Sound

Sound Facts

Sound is a *longitudinal mechanical wave* and can travel through solids, liquids, and gases.

Sound is produced by the *compression* and *rarefaction* of matter resulting in oscillations in the pressure of the medium.

The speed of sound in air at 20˚C is 343 m/s, and varies with temperature.

$$v \approx (331 + 0.60T)\ \frac{\text{m}}{\text{s}}$$

Still Sound

Sound can be classified by frequency:

infrasonic	**$f < 20$ Hz**
audible	**20 Hz to 20,000 Hz**
ultrasonic	**> 20,000 Hz up to 600 MHz**

The *frequency* of a sound wave is also called *pitch*.

Sound Level

***Loudness* - depends upon the amplitude of the pressure variation. The human ear is sensitive to pressure variations as low as 2 x 10^{-5} Pa to those which cause pain (20 Pa).**

Because of this wide range, sound pressures are typically measured by a quantity called *sound level* which is measured in *decibels* (dB).

Sound Level

$$\text{sound level: } \beta = 10\log\left(\frac{I}{I_o}\right) \text{ (dB)}$$

I - the sound intensity. It is the rate that sound energy flows through a unit area normal to the direction of propagation (W/m^2).

I_o-is the threshold of hearing ($I_o = 10^{-12}\ W/m^2$).

Sound Levels

Type of Sound	Sound Level (dB)
threshold of hearing	0
whisper	10 - 20
soft music	30
conversation	60 - 70
heavy street traffic	70 - 80
thunder	110
threshold of pain	120
jet engine	170

Sources of Sound

Sound is produced by vibrating objects. There are three types of vibrating objects:

1.) ***Membranes*** **(drums, vocal cords, loud speakers)**

2.) ***Air columns*** **(trumpets, flutes, pipe organs)**

3.) ***Strings*** **(guitar, piano, harp, banjo)**

Closed and Open End Pipes

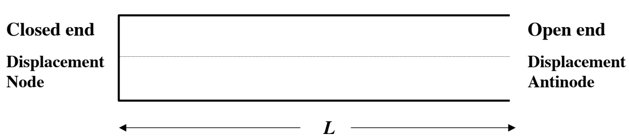
The end of a pipe can either be closed or open and this affects the boundary condition on the sound wave produced.

A ***closed end*** **of pipe is a** ***displacement node*** **(analogous to fixed end of string) and a** ***pressure antinode*****.**

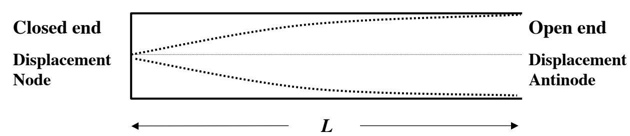
An ***open end*** **of pipe is a** ***displacement antinode*** **and a** ***pressure node*** **(open to atmosphere).**

Closed Pipe Resonators

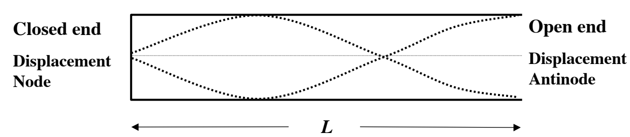
A ***closed pipe resonator*** **has one open end and one closed end (like blowing on a bottle).**



Modes for Closed Pipe Resonators

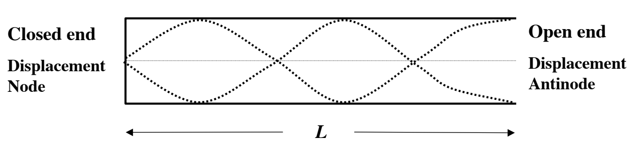


$$\lambda = 4L$$

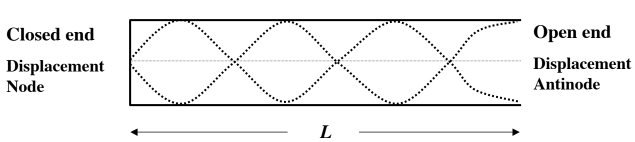


$$\lambda = \tfrac{4}{3}L$$

Modes for Closed Pipe Resonators



$$\lambda = \tfrac{4}{5}L$$



$$\lambda = \tfrac{4}{7}L$$

Modes for Closed Pipe Resonators

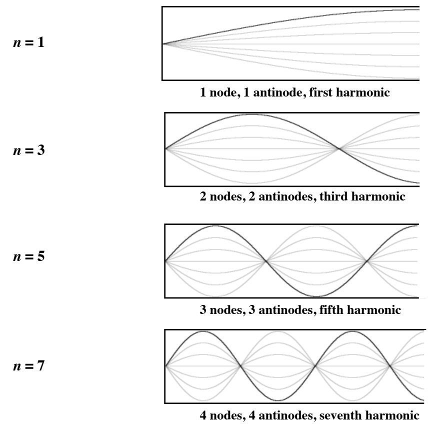
Mode	Wavelength
1	$4L$
3	$\tfrac{4}{3}L$
5	$\tfrac{4}{5}L$
7	$\tfrac{4}{7}L$
.	.
.	.
n	$\lambda_n = \dfrac{4L}{n}$ $(n = 1, 3, 5, ...)$

Modes for Closed Pipe Resonators

Mode	Frequency
1	$\frac{v}{4L} = f_1$
3	$\frac{3v}{4L} = 3f_1$
5	$\frac{5v}{4L} = 5f_1$
7	$\frac{7v}{4L} = 7f_1$
.	.
.	.
n	$\frac{n\,v}{4L} = n\,f_1 \quad (n = 1, 3, 5, ...)$

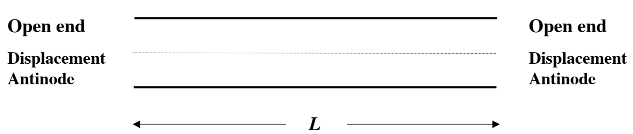
(only odd harmonics are formed)

Closed Pipe Resonators

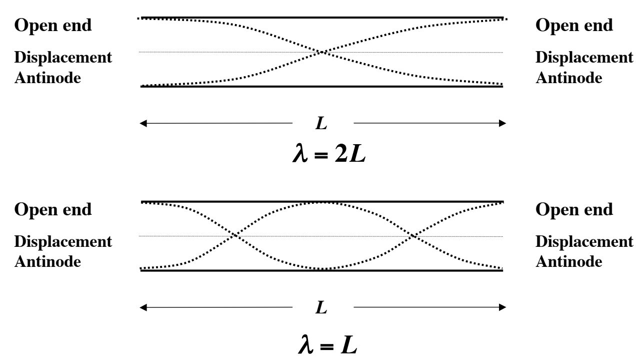


Open Pipe Resonators

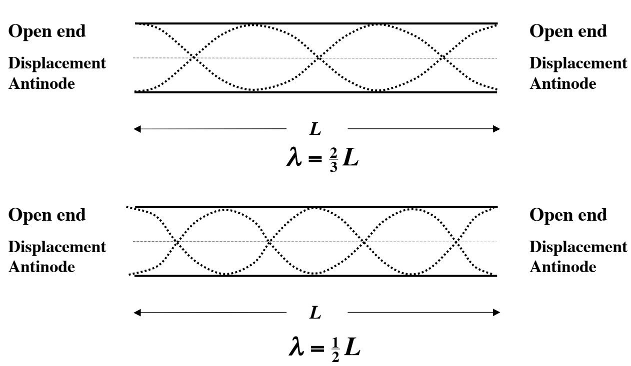
An *open pipe resonators* has both ends open.



Modes for Open Pipe Resonators



Modes for Open Pipe Resonators



Modes for Open Pipe Resonators

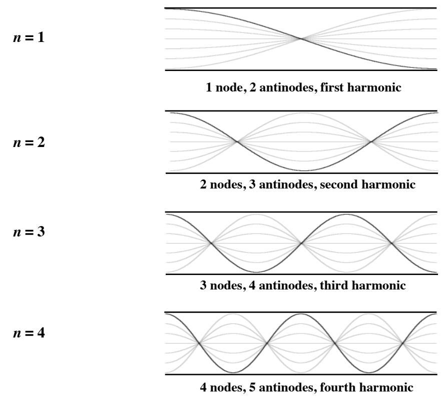
Mode	Wavelength
1	$2L$
2	L
3	$\frac{2}{3}L$
4	$\frac{1}{2}L$
.	.
.	.
n	$\lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, ...)$

Modes for Open Pipe Resonators

Mode	Frequency
1	$\frac{v}{2L} = f_1$
2	$\frac{v}{L} = 2f_1$
3	$\frac{3v}{2L} = 3f_1$
4	$\frac{2v}{L} = 4f_1$
.	.
.	.
n	$\frac{n\,v}{2L} = nf_1 \quad (n = 1, 2, 3, \ldots)$

(all harmonics are formed)

Open Pipe Resonators



Air Resonators (Summary)

Closed Pipe Resonators

Displacement *node* and *antinode* on ends

For a pipe of length *L*:

wavelengths are $\lambda_n = \frac{4L}{n} \quad (n = 1, 3, 5, \ldots)$

frequencies are $f_1, 3f_1, 5f_1, \ldots$

Mode *n* has $\frac{n+1}{2}$ **nodes and antinodes**

Air Resonators (Summary)

Open Pipe Resonators

Displacement *antinodes* on both ends

For a pipe of length *L*:

wavelengths are $\lambda_n = \frac{2L}{n} \quad (n = 1, 2, 3, \ldots)$

frequencies are $f_1, 2f_1, 3f_1, \ldots$

Mode *n* has *n* nodes and *n* + 1 antinodes

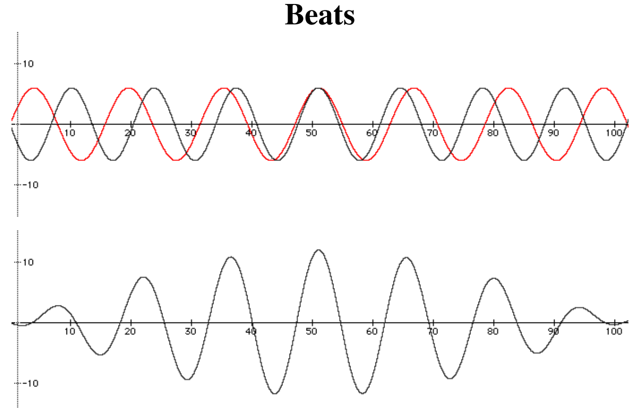
Beats

***Beats* are the result of the interference (algebraic sum) of two waves of slightly different frequencies.**

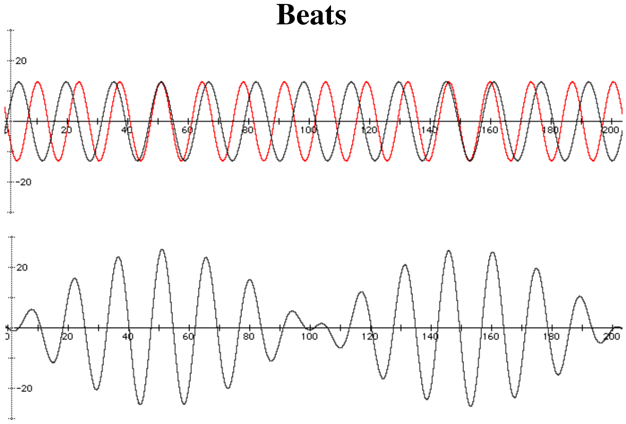
The beat frequency is the difference in the wave frequencies.

$$f_b = |f_1 - f_2|$$

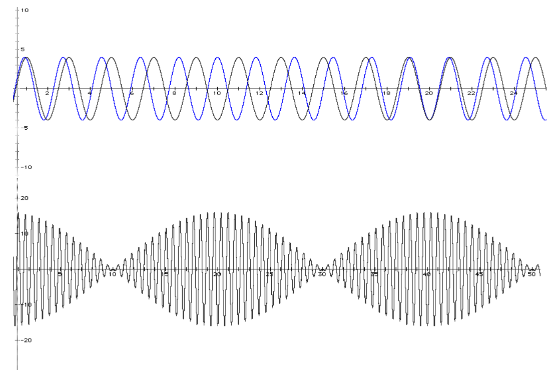
Beats



Beats



Beats



Doppler Effect

If there is relative motion between the source and the detector, then the waves that the detector receives are different in frequency.

A *doppler shift* occurs if either the detector or source is moving or both the detector and source are moving.

If the relative motion is such that the source and detector are moving towards one another then a higher frequency is detected.

If the relative motion is such that the source and detector are moving away from one another then a lower frequency is detected.

Doppler Effect

The apparent frequency sensed by the detector is:

$$f_d = \frac{(v + v_d)}{(v - v_s)} \cdot f_s$$

where

f_s = frequency emitted by source (Hz)

f_d = frequency sensed by detector (Hz)

v_s = velocity of source (m/s)

v_d = velocity of detector (m/s)

v = velocity of sound (m/s)

(v_s and v_d are positive when moving toward one another.)