Musical Instruments

Turn off all electronic devices

Observations about Musical Instruments

- They can produce different notes
- They must be tuned to produce the right notes
- They sound different, even on the same note
- They require energy to create sound

7 Questions about Musical Instruments

1. Why does a taut string have a specific pitch?
2. Why does a vibrating string sound like a string?
3. How does bowing cause a string to vibrate?
4. Why do stringed instruments need surfaces?
5. What is vibrating in a wind instrument?
6. Why does a drum sound particularly different?
7. How does sound travel through air?

Question 1

Q: Why does a taut string have a specific pitch?
A: A taut string is a harmonic oscillator

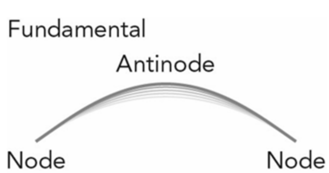
A taut string
- has a stable equilibrium shape: a straight line
- has a mass that provides an inertial aspect
- has tension and length that together provide a spring-like restoring aspect

A taut string is a harmonic oscillator
- It vibrates about its equilibrium shape
- Its pitch is independent of its amplitude/volume!

Fundamental Vibration

A string has a <u>fundamental vibrational mode</u>
- string vibrates up and down as a single arc
- 1 displacement antinode at string's center
- 2 displacement nodes, 1 node at each end of string

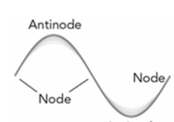
Its <u>fundamental pitch</u> (frequency of vibration) is proportional to
- $\text{tension}^{1/2}$
- 1/length
- $1/\text{mass}^{1/2}$

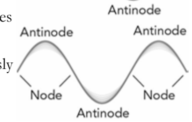


Question 2

Q: Why does a vibrating string sound like a string?
A: It has specific harmonics that define its sound

- A string can also vibrate as
  - 2 half-strings (2 antinodes)
  - 3 third-strings (3 antinodes)
  - and other <u>higher-order</u> modes
- Higher-order vibrational modes
  - provide <u>overtones</u> (over the fundamental pitch)
  - string's overtones are <u>harmonics</u>: integer multiples
- Bowing or pluck the string
  - initiates vibration of several modes simultaneously
  - and give the string its timbre (sound character)





Question 3

Q: How does bowing cause a string to vibrate?

A: Bowing adds a little energy to the string every cycle

- Plucking a string transfers energy all at once
- Bowing a string transfers energy gradually
  - The bow does a little work on the string every cycle
  - That energy accumulates via <u>resonant energy transfer</u>
- A string will exhibit <u>sympathetic vibration</u> when
  - another object vibrates at string's resonant frequency
  - resonant energy transfer goes from object to string

Question 4

Q: Why do stringed instruments need surfaces?

A: Surfaces project sound much better than strings

- In air, sound consists of density fluctuations
  - Air has a stable equilibrium: uniform density
  - Disturbances from uniform density make air vibrate
- Vibrating strings don't project sound well
  - air flows easily around narrow vibrating strings
- Surfaces project sound much better
  - air can't flow easily around vibrating surfaces
  - air is substantially compressed or rarefied: sound

Question 5

Q: What is vibrating in a wind instrument?

A: Air in a tube is a harmonic oscillator

Air in a tube has
- a stable equilibrium arrangement: uniform air density
- The air's mass provides an inertial aspect
- The air's pressure and length provide a spring-like restoring aspect

Air in a tube is a harmonic oscillator
- vibrates about its equilibrium arrangement
- pitch is independent of its amplitude/volume!

Fundamental Vibration Open-Open Column

- Air column has a fundamental vibrational mode
  - air column vibrates up and down as a single object
  - 1 pressure antinode at air column's center
  - 2 pressure nodes, 1 node at each open end of column
- Its fundamental pitch is proportional to
  - $\text{pressure}^{1/2}$,
  - 1/length,
  - $1/\text{density}^{1/2}$.

Fundamental Vibration Open-Closed Column

- Air column has a fundamental vibrational mode
  - air column vibrates up and down as a single object
  - 1 pressure antinode at air column's closed end
  - 1 pressure node at air column's open end
- The air column in a open-closed pipe vibrates
  - like half the air column in an open-open pipe
  - at half the frequency of an open-open pipe

Air Column Harmonics

- In an open-open pipe, the overtones are at
  - 2 × the fundamental (2 pressure antinodes)
  - 3 × the fundamental (3 pressure antinodes)
  - and all integer harmonics
- In an open-closed pipe, the overtones are at
  - 3 × the fundamental (2 antinodes)
  - 5 × the fundamental (3 antinodes)
  - and all odd-integer harmonics

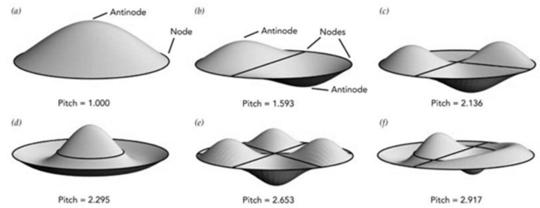
Question 6

Q: Why does a drum sound particularly different?

A: Its overtones are not harmonics

- Most 1-dimensional instruments
  - can vibrate at half, third, quarter length, etc.
  - have harmonic overtones
- Most 2- or 3- dimensional instruments
  - have complicated higher-order vibrations
  - have non-harmonic overtones.
- Examples: drums, cymbals, bells

Drumhead Vibrations



Question 7

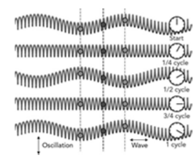
Q: How does sound travel through air?

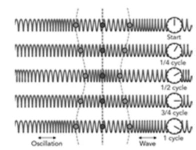
A: Air exhibits longitudinal traveling waves

- Basic modes of finite objects are standing waves
  - Standing wave: nodes and antinodes don't move
- Basic modes of infinite objects are traveling waves
  - Traveling wave: nodes and antinodes travel
- Open air is infinite, so it exhibits traveling waves

Transverse and Longitudinal Waves

- Some objects vibrate side-to-side: transverse waves
  - Finite strings: transverse standing
  - Open string: transverse traveling
- Some objects vibrate along their lengths: longitudinal waves
  - Air column: longitudinal standing
  - Open air: longitudinal traveling





Summary of Musical Instrument

- They use strings, air, etc. as harmonic oscillators
- Pitches are independent of amplitude/volume
- Tuned by tension/pressure, length, density
- Often have harmonic overtones
- Project vibrations into the air as sound