HEARING

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Outline

• Sound and its wave properties
• Sound intensity
• Structure of the ear
• Signal transduction in the ear
• Function of the inner ear, hair cells
1. Frequency (Pitch, temporal periodicity, Hz)

2. Wavelength (spatial periodicity, m)

3. Amplitude (pressure, Pa)

4. Intensity (power density, W/m²)

   \[ I = \frac{\Delta E}{\Delta t \cdot \Delta A} = \frac{p^2}{2Z} \quad p_{eff} = \frac{p}{\sqrt{2}} \]

   \[ Z = \rho \cdot c \]

5. Absorption

   \[ I = I_0 \cdot e^{-\mu \cdot x} \]

   \[ \mu (Z, f) \]

6. Reflection

   \[ R = \frac{l_{refl}}{l_{in}} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2} \]
## Sound and tone

<table>
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<tr>
<th>PHYSICS</th>
<th>PSYCHOLOGY</th>
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<td>Pressure</td>
<td>Sound perception</td>
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<tr>
<td>Intensity (W/m²)</td>
<td>Loudness (Phon, Son)</td>
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<td>fundamental tone, fundamental frequency</td>
<td>Pitch</td>
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<tr>
<td>Harmonic, spectrum</td>
<td>Quality, timbre</td>
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</table>

![Musical notes and sound wave diagram]
Absolute and relative intensity

\[ I = \frac{p^2}{2 \cdot \rho \cdot c} \]

\[ n = 10 \cdot \log_{10} \frac{I}{10^{-12} \text{ W/m}^2} \]

**Psychological Responses to Various Sound Intensities**

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<tr>
<th>Psychological Response</th>
<th>Decibel Scale</th>
<th>Examples</th>
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<tr>
<td>Threshold of severe pain/Painfully loud</td>
<td>140</td>
<td>Rock band at 15 ft</td>
</tr>
<tr>
<td>Very annoying</td>
<td>120</td>
<td>Jet takeoff at 200 ft</td>
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<tr>
<td>Prolonged exposure produces damage to hearing</td>
<td>100</td>
<td>Riveting machine</td>
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<tr>
<td>Quiet</td>
<td>80</td>
<td>Subway train at 15 ft</td>
</tr>
<tr>
<td>Very quiet</td>
<td>60</td>
<td>Water at foot of Niagara Falls</td>
</tr>
<tr>
<td>Just audible</td>
<td>40</td>
<td>Inside automobile at 55 mph</td>
</tr>
<tr>
<td>Threshold of hearing</td>
<td>0</td>
<td>Normal traffic at 50 ft</td>
</tr>
<tr>
<td>Normal conversation at 3 ft</td>
<td>30</td>
<td>Quiet restaurant</td>
</tr>
<tr>
<td>Quiet hospital</td>
<td>20</td>
<td>Quiet office</td>
</tr>
<tr>
<td>Whisper at 3 ft</td>
<td>10</td>
<td>Library</td>
</tr>
<tr>
<td>Normal Breathing</td>
<td>0</td>
<td>TV</td>
</tr>
</tbody>
</table>
Structure of ear

Auditory duct: 2.5x0.7 cm
Tympanic membrane: 65-75 mm²
Sound waves are collected by the pinna and travel down the auditory canal to the tympanic membrane, which vibrates at the same frequency as the sound.

The first of the ossicles is attached to the tympanic membrane, and this bone begins to vibrate, amplifies the vibration and then passes the vibration on to the other two ossicles, which also amplify the vibration.

The hair cells of the organ of Corti detect the vibration and pass a message to the brain via the auditory nerve. Different sounds move the hair cells in different ways, thus allowing the brain to distinguish various sounds.
The organ of Corti

~ 3500 inner and 12,000-15,000 outer hair cells
WHEN STEREOLCILIA BEND, A SEQUENCE OF EVENTS RESULTS IN THE RELEASE OF NEUROTRANSMITTER.

1. Arrival of pressure wave bends stereocilia.
2. Potassium channels open in response to bending.
3. Membrane depolarizes due to influx of K⁺.
4. Depolarization triggers influx of calcium ions.
5. Ca²⁺ causes synaptic vesicles to fuse with plasma membrane.
6. Neurotransmitter is released and diffuses to afferent neuron.

Figure 46-4b Biological Science, 2/e © 2005 Pearson Prentice Hall, Inc.
Traveling wave

- High-frequency waves (1,500–20,000 Hz)
- Medium-frequency waves (600–1,500 Hz)
- Low-frequency waves (200–600 Hz)
Loudness

The curves represent equal loudness as perceived by the average human ear.

The ear is less sensitive to low frequencies, and the discrimination against lows becomes steeper for softer sounds.

The maximum sensitivity region for human hearing is around 3-4 kHz and is associated with the resonance of the auditory canal.

Sound intensity in decibels does not directly reflect the changes in the ear's sensitivity with frequency and with sound level.

\[ H = \left( \frac{L-40}{10} \right)^{0.301} \]
Thank you for your attention!

Superglue is no toy!