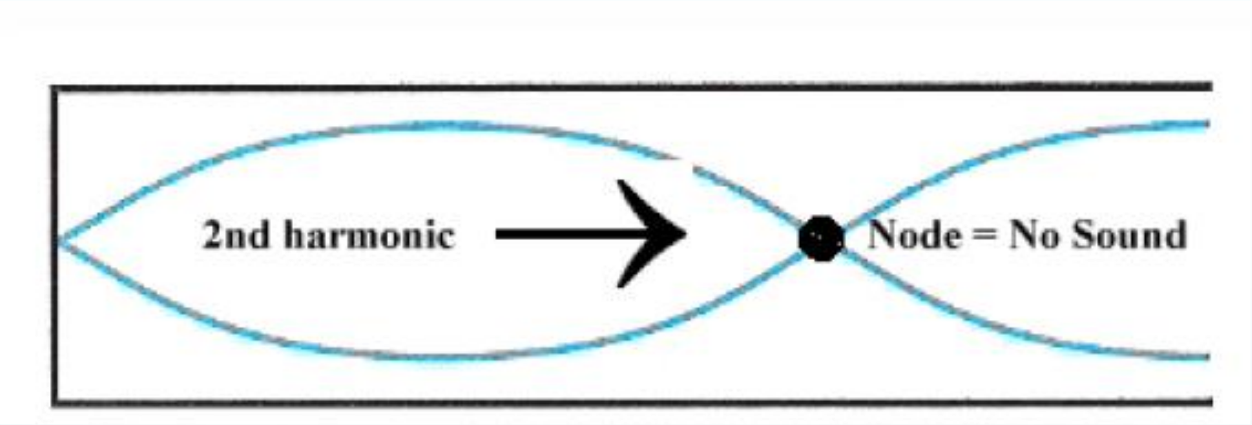
Harmonics are MULTIPLES of the fundamental frequency.

$\frac{1}{4}\lambda = Fundamental = sound$

$\frac{1}{2}\lambda = Second\ Harmonic = no\ sound$

$\frac{3}{4}\lambda = Third\ Harmonic = sound$

etc.....

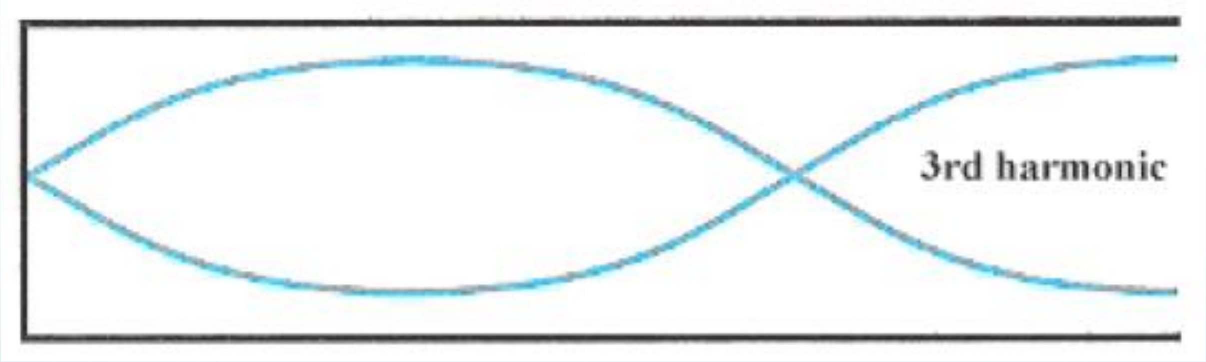


In a closed pipe, you have a NODE at the 2nd harmonic position, therefore NO SOUND is produced

Closed Pipes - Harmonics

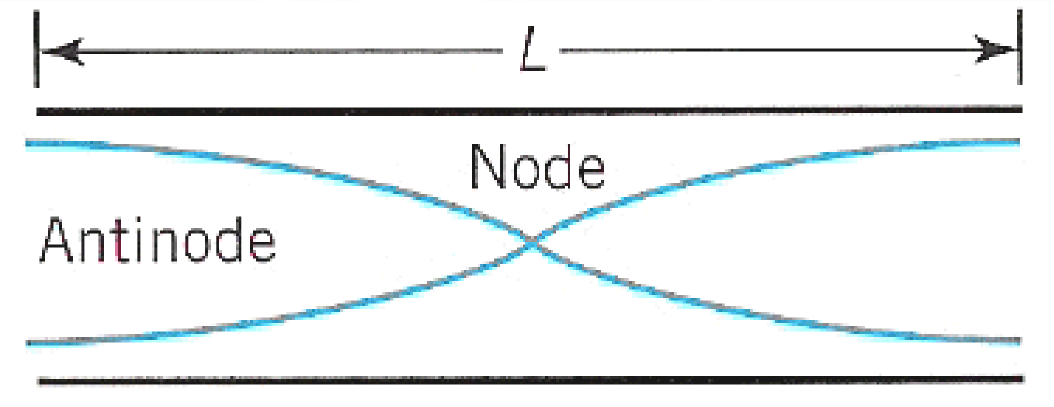
In a closed pipe you have an ANTINODE at the 3rd harmonic position, therefore SOUND is produced.

CONCLUSION: Sounds in CLOSED pipes are produced ONLY at ODD HARMONICS!



Open Pipes

OPEN PIPES- have an antinode on BOTH ends of the tube. **What is the SMALLEST length of pipe you can have to hear a sound?**



$$l = \frac{1}{2}\lambda$$

$$2l = \lambda$$

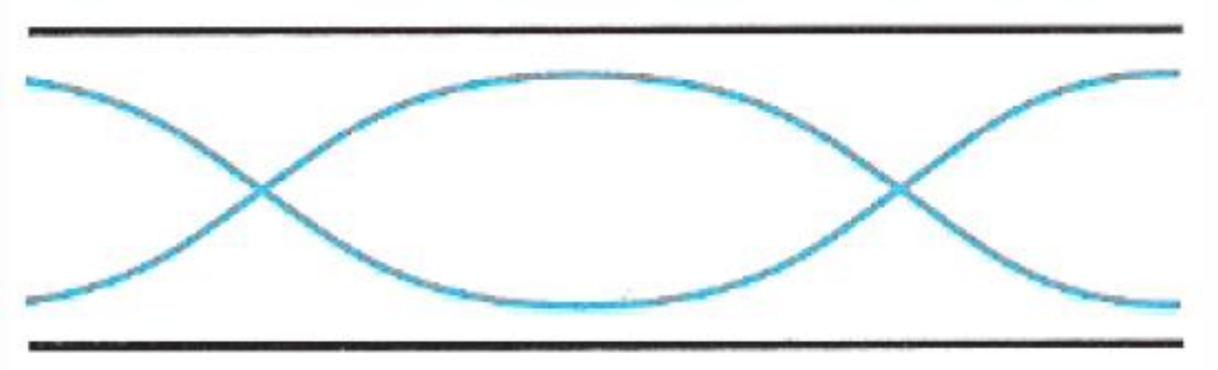
$$v = \lambda f$$

$$v_{open} = 2lf$$

You will get your FIRST sound when the length of the pipe equals one-half of a wavelength.

Open Pipes - Harmonics

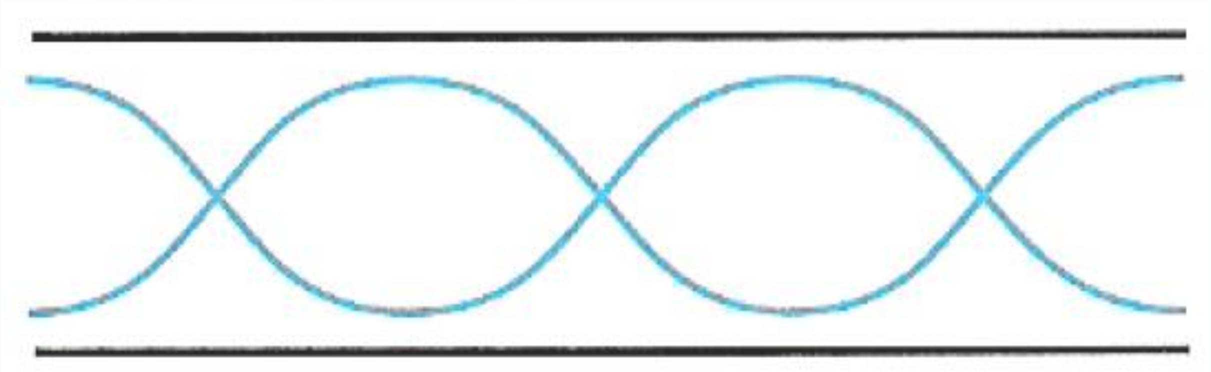
Since harmonics are MULTIPLES of the fundamental, the second harmonic of an "open pipe" will be ONE WAVELENGTH.



The picture above is the **SECOND** harmonic or the **FIRST OVERTONE**.

Open pipes - Harmonics

Another half of a wavelength would ALSO produce an antinode on BOTH ends. In fact, no matter how many halves you add you will always have an antinode on the ends



The picture above is the **THIRD** harmonic or the **SECOND OVERTONE**.

CONCLUSION: Sounds in OPEN pipes are produced at ALL HARMONICS!

Example

The speed of sound waves in air is found to be 340 m/s. Determine the fundamental frequency (1st harmonic) of an open-end air column which has a length of 67.5 cm.

$$v = 2lf$$

$$340 = 2(0.675)\,f$$

$$f =$$ **251.85 HZ**

Example

The windpipe of a typical whooping crane is about 1.525-m long. What is the lowest resonant frequency of this pipe assuming it is a pipe closed at one end? Assume a temperature of 37° C.

$$[(0.6)(37)] + 331 =$$ **353.2 m/s**

$$v = 4lf$$

$$v = 4(1.525)f$$

$$f =$$ **57.90 Hz**

Thank you