Sound Waves

The Physics of Music

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Pitch - Octaves

- Pythagoras determined musical scales based on the length of string when plucked.
- Octaves
  - difference in pitch when the two notes' frequencies have a ratio of 2:1

220 Hz ↖ Octave ↗ 440 Hz ↖ Octave ↗ 880 Hz

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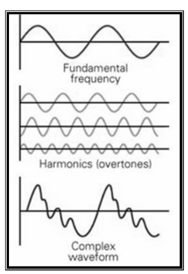
Sound Quality

- Timbre or Quality
  - instrument dependent
  - combined frequencies
  - complex wave forms



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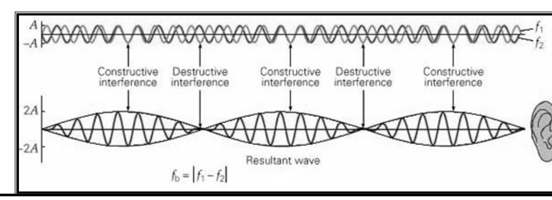
Sound Quality

- Beats
  - pulsing variation of loudness
  - Humans can detect beat frequencies up to approximately 7Hz
  - Over 7Hz we hear a complex wave



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Forced Vibrations and Resonance

- Forced Vibrations
  - The forced transfer of a vibration to other media (Ex: guitar)
- Resonance
  - Occurs when the forced vibration matches the natural frequency of an object
- Resonance can produce a standing wave, creating a louder noise or other results…

https://www.youtube.com/watch?v=uVvnw3MfxkI
https://www.youtube.com/watch?v=rRZT7xO5KN4
https://www.youtube.com/watch?v=sH7XSX10QkM

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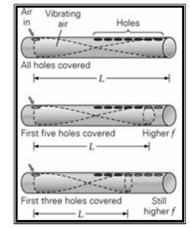
Resonance

- How it works
  - Certain frequencies will produce standing waves in a given length of pipe or string
  - These standing waves produce the sound we hear in musical instruments.
  - By changing the length of the string or pipe, we can change the frequency that resonates
  - Resonant frequency can also depend slightly on the diameter of the pipe



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Resonance

- Fundamental
  - the lowest frequency making up a sound
- Harmonics
  - whole number multiples of the fundamental frequency
- Overtones
  - The first occurrence of resonance above the fundamental frequency

Note on musical vocabulary:
- The fundamental is also the first harmonic
- The first overtone is the second harmonic

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Resonance

- Closed pipe resonator
  - resonating tube with one end closed
  - produces a standing wave
  - Minimum length is approx. 1/4 λ

$\lambda = 4L$

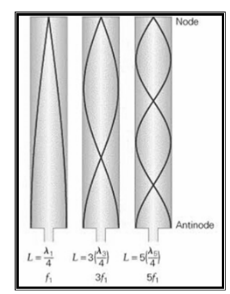
$v = \lambda f_1$ — Use 343 m/s unless given temperature or velocity

$f_1 = \left(\frac{v}{4L}\right) \quad (n = 1,3,5\ldots)$

$f_n = nf_1$

Notice only odd harmonics resonate in a closed tube

If given two tube lengths, $L_2 - L_1 = \frac{1}{2}\lambda$



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Resonance

- Open-pipe resonator
  - open at both ends
  - produces a standing wave
  - Minimum length is 1/2 λ

If given two tube lengths, $L_2 - L_1 = \frac{1}{2}\lambda$

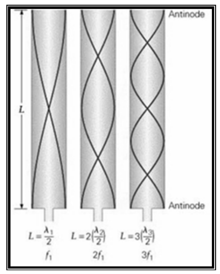
$\lambda = 2L$

$v = \lambda f_1$ — Use 343 m/s unless given temperature or velocity

$f_1 = \left(\frac{v}{2L}\right)$ $\quad (n = 1,2,3\ldots)$

$f_n = n f_1$

Notice all harmonics resonate in an open tube



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Harmonics Sample Problem

- What are the first two harmonics (resonant frequencies) in a 2.45 m long pipe that is open at both ends? Assume the speed of sound is 345 m/s.

↳ All harmonics are heard

$\lambda = 2L$

$= 2(2.45) = 4.9\,m$

$v = \lambda f$

$345 = (4.9) f$

$f_1 = 70.4$ Hz $\quad f_2 = 140.8$ Hz

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Harmonics Sample Problem

- A 392 Hz tuning fork is used with a closed pipe resonator. The length is 0.32 m when the loudest sound is produced. What is the speed of sound?

$\lambda = 4L$

$\lambda = 1.28\,m$

$v = \lambda f$

$v = 1.28(392) = 501.76$ m/s

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