Modes of Vibration

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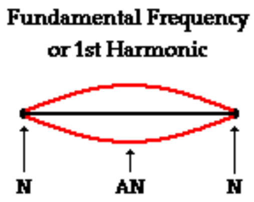
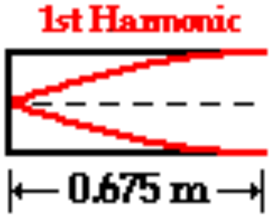
- Vibrations in musical instruments create the sounds we hear from them.
- These sounds are standing waves which are created in the instruments.
- The standing wave can be:
  - Closed at BOTH ends (guitar strings)



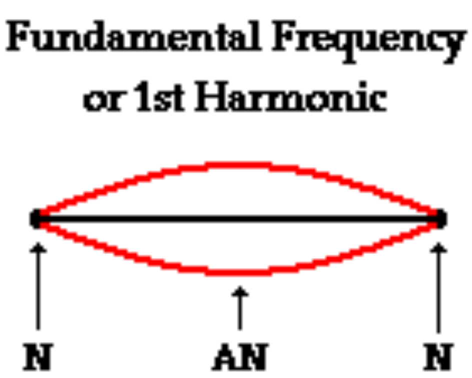
  - Open at both ends (flutes)

  - Closed at one end and open at the other (pipe organs)



1. **Closed Ends:** Standing Waves in Strings

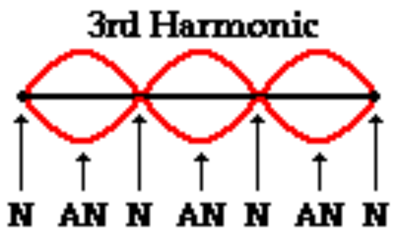
- When a guitar string vibrates at its natural frequency, the ends become nodes.
  - In between these two nodes at the end of the string, there must be at least one antinode.
- This produces a standing wave in the string with the lowest frequency (and therefore longest wavelength) possible.
- This is known as the **fundamental frequency** – also called the **first harmonic.**



Harmonics & Overtones

- Multiples of the fundamental frequency are called **overtones.**
- The second harmonic (first overtone) of a guitar string is produced by adding one more node between the ends of the guitar string. The second harmonic is one **octave** higher than the first.

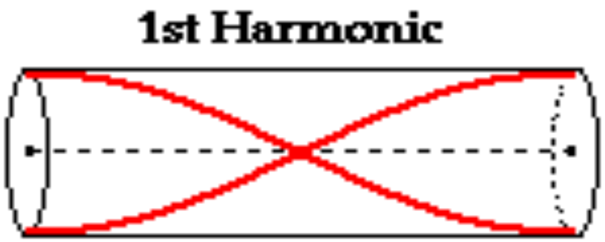
- The third harmonic (second overtone) of a guitar string is produced by adding two nodes between the ends of the guitar string.



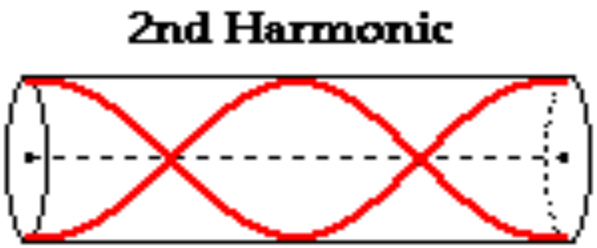
2. Open Ends

- Antinodes always form at the end of **open pipes.**

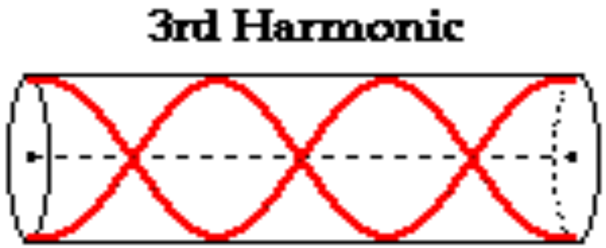
<u># of quarter $\lambda' s$</u>



Fundamental frequency



First overtone



Second overtone

Closed/Closed & Open/Open

$$f = \frac{nv}{4L}$$

n = # of quarter wavelengths
L = length of string

Harmonic Number	Overtone Number	n (same ends)	frequency
First harmonic	Fundamental frequency	2	f
Second harmonic	First overtone	4	2f
Third harmonic	Second overtone	6	3f
N^{th} harmonic	$(N^{th}$-1) overtone	N*2	N*f

Examples: Closed/Closed & Open/Open

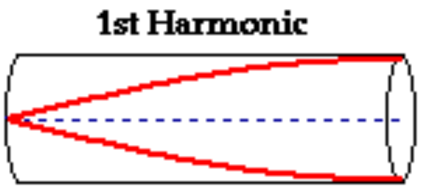
- The speed of sound waves in air is 340 m/s. Draw a diagram and determine the fundamental frequency (1st harmonic) of an open-end air column that has a length of 0.675 m.

- Draw a diagram and determine the second harmonic for a wave in a string of the same length.

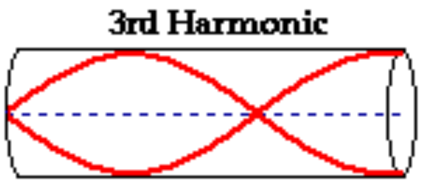
3. Closed/Open

- Nodes form at the **closed end** and antinodes form at the **open end.**
- Instruments that are closed at one end only have odd numbered harmonics.

<u># of quarter $\lambda' s$</u>



Fundamental frequency



First overtone

Second overtone

Closed/Open

$$f = \frac{nv}{4L}$$

n = # of quarter wavelengths
L = length of string

Harmonic Number	Overtone Number	n (diff ends)
First harmonic	Fundamental frequency	1
Third harmonic	First overtone	3
Fifth harmonic	Second overtone	5

Examples: Closed/Open

- The speed of sound waves in air is 340 m/s. Draw a diagram and determine the fundamental frequency (1st harmonic) of a closed-end air column that has a length of 0.675 m.

- Draw a diagram and determine the second overtone for a closed end air column of the same length.

$$f = \frac{nv}{4L}$$

n = # of quarter wavelengths
L = length of string

Closed/Closed & Open/Open

Harmonic Number	Overtone Number	n (same ends)	frequency
First harmonic	Fundamental frequency	2	f
Second harmonic	First overtone	4	2f
Third harmonic	Second overtone	6	3f
N^{th} harmonic	(N^{th}-1) overtone	N*2	N*f

Closed/Open

Harmonic Number	Overtone Number	n (diff ends)
First harmonic	Fundamental frequency	1
Third harmonic	First overtone	3
Fifth harmonic	Second overtone	5