Physics of Sound

What is sound?

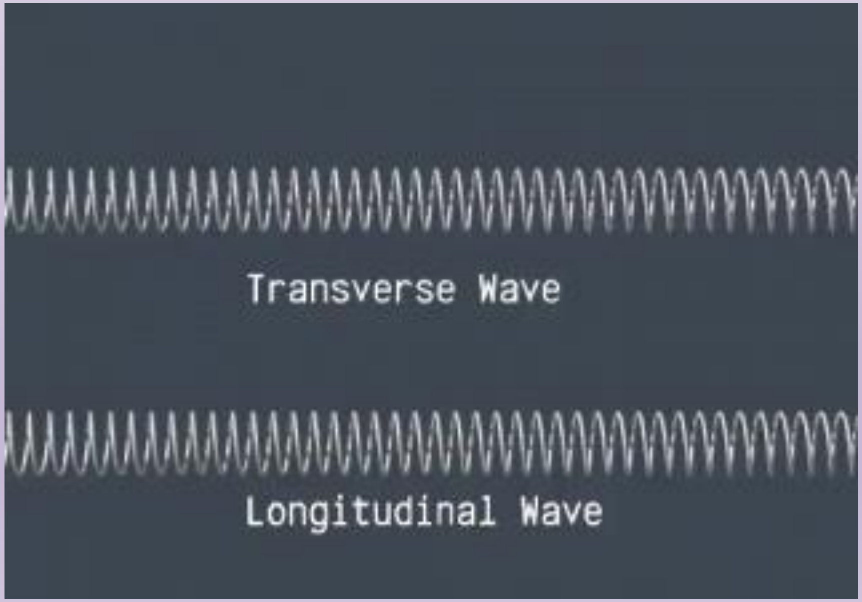
- Vibrations that travel through the air (or another medium) that can be heard when they reach the ear

- Sound may be classified as noise based on its magnitude, characteristics, duration and time of occurrence

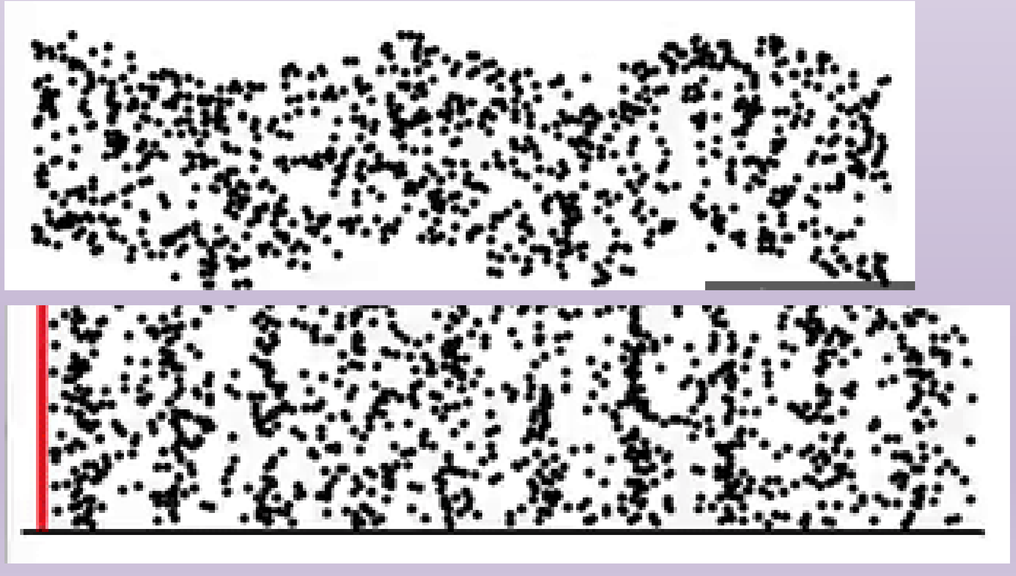
Sound Waves

Transverse vs. longitudinal

- Transverse wave: A wave vibrating at right angle to the direction of its propagation
- Longitudinal wave: A wave vibrating parallel to the direction of its propagation



Transverse vs. longitudinal wave; Physics007animations [1]

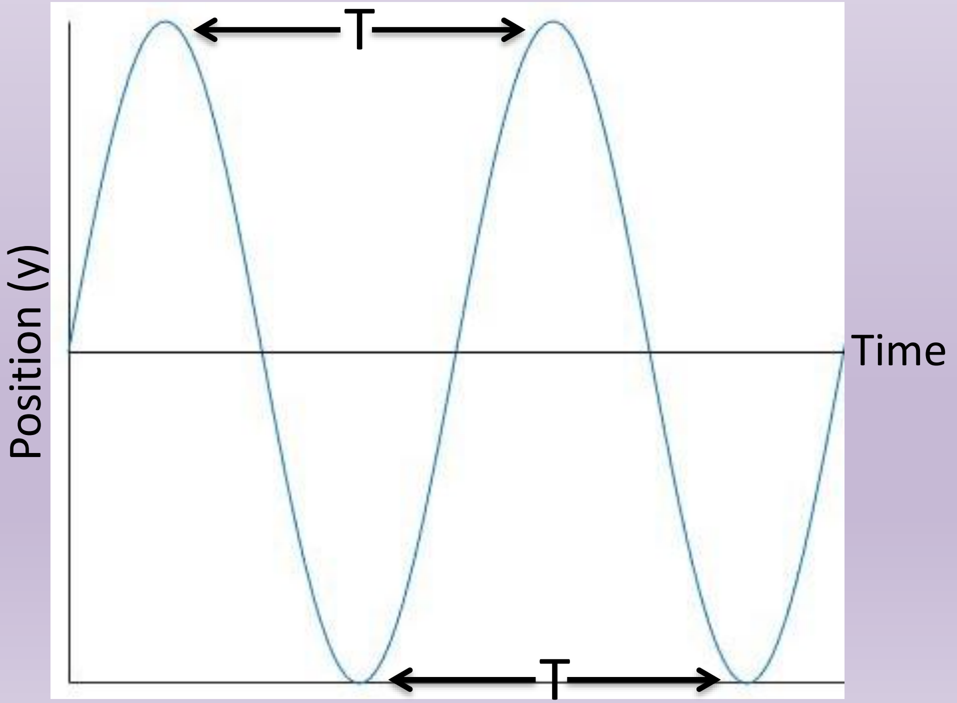


Transverse vs. longitudinal; 2011 Dan Russell [2]

Wave Properties

Frequency (f)

- The number of waves passing a point in a certain time
  A sound wave consists of a repeating pattern of high-pressure and low-pressure regions moving through a medium
- Frequency units are hertz (Hz)
  1 hertz = 1 wave per second



$f = 1/T$

OR $f = v/\lambda$

f = frequency

v = wave velocity

λ = wave length

T = time or period

Frequency

- Sound is classified according to its frequency and pressure
- High and low hertz numbers characterize high and low tones, respectively
- Humans are able to perceive sounds in the range of ~20 Hz to 20,000 Hz[3]

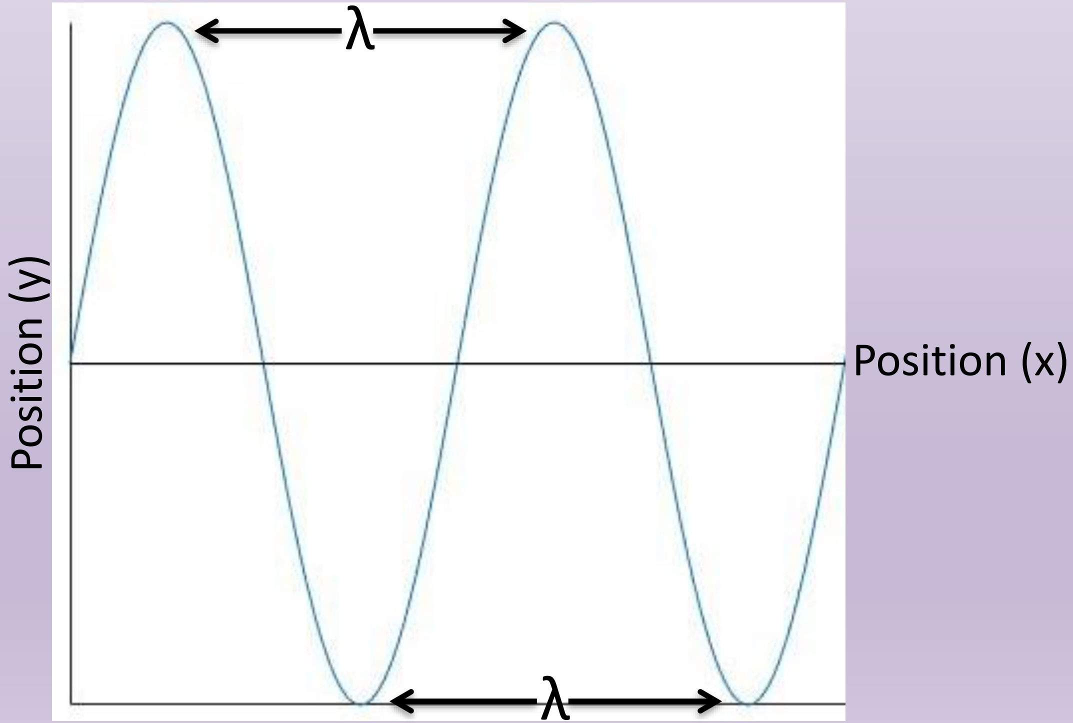
Wave Properties

Wavelength (λ)

- Distance from a particular point on a wave to the next point that is at the same height, going in the same direction
- Wavelength is measured in meters

Again $f=v/\lambda$

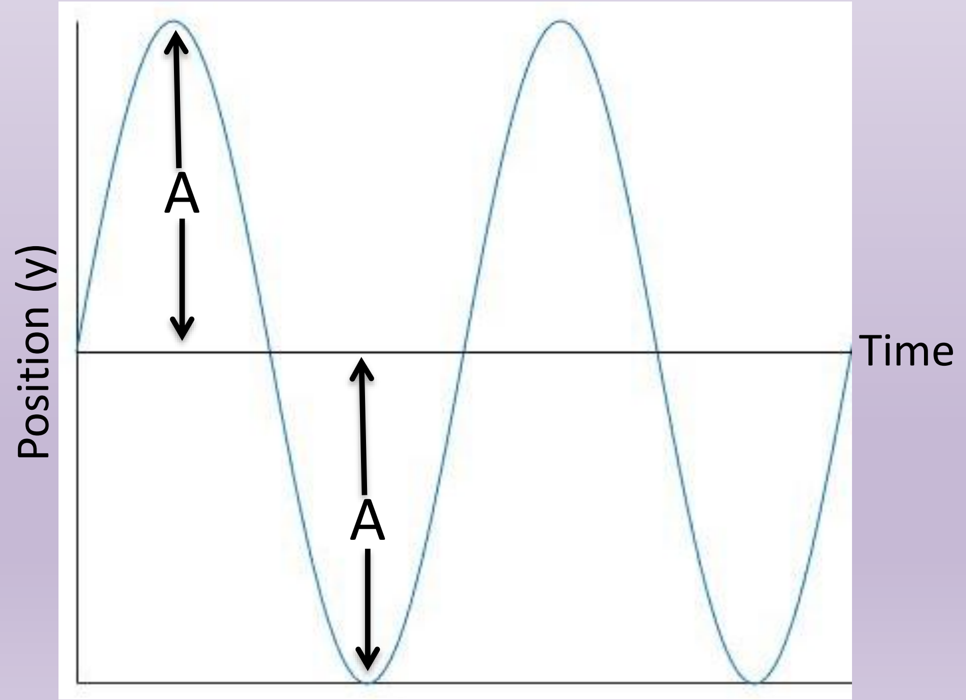
➔ $\lambda=v/f$



Wave Properties

Amplitude (A)

- The distance from the center line to the top of a crest or to the bottom of a trough
- Measured in meters



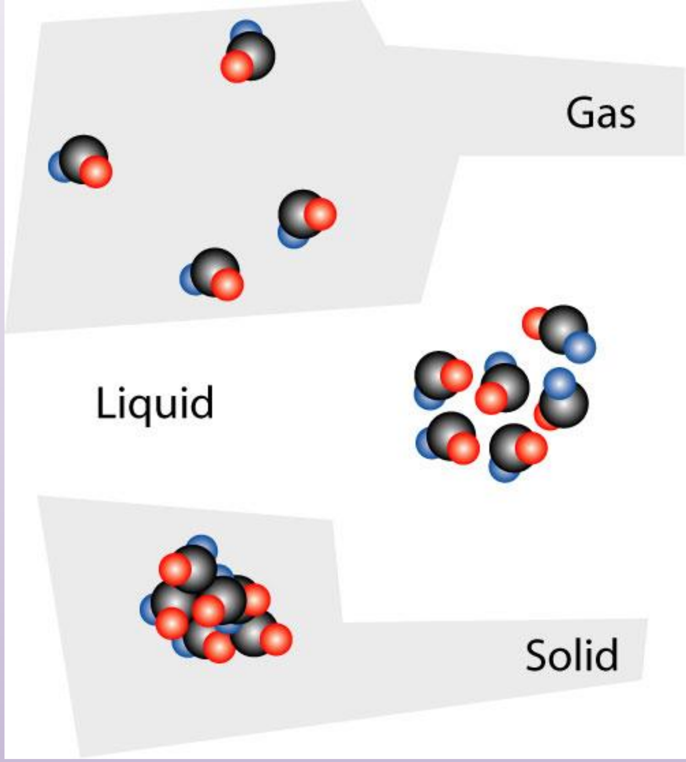
Speed of Sound

- Sound waves need to travel through a medium (for example, solids, liquids, gases)
- Sound waves move through various mediums by vibrating the molecules in the matter
- The speed of sound varies in different media (for example, solids, liquids, gases)
- Temperature also dictates how fast sound waves travel

Sound Waves in Solids, Liquids and Gases

Molecules are:

- tightly packed in rigid material
- less tightly packed in liquid
- loosely packed in gas



In close proximity, molecules collide with one another to propagate waves of vibrations

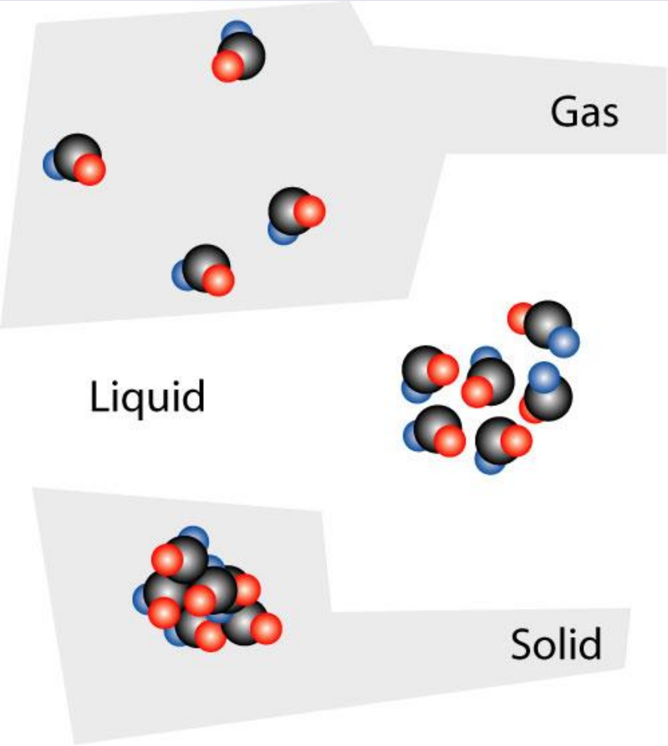
Sound Waves in Solids, Liquids and Gases

- Sound travels faster in solids than in gases

  For example, sound waves move ~13 times faster in wood than in air[4]

- Sound travels faster in liquids than in gases

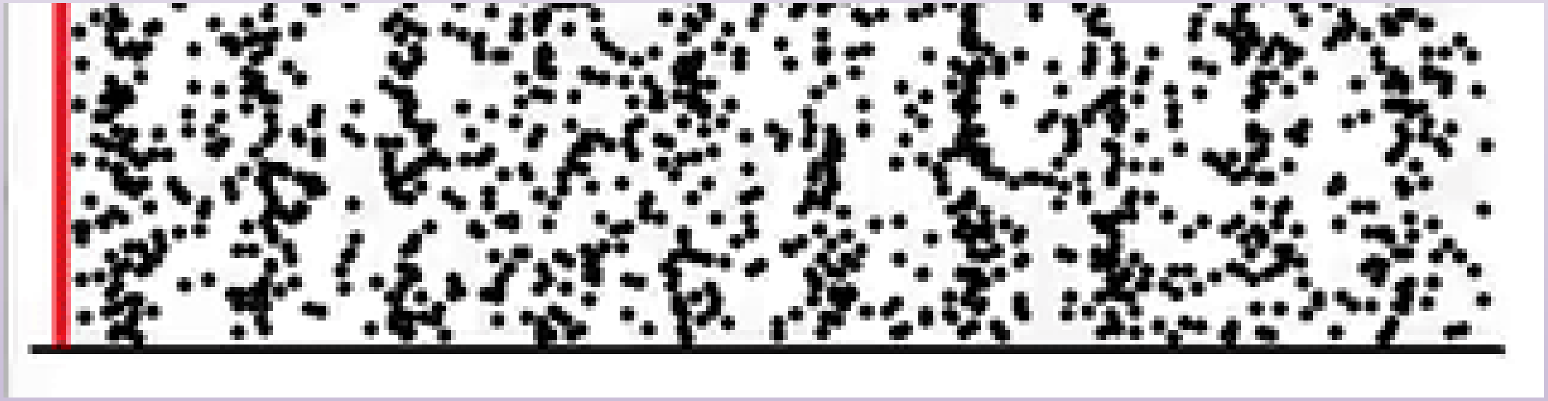
- Loosely packed molecules have further to travel and take longer to collide with one another



Graphic of molecules of solid, liquid and gas

Sound Waves in Media

Recall the longitudinal wave:



Transverse vs. longitudinal; 2011 Dan Russell [2]

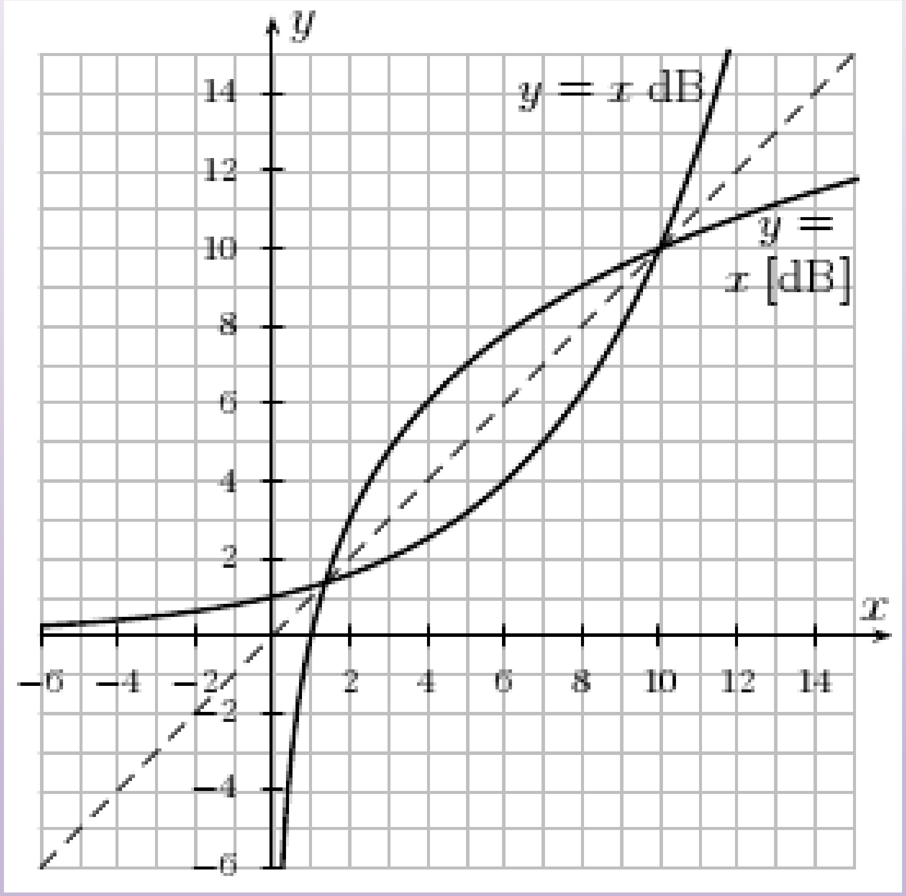
Sound Measurement

- The scale for measurement of sound pressure is called decibels (dBs)
- Decibels are measured on a logarithmic scale
  - A small change in the number of decibels results in a huge change in the amount of noise and the potential damage to a person's hearing[5]

Decibel

$$b(dB) = 10\log\left(\frac{I}{I_0}\right)$$

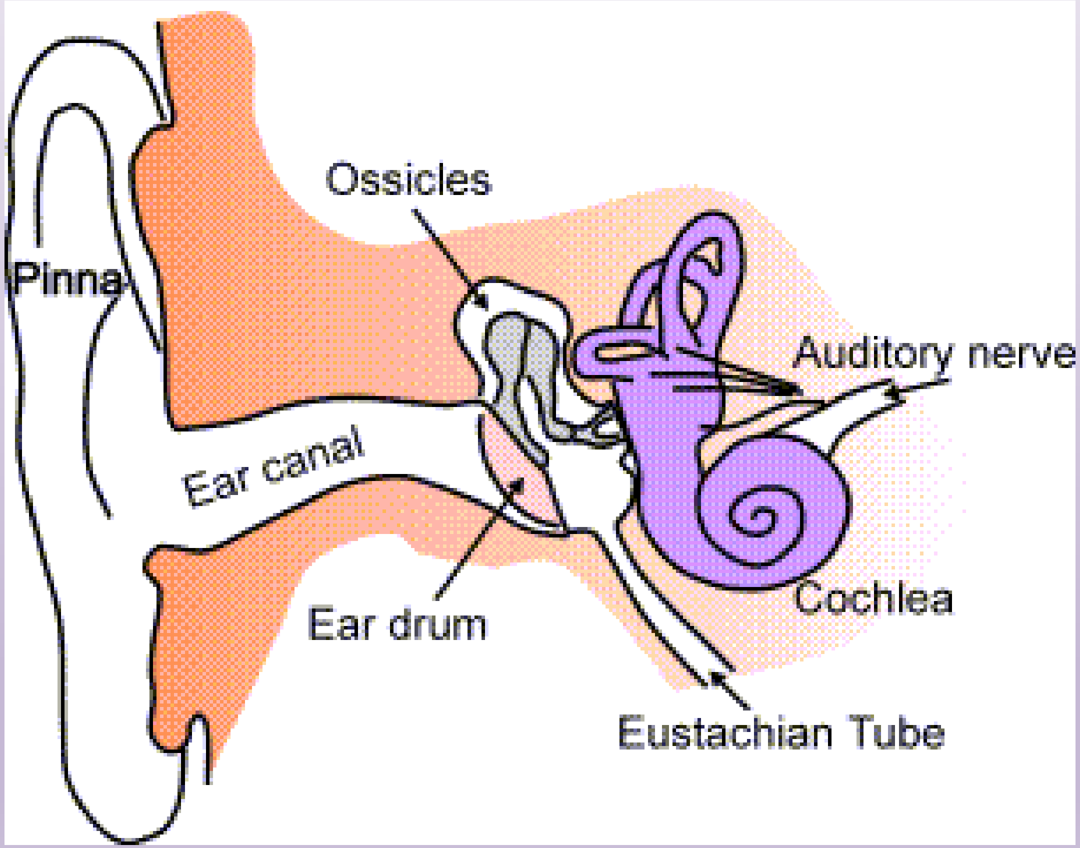
- When a sound increases by 10 units on the decibel scale, its loudness becomes 10 times more powerful
- β represents sound intensity level measured in dB



Graph of the decibel function and its inverse
2010 Name, Wikimedia Commons CC BY-SA 3.0
https://commons.wikimedia.org/wiki/File:Plot_of_decibel_and_inverse.png

How do people hear?

The human ear translates the energy from sound waves into neurologic impulses that are heard as sound[5]

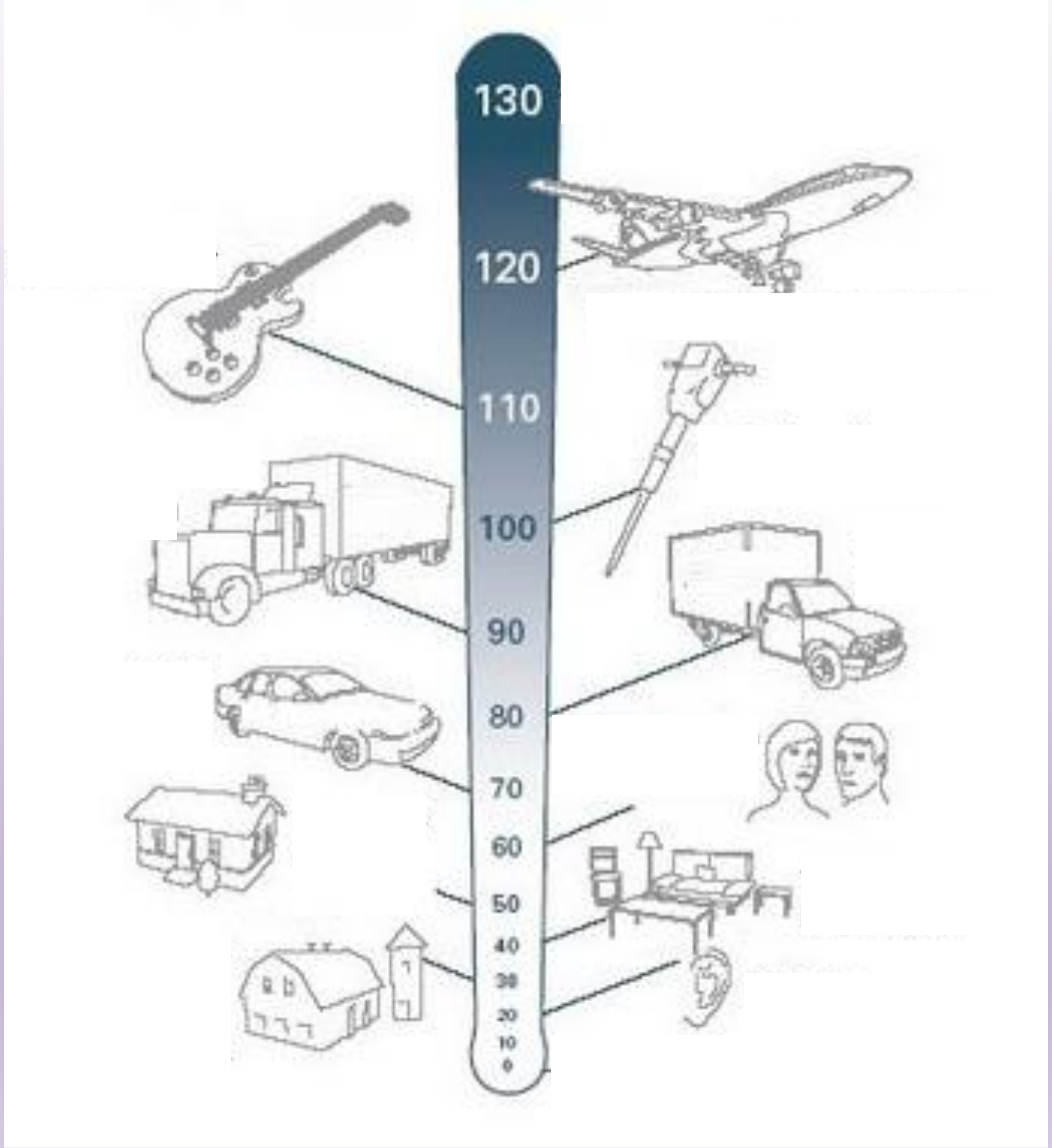


Cutaway diagram of human ear anatomy
2003 Iain at English Wikipedia
https://commons.wikimedia.org/wiki/File:Ear-anatomy-text-small-en.png

Sound vs. Noise

Noise is unwanted or unpleasant sound

- One person may hear something as sound, while another person considers it noise
- Sound may be classified as noise based on its magnitude, characteristics, duration and time of occurrence[6]



The A-weighted sound levels closely match the perception of loudness by the human ear

Decibel scale
2017 Department4,

Health Hazards/Impacts

- Exposure to loud noises can cause a temporary threshold shift (TTS) in hearing sensitivity or a permanent threshold shift (PTS)[5]
- A noise-induced permanent threshold shift (NIPTS) is a permanent threshold shift that can be attributable to noise exposure

Health Hazards/Impacts to Students

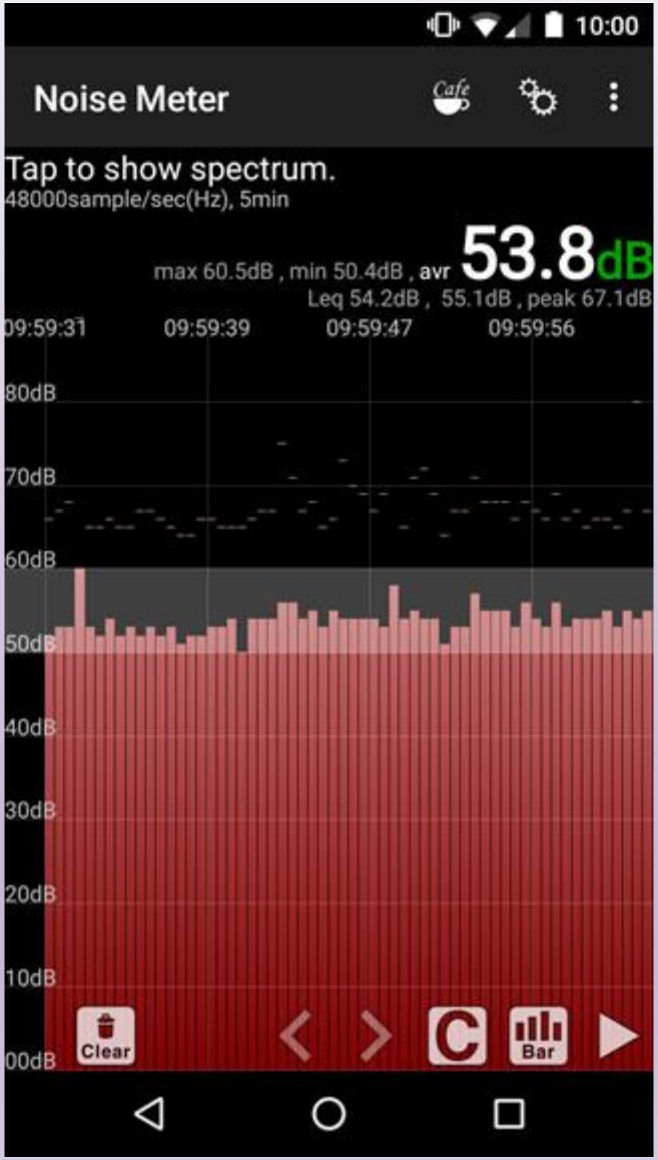
High noise levels may obstruct students' recognition of teachers' speech

- The extra effort required to identify and remember the words may result in fewer resources available for understanding[7]

Sound Measurement

Sound level meter:

- Commonly, a handheld instrument with a microphone
- The microphone diaphragm responds to air pressure changes caused by sound waves[5]
- Smart phones now have sound monitor apps



Noise Meter app on smart phone
2016 Kent Kurashima and Jana B. Milford, College of Engineering and Applied Science, University of Colorado Boulder (authors)

Sound Measurements

- Dosimetry: The use of body-worn instruments to monitor people's noise exposure[5]
- Engineering surveys: Noise exposure monitoring

Pocket dosimeter; a NMR monitoring device with three Hall-effect sensors
2010 Elia.braggio, Wikimedia Commons (public domain)
https://commons.wikimedia.org/wiki/File:Pocket_Dosimeter.jpg

References

[1] "Transverse wave and longitudinal Wave." (6-second video) YouTube. Physics007animations, Sept. 2, 2011. https://www.youtube.com/watch?v=2Wlh3M2a10U

[2] Russell, Dan. "Acoustics and Vibration Animations." Longitudinal and Transverse Wave Motion. Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

[3] Serway, Raymond A, and John W. Jewett, Jr. *Physics for Scientists & Engineers with Modern Physics*. 8th edition. Belmont: Brooks/Cole Cengage Learning, 2010. Print.

[4] Hall, Debra, and Crystal Patillo. "2.7 How does sound travel in different environments?" Kenan Fellows Program, BioMusic, Learn NC, School of Education, University of North Carolina. http://www.learnnc.org/lp/editions/biomusic/6517

[5] Friis, Robert H. *Occupational Health and Safety for the 21st Century*. Burlington, MA: Jones & Bartlett Learning, 2015. Web. library.books24x7.com.colorado.idm.oclc.org/toc.aspx?bookid=93068 (e-book access requires login)

[6] "Perception of Sound - Human Ear." Sound and Noise - Perception of Sound - Human Ear. Web. http://www.epd.gov.hk/epd/noise_education/web/text/ENG_EPD_HTML/m1/intro_1.html

[7] Kjellberg, Anders, Robert Ljung, and David Hallman. "Recall of Words Heard in Noise." *Applied Cognitive Psychology*, vol. 22, no. 8, 2008, pp. 1088-98. Web. http://onlinelibrary.wiley.com/doi/10.1002/acp.1422/abstract