Hearing

- Sound and its characteristics. The decibel scale.
- Structure and function of the ear.
- Békésy’s theory.
- Molecular basis of hair cell function.

Sound

- A type of **longitudinal mass wave** that originates as the vibration of a medium (such as a person's vocal cords or a guitar string) and travels through gases, liquids, and elastic solids as **variations of pressure and density**.
Waves
A disturbance, oscillation, or vibration either of a medium or of some quantity with different values at different points in space, moving through space.

Energy is transferred with waves.

Classification
- based on the needs for a medium to propagate
  - mass waves (propagate through a medium)
  - electromagnetic waves (travels through vacuum)
- based on the direction of its vibration (oscillation) and the direction of propagation
  - transverse (A wave that oscillates perpendicular to the axis along which the wave travels (e.g. electromagnetic waves)
  - longitudinal (A wave that oscillates back and forth on an axis that is the same as the axis along which the wave propagates (e.g. sound waves).

Wave equation
\[ c = v \lambda \]
- \( c \): speed of the wave (m/s)
- \( v \): frequency of the wave \((s^{-1})\) – number of waves/seconds
- \( \lambda \): wavelength (m)

Longitudinal wave

Compression (high density or high pressure)    Expansion (low density or low pressure)

Direction of travel
**Sound intensity (loudness)**

\[ I(dB) = 10 \log_{10} \frac{I}{I_0} \]

- \( I_0 \): threshold intensity \((10^{-12} \text{ W/m}^2)\)
- Bel (B): a unit for comparing two power levels (Alexander Graham Bell (1847-1922)).
  - equal to the logarithm to the base ten of the ratio of the two powers
  - 1 Bel = 10 dB
  - 1 dB \( \Rightarrow \) the just noticeable difference in sound intensity for the normal human ear

**Sound pressure**

\[ I(dB) = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \left[ \frac{p^2}{p_0^2} \right] = 20 \log_{10} \frac{p}{p_0} \]

- \( P_0 = 2 \times 10^{-5} \text{ N/m}^2 = 20 \mu\text{Pa} \) (in air)
- The power \((I)\) carried by a traveling wave is proportional to the square of the amplitude of the pressure wave \((p)\).
Pitch

- The **pitch** of a sound depends on its frequency (hertz).
- audible sound: 20-20.000 Hz
  - bass: deep tone – low frequency
  - treble: high tone – high frequency

Timbre (tone)

- ~ the quality of the sound
- mainly determined by the **harmonic content** of a sound
- harmonics: a component of a sound, with a frequency that is an integral multiple of the fundamental frequency.
  - first harmonic: the fundamental frequency \( f_0 \)
  - second harmonic (first overtone) (twice the fundamental frequency \( 2f_0 \))
  - third harmonic (second overtone) (three times the fundamental frequency \( 3f_0 \))
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<tr>
<th>REGIONS OF THE EAR AND KEY STRUCTURES</th>
<th>FUNCTIONS</th>
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<tr>
<td><strong>EXTERNAL EAR</strong></td>
<td></td>
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<tr>
<td>• Auricle</td>
<td>Collects sound waves.</td>
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<tr>
<td>• External auditory canal</td>
<td>Directs sound waves to the eardrum.</td>
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<tr>
<td>• Tympanic membrane (eardrum)</td>
<td>Sound waves vibrate it and the vibration will be transferred to malleus.</td>
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<tr>
<td><strong>MIDDLE EAR</strong></td>
<td></td>
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<tr>
<td>• Auditory ossicles (malleus, incus, stapes)</td>
<td>Transmit and amplify vibrations from tympanic membrane to oval window.</td>
</tr>
<tr>
<td>• Auditory (Eustachian) tube</td>
<td>Equalizes air pressure on both sides of the tympanic membrane.</td>
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<tr>
<td><strong>INTERNAL (INNER) EAR</strong></td>
<td></td>
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<tr>
<td>• Cochlea</td>
<td>Contains the spiral organ (organ of Corti), the organ of hearing. Hair cells are produce receptor potential.</td>
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<tr>
<td>• Vestibular apparatus</td>
<td>Responsible for balancing.</td>
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</table>

**Georg von Békésy**

- The Nobel Prize in Physiology or Medicine in 1961: "for his discoveries of the physical mechanism of stimulation within the cochlea"
- Traveling wave theory
Traveling wave

The wave is moving in one direction.

Vibration transferred to the basilar membrane

- position of the protrusion $\sim$ frequency
- height of the amplitude $\sim$ intensity
The shift in the place of maximum vibration at different frequencies

Vibration in the basilar membrane

- Based on the mechanical properties the basilar membrane respond at different positions to different frequencies.
  - high frequency: big response near the base of the cochlea
  - low frequency: big response at the apex of the cochlea
- The basilar membrane is able to “decompose” a complex sound into its component frequencies.
Hair cells

• convert a mechanical vibration (stimulus) into an electrical signal (receptor potential).
• Mechanical vibration moves hair cells against tectorial membrane → bending of the hair cell stereocilia → receptor potential → nerve impulse

The end!