Speakers push and pull surrounding air molecules in waves that the human ear interprets as sound. You could even say that hearing is the detection of movement!

Last time...

\[ v = \lambda f = \sqrt{\frac{F}{\mu}} \]

- \( v \): string tension
- \( \mu \): mass density

Important ideas today

Sound as a wave
How does it work?

Calculating the speed of sound
in gasses, liquids, and solids.

Quantifying loudness.
What makes sound?

Pitch: determined by wavelength or frequency of vibration.
High pitch: high frequency.

\[ v = \lambda f \]

Thinking about sound...

Pitch: determined by wavelength or frequency of vibration.
High pitch: high frequency (short wavelength).

Middle G:
\[ f = 392 \text{ Hz} \]

Thinking about sound...

Pitch: determined by wavelength or frequency of vibration.
High pitch: high frequency (short wavelength).

Which fork will make the higher pitch (assuming they’re made from the same material)?

A. Longer fork
B. Shorter fork
C. Both will make the same pitch
D. Not enough info

\[ v = \lambda f \]
What this means...

Sound moves via compression of molecules!

Note: propagation speed of sound is independent of wave properties!

Speed depends ONLY upon the material sound is in.

You say... but $v = \lambda f$?!!

Raise pitch $f$, and wavelength $\lambda$ will decrease!
Density of air:
1 kg/m³
Density of outer space:
0.000000000000000000000001 kg/m³

**Speed of Sound in a Solid**

- The speed of sound in a solid depends on the material’s compressibility and density

\[ v = \sqrt{\frac{Y}{\rho}} \]

Remember last time: wave on a string!

- \( Y \) is the Young’s Modulus of the material
- \( \rho \) is the density of the material

\[ Tensile Stress = \frac{F}{A} = \frac{\Delta L}{L_0} \]

\( Y_{\text{air}} \approx 4 \times 10^5 \) Pa
\( Y_{\text{steel}} \approx 2 \times 10^{11} \) Pa
\( \rho_{\text{air}} \approx 1250 \) kg/m³
\( \rho_{\text{steel}} \approx 8050 \) kg/m³

*Note: doing this is not a good idea*

A train turns on < mile away and heads down the line toward you. Will you hear the train first with your ear to the steel tracks, or to the ground (made of loose dirt)?

A. Ground
B. Tracks
C. Not enough info
Speed of Sound in a Liquid
- In a liquid, the speed also depends on the liquid’s compressibility and density
  \[ v = \sqrt{\frac{B}{\rho}} \]
  \[ \text{Volume Stress} = -B \frac{\Delta V}{V_0} \]
- \( B \) is the Bulk Modulus of the liquid
- \( \rho \) is the density of the liquid

BUT REMEMBER!!!
Temperature affects the volume and density of materials.

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Speed of Sound in Air
For Earth’s atmosphere, the speed of sound is 331 m/s at 0°C (273 K)

Note: for all the materials so far, sound speed goes as \( 1/\sqrt{\text{density}} \)!

As the temperature increases, the speed of sound in air

A. increases.
B. decreases.
C. stays the same.

If you don’t know, you can think about what should happen to a typical material that’s heated.

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Speed of Sound in Air
For Earth’s atmosphere, the speed of sound is 331 m/s at 0°C (273 K)

\[ v = \frac{331 \text{ m/s}}{\sqrt{\frac{T}{273K}}} \]

T is in Kelvin!!

Speed of sound \(~343\text{m/s}\)
at room temperature (293 K – 20 °C)
A man shouts and hears his echo off a mountain 5 seconds later. How far away is the mountain?

Speed of sound in air at room temperature ~343m/s.

How loud is loud?

The Intensity of Sound

- Sound energy moves outward in all directions
- Energy spread over a bigger and bigger sphere
- Surface area of sphere:
  \( A = 4\pi r^2 \)

If you get 2x as far, you’ll hear a sound with 4x less intensity!

\[
I = \frac{\text{power}}{\text{area}} = \frac{P}{4\pi r^2}
\]

Units of power: Watts (W)
Units of intensity: W/m²
Quietest sounds we can hear:
$10^{-12}$ W/m²

Sounds that hurt:
1 W/m²

**Difference of $10^{12}$! This is huge!**

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**Alternate Measurement of Intensity**

Decibels (dB)  \[ \beta = 10 \log(I/I_0) \]

$I_0 = 10^{-12}$ W/m²

“How many times 10 louder is this sound than the faintest hearable sound?”

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**What u say?**

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**ARGH!**
The rods on the xylophone below generate different frequencies. Why?

A) The rods have different densities
B) The velocity of sound changes through the rods of differing length.
C) The wavelengths vary.
D) More than one of the above.

\[ v = \sqrt{\frac{Y}{\rho}} = \lambda f \]

The Frequency of Sound

- Audible waves
  - Lay within the normal range of hearing of the human ear
  - Normally between 20 Hz to 20,000 Hz
- Infrasonic waves
  - Frequencies are below the audible range
  - Earthquakes are an example
- Ultrasonic waves
  - Frequencies are above the audible range
  - Dog whistles are an example
Applications of Ultrasound

High frequency means small wavelength, thus can be used to produce images of small objects

\[ \nu = \lambda f \]

Widely used as a diagnostic and treatment tool
- Ultrasounds to observe babies in the womb
- Ultrasonic flow meter to measure blood flow
- Cavitron Ultrasonic Surgical Aspirator (CUSA) used to surgically remove brain tumors

Suppose that you hear two notes, note 1 at 400 Hz and note 2 at 800 Hz. Which of the following statements are true?

A. The wavelength of note 1 is twice that of note 2
B. The wavelength of note 2 is twice that of note
C. The speed of note 2 is twice the speed of note 1.
D. The speed of note 1 is twice the speed of note 2.