

Physics 1240: Sound and Music

Today (7/16/19): Psychoacoustics: The Ear

Next time: Psychoacoustics: The Brain, Auditory Illusions, Dissonance

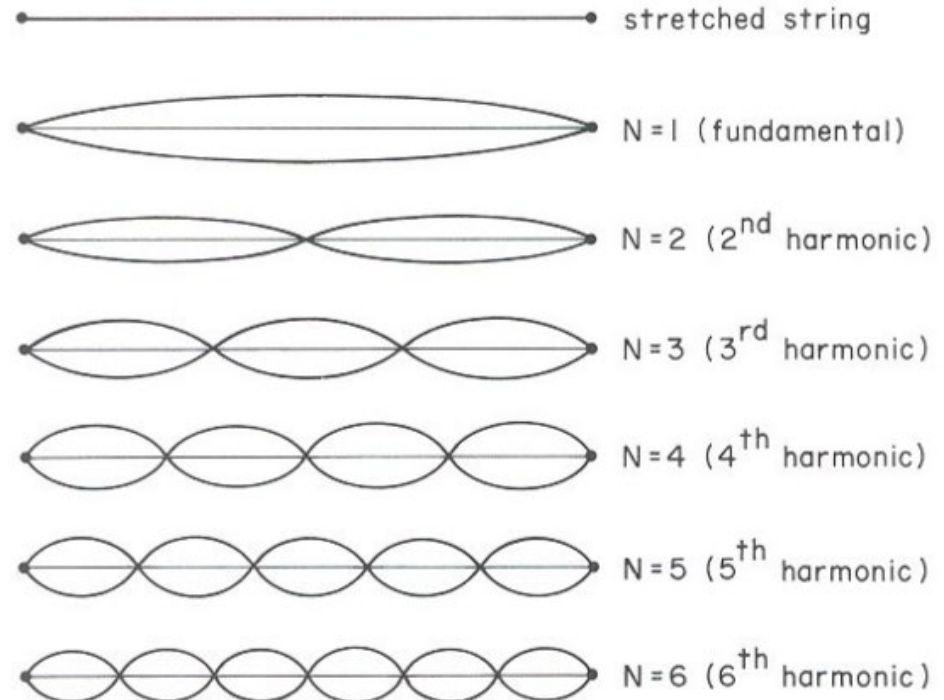


Review: Waveform/Timbre

- Tones: **periodic**; composed of **integer multiples** of the **fundamental** frequency
- Noise: not periodic
- Harmonics: set of frequencies $f_0, 2f_0, 3f_0, 4f_0, 5f_0, \dots$

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

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



Review: Amplitude/Loudness

- Intensity: energy flow per unit area (W/m^2)
 - proportional to the pressure amplitude squared
- SIL: logarithmic version of intensity, relative to reference value $I_0 = 10^{-12} \text{ W}/\text{m}^2$, measured in decibels

$$SIL \text{ [dB]} = 10 \log \left(\frac{I}{10^{-12} \text{ W}/\text{m}^2} \right)$$

$$SIL_1 - SIL_2 = 10 \log \left(\frac{I_1}{I_2} \right)$$

- Two sounds playing together \Rightarrow add their intensities

Review:

	<u>Intensity (W/m²)</u>	<u>SIL (dB)</u>	<u>Example</u>
<u>Useful tips</u>	10 ⁻¹²	0 dB	Inaudible
• Multiplying the intensity by 10 means adding 10 dB to the <i>SIL</i>	10 ⁻¹¹	10 dB	Pin drop
	10 ⁻¹⁰	20 dB	Recording studio
• Doubling the intensity means adding 3 dB to the <i>SIL</i>	10 ⁻⁹	30 dB	
	10 ⁻⁸	40 dB	Library
• Halving the intensity means subtracting 3 dB from the <i>SIL</i>	10 ⁻⁷	50 dB	City of Boulder nighttime noise ordinance
	10 ⁻⁶	60 dB	Conversation
• Doubling the distance away from a source means subtracting 6 dB from the <i>SIL</i>	10 ⁻⁵	70 dB	
	10 ⁻⁴	80 dB	Vacuum cleaner
	10 ⁻³	90 dB	Subway Train



Clicker Question 6.1

If a typical vacuum cleaner produces a sound intensity level of 80 dB, how many vacuums would you need operating simultaneously next to each other to produce double this S/L (160 dB)?

- A) 2
- B) 80
- C) 100
- D) a thousand
- E) a hundred million



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Adding 10 dB corresponds to multiplying the intensity by 10

Adding 80 dB means multiplying the intensity by 10^8

Psychoacoustics

- Psychoacoustics: the study of human perception of sound
- Does loudness just depend on amplitude?

Range of Hearing

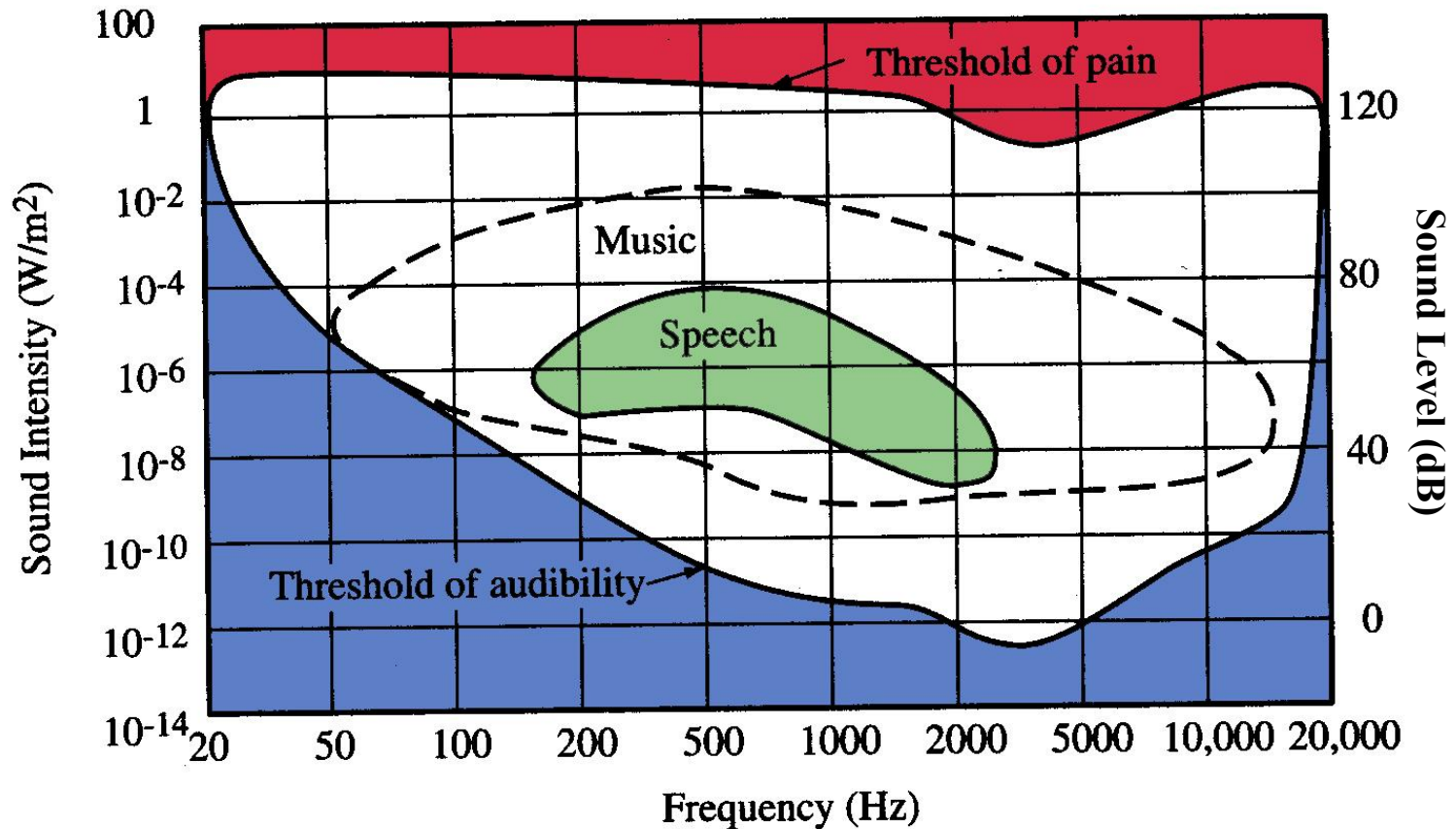
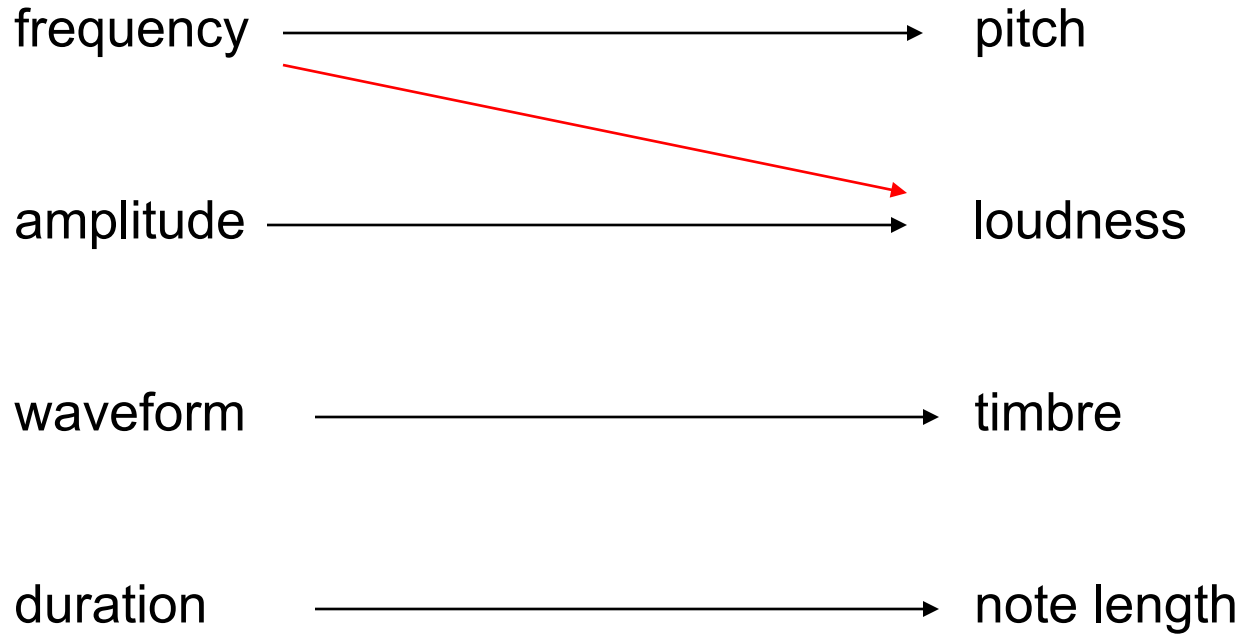


FIGURE 5.1 Range of frequencies and intensities to which the auditory system (ear) responds

stimuli

sensation

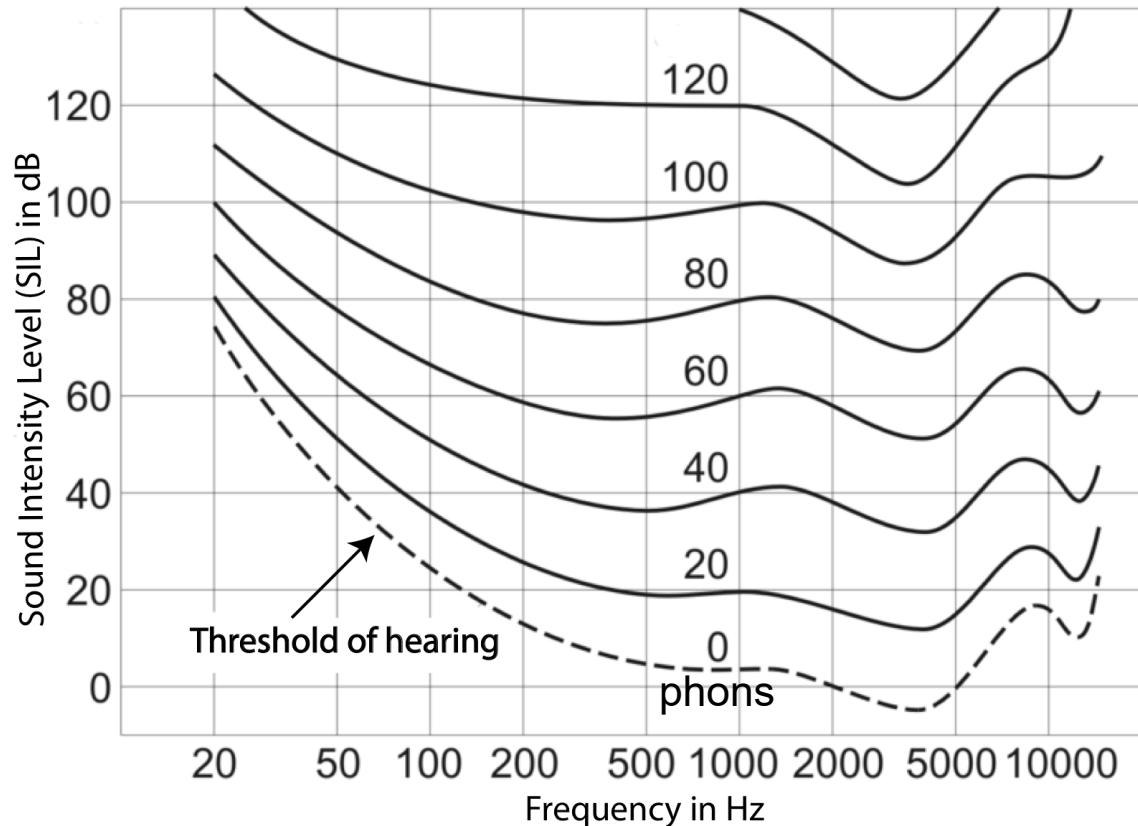


Loudness Level

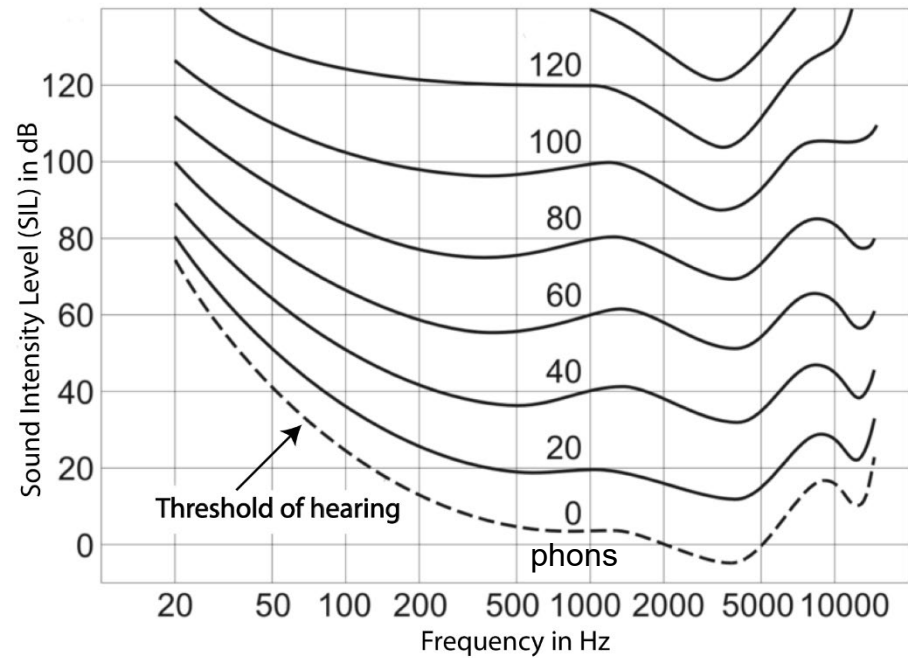
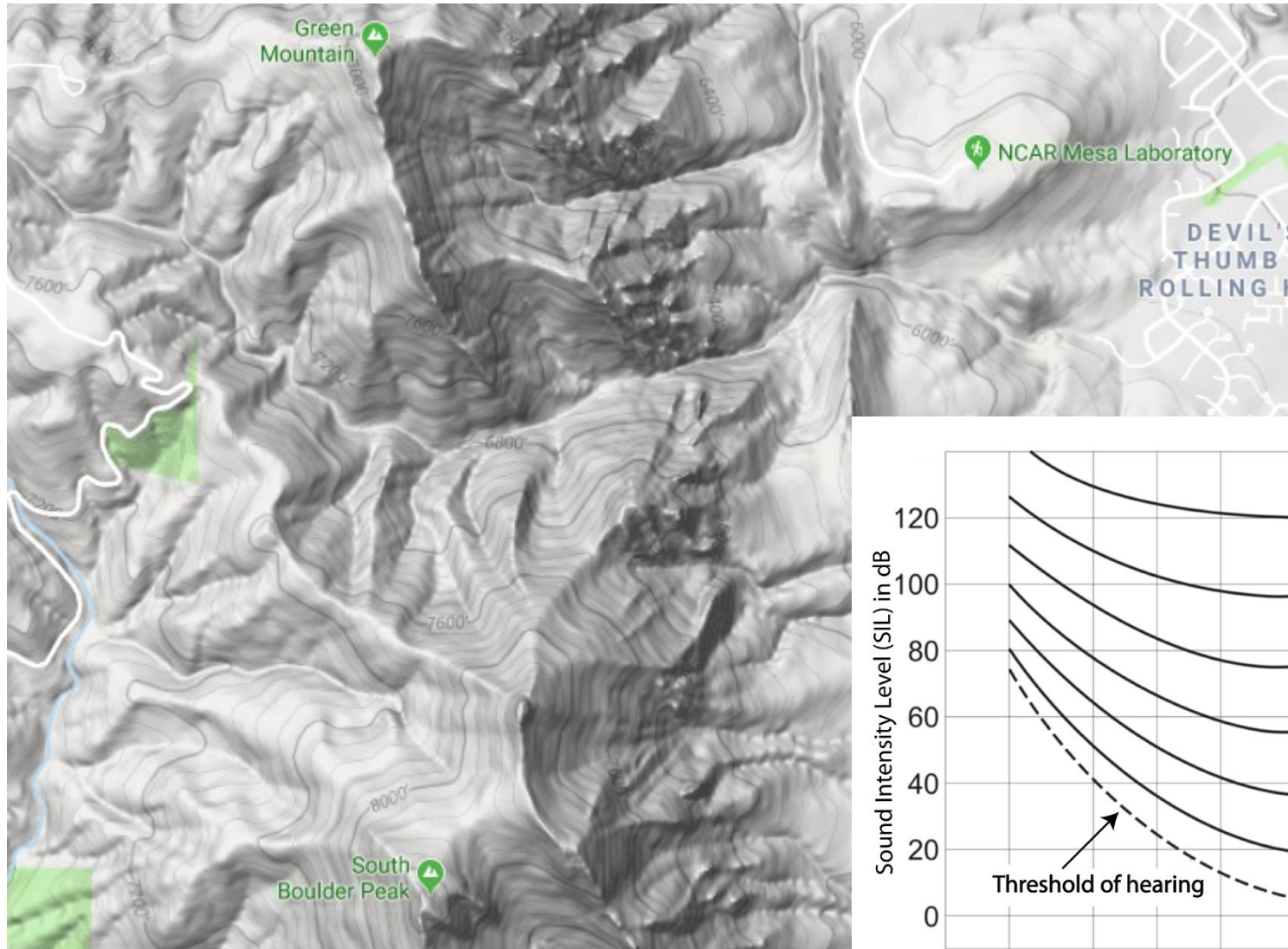
- Phon: unit of perceived loudness level
 - equal to the *S/L* measured at 1000 Hz

- Equal-Loudness Contours :

used to convert
between *S/L* [dB]
and loudness
level [phons]

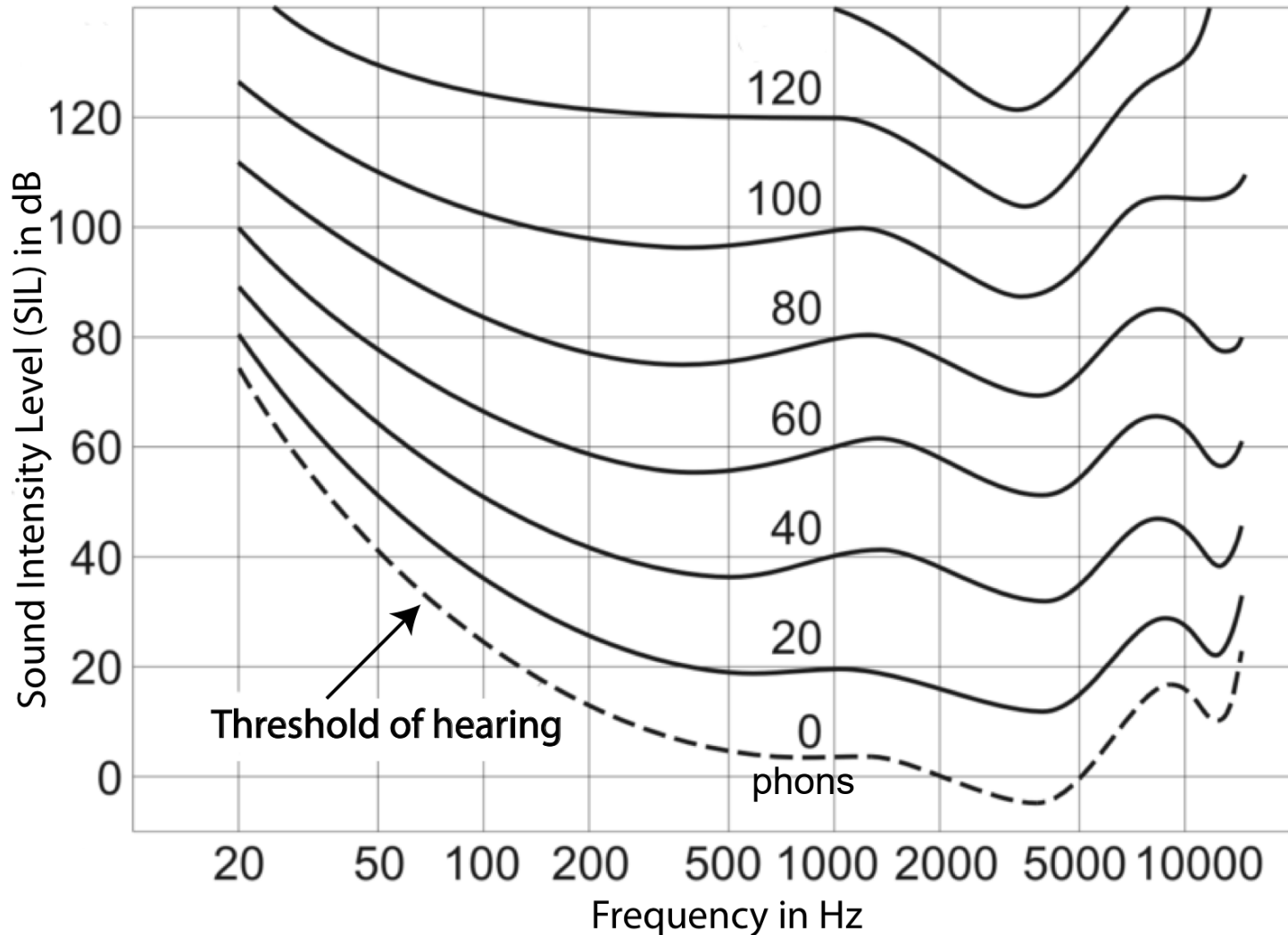


Contour Map



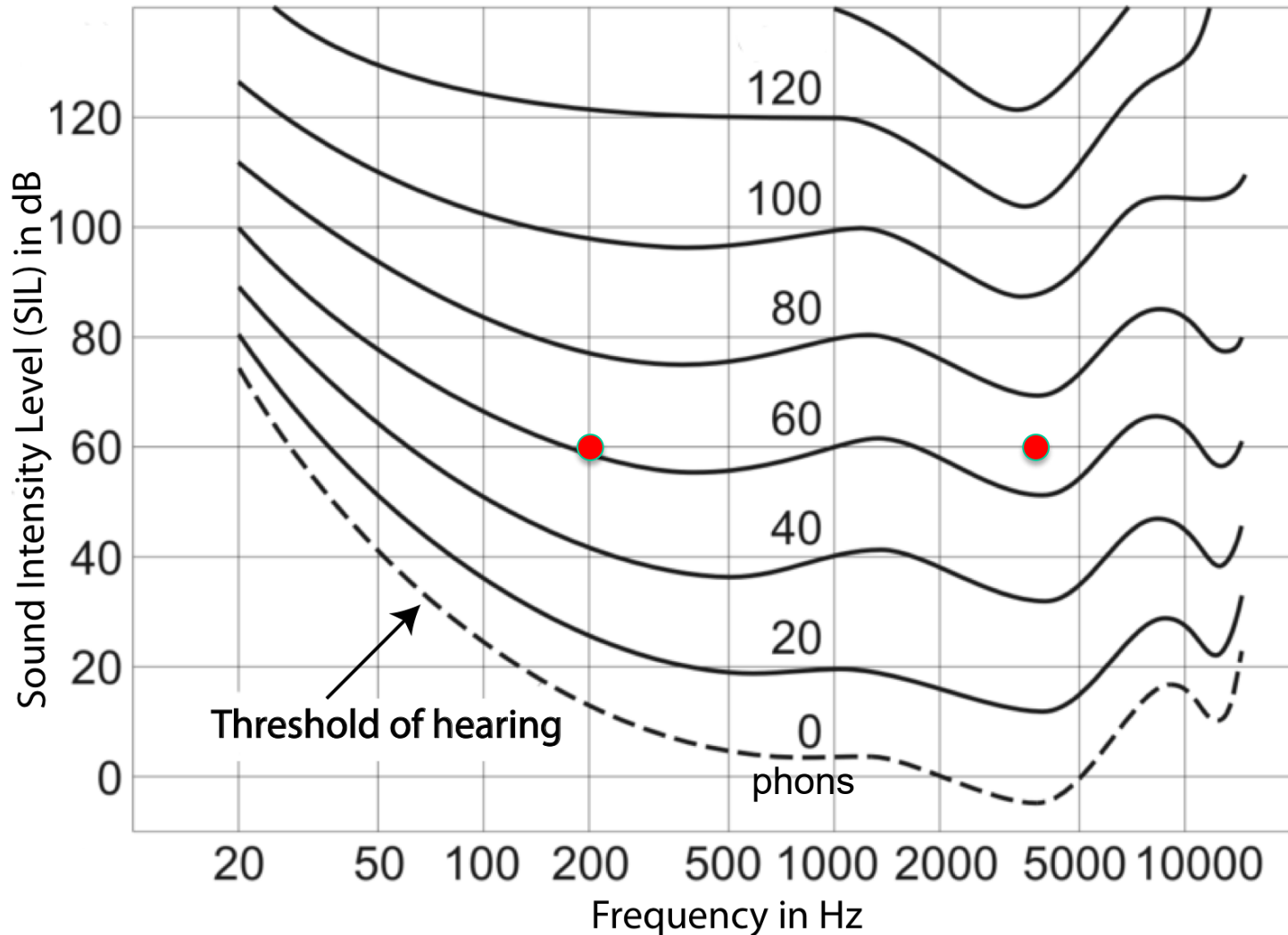
Example:

If you hear two pure tones with $f=200$ Hz and $f=4,000$ Hz, both at 60 dB SIL, which will be the loudest?



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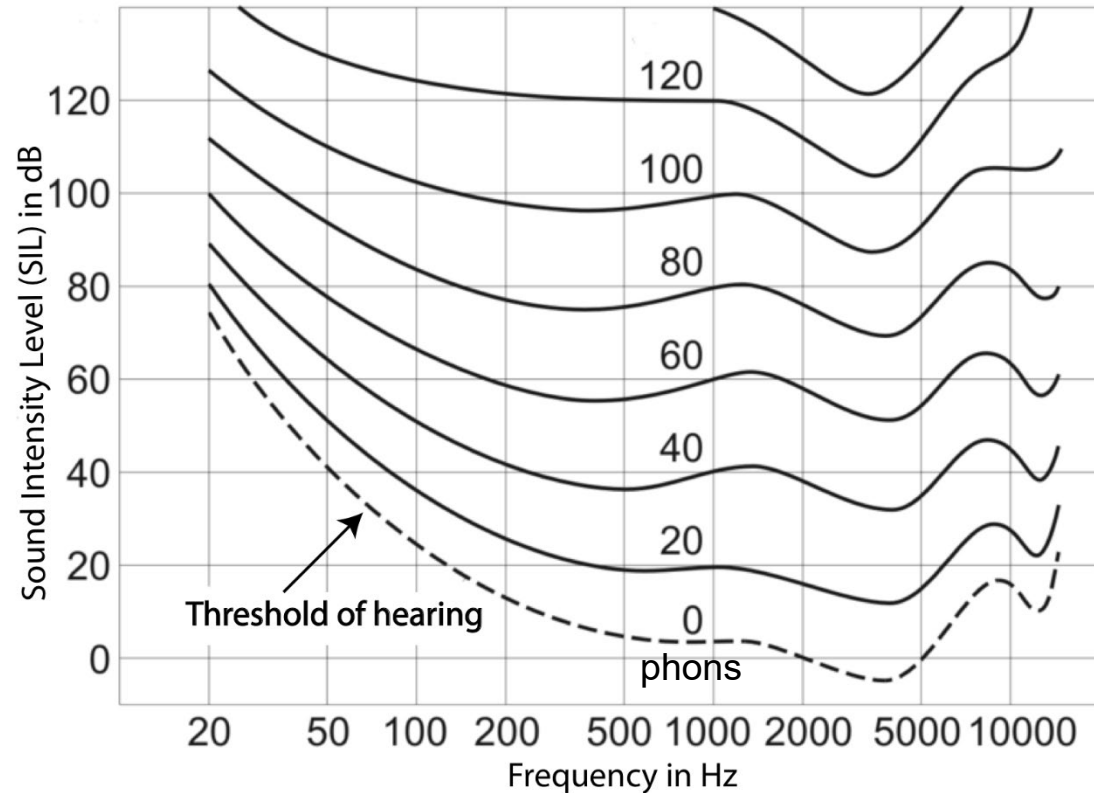


BA

Clicker Question 6.2

If you play a piano chord with notes of frequencies 130 Hz, 330 Hz, 2000 Hz, and 4000 Hz so that all sound the same loudness, which note will you have to play the hardest?

- A) 130 Hz
- B) 330 Hz
- C) 2000 Hz
- D) 4000 Hz
- E) All the same



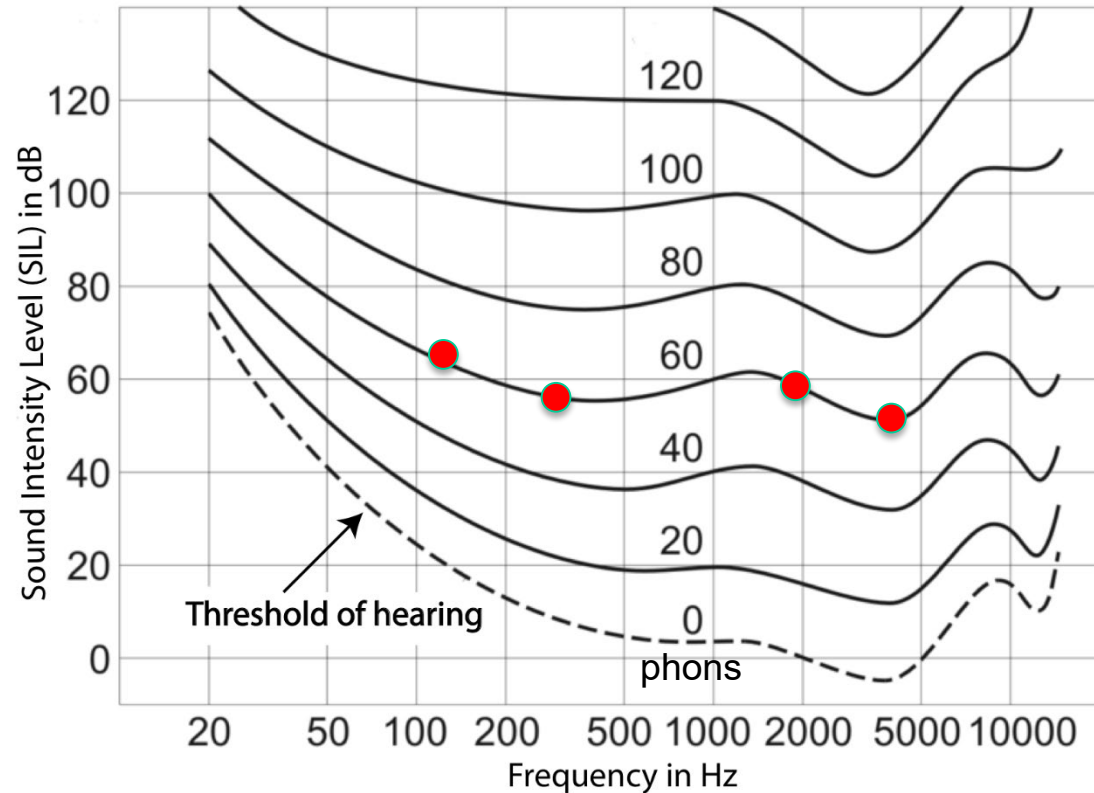


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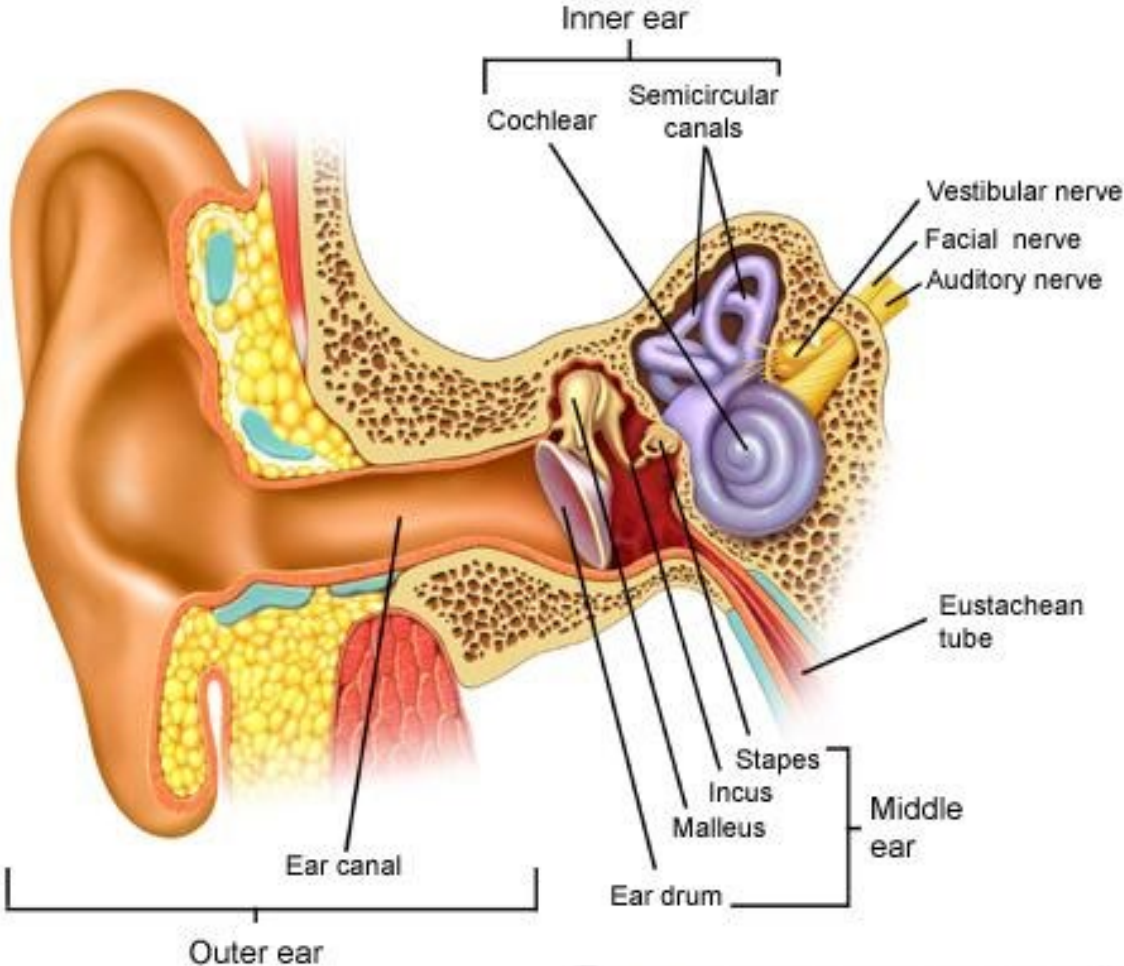
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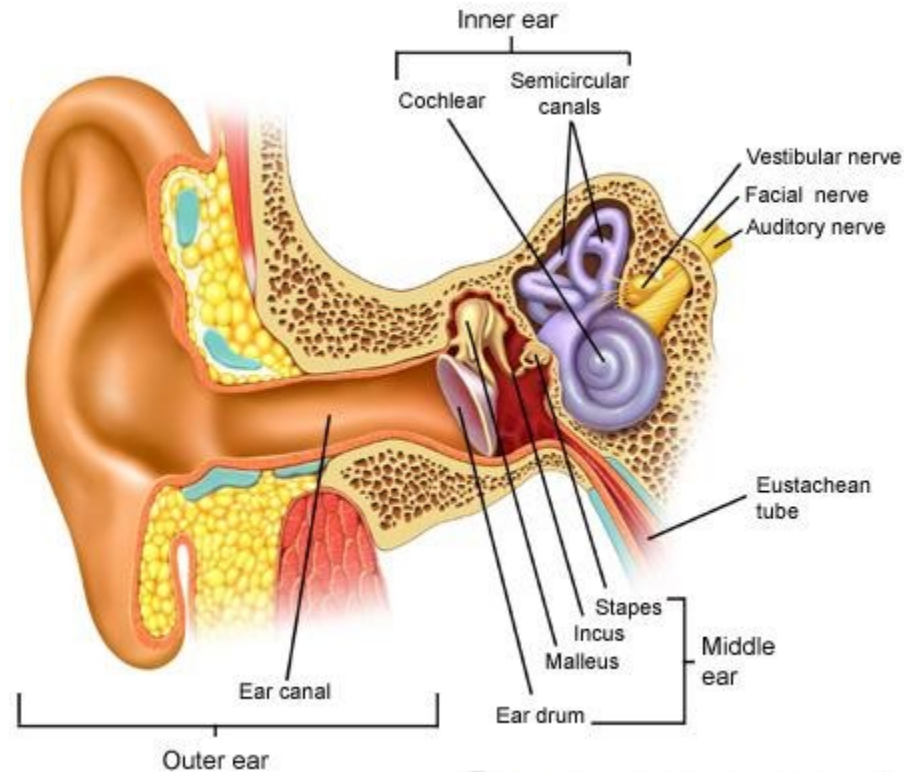


The Human Ear

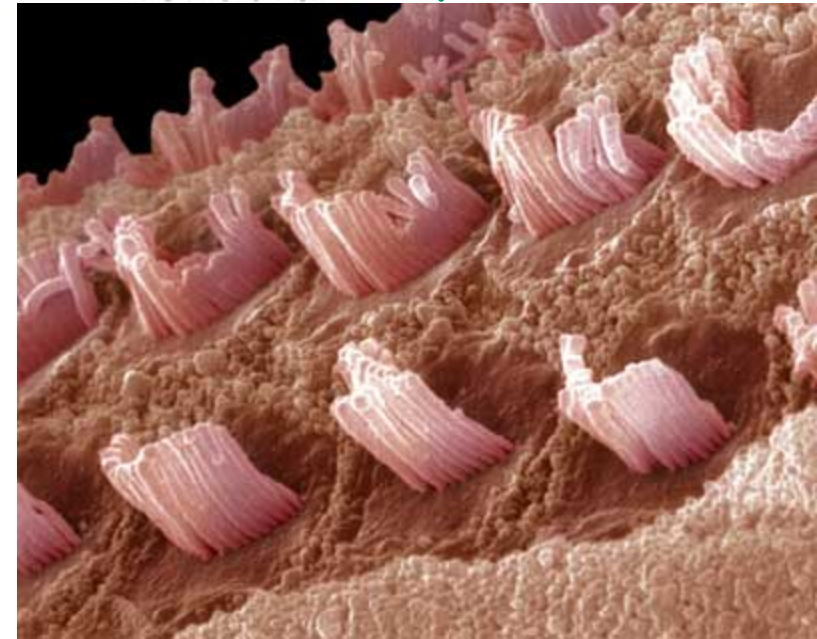
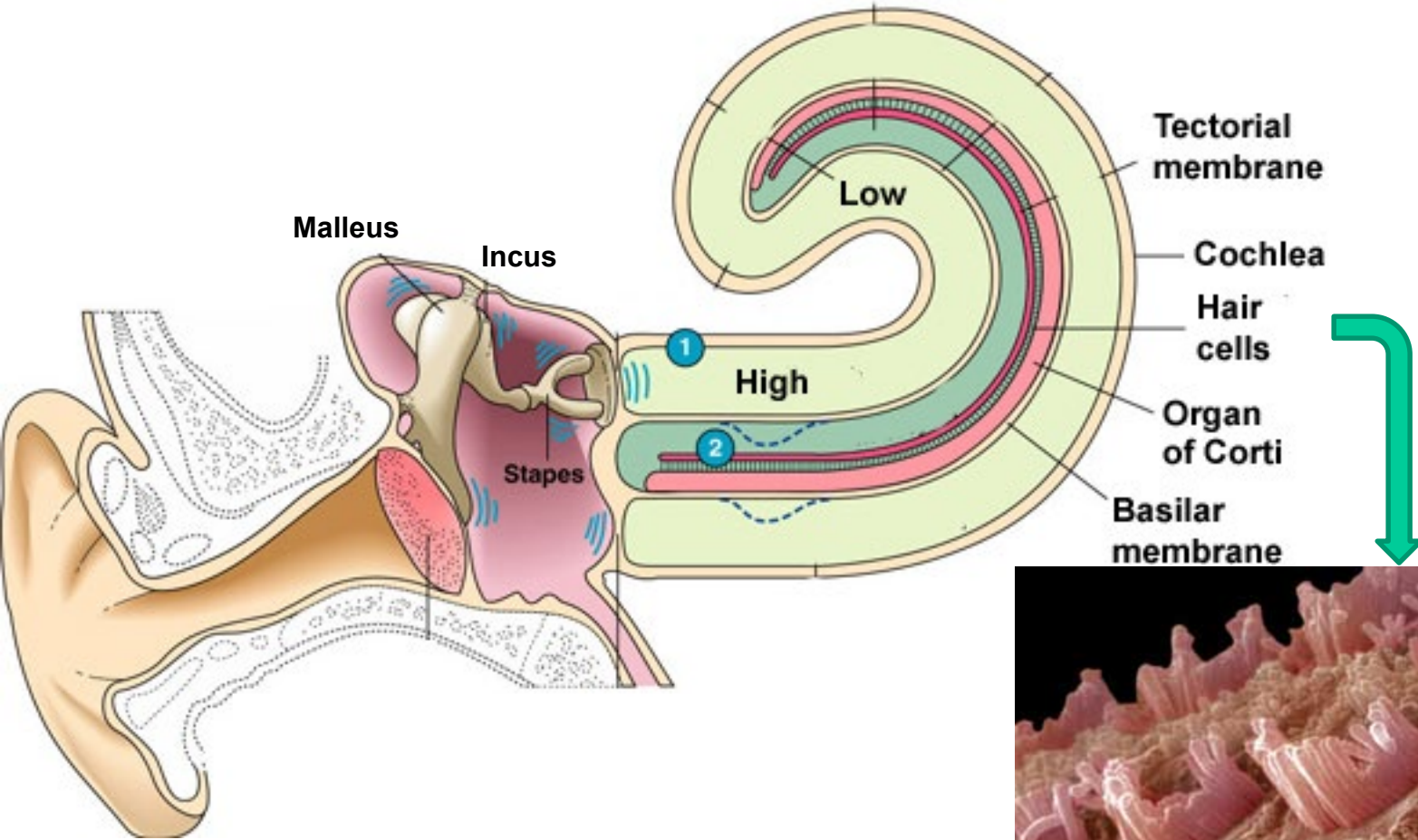


Why is there a middle ear?

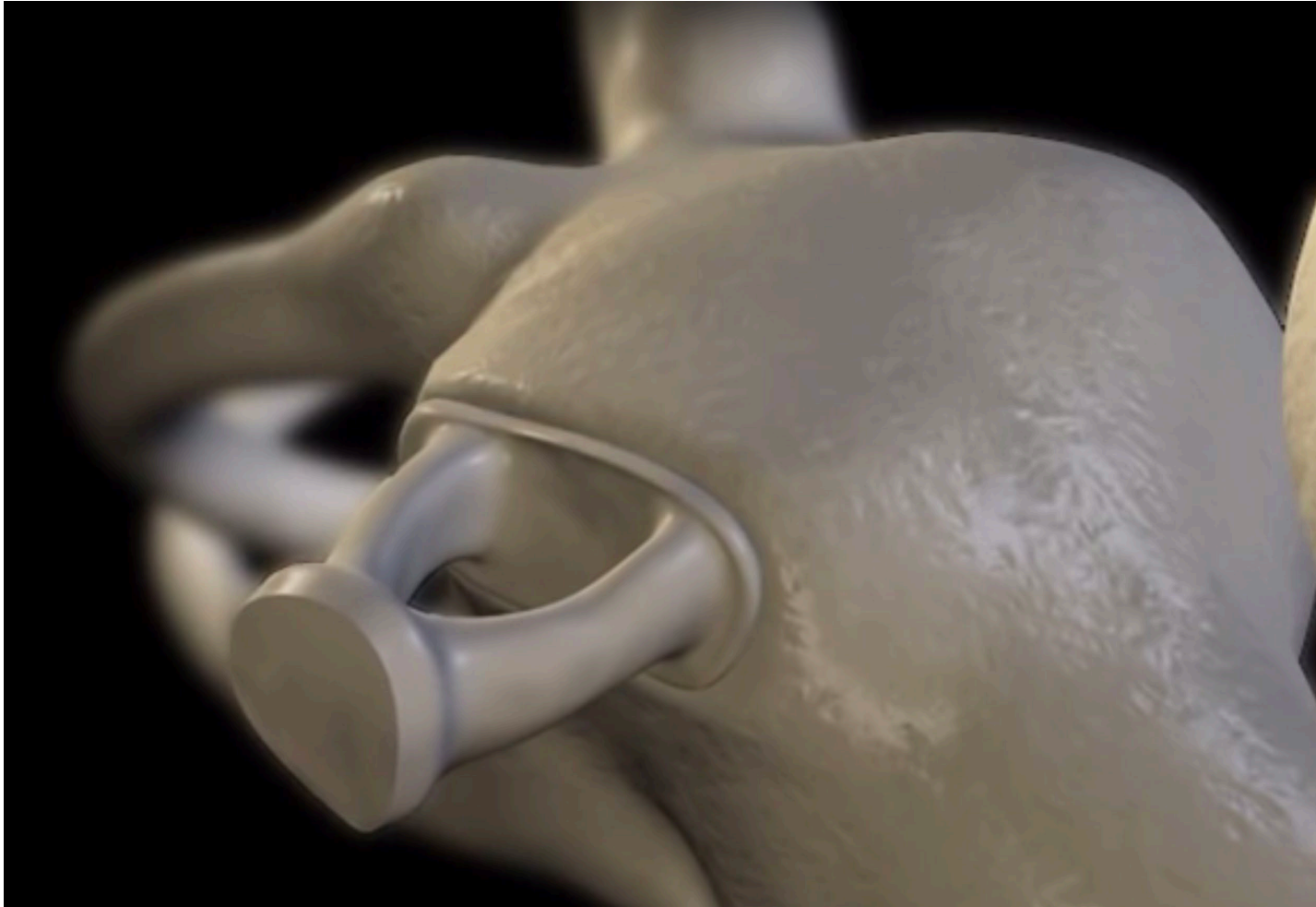
- To provide some amplification of pressure waves
- To better couple pressure waves to vibrations in the cochlea
- To protect the inner ear from extremely loud sounds
- To maintain the tympanic membrane (eardrum) in proper pressure equilibrium



The Middle and Inner Ears



VIDEO on how the ear works



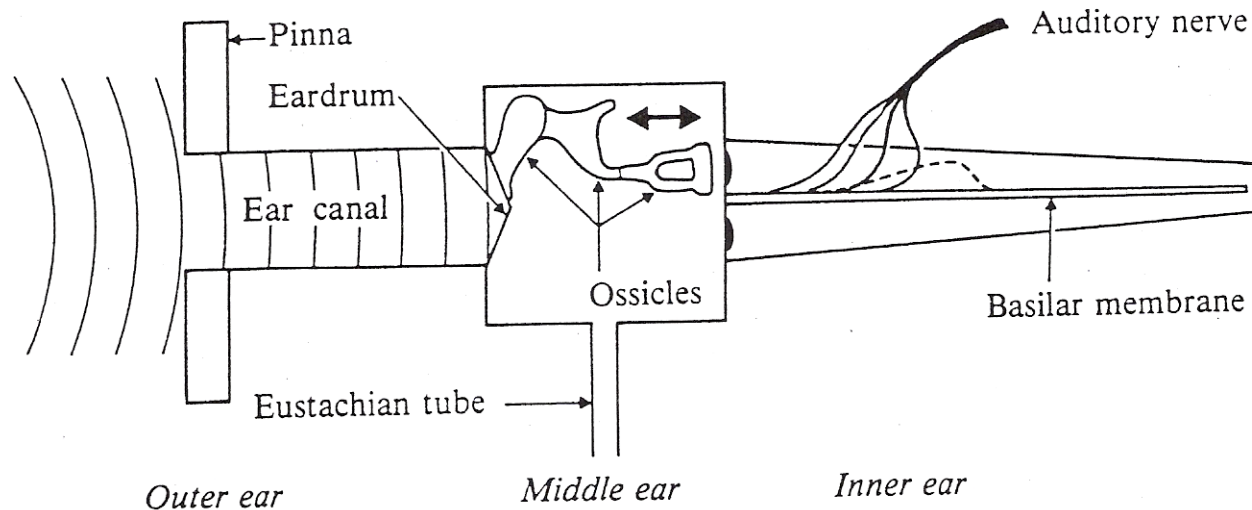
<https://www.youtube.com/watch?v=46aNGGNPm7s>

Need to know:

Outer ear: pinna, auditory canal

Middle ear: ear drum, Eustachian tube, ossicles:
hammer (malleus), anvil (incus), stirrup (stapes)

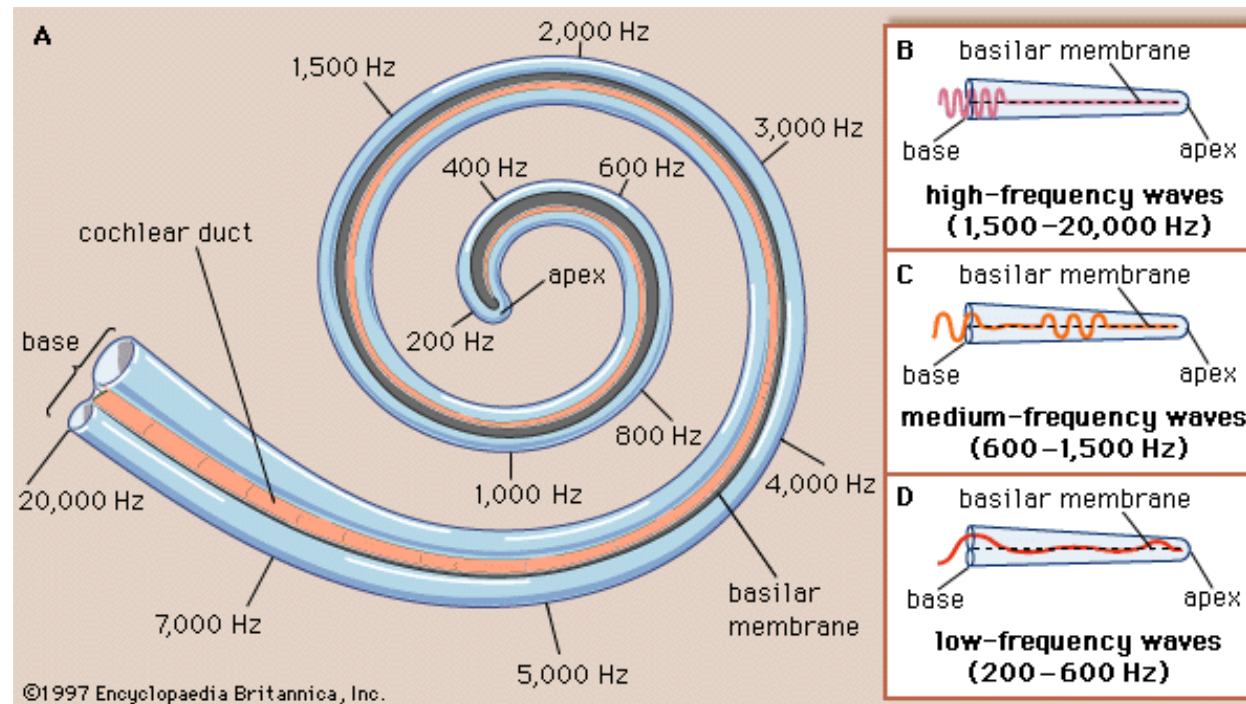
Inner ear: cochlea, oval window, round window, basilar membrane, hair cells, auditory nerve



Place theory

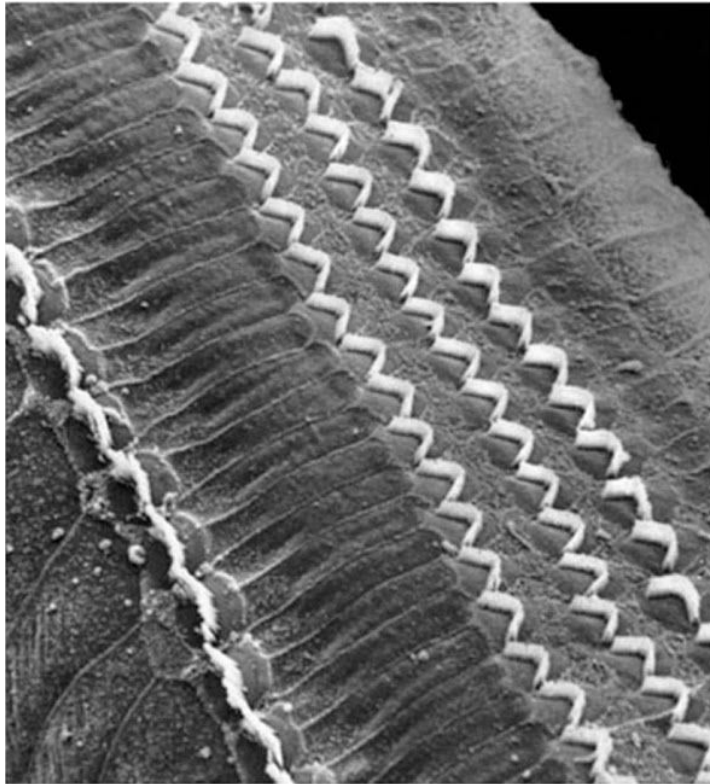
- Inner ear converts intensity information to frequency information (cochlea=“mechanical spectrum analyzer”)
- Different places on the basilar membrane pick up different frequencies

The closer to the base, the higher the resonant frequency



Tinnitus (ringing)

Caused by random movement of damaged hair cells in cochlea, which the brain interprets as sound.



Intact cochlea



Damaged cochlea

Protect your hearing!!

- Hearing damage is cumulative and permanent.
- Very high quality hearing protection can be had for ~\$20 (universal fit) or ~\$200 (custom fit). They are spectrally flat and sound great!



Gross-looking custom earplugs sound great and save your ears!

Noise Source	Decibel Level (dB)	How long can you listen without protection?
Jet take off	130	0 minutes
Ambulance siren	109	Less than 2 minutes
Personal music player at maximum volume	106	3.75 minutes
Pop/Rock concert	103	7.5 minutes
Riding a motorcycle	97	30 minutes
Using an electric drill	94	1 hour
Lawnmower or leaf blower	85	2 hours