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

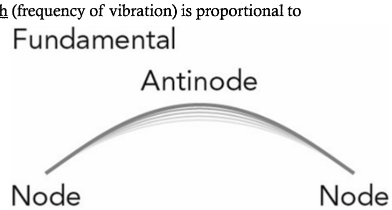
A taut string is a harmonic oscillator
- It vibrates (oscillates) about its equilibrium shape
- The period of its vibration is independent of the vibration's amplitude!

The reciprocal of period is frequency (i.e., frequency = 1/period)
- The vibration's frequency is independent of its amplitude
- The vibration's pitch is independent of its loudness

Fundamental Vibration

A string has a fundamental vibrational mode
- 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 fundamental pitch (frequency of vibration) is proportional to
- $\text{tension}^{1/2}$
- 1/length
- $1/\text{mass}^{1/2}$



Question 2

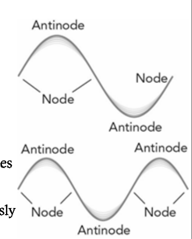
Q: Why does a vibrating string sound like a string?

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 higher-order modes

Higher-order vibrational modes
- provide overtones (over the fundamental pitch)
- string's overtones are harmonics: 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 resonant energy transfer

A string will exhibit sympathetic vibration 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/loudness!

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

- pressure$^{1/2}$,
- 1/length,
- 1/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?

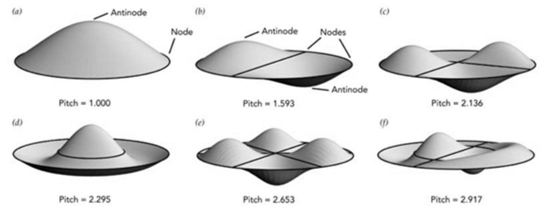
A: Its overtones are not harmonics

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
- <u>Standing wave</u>: nodes and antinodes don't move

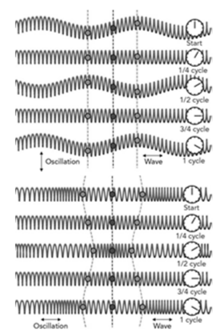
Basic modes of infinite objects are traveling waves
- <u>Traveling wave</u>: nodes and antinodes travel

Open air is infinite, so it exhibits traveling waves

Transverse and Longitudinal Waves

Some objects vibrate side-to-side:
<u>transverse waves</u>
- Finite strings: transverse standing
- Open string: transverse traveling

Some objects vibrate along their lengths:
<u>longitudinal waves</u>
- 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/loudness

Tuned by tension/pressure, length, density

Often have harmonic overtones

Project vibrations into the air as sound