EAS 4801 - Planetary Sound
Lec#2: Wave Properties

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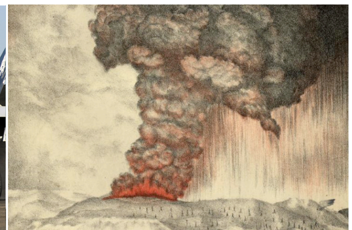
Spring 2020



Last Class's Outline

- Introduction to the course
  - Class logistics, requirements and policies
  - Intro to your instructor
- Course goals and tentative plan
- A brief introduction of sound and wave propagation

Class Website: http://geophysics.eas.gatech.edu/classes/PlanetarySound/
Username: geophysics
Passwd: tectosphere

Measuring sound

Frequency (pitch) – vibrations or cycles per second (Hz, KHz)

Speed – how fast does sound wave propagate

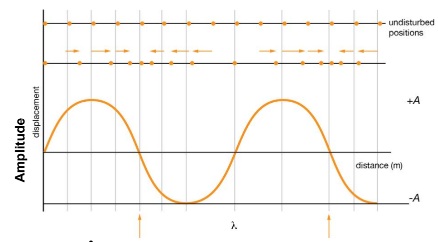
Amplitude – size of the vibration

Loudness – perceived strength of a sound (frequency dependent)

Intensity – energy carried by a sound (dB scale)

Representing waves graphically

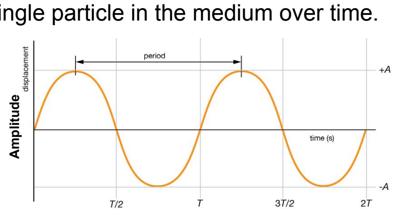
displacement – distance graph shows where the particles are at one instant of time. A snapshot.



Gives wavelength, λ.

Representing waves graphically

displacement – time graph shows what happens to a single particle in the medium over time.

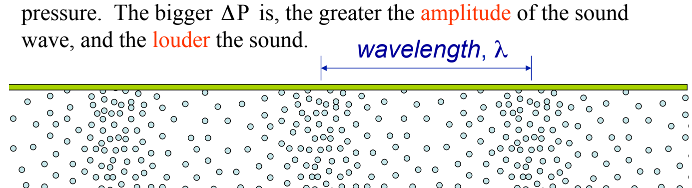


'Period', *T*, is time for one complete cycle. Gives frequency,

$$f = \frac{1}{T}$$

Pressure vs. Position

The pressure at a given point in a medium fluctuates slightly as sound waves pass by. The wavelength is determined by the distance between consecutive compressions or consecutive rarefactions. At each compression the pressure is a tad bit higher than its normal pressure. At each rarefaction the pressure is a tad bit lower than normal. Let's call the equilibrium (normal) pressure P_0 and the difference in pressure from equilibrium ΔP. ΔP varies and is at a max at a compression or rarefaction. In a fluid like air or water, ΔP_{max} is typically very small compared to P_0 but our ears are very sensitive to slight deviations in pressure. The bigger ΔP is, the greater the amplitude of the sound wave, and the louder the sound.



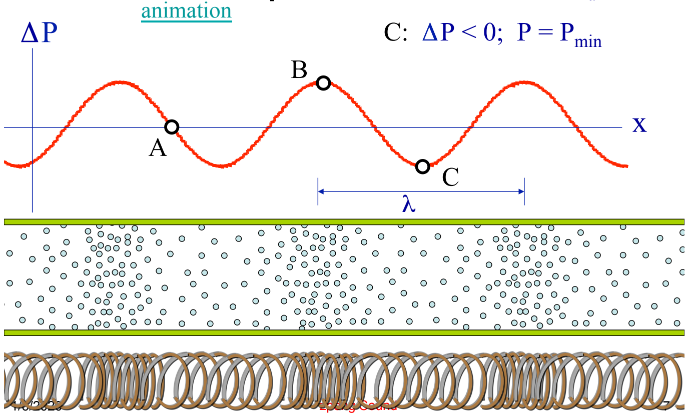
Pressure vs. Position Graph

animation

A: $\Delta P = 0;\ P = P_0$

B: $\Delta P > 0;\ P = P_{max}$

C: $\Delta P < 0;\ P = P_{min}$



Pressure vs. Time

The pressure at a given point does not stay constant. If we only observed one position we would find the pressure there varies sinusoidally with time, ranging from:

P_0 to $P_0 + \Delta P_{max}$ back to P_0 then to $P_0 - \Delta P_{max}$ and back to P_0

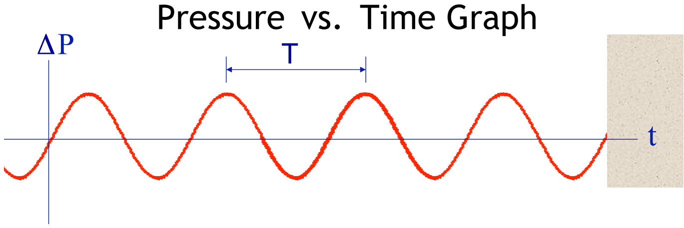
The cycle can also be described as:

equilibrium → compression → equilibrium → rarefaction → equilibrium

The time it takes to go through this cycle is the period of the wave. The number of times this cycle happens per second is the frequency of the wave in Hertz.

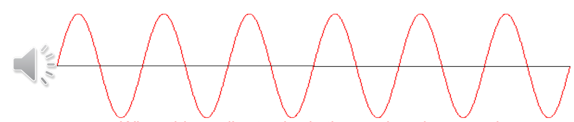
Therefore, the pressure in the medium is a function of both position and time!

Pressure vs. Time Graph



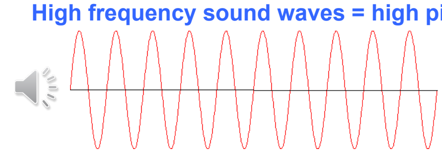
Rather than looking at a region of space at an instant in time, here we're looking at just one point in space over an interval of time. At time zero, when the pressure readings began, the molecules were at their normal pressure. The pressure at this point in space fluctuates sinusoidally as the waves pass by: normal → high → normal → low → normal. The time needed for one cycle is the period. The higher the frequency, the shorter the period. The amplitude of the graph represents the maximum deviation from normal pressure (as it did on the pressure vs. position graph), and this corresponds to loudness.

- Low frequency sound waves = low pitch



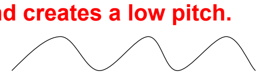
When things vibrate slowly they make a low sound.

High frequency sound waves = high pitch

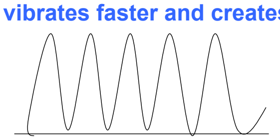


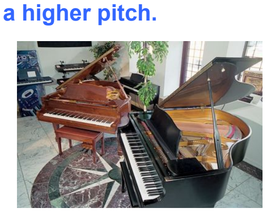
When things vibrate quickly they make a high pitched sound.

- **When a longer piano string vibrates, it vibrates more slowly and creates a low pitch.**



- **When a shorter piano string vibrates, it vibrates faster and creates a higher pitch.**

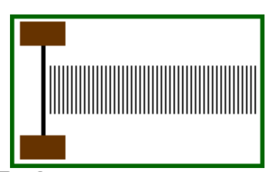


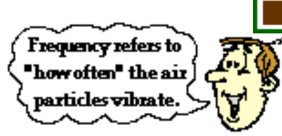


Listen to different pitches:

Frequency:

Frequency: the number of waves produced per second (C)

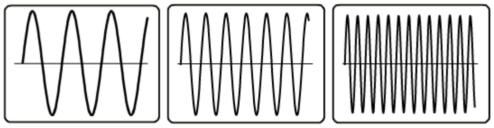




Pitch (Frequency)

Pitch is the **rate at which the vibrations are produced**.

The higher the frequency, the higher the pitch.



Which picture above would have the lowest pitch? Highest pitch?

The Frequency of a Sound Wave

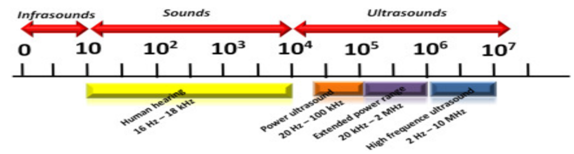
Audible Range: 20 Hz ----- 20,000 Hz.

Infrasonic waves: Sound waves with frequencies < 20 Hz.

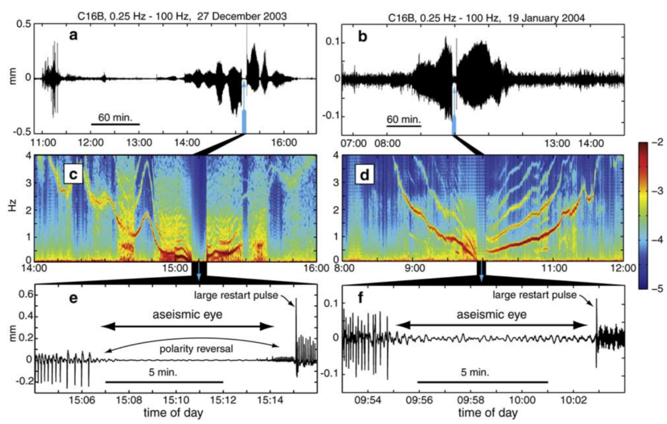
Rhinoceroses use infrasonic frequencies as low as 5 Hz to call one another

Ultrasonic waves: Sound waves with frequencies > 20,000 Hz.

Bats use ultrasonic frequencies up to 100 kHz for locating their food sources and navigating.



What's this sound?



Wave speed

distance wave travels in a second (m/s)

= wavelength (m) x number of waves each second (s^{-1})

In symbols,

$$v = f\lambda = \lambda / T$$

- Here T is period, which is inversely proportional to frequency f.
- To find the speed of sound, measure a distance and a time.

Sound Speed

As with all waves, the speed of sound depends on the medium through which it is traveling. In the wave unit we learned that the speed of a wave traveling on a rope is given by:

Rope: $v = \sqrt{\frac{F}{\mu}}$ — F = tension in rope; μ = mass per unit length of rope

In a rope, waves travel faster when the rope is under more tension and slower if the rope is denser. The speed of a sound wave is given by:

Sound: $v = \sqrt{\frac{B}{\rho}}$ — B = bulk modulus of medium; ρ = mass per unit volume (density)

The bulk modulus, B, of a medium basically tells you how hard it is to compress it, just as the tension in a rope tells you how hard it is stretch it or displace a piece of it. *(continued)*

Sound Speed

Rope: $v = \sqrt{\frac{F}{\mu}}$

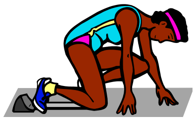
Sound: $v = \sqrt{\frac{B}{\rho}}$

Notice that each equation is in the form

$$v = \sqrt{\frac{\text{elastic property}}{\text{inertial property}}}$$

The bulk modulus for air is tiny compared to that of water, since air is easily compressed and water nearly incompressible. So, even though water is much denser than air, water is so much harder to compress that sound travels over 4 times faster in water.

Steel is almost 8 times denser than water, but it's over 70 times harder to compress. Consequently, sound waves propagate through steel about 3 times faster than in water, since $(70/8)^{0.5} \approx 3$.



Sound Speed

Medium	Speed (m/s)
Air	343
Helium	972
Water	1500
Steel	5600

Question: does sound travel faster in cold or hot air? Why?

Temperature and Sound Speed

$$v = \sqrt{\frac{B}{\rho}}$$

Because the speed of sound is inversely proportional to the medium's density, the less dense the medium, the faster sound travels. The hotter a substance is, the faster its molecules/atoms vibrate and the more room they take up. This lowers the substance's density, which is significant in a gas. So, in the summer, sound travels slightly faster outside than it does in the winter. To visualize this keep in mind that molecules must bump into each other in order to transmit a longitudinal wave. When molecules move quickly, they need less time to bump into their neighbors.

The speed of sound in dry air is given by:
$v \approx 331.4 + 0.60\,T$, where T is air temp in°C.

Here are speeds for sound:

Air, 0 °C: 331 m/s Air, 20 °C: 343 m/s Water, 25 °C: 1493 m/s
Iron: 5130 m/s Glass (Pyrex): 5640 m/s Diamond: 12000 m/s