Violins and Pipe Organs

Question:

Sound can break glass. Which is easiest to break:

- A glass pane exposed to a loud, short sound
- A glass pane exposed to a certain loud tone
- A crystal glass exposed to a loud, short sound
- A crystal glass exposed to a certain loud tone

Observations About Violins and Pipe Organs

- They can produce different pitches
- They must be tuned
- They sound different, even on same pitch
- Sound character is adjustable
- Both require power to create sound
- Can produce blended or dissonant sounds

Strings as Harmonic Oscillators

- A string is a harmonic oscillator
  – Its mass gives it inertia
  – Its tension gives it a restoring force
  – It has a stable equilibrium
  – Restoring forces proportional to displacement
- Pitch independent of amplitude (volume)!

String's Inertia and Restoring Forces

- String's restoring force stiffness set by
  – string's tension
  – string's curvature (or, equivalently, length)
- String's inertial characteristics set by
  – string's mass per length

Fundamental Vibration

- String vibrates as single arc, up and down
  – velocity antinode occurs at center of string
  – velocity nodes occur at ends of string
- This is the fundamental vibrational mode
- Pitch (frequency of vibration) is
  – proportional to tension
  – inversely proportional to string length
  – inversely proportional to mass per length

Overtone Vibrations

- String can also vibrate as
  - two half-strings (one extra antinode)
  - three third-strings (two extra antinodes)
  - etc.
- These are higher-order vibrational modes
- They have higher pitches
- They are called “overtones”

String Harmonics Part 1

- In a string, the overtone pitches are at
  - twice the fundamental frequency
    - One octave above the fundamental frequency
    - Produced by two half-string vibrational mode
  - three times the fundamental frequency
    - An octave and a fifth above the fundamental
    - Produced by three half-string vibrational mode
  - etc.

String Harmonics Part 2

- Integer overtones are called “harmonics”
- Bowing or plucking a string tends to excite a mixture of fundamental and harmonic vibrations, giving character to the sound

Producing Sound

- Thin objects don’t project sound well
  - Air flows around objects
  - Compression and rarefaction is minimal
- Surfaces project sound much better
  - Air can’t flow around surfaces easily
  - Compression and rarefaction is substantial
- Many instruments use surfaces for sound

Plucking and Bowing

- Plucking a string transfers energy instantly
- Bowing a string transfers energy gradually
  - Rhythmic excitation at the right frequency causes sympathetic vibration
  - Bowing always excites string at the right frequency
  - The longer the string’s resonance lasts, the more effective the gradual energy transfer

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Air as a Harmonic Oscillator

- A column of air is a harmonic oscillator
  - Its mass gives it inertia
  - Pressure gives it a restoring force
  - It has a stable equilibrium
  - Restoring forces proportional to displacement
- Pitch independent of amplitude (volume)!

Air's Inertia and Restoring Forces

- Air's restoring force stiffness set by
  - pressure
  - pressure gradient (or, equivalently, length)
- Air's inertial characteristics set by
  - air's mass per length (essentially density)

Fundamental Vibration Open-Open Column

- Air column vibrates as a single object
  - Pressure antinode occurs at column center
  - Pressure nodes occur at column ends
- Pitch (frequency of vibration) is
  - proportional to air pressure
  - inversely proportional to column length
  - inversely proportional to air density

Fundamental Vibration Open-Closed Column

- Air column vibrates as a single object
  - Pressure antinode occurs at closed end
  - Pressure node occurs at open end
- Air column in open-closed pipe vibrates
  - as half the column in an open-open pipe
  - at half the frequency of an open-open pipe

Air Harmonics Part 1

- In open-open pipe, the overtones are at
  - twice fundamental (two pressure antinodes)
  - three times fundamental (three antinodes)
  - etc. (all integer multiples or "harmonics")
- In open-closed pipe, the overtones are at
  - three times fundamental (two antinodes)
  - five times fundamental (three antinodes)
  - etc. (all odd integer multiples or "harmonics")

Air Harmonics Part 2

- Blowing across column tends to excite a mixture of fundamental and harmonic vibrations

Other Instruments

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

Summary of Violins and Pipe Organs

- use strings and air as harmonic oscillators
- pitches independent of amplitude/volume
- tuned by tension/pressure, length, density
- have harmonic overtones
- project vibrations into the air as sound