

## Science and Life

Hippos aren't fat, and they can't swim. A mouse can survive a fall from any height. There are salamanders one foot long that don't have lungs or gills. There are snakes that can see in complete darkness, and dolphins that can sense your heartbeat. And the animal with the largest brain relative to its body size is a fish—a fish with an amazing superpower. In this class, we'll talk about the laws of nature that explain how creatures live and breathe and move around, and the senses they use to understand their world.

### As you come in:

- Get a name tent
- Introduce yourself to your neighbors
- Start chatting
- Introduce yourself to me, if you'd like!

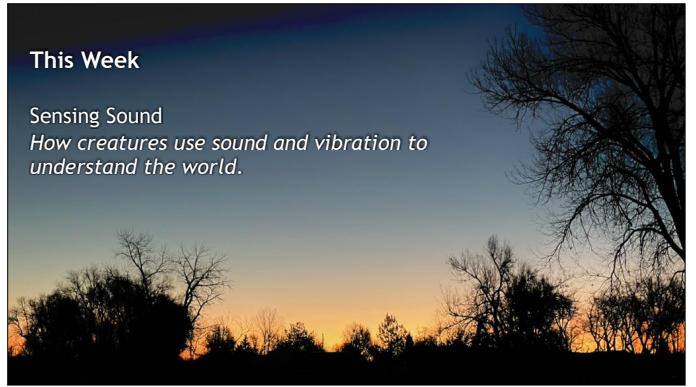


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## This Week

### Sensing Sound

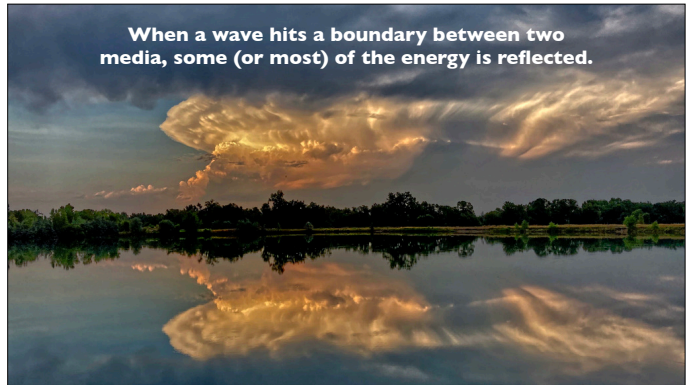
*How creatures use sound and vibration to understand the world.*



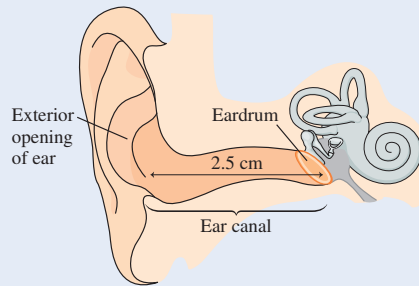
**A warmup:**  
**Why, and where, do we have ears?**



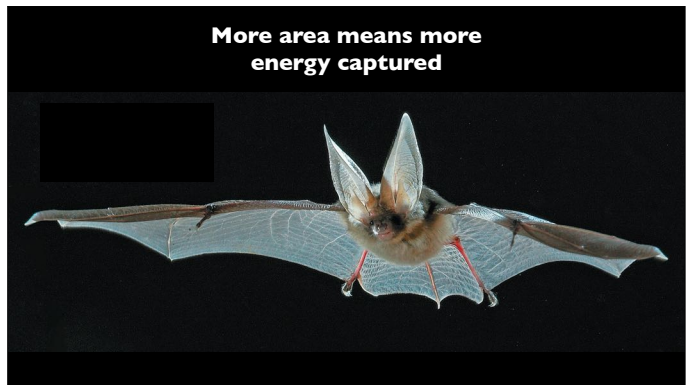
**When a wave hits a boundary between two media, some (or most) of the energy is reflected.**



The ear takes sound from the air and transmits the vibration into the watery medium in the cochlea.



**More area means more energy captured**



**A difference in arrival time lets you determine location.**



**No need for external ears.**



## Hearing Through The Feet



Some spiders can sense a vibration with an amplitude 1/10 the diameter of an atom.

## OK, now for some physics principles:

Properties of sound waves  
The decibel scale  
Standing waves  
Harmonics  
Formants

## Frequency: Cycles, or oscillations, per second

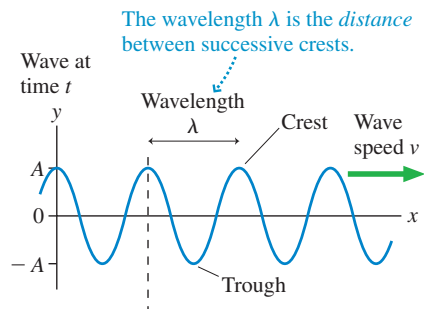
200 Hz

400 Hz

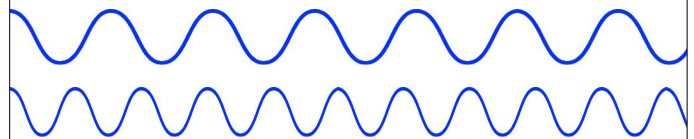
800 Hz

Pitch is to frequency as color is to wavelength

Symbol for frequency:  $f$



Longer wavelengths have lower frequencies.



Here's an equation to bring this all together:

$$\lambda = \frac{v}{f}$$

You can locate the source of a sound with an uncertainty that is proportional to the wavelength:

**Smaller wavelength means less uncertainty.**



So, would you expect owls to have their most sensitive hearing at high frequencies or low frequencies?

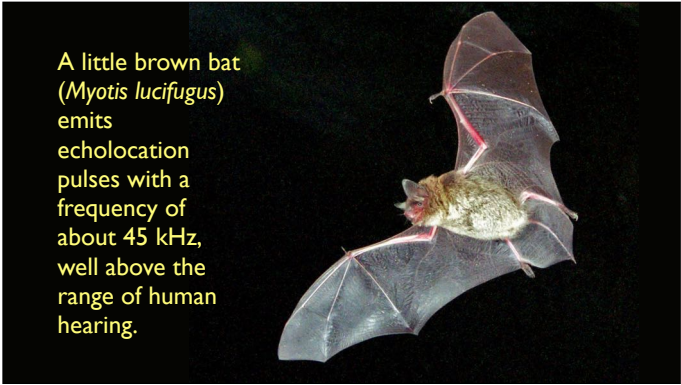




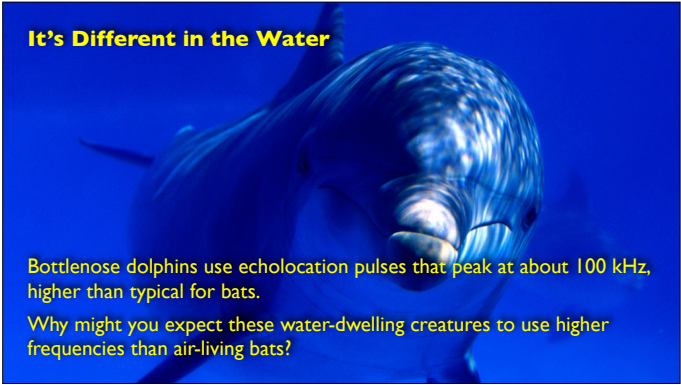
**Your ears are most sensitive to frequencies around 3,500 Hz. Why would you need to be sensitive to such high frequencies?**



**Would you expect bats, which catch smaller prey, to rely on higher or lower frequencies than owls?**



A little brown bat (*Myotis lucifugus*) emits echolocation pulses with a frequency of about 45 kHz, well above the range of human hearing.

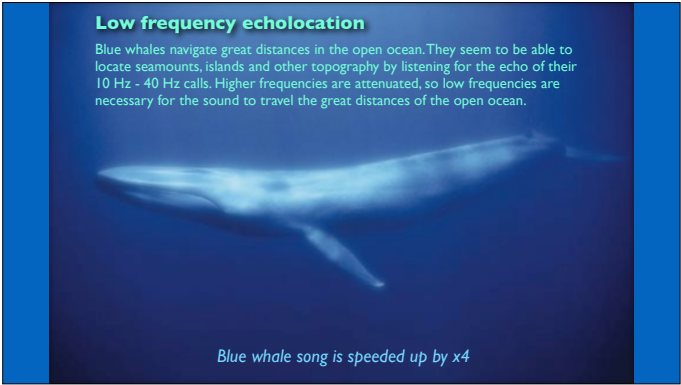


**It's Different in the Water**

Bottlenose dolphins use echolocation pulses that peak at about 100 kHz, higher than typical for bats.  
Why might you expect these water-dwelling creatures to use higher frequencies than air-living bats?



**At the other end of the spectrum...**



**Low frequency echolocation**

Blue whales navigate great distances in the open ocean. They seem to be able to locate seamounts, islands and other topography by listening for the echo of their 10 Hz - 40 Hz calls. Higher frequencies are attenuated, so low frequencies are necessary for the sound to travel the great distances of the open ocean.

Blue whale song is speeded up by x4

**Sound intensity levels**

Sound	$\beta$ (dB)	$I$ (W/m <sup>2</sup> )
Threshold of hearing	0	$1.0 \times 10^{-12}$
Person breathing, at 3 m	10	$1.0 \times 10^{-11}$
A whisper, at 1 m	20	$1.0 \times 10^{-10}$
Classroom during test, no talking	30	$1.0 \times 10^{-9}$
Residential street, no traffic	40	$1.0 \times 10^{-8}$
Quiet restaurant	50	$1.0 \times 10^{-7}$
Normal conversation, at 1 m	60	$1.0 \times 10^{-6}$

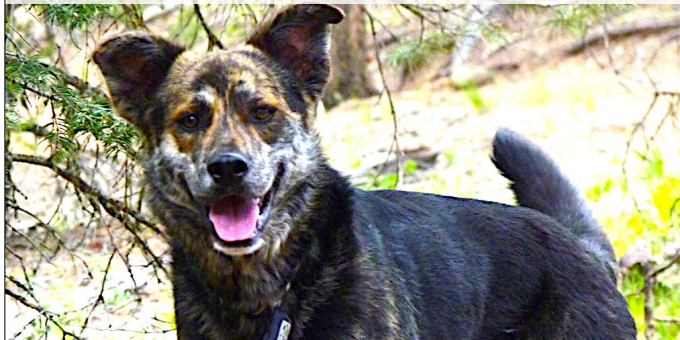
Sound	$\beta$ (dB)	$I$ (W/m <sup>2</sup> )
Busy traffic	70	$1.0 \times 10^{-5}$
Vacuum cleaner, for user	80	$1.0 \times 10^{-4}$
Niagara Falls, at viewpoint	90	$1.0 \times 10^{-3}$
Pneumatic hammer, at 2 m	100	0.010
Home stereo at max volume	110	0.10
Rock concert	120	1.0
Threshold of pain	130	10



**Some animals can do better.**

Dogs may have a threshold of hearing of  $1.0 \times 10^{-13}$  W/m<sup>2</sup>, corresponding to -10 dB.

Why would you expect Milo to have more sensitive hearing?



Your ears are super sensitive.



This candle gives off about 20 milliwatts of light



If you could hear the sun: 110 dB  
(Home stereo at max volume)

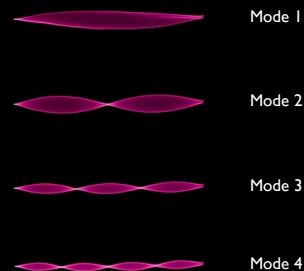


120 dB at 1 m  
(10x the power of a person shrieking at the top of their lungs)



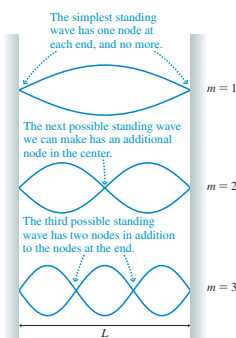
It's a good thing we can't hear them.

Standing waves with slinkies



## Standing Waves on Strings

Only certain conditions work.



The frequencies have a specific relationship.

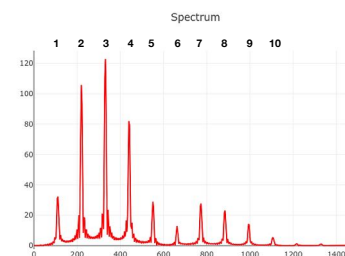
Suppose  $f_1 = 100$  Hz.

Then:

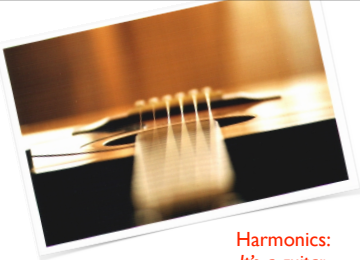
$$\begin{aligned} f_1 &= 100 \text{ Hz} \\ f_2 &= 200 \text{ Hz} \\ f_3 &= 300 \text{ Hz} \end{aligned}$$

And so on.

When you pluck a guitar string—or any musical instrument string—you get all of the modes, all of the frequencies.







**Fundamental and Harmonics**

Fundamental:  
It's a low A.

Harmonics:  
It's a guitar.

110 Hz  
220 Hz  
330 Hz  
440 Hz  
⋮

### Standing Sound Waves

Only certain conditions work.... Similar math to waves on strings.

(a) Open-open

The ends of the open-open tube are nodes, so possible modes have a node at each end.

The mode number equals the number of antinodes.

(b) Closed-closed

The ends of the closed-closed tube are antinodes, so possible modes have an antinode at each end.

The mode number equals the number of nodes.

(c) Open-closed

The open-closed tube has a node at one end and an antinode at the other. Only odd-numbered modes are possible.

To determine mode number, imagine doubling the length at the closed end, and count the antinodes.

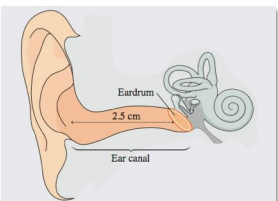
### Palm Pipes

A very simple musical instrument



### Increased sensitivity of the ear

Your ear canal is an open-closed tube. It has certain resonances that increase the amplitude at certain frequencies—including, for most folks, about 3,400 Hz.

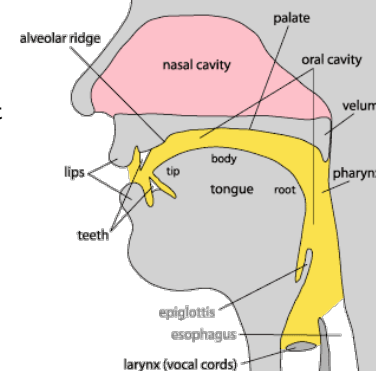


Tones:  
2000 Hz  
3400 Hz  
5000 Hz

$f_1 = 3,400 \text{ Hz}$

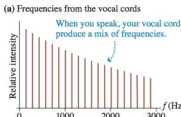
### Formants

Resonances of Vocal Tract  
Source-Filter Model



### Making Different Vowel Sounds

(a) Frequencies from the vocal cords  
When you speak, your vocal cords produce a mix of frequencies.



(b) Actual spoken frequencies (Vowel sound "ee")  
When you form your vocal tract to make a certain vowel sound it increases the amplitudes of certain frequencies and suppresses others.

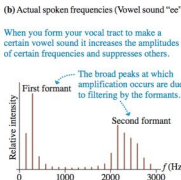
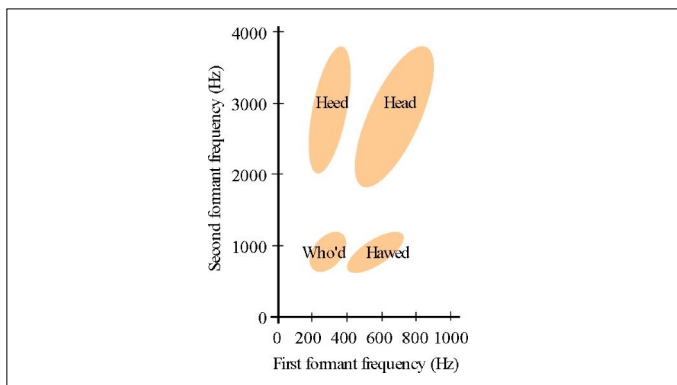


FIGURE 14.33 The frequency spectrum from the vocal cords, and after passing through the vocal tract.



### The Importance of Higher Harmonics

The higher harmonics determine the "tone quality" of a musical instrument, or the vowel sounds and plosives of speech.

As people age, their hearing gets less sharp. The higher frequencies are the first to go. The loss makes speech hard to interpret.

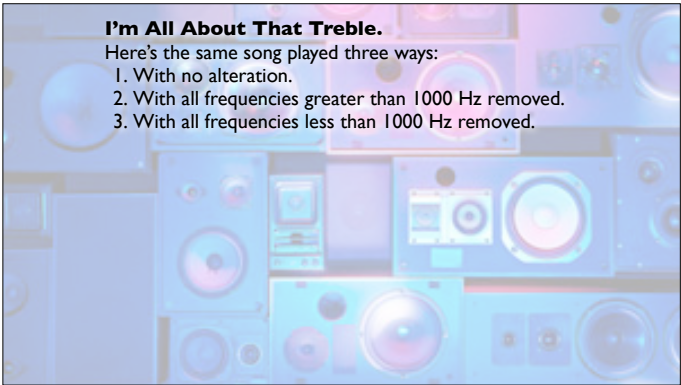
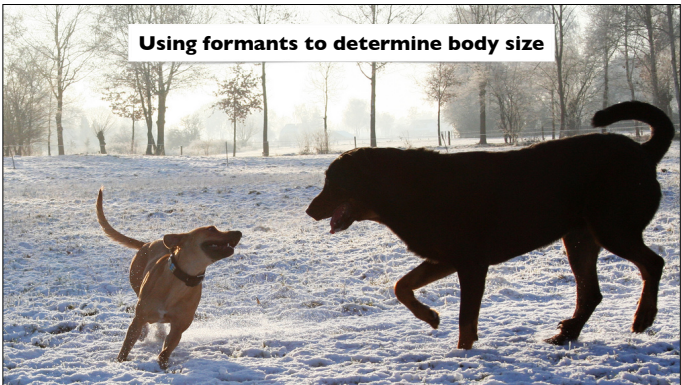
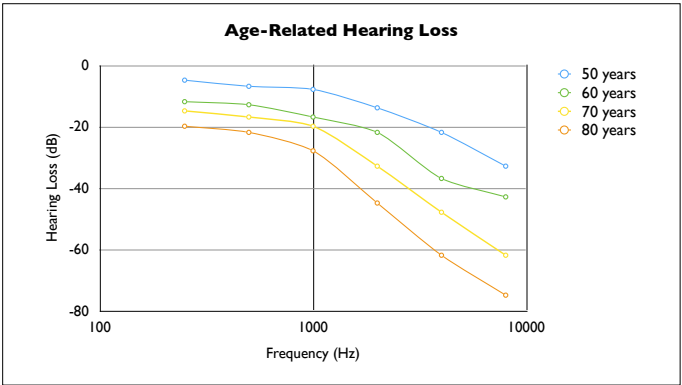
The first sound has had all frequencies > 1000 Hz removed.

The second sound has all harmonics intact.

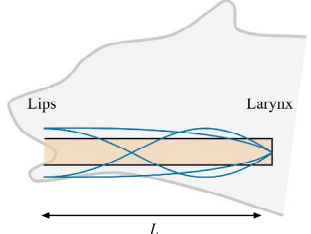
The final sound has frequencies < 1000 Hz removed.

**I'm All About That Treble.**  
 Here's the same song played three ways:

1. With no alteration.
2. With all frequencies greater than 1000 Hz removed.
3. With all frequencies less than 1000 Hz removed.

What are the frequencies of the first two formants?



Breed	Mass (kg)	L (m)
Westie	8	0.13
Doberman	38	0.24

