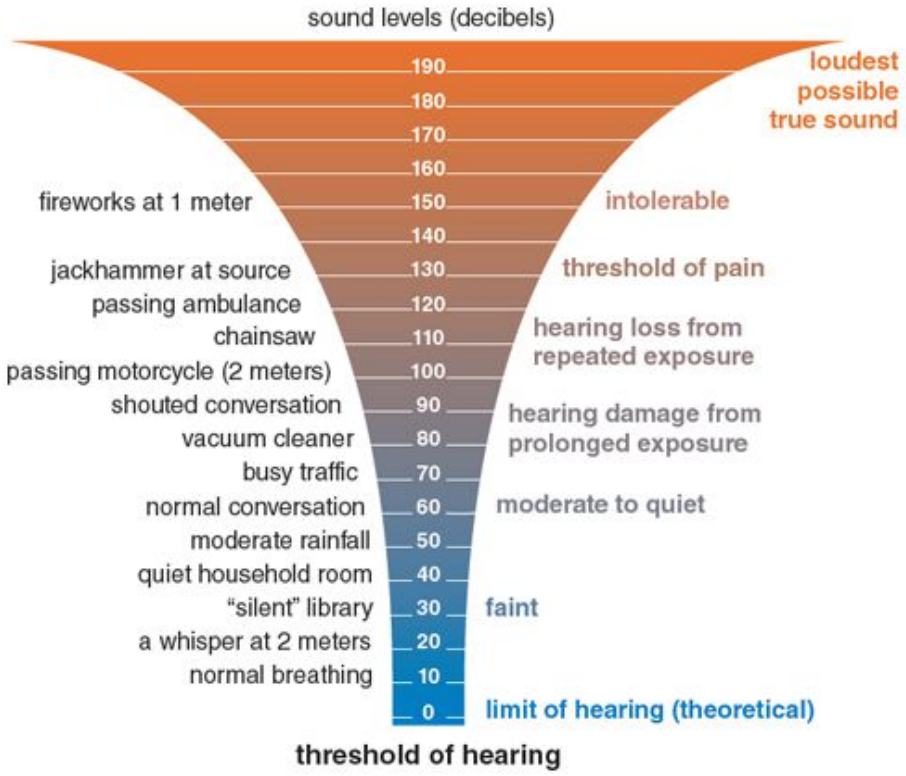
Physics 1240: Sound and Music

Today (7/15/19): Harmonics, Decibels

Next time: Psychoacoustics: The Ear



Review

- *Sound*: a mechanical disturbance of the **pressure** in a **medium** that travels in the form of a **longitudinal wave**.

- *Simple harmonic motion*: frequency increases when **stiffness** increases and increases when **mass** decreases

- *Sound propagation*: **reflection**, **absorption**, **refraction**, **diffraction**
  - Doppler effect, sonic booms, factors affecting speed of sound (temperature, composition of medium, weather)

- *Overlapping sounds*: 2-source interference, beats

BA

Clicker Question 5.1

If you are in a room with two speakers each producing sine waves with a wavelength of 2 meters, where should you stand if you don't want to hear any sound?

A) 2 meters from one speaker and 2 meters from the other
B) 2 meters from one speaker and 4 meters from the other
C) 2 meters from one speaker and 3 meters from the other
D) 3 meters from one speaker and 5 meters from the other
E) 1 meter from one speaker and 0.5 meters from the other

BA

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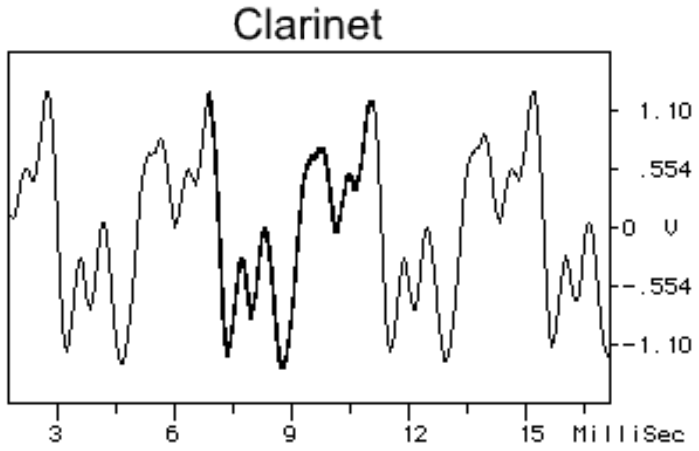
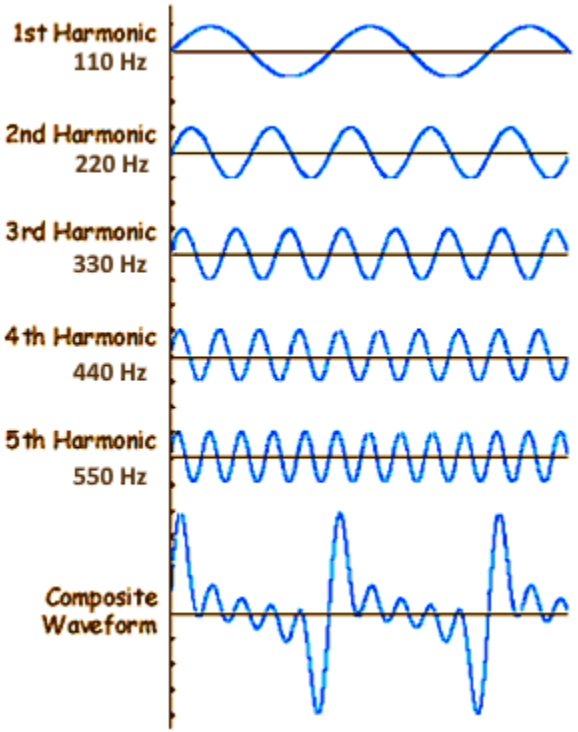
Review

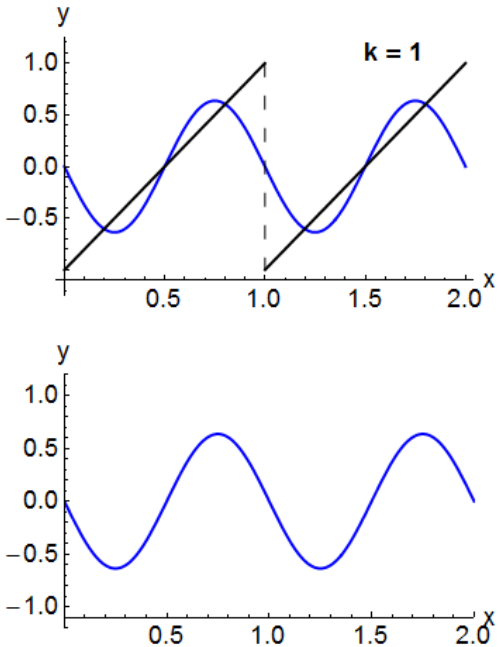
- Characteristics of Sound: What do we need to completely describe a single, steady tone?
  - Frequency ↔ pitch
  - Amplitude ↔ loudness
  - Duration ↔ note length
  - Waveform ↔ timbre



Characteristics of Sound

- Waveform: the shape that forms the repeating pattern of a wave
- Fourier's Theorem: every **periodic** sound can be written as the sum of sine waves with **integer multiples of frequency**

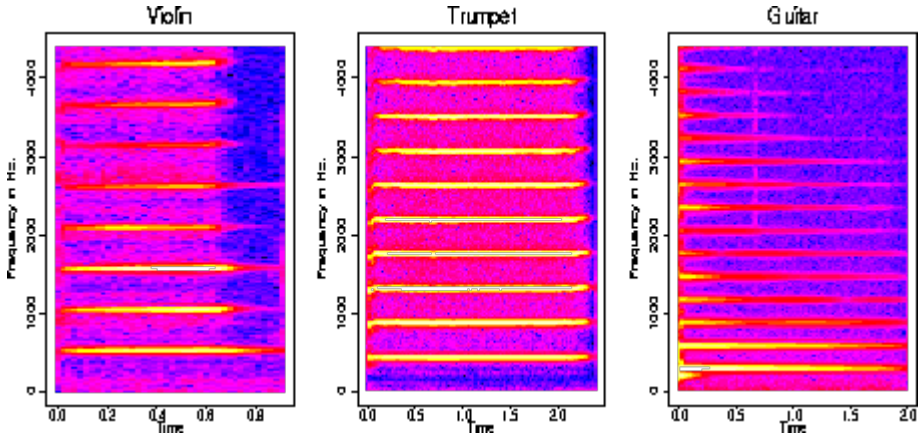




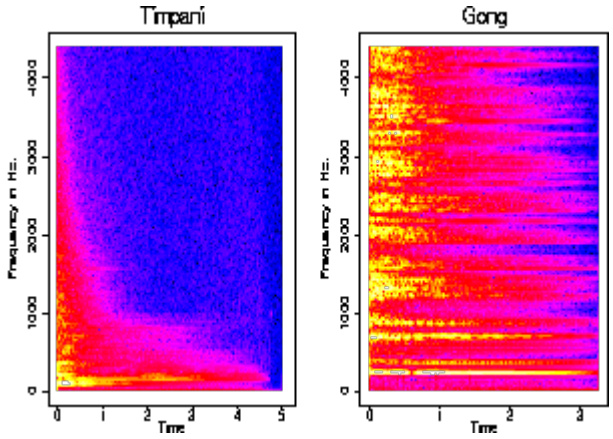
- Fourier's Theorem: every **periodic** sound can be written as the sum of sine waves with **integer multiples of frequency**

- Timbre: the relative amplitudes of each of the sine waves that combine to form a sound

Periodic sounds ("tones")

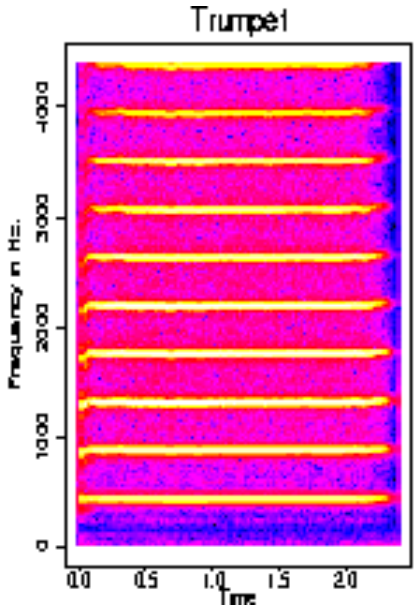


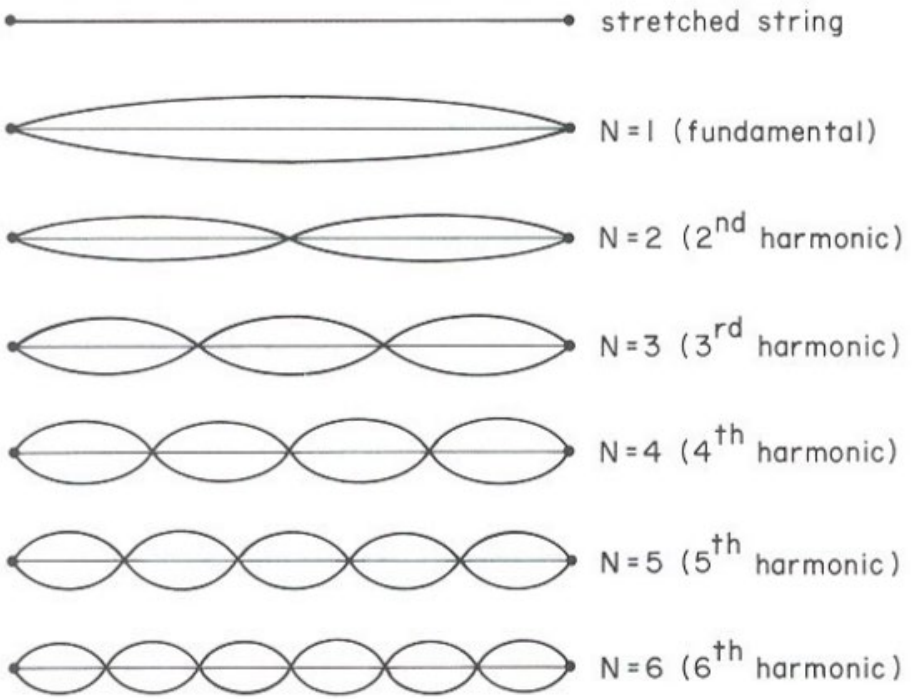
Non-periodic sounds ("noise")



Harmonic Series

- Fundamental (f_0): lowest frequency in the harmonic series
- Harmonics: set of frequencies f_0, $2f_0$, $3f_0$, $4f_0$, $5f_0$, …



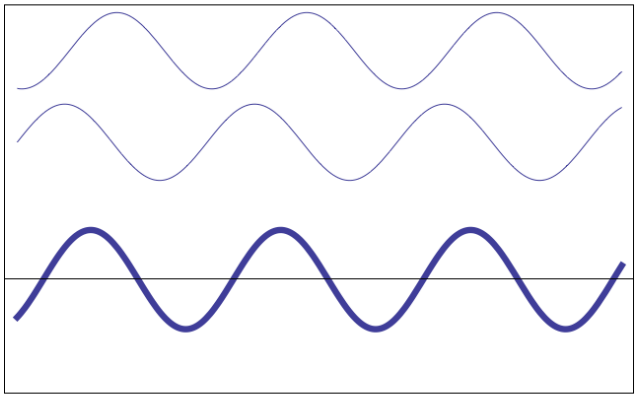


Phet simulation:
Fourier: Making Waves

Standing Waves

- (Dan Russell's animations)

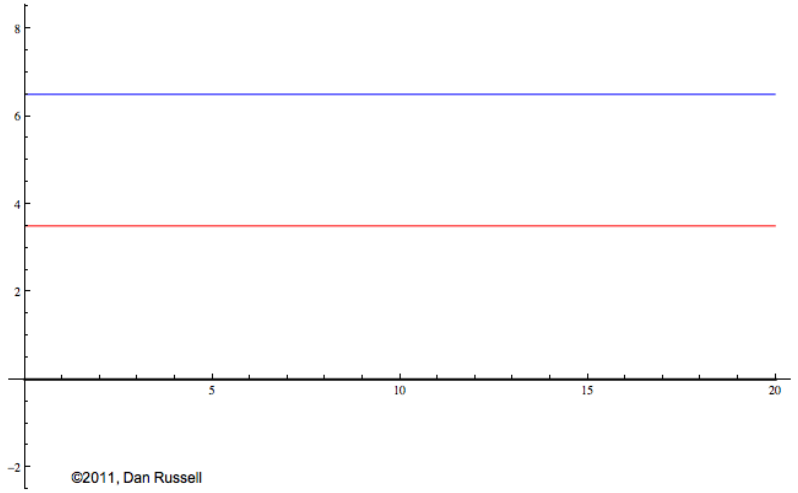
Combine wave pulses by adding amplitudes



Constructive / destructive interference

Standing Waves

Reflection of wave pulse from hard boundary

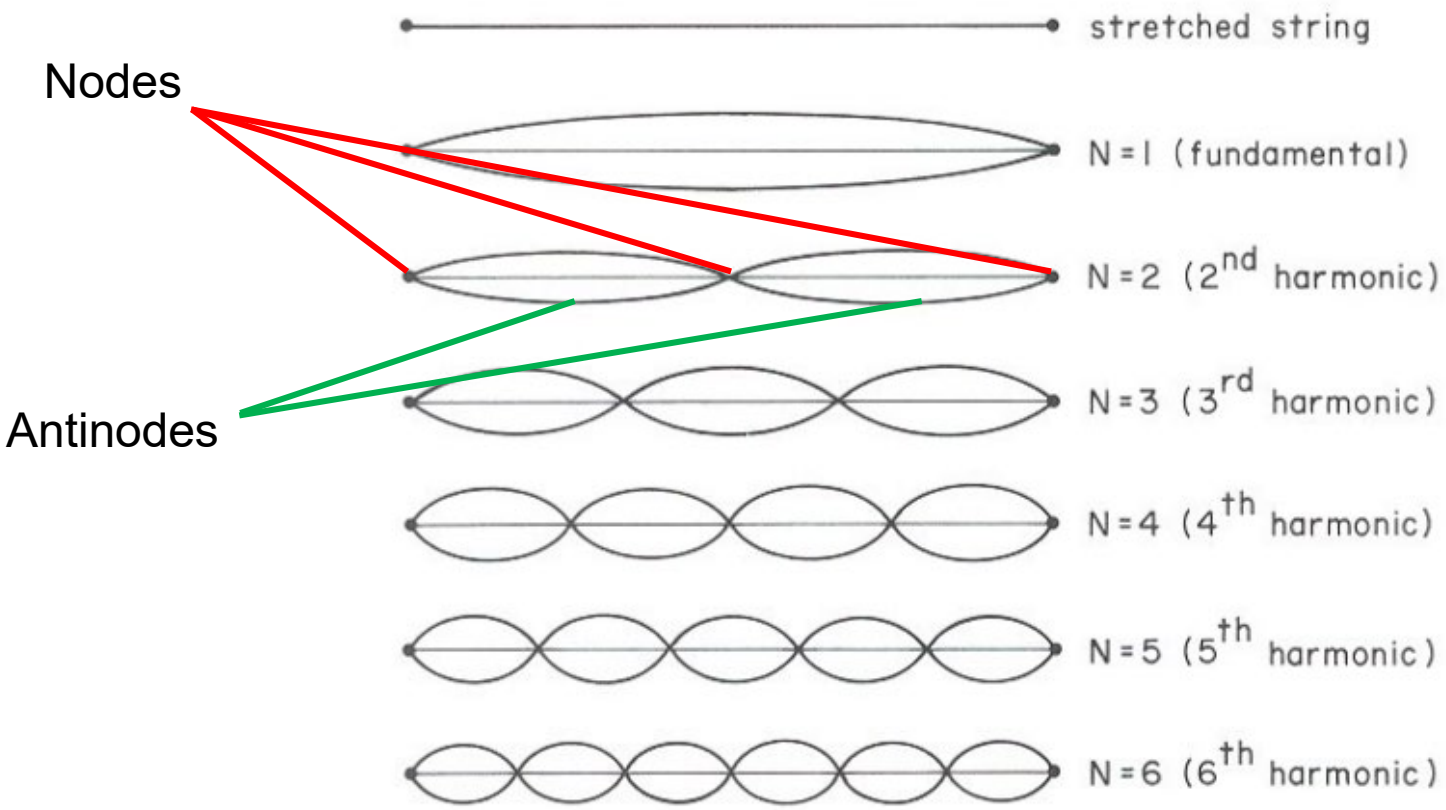


Two waves travelling in opposite directions

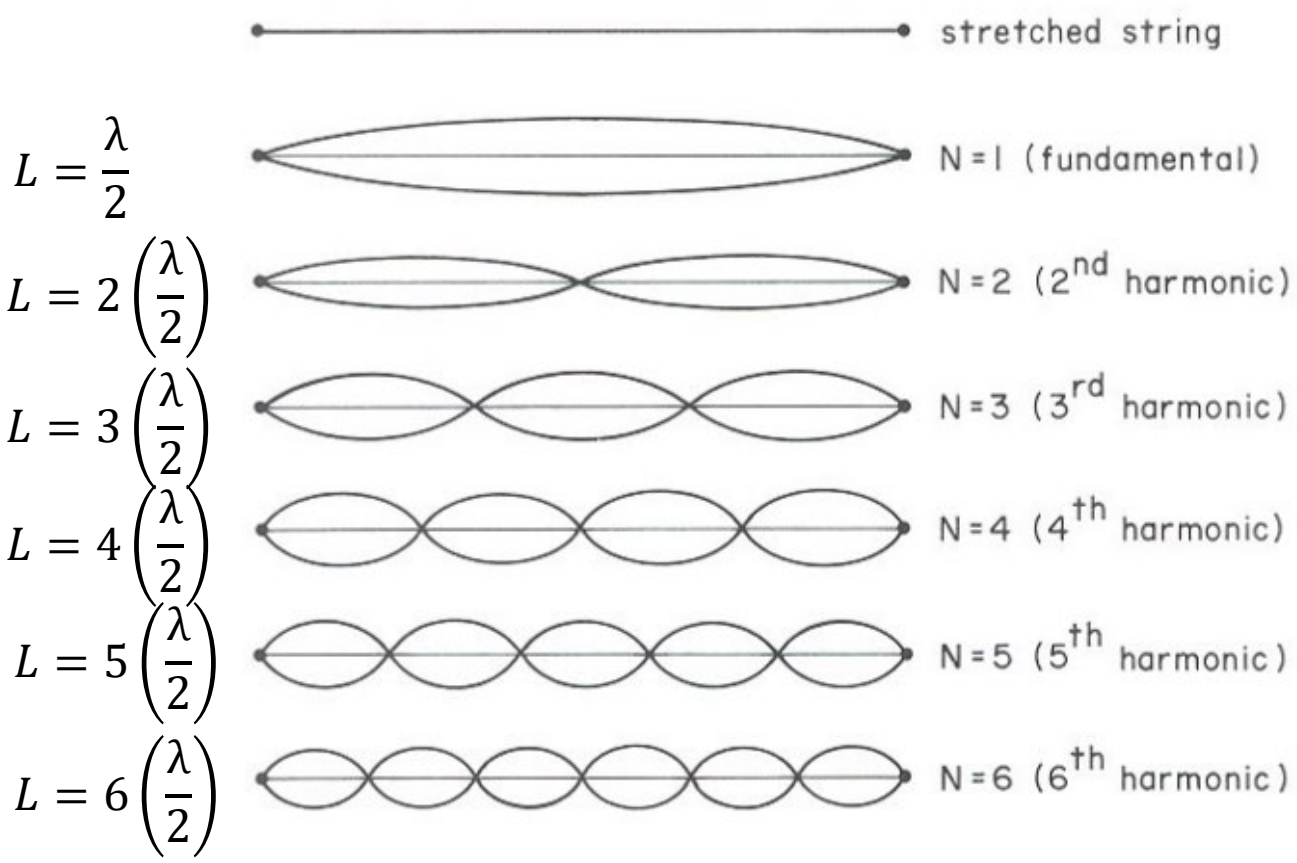
Standing Waves

Overlapping waves from
reflection off hard boundary

Standing Waves



Standing Waves



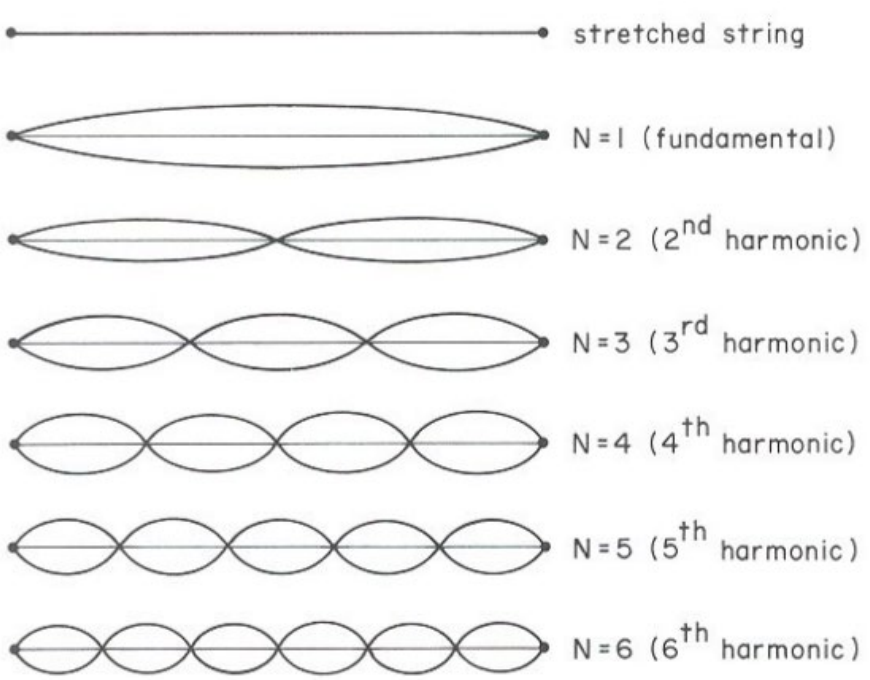
Harmonic Series

- For the nth harmonic,

$$L = n\left(\frac{\lambda}{2}\right)$$

- Recall: $v = \lambda f$

$$\Rightarrow \quad f = n\left(\frac{v_t}{2L}\right)$$



Demo: Standing Waves on a String

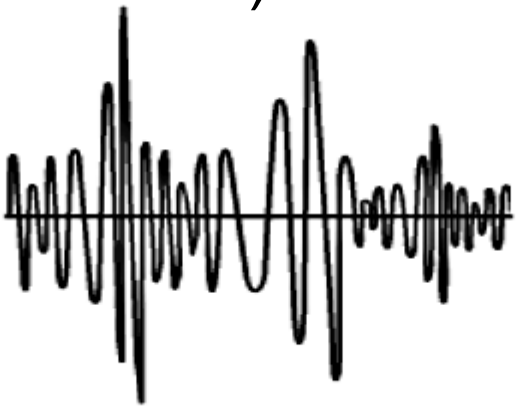
BA

Clicker Question 5.2

Which of the following waves can be broken down into sine waves with frequencies that are part of the harmonic series?

A)

B)



C)

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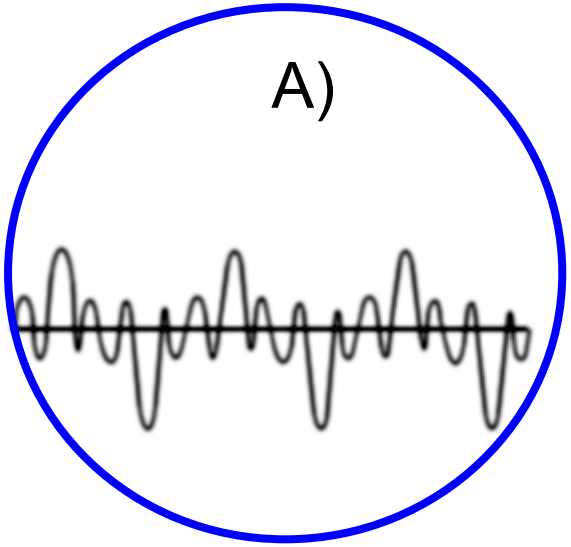
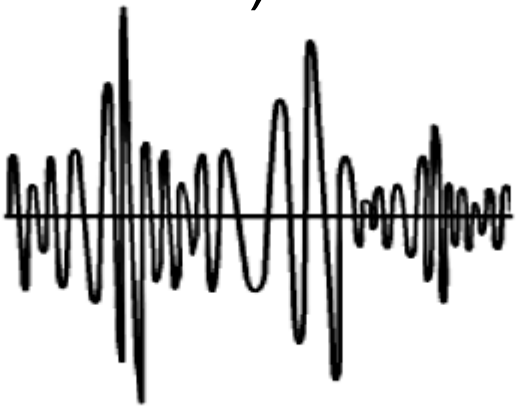


B)



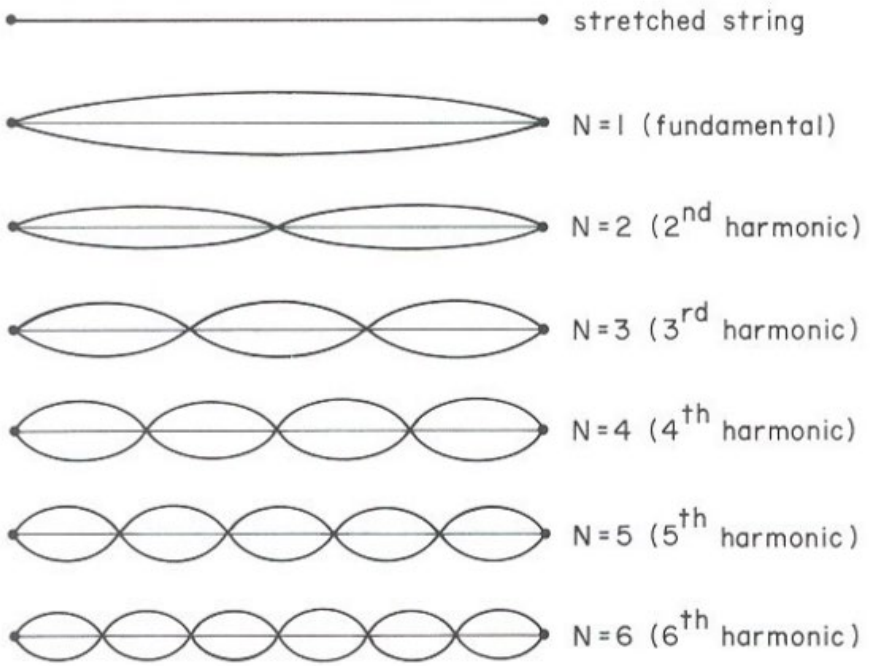
C)

Only (A) has a harmonic series representation, since it's periodic

Clicker Question 5.3

How many nodes are present in the fourth harmonic of a standing wave on a string?

A) 2
B) 3
C) 4
D) 5
E) 6



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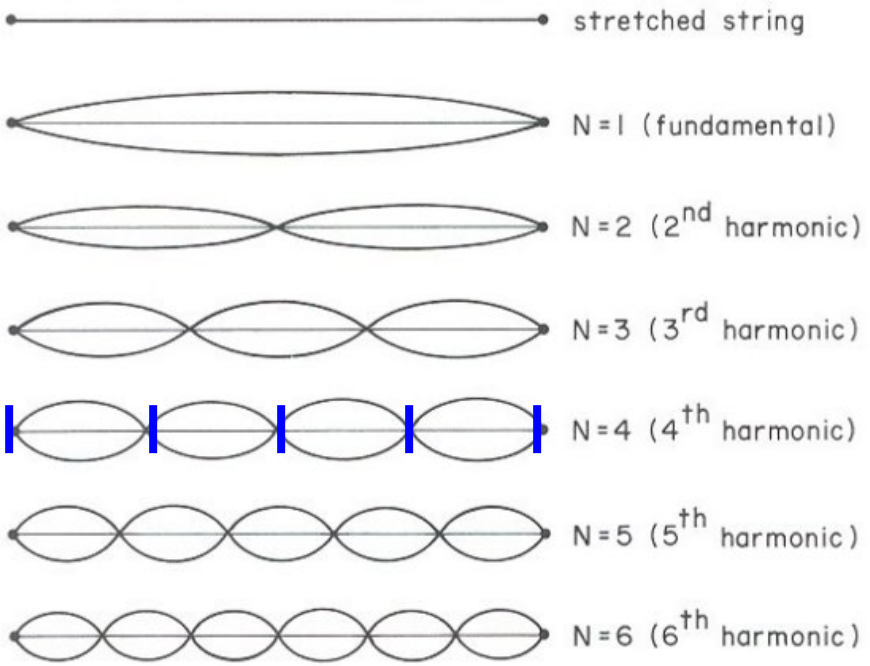

BA

Clicker Question 5.4

If the fundamental frequency of a clarinet note is 200 Hz, what is the frequency of the third harmonic?

A) 200 Hz
B) 300 Hz
C) 400 Hz
D) 600 Hz
E) None of the above

BA

Clicker Question 5.4

If the fundamental frequency of a clarinet note is 200 Hz, what is the frequency of the third harmonic?

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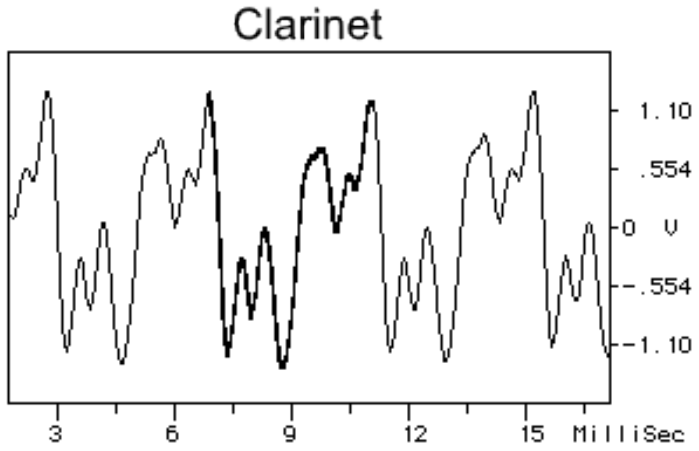
B) 300 Hz
C) 400 Hz
D) 600 Hz
E) None of the above

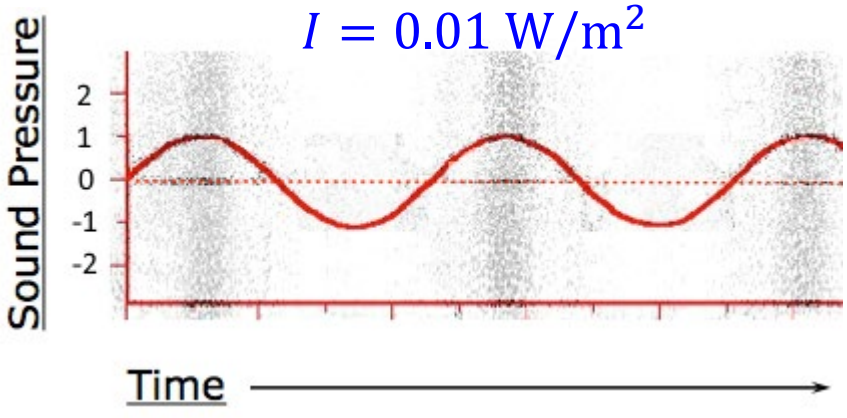
5 minute break

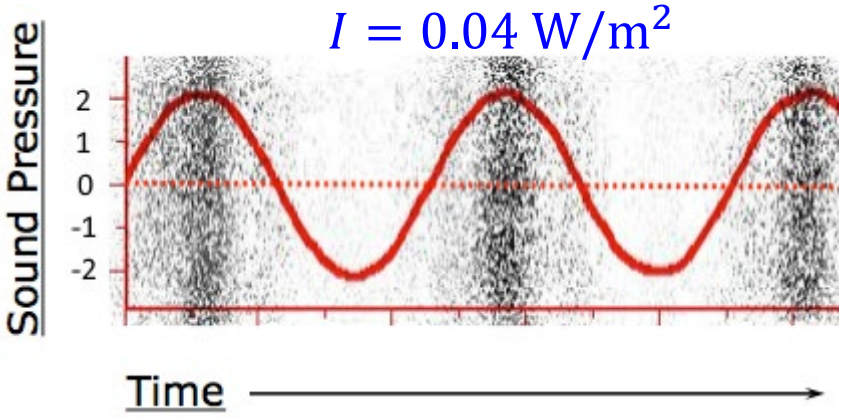
- Characteristics of Sound: What do we need to completely describe a single, steady tone?
  - Frequency ↔ pitch
  - Amplitude ↔ loudness
  - Duration ↔ note length
  - Waveform ↔ timbre



Intensity

- The loudness of a sound isn't directly related to the air's pressure; instead, what matters is the wave's *intensity*
- Intensity: amount of energy flow hitting a certain area [W/m^2]
- Intensity is proportional to the square of the pressure amplitude $(I \propto p^2)$





BA

Clicker Question 5.5

Two sound waves X & Y are measured to have intensities of 1 W/m^2 and 9 W/m^2, respectively. How do their pressure amplitudes compare?

A) X's amplitude is the same as Y's amplitude
B) X's amplitude is 3 times larger than Y's amplitude
C) X's amplitude is 9 times larger than Y's amplitude
D) Y's amplitude is 3 times larger than X's amplitude
E) Y's amplitude is 9 times larger than X's amplitude

BA

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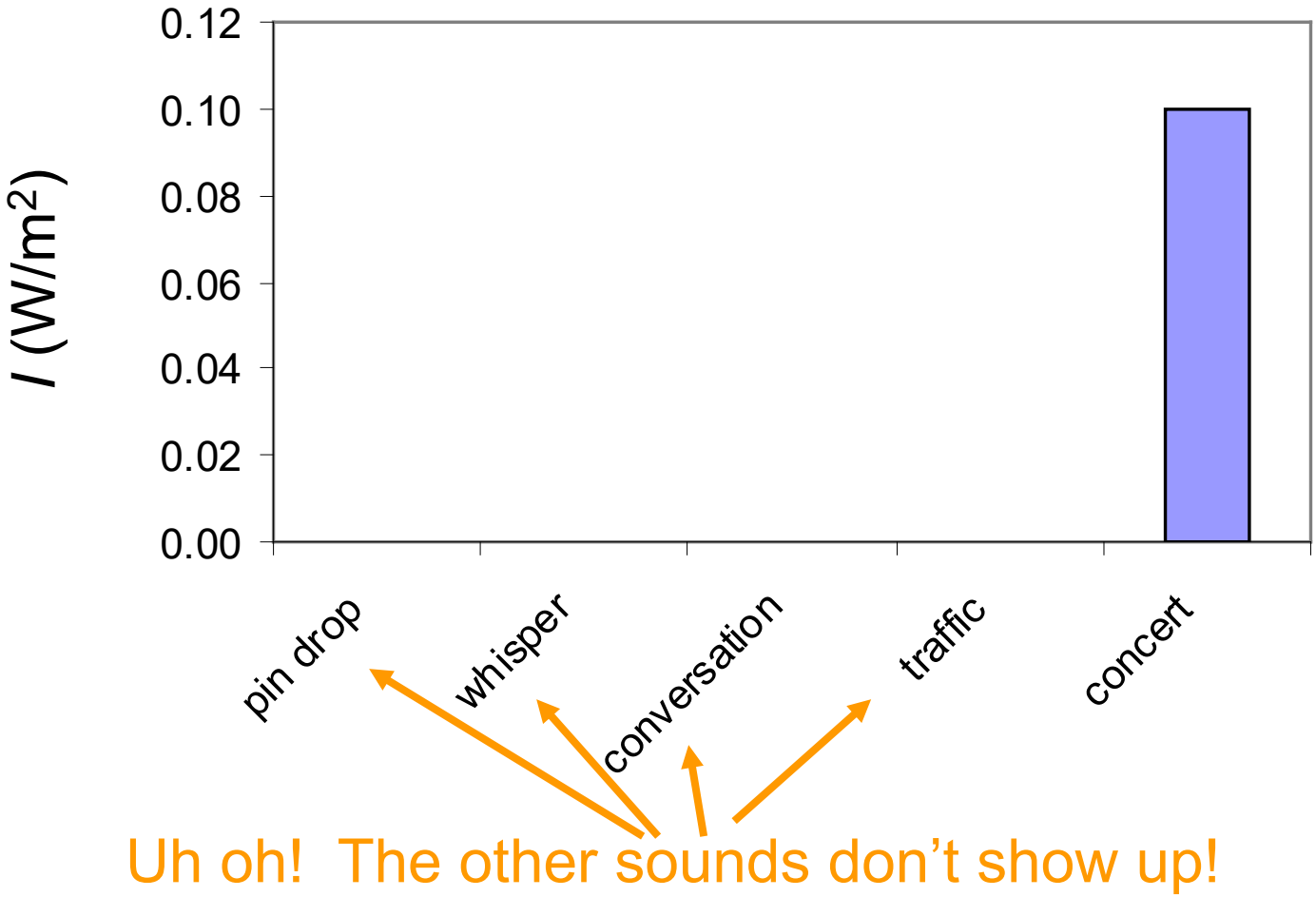
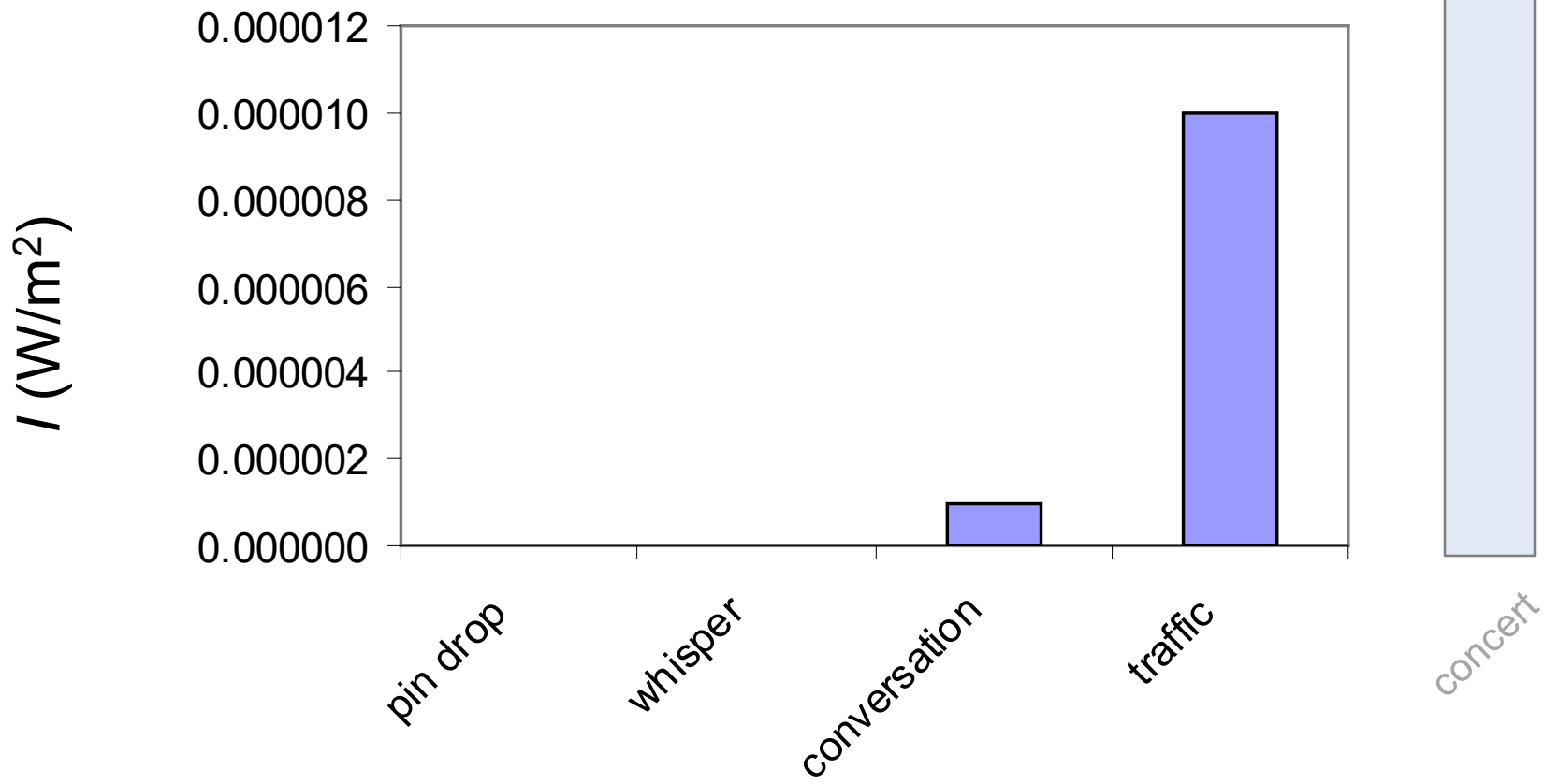
Common Sound Sources

Sound	Amplitude (N/m^2)	Intensity (W/m^2)
pin drop	0.000091	1.0×10^{-11}
whisper	0.00029	1.0×10^{-10}
conversation	0.029	1.0×10^{-6}
traffic	0.091	1.0×10^{-5}
jet engine	9.1	1.0×10^{-1}

Range of Intensities

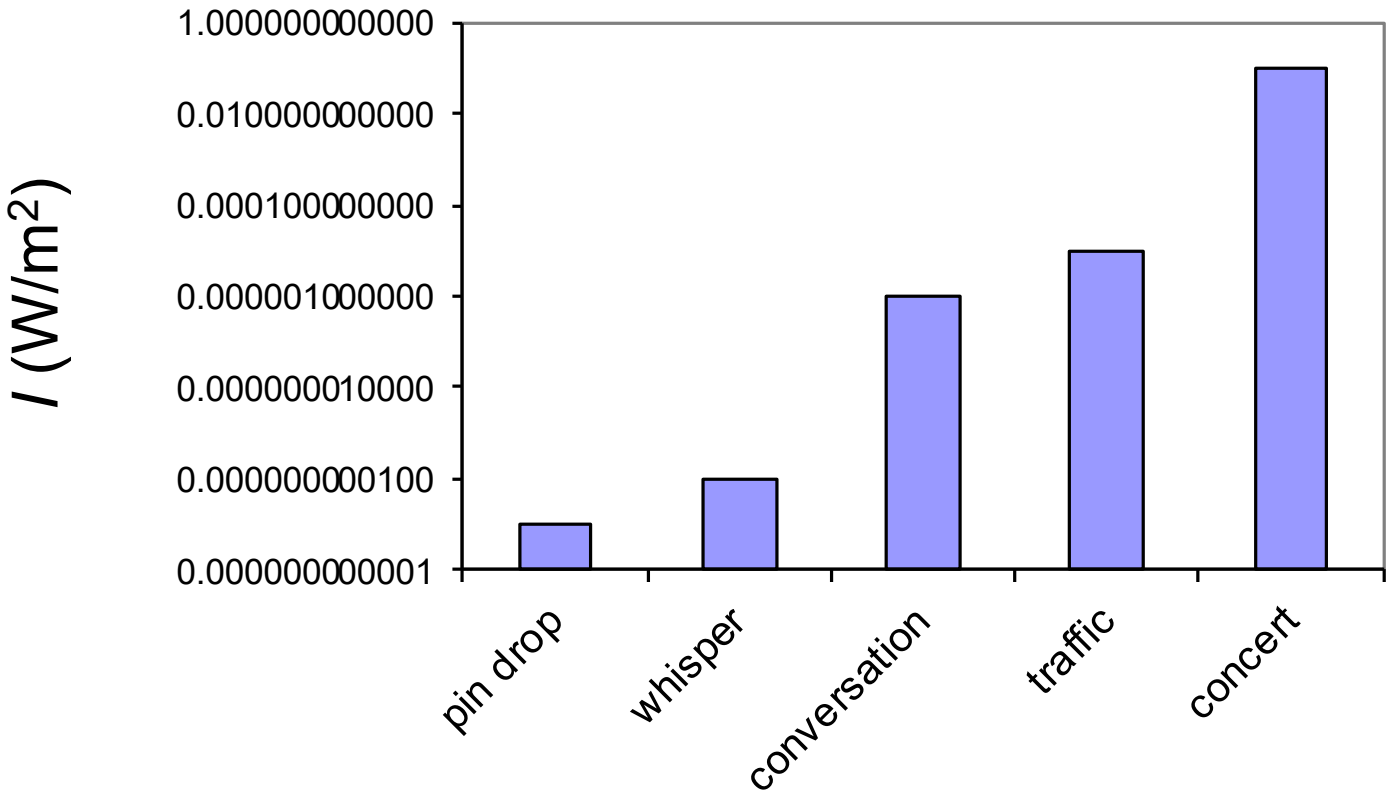


Zoom in a little at the low end

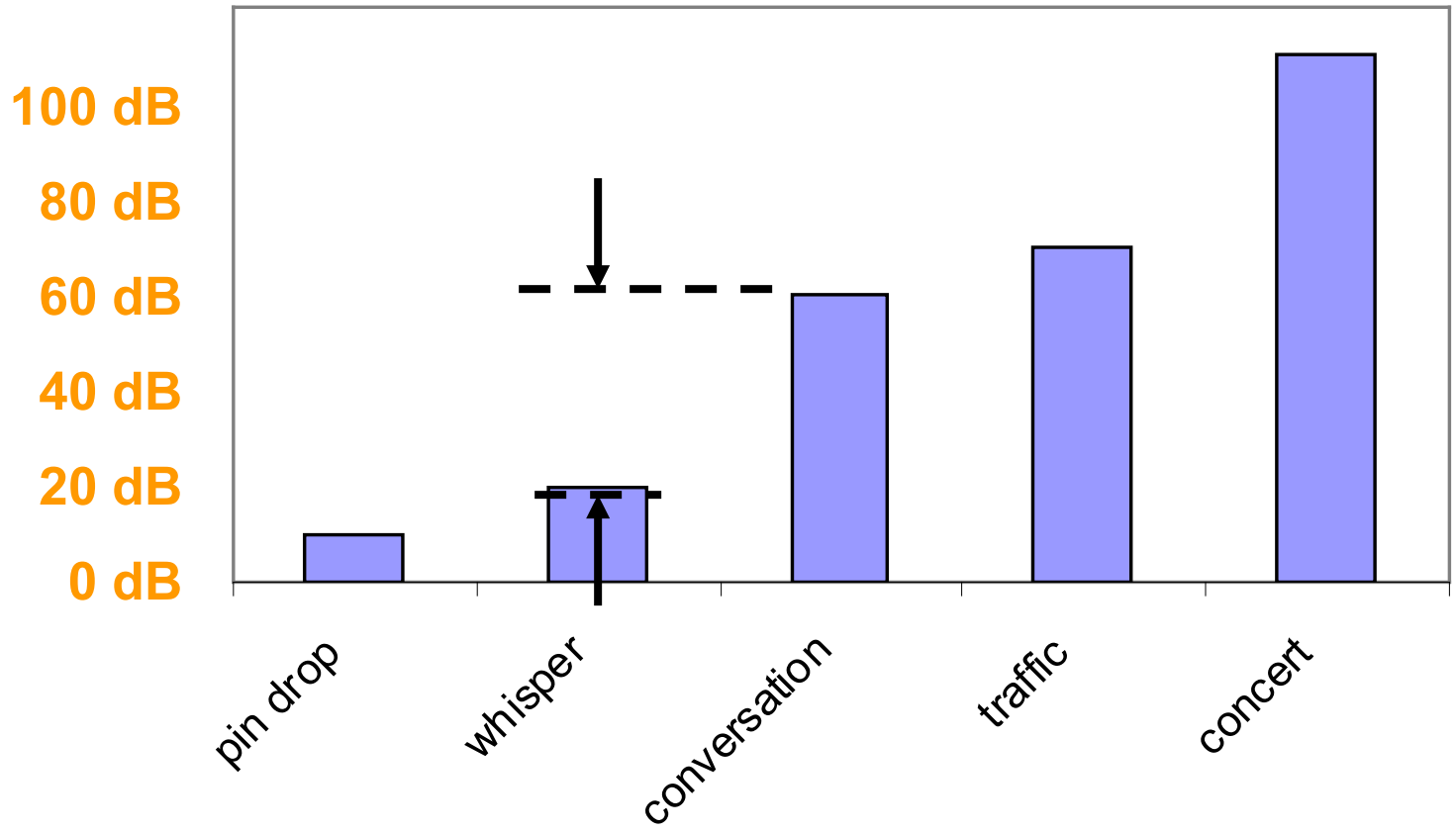


Doesn't help much!

Intensity with a logarithmic Scale



decibels (dB)



A 40 dB increase in sound level corresponds to a 10,000-fold increase in intensity

A 40 dB increase in sound level corresponds to a 10,000-fold increase in intensity.

?

Let's start more simply:

A 10 dB increase in level is a 10-fold increase in intensity

A 20 dB increase in level is two increases of 10 dB

So, the intensity increase is 10 x 10 = 100

30 dB → 1,000 (10 x 10 x 10)
40 dB → 10,000 (10 x 10 x 10 x 10)

Decibel scale

- Sound Intensity Level (SIL): logarithmic intensity scale; measured in decibels [dB]

- Threshold of hearing: $I_0 = 10^{-12}\ \mathrm{W/m^2}$

  (corresponds to 0 dB)

$$\boxed{SIL\ [\mathrm{dB}] = 10 \log_{10}\left(\frac{I}{I_0}\right)}$$

$$1\ \mathrm{bel}\ [\mathrm{B}] = \log\left(\frac{I}{I_0}\right)$$

Review of logarithms:

$$y = \log_{10}(x) \quad \leftrightarrow \quad x = 10^{y}$$

$\log(1) = \log(10^{0}) = 0$

$\log(10) = \log(10^{1}) = 1$

$\log(100) = \log(10^{2}) = 2$

$\log(1000) = \log(10^{3}) = 3$

BA

Clicker Question 5.6

A trombone can make a sound intensity of 10^{-4} W/m^2 as measured near the bell. What is the *SIL* in dBs?

A) 40 dB
B) 400 dB
C) 10,000 dB
D) 100 dB
E) None of the above

Clicker Question 5.6

A trombone can make a sound intensity of 10^{-4} W/m^2 as measured near the bell. What is the *SIL* in dBs?

A) 40 dB
B) 400 dB
C) 10,000 dB
D) 100 dB
E) None of the above

$$SIL = 10\log\left(\frac{10^{-4}}{10^{-12}}\right) = 10\log(10^{8})$$

$$= 10 \times 8 = 80 \text{ dB}$$

Intensities add to combine

- When two sounds with intensities I_1 and I_2 are played together,

  intensity of combined sound = $I_1 + I_2$

- SILs [dB] do NOT add to combine, since they are on a logarithmic scale!

BA

Clicker Question 5.7

The drummer in our band is out of control! His intensity is 0.01 W/m^2 while the rest of us have a combined intensity of 0.0001 W/m^2. How much higher is his sound intensity level (SIL)?

A) 0.099 dB
B) 10 dB
C) 20 dB
D) 30 dB
E) 110 dB

Clicker Question 5.7

The drummer in our band is out of control! His intensity is 0.01 W/m^2 while the rest of us have a combined intensity of 0.0001 W/m^2. How much higher is his sound intensity level (SIL)?

A) 0.099 dB
B) 10 dB
C) 20 dB
D) 30 dB
E) 110 dB

Simple formula: $\Delta SIL = SIL_2 - SIL_1 = 10 \log\left(\frac{I_2}{I_1}\right)$

$$\Delta SIL = 10 \log\left(\frac{0.01}{0.0001}\right) = 10 \log(10^2) = 20 \text{ dB}$$

Clicker Question 5.8

How many dBs does the SIL increase when two trumpets play together, assuming they each individually have the same intensity?

A) 2 dB
B) 3 dB
C) 4 dB
D) 5 dB
E) 6 dB

BA

Clicker Question 5.8

How many dBs does the SIL increase when two trumpets play together, assuming they each individually have the same intensity?

A) 2 dB
B) 3 dB
C) 4 dB
D) 5 dB
E) 6 dB

$$\Delta SIL = 10\log\left(\frac{2I_{tpt}}{I_{tpt}}\right) = 10\log(2) \cong 3.01\ \text{dB}$$

Useful tips

- Doubling the intensity means adding 3 dB to the *SIL*
- Halving the intensity means subtracting 3 dB from the *SIL*
- Multiplying the intensity by 10 means adding 10 dB to the *SIL*
- Doubling the distance away from a source means subtracting 6 dB from the *SIL*

Intensity (W/m^2)	SIL (dB)	Example
10^{-12}	0 dB	Inaudible
10^{-11}	10 dB	Pin drop
10^{-10}	20 dB	Recording studio
10^{-9}	30 dB	
10^{-8}	40 dB	Library
10^{-7}	50 dB	City of Boulder nighttime noise ordinance
10^{-6}	60 dB	Conversation
10^{-5}	70 dB	
10^{-4}	80 dB	Vacuum cleaner
10^{-3}	90 dB	Subway Train