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
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
- \( \lambda \) = 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 \( f = \frac{v}{\lambda} \)

\[ \Rightarrow \lambda = \frac{v}{f} \]
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

Graphic of molecules of solid, liquid and gas
2007 Yupi666 at English Wikipedia CC BY-SA 3.0
https://commons.wikimedia.org/wiki/File:Solid_liquid_gas.jpg
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

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Graphic of molecules of solid, liquid and gas

2007 Yupi666 at English Wikipedia CC BY-SA 3.0
https://commons.wikimedia.org/wiki/File:Solid_liquid_gas.jpg
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**

\[(dB) = 10 \log \left( \frac{I}{I_0} \right)\]

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

![Graph of the decibel function and its inverse](https://commons.wikimedia.org/wiki/File:Plot_of_decibel_and_inverse.png)

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\textsuperscript{[5]}
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,
Wikimedia Commons CC BY SA-4.0
https://commons.wikimedia.org/wiki/File:Decibel_scale.jpg
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\textsuperscript{[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

[^5]: Elia.braggio, Wikimedia Commons (public domain) - 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


