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

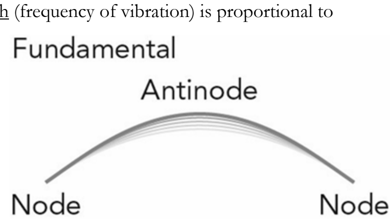
A taut string is a harmonic oscillator
- It vibrates (oscillates) about its equilibrium shape
- The period of its vibration is independent of the vibration's amplitude!

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 volume

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
- $tension^{1/2}$
- 1/length
- $1/mass^{1/2}$



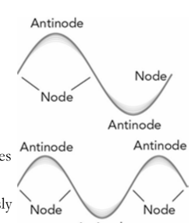
Question 2

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/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
- 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?

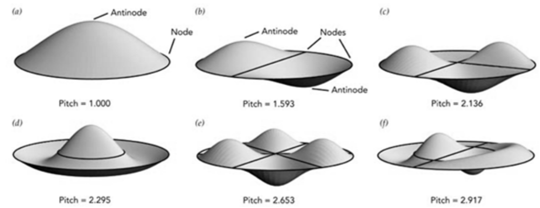
A: Its overtones are not harmonics

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

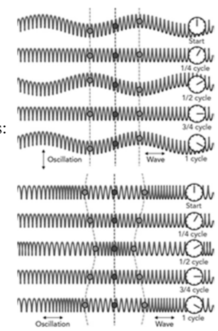
Basic modes of infinite objects are traveling waves
- <u>Traveling wave</u>: nodes and antinodes travel

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/volume

Tuned by tension/pressure, length, density

Often have harmonic overtones

Project vibrations into the air as sound