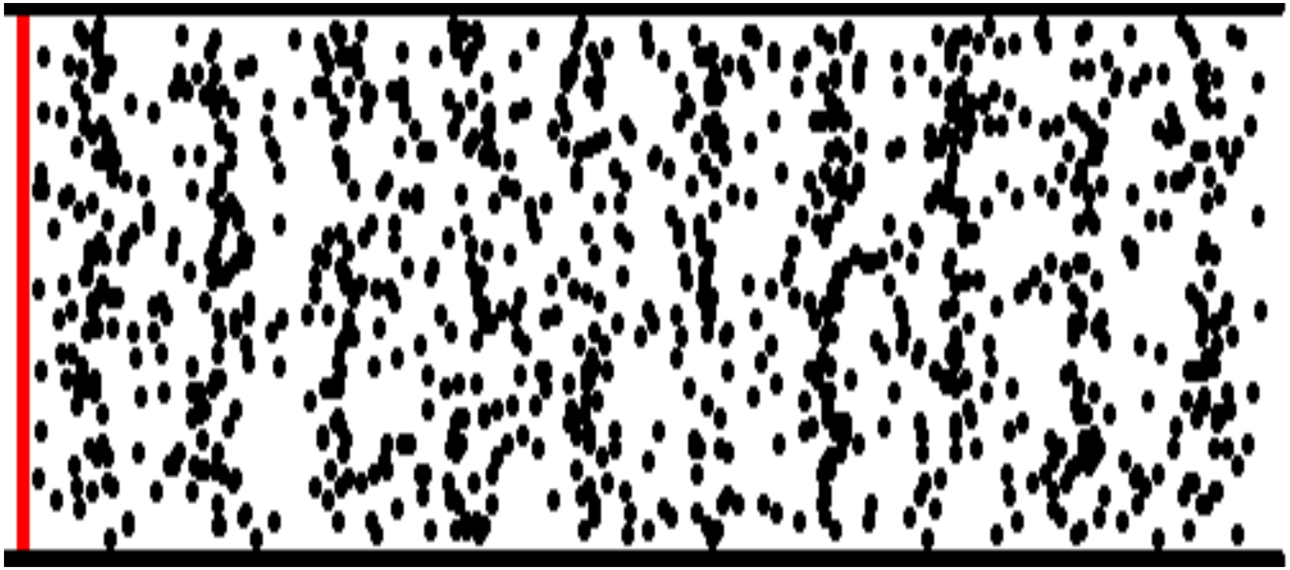
Sound waves are longitudinal “pressure waves”

- Compressions of air molecules (wave crests, areas of high pressure) and rarefactions (wave troughs, areas of low pressure)



http://www.kettering.edu/~drussell/Demos/waves/wavemotion.html

Sound Waves

Transmission of Sound waves –

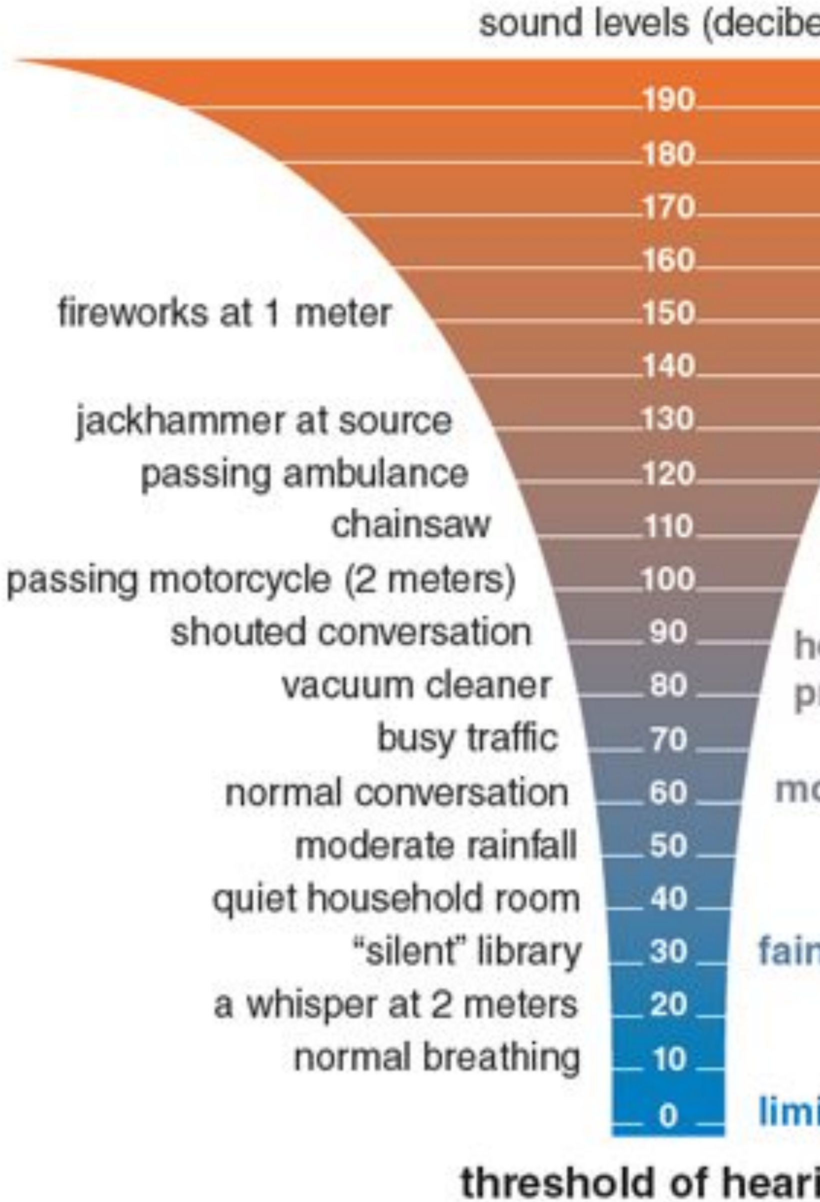
- Vibration of source (such as vocal cord)
- Causes compression waves through media (such as air)
- Causes vibration of our eardrums
- Causes electrical signals in our brain.

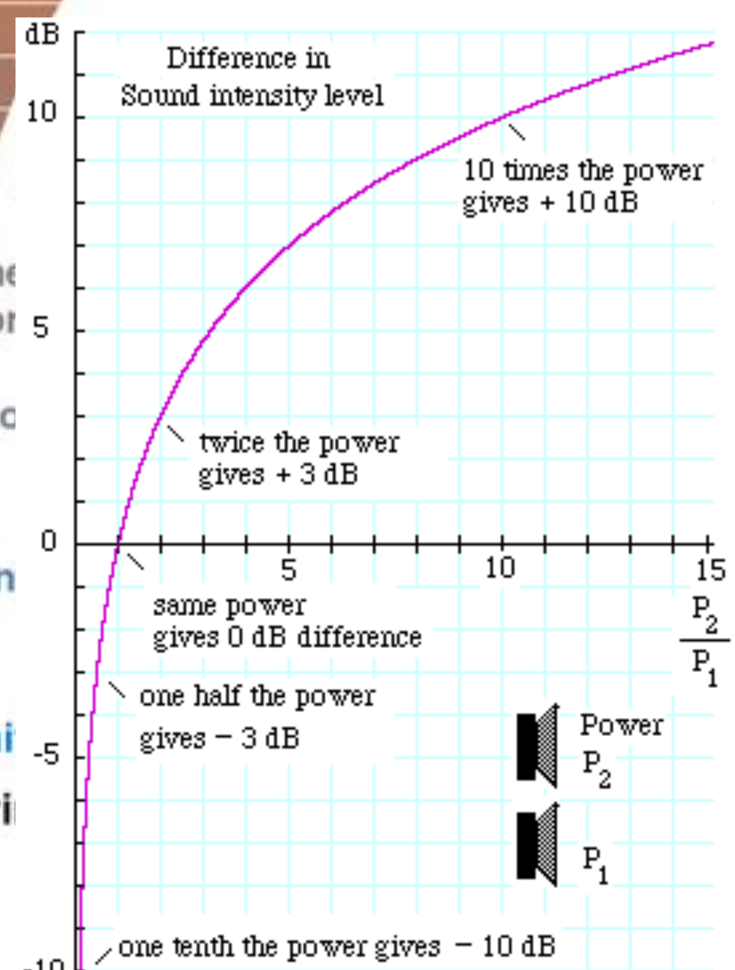
Loudness: brain's interpretation of intensity

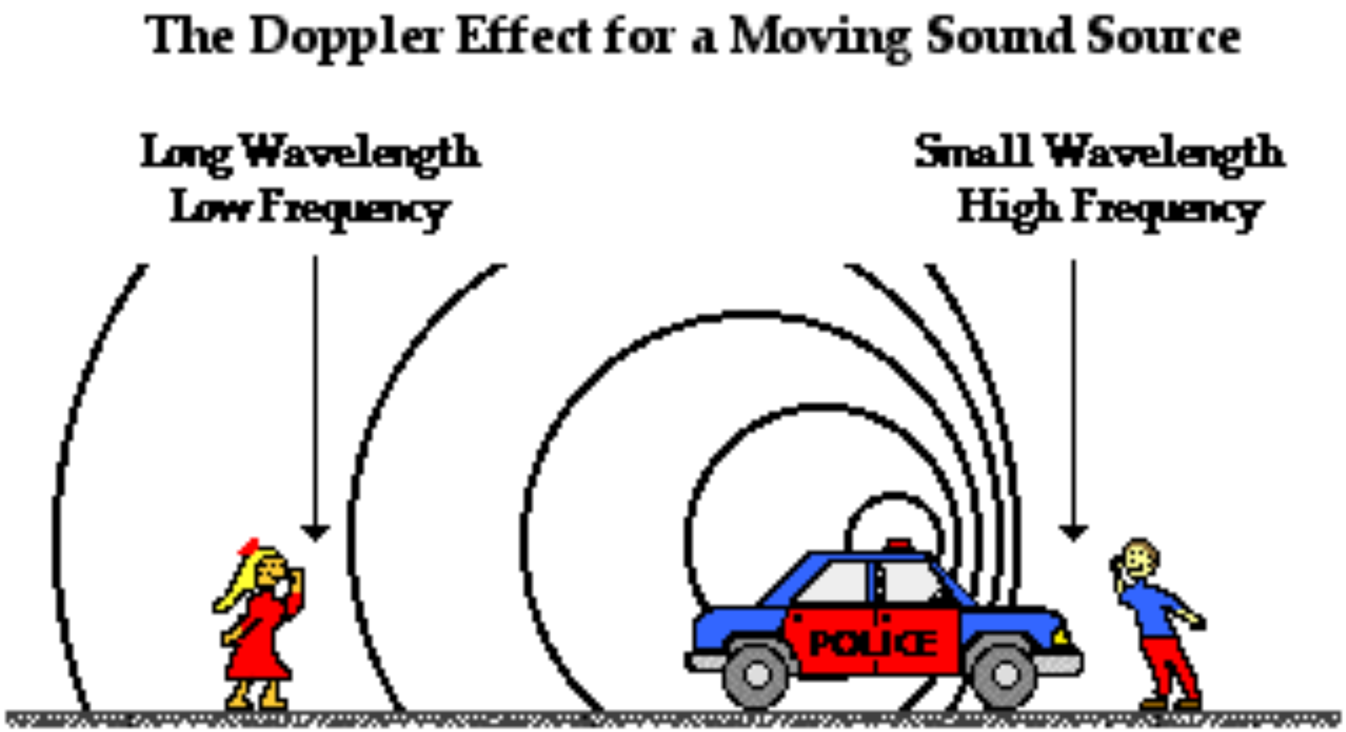
- Intensity (I) is proportional to A^2 and $1/r^2$. (A = amplitude of the sound wave)
  - If you double the distance from a sound source, the intensity decreases by a factor of 4.
- More compression of the air molecules = higher amplitude (A).

Pitch is our brain's interpretation of frequency.

- Average young person can hear pitches from around 20 Hz to 20000Hz
- Below 20 Hz: infrasonic frequency
- Above 20,000 Hz: ultrasonic frequency


sound levels (decibels)
loudest possible true sound
intolerable
fireworks at 1 meter
jackhammer at source
passing ambulance
chainsaw
passing motorcycle (2 meters)
shouted conversation
vacuum cleaner
busy traffic
normal conversation
moderate rainfall
quiet household room
"silent" library
a whisper at 2 meters
normal breathing
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0


dB
Difference in Sound intensity level
10 times the power gives + 10 dB
twice the power gives + 3 dB
same power gives 0 dB difference
one half the power gives − 3 dB
one tenth the power gives − 10 dB
Power P_2
P_1
$\frac{P_2}{P_1}$
10
5
0
-5
-10
5
10
15

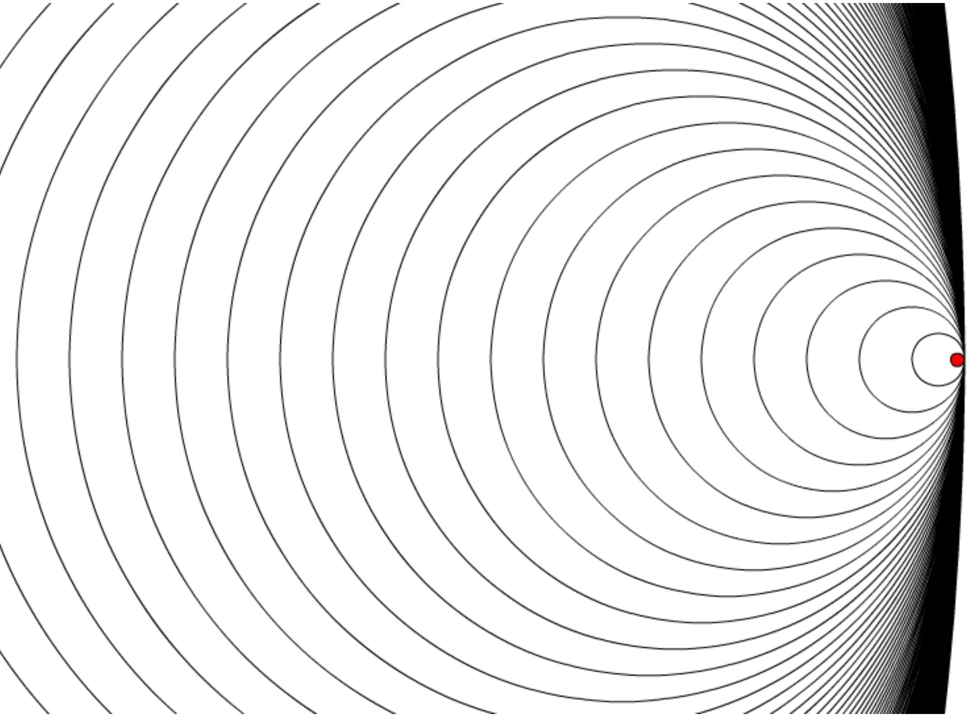


Doppler effect: apparent change in frequency due to the motion of source or receiver

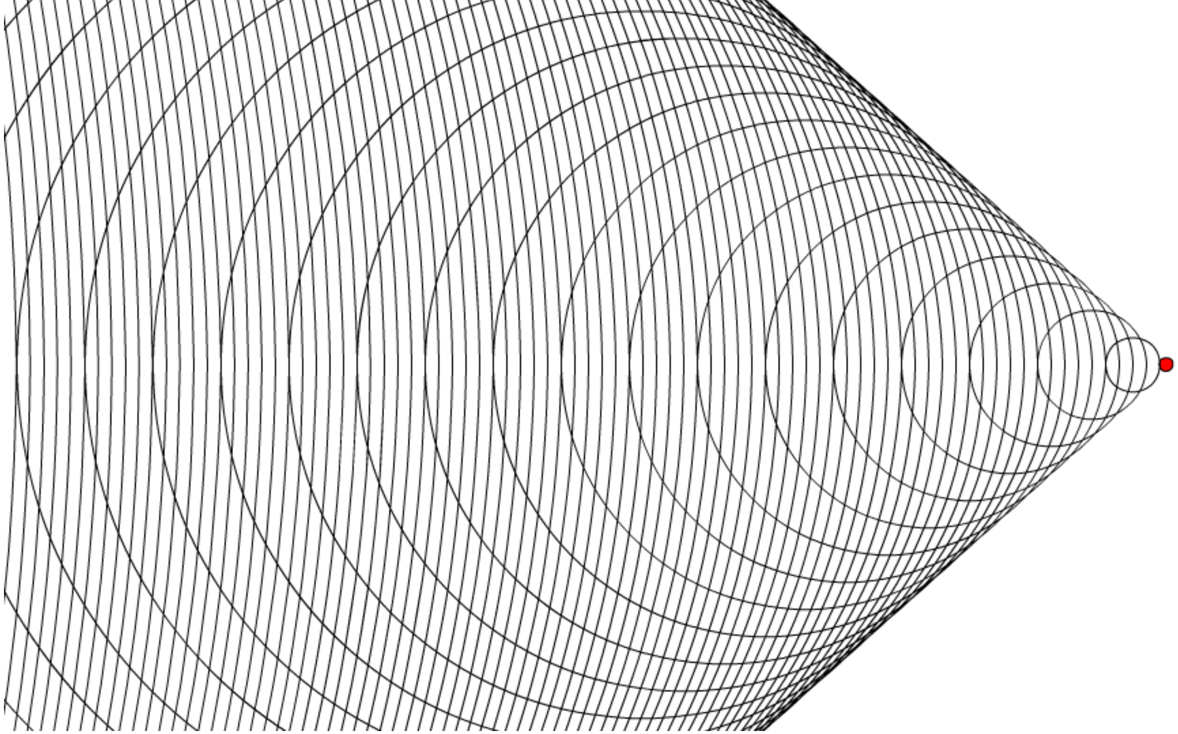
$f' = f_{actual}(\frac{1}{1 \pm v_s/v})$, where v = speed of sound in air and v_s= speed of sound source

+ if source is moving away from observer

- If source is moving toward observer



Air molecules bunching up, drag increases due to large compression of air molecules – this is the “sound barrier”



Condensation allows us to see the shock wave

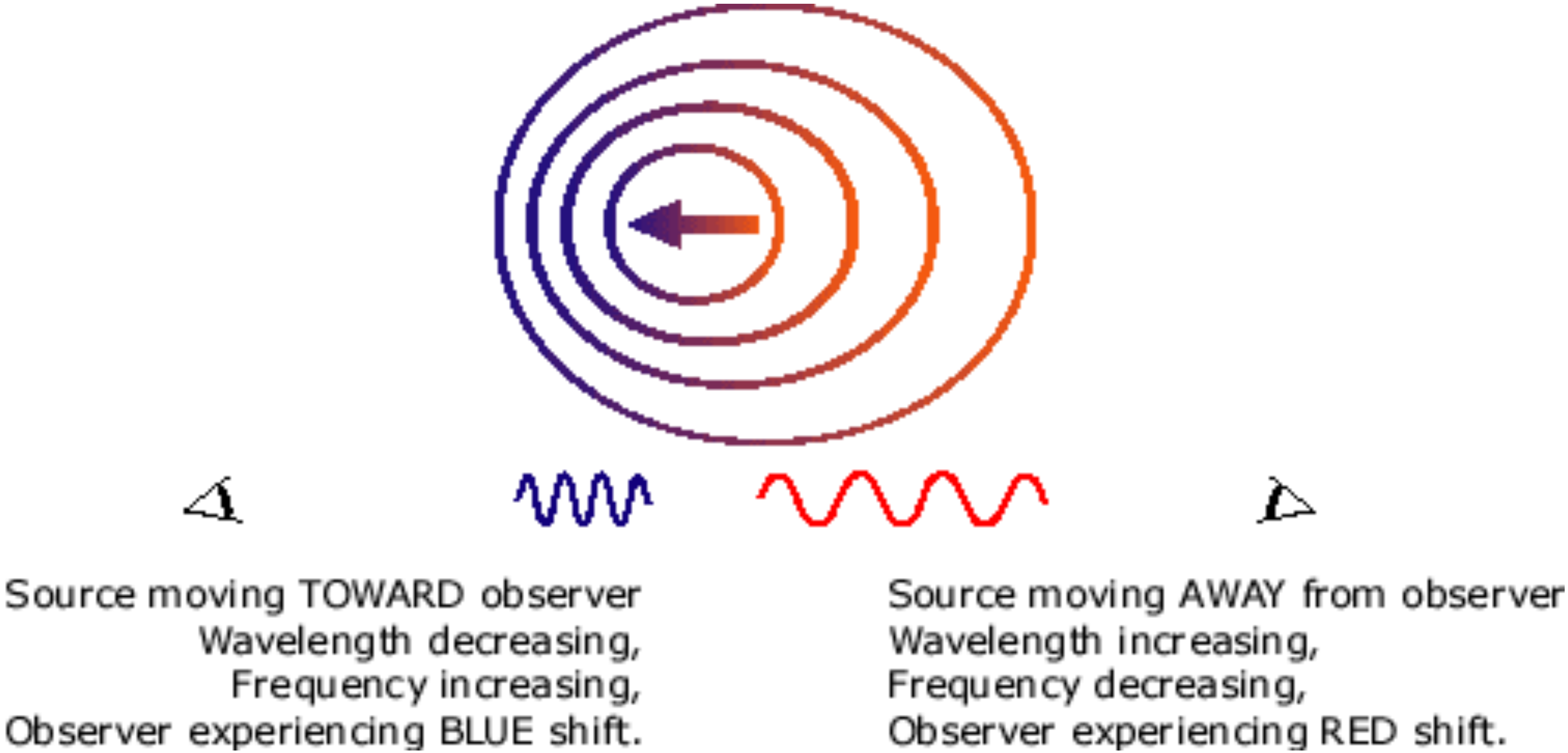
Subsonic = less than the speed of sound

Supersonic = more than the speed of sound

Mach # = speed of object/speed of sound

What's the difference between ultrasonic, infrasonic, subsonic, and supersonic?

Sonic boom is due to interference of sound waves at the edge of the cone. Get large amplitude, so hear loud boom



Doppler effect also used for light: shows expanding universe.

Sanity check:

When a source of a sound wave moves toward you, do you measure an increase in speed, decrease in speed, or neither?

- Neither: it's the frequency that changes. The speed remains the same.

Sound needs a material medium through which to travel

- Can’t travel in a vacuum (like space).
- Speed depends on elasticity of medium.
- Elasticity of solids >liquids> gases, so speed of sound solids > liquids> gases

Speed of sound in dry air at 20 C =343 m/s
Speed of sound in 20 C fresh water = 1498 m/s
Speed of sound in steel = 5920 m/s

In addition to being faster, clearer and louder sound too

How far away is a storm if you notice a 3 second delay between a lightning flash and the sound of thunder?

$D = vt = 343 \text{ m/s} \times 3 \text{ seconds} = 1029 \text{ m.} = 0.64 \text{ miles}$

Measuring Speed of Sound

- Groups of 3
- In 10 min, come up with a proposal of how to measure the speed of sound
- You can use the tools we have in this room or tools you have on you
- *Minimize error*
- *Note: the average human reaction time is 0.22 seconds*

Acoustic Levitation

Forced vibrations - When vibrations in one medium cause, or force, vibrations in another medium

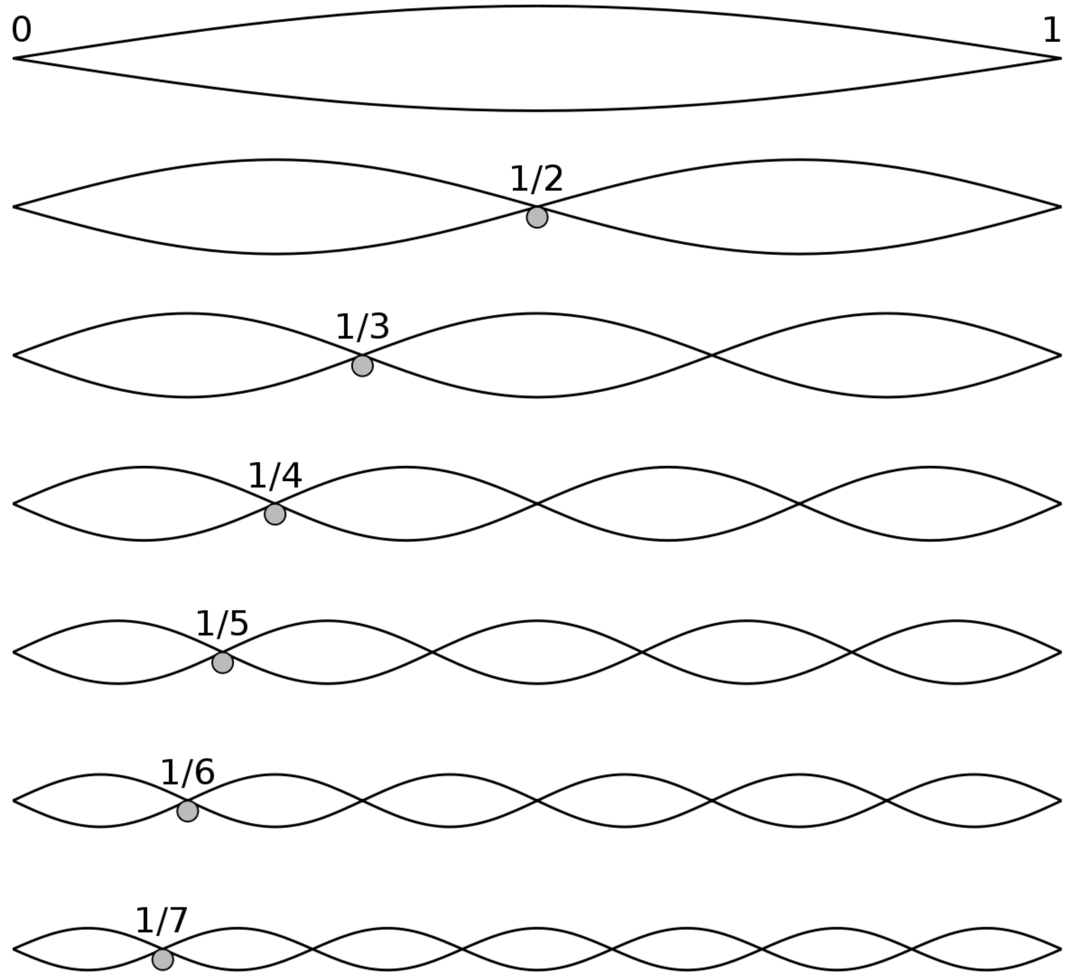
- Virtually unavoidable, but much more interesting when used in clever ways
- Such as by utilizing the natural frequency of the vibrating medium

Natural frequency - Frequency at which minimum energy is required to produce and sustain forced vibrations

- Depends on the elasticity and shape of the vibrating object
- When the frequency of a forced vibration on an object matches the object's natural frequency, a dramatic increase in amplitude occurs
- This phenomenon is called **resonance**
- Ex. Pushing someone on a swing

Standing waves - Also known as a stationary wave

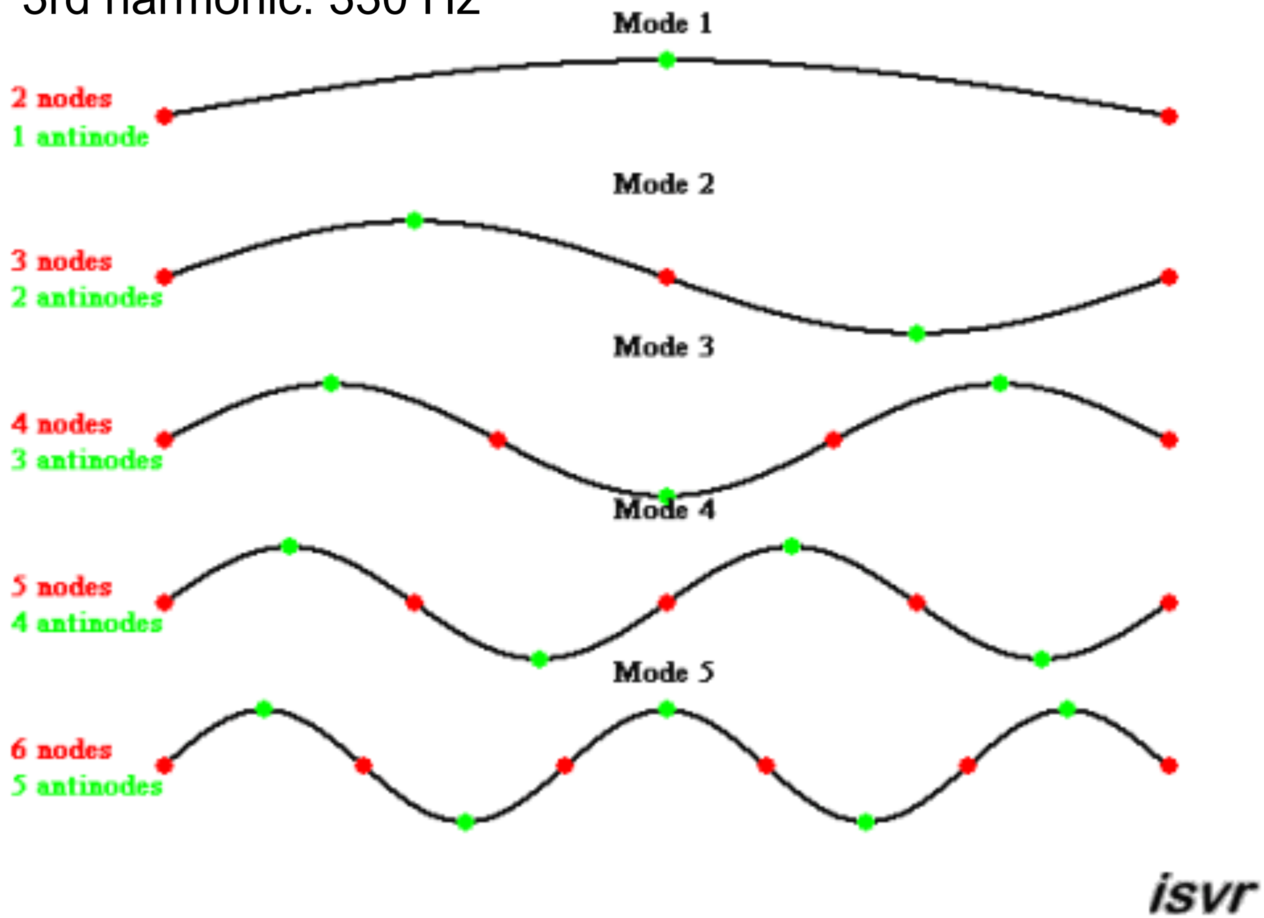
- A standing wave is one where particular points on the wave are “fixed,” or stationary
- Fixed points on a standing wave are called nodes
- Positions on a standing wave with the largest amplitudes are called antinodes
- Antinodes occur halfway between nodes



Standing waves are the result of interference

- Two waves of equal amplitude, frequency, and wavelength pass through each other in opposite directions

Harmonic corresponds to number of antinodes
The sequence off all multiples of a base frequency
E.g. base frequency, 1st harmonic: 110 Hz
2nd harmonic: 220 Hz
3rd harmonic: 330 Hz

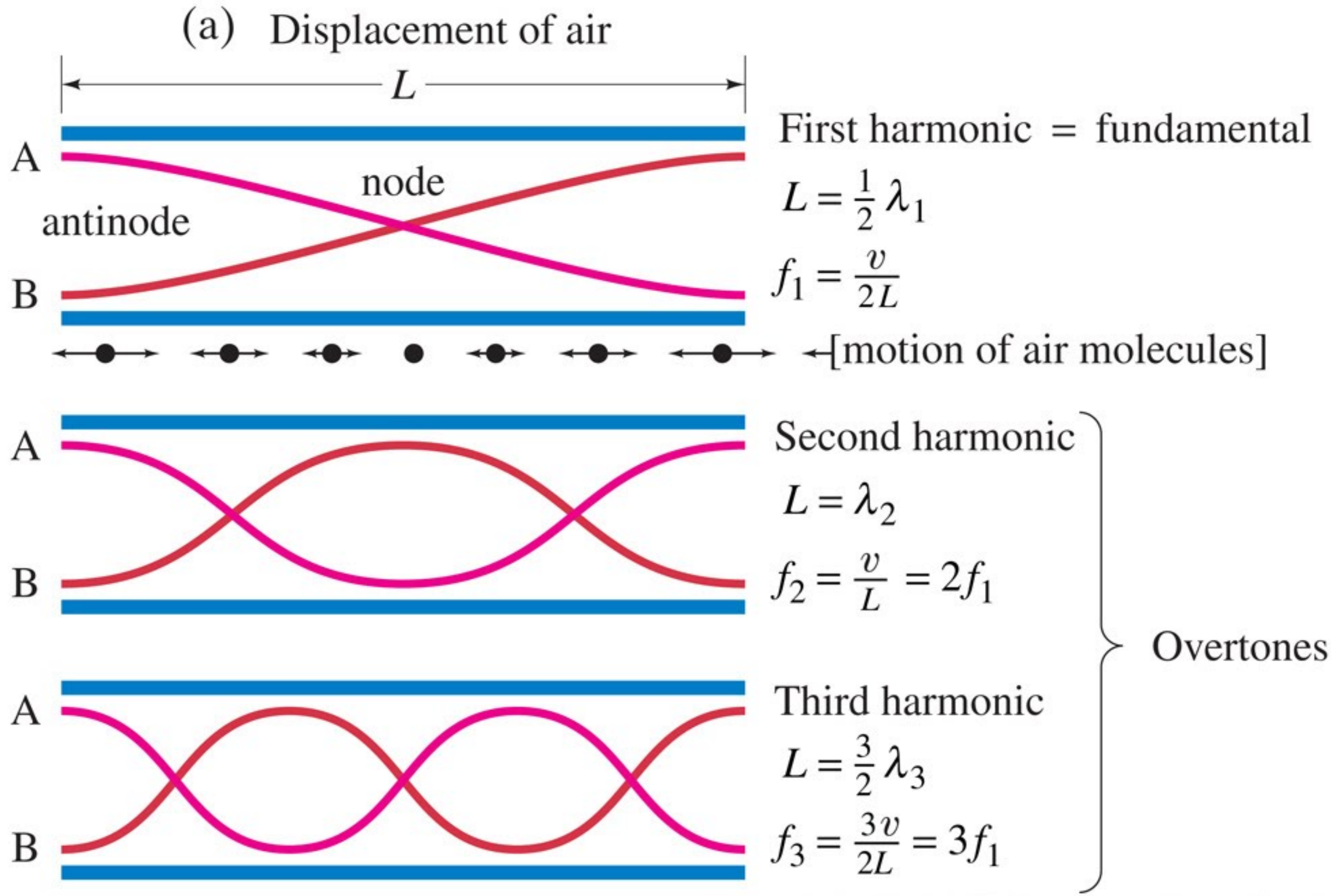


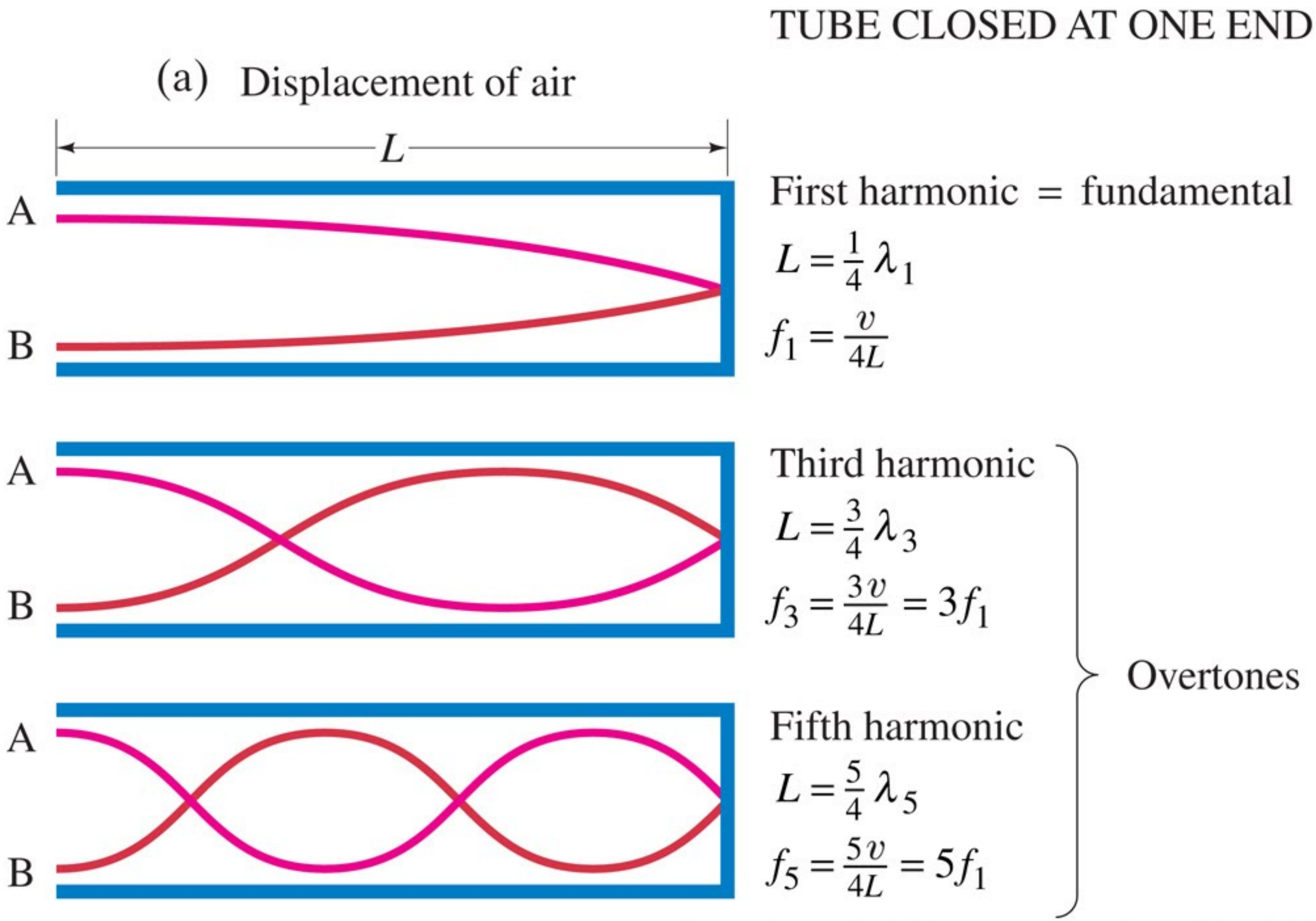
A 0.32-m-long violin string is tuned to play A above middle C at 440 Hz. What is the wavelength of the fundamental string vibration? What is the frequency and wavelength of the sound wave produced?

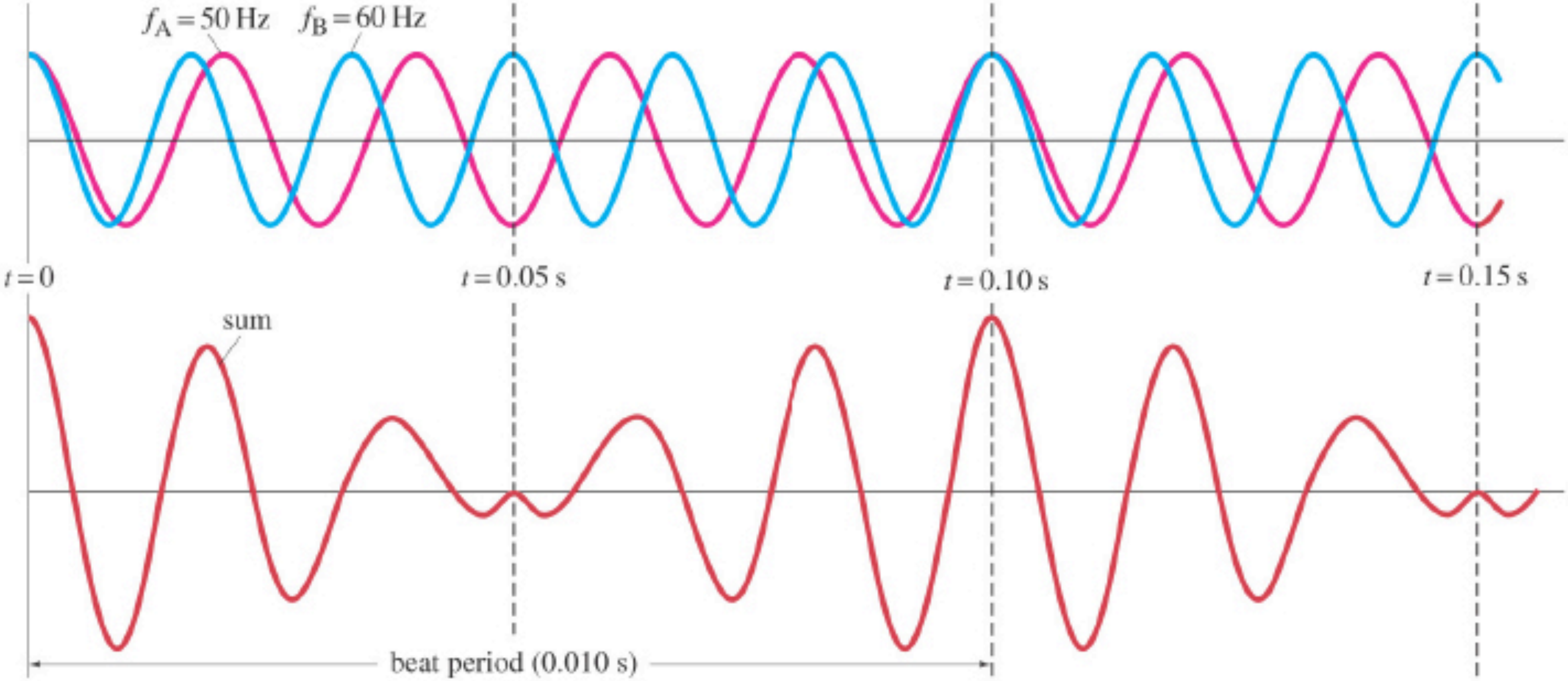
The wavelength of the fundamental is the wavelength of the standing wave on the string

- $\lambda = 2L = 0.64$ m, or 64 cm
- The sound wave that travels outward in the air has the same frequency, 440 Hz.
- Its wavelength is $\lambda = v/f = (343 \text{ m/s})/(440 \text{ Hz}) = 0.78$ m, or 78 cm
- Why is there a difference?
    - Speed of the wave is different in a different medium!

TUBE OPEN AT BOTH ENDS




TUBE CLOSED AT ONE END
(a) Displacement of air
L
A
B
First harmonic = fundamental
$L = \frac{1}{4}\lambda_1$
$f_1 = \frac{v}{4L}$
Third harmonic
$L = \frac{3}{4}\lambda_3$
$f_3 = \frac{3v}{4L} = 3f_1$
Overtones
Fifth harmonic
$L = \frac{5}{4}\lambda_5$
$f_5 = \frac{5v}{4L} = 5f_1$



What happens when you get interference of sound waves with slightly different frequencies?

Beats – interference of sound waves when 2 sound sources are close in frequency but not exactly the same.

At t = 0.1 seconds, the sound wave interfere perfectly constructively again. So the beat period is the amount of time it takes to get from 1 beat to the next beat.

Beat frequency = difference in frequency of sources.
In the wave above, the beat frequency = 60 Hz - 50 Hz = 10 Hz

What causes acoustic levitation?