Acoustics

Acoustics

- Deals with the creation of sound waves, their transmission in space and with perception of sound
  - Physical Acoustics - observes the way of sound creation and transmission in space, reflection and absorption of different materials
  - Physiological acoustics – sound creation in the vocal cords and the perception of sound in the auditory system, the effect of noise

Sound

- The origin of the sound comes from an arranged oscillatory motion of a particle environment, which occurs when the particles are supplied with energy

- As a result of the interaction of particles, oscillating movement is transmitted to the neighboring particles = sound wave propagation

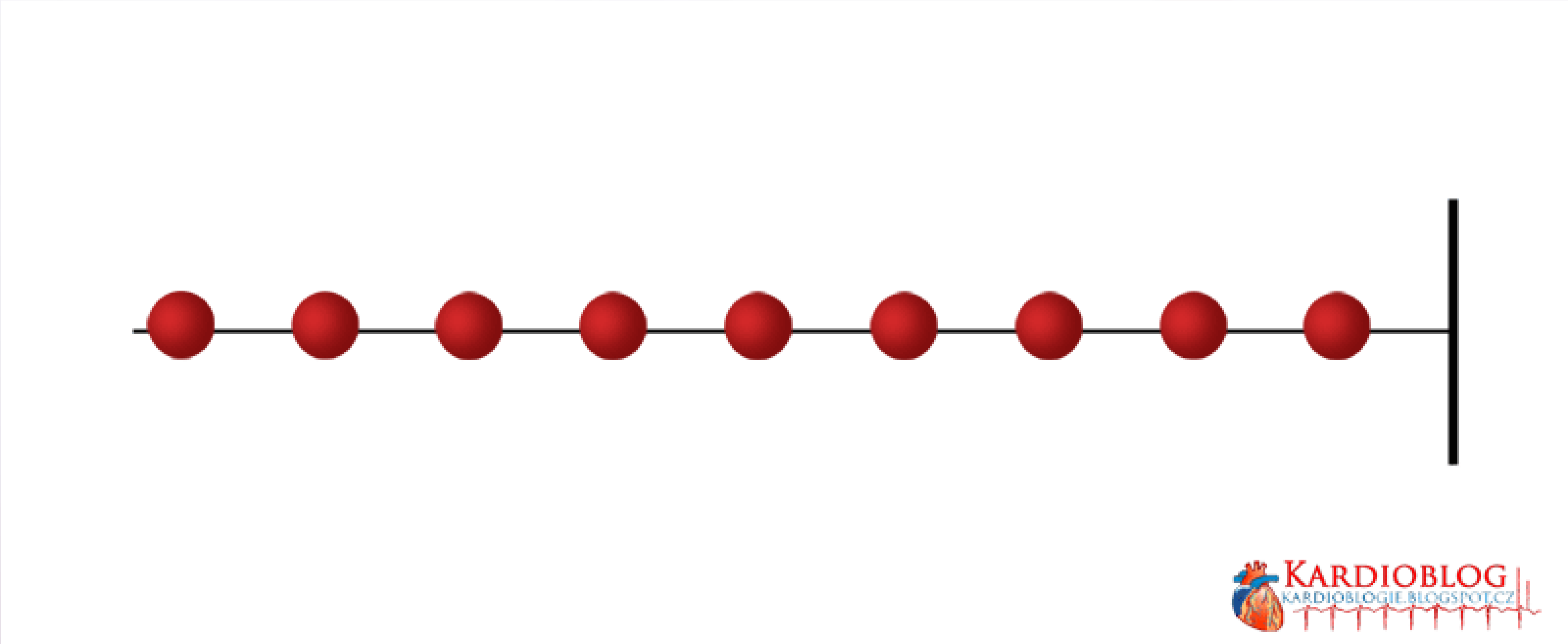
Sound wave propagation

- Propagation speed depends on:
  - Environment
  - Temperature, pressure
  - Humidity

- Sound waves propagation can happen by longitudinal or by transverse oscillation

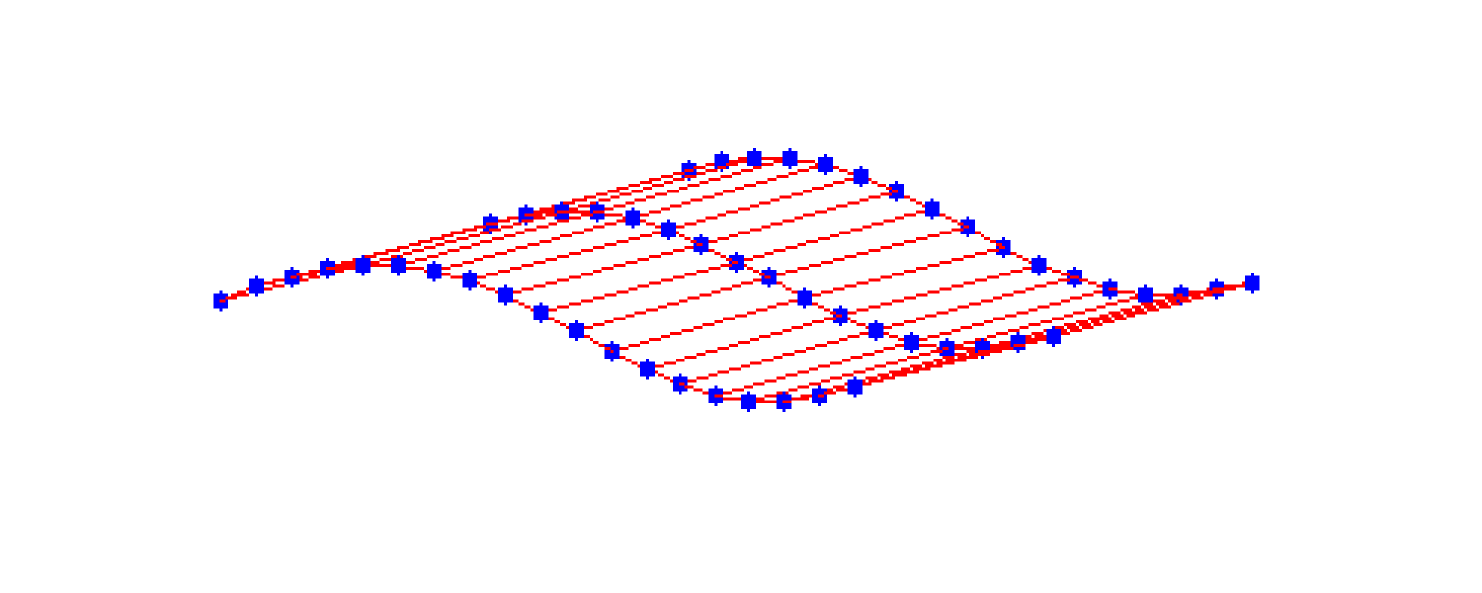
Sound wave propagation

- Longitudinal oscillation
  - Gaseous, liquid and solid environment
  - Thickening and thinning of particles



Sound wave propagation

- Transversal oscillation
  - Solid environment
  - Oscillation is perpendicular to the direction of the sound wave propagation



Basic quantities

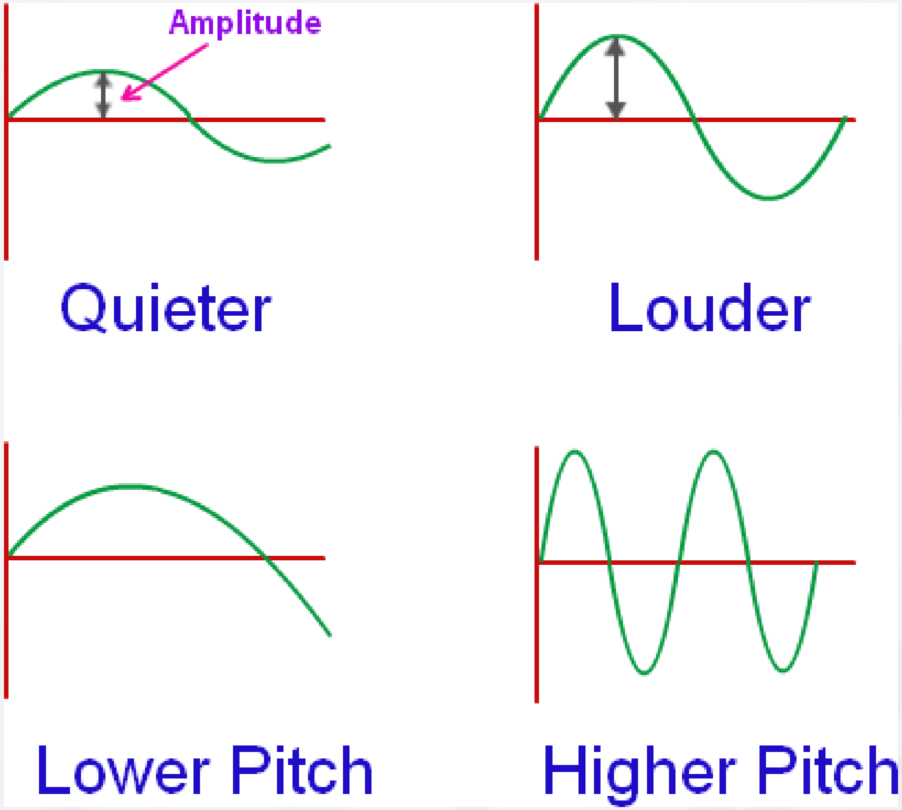
- Frequency of oscillatory motion f (Hz)
- Period of oscillatory motion T (s)
- Propagation speed c ($m.s^{-1}$)
- Wave lenght λ (m)

$$\lambda = \frac{c}{f} \qquad \lambda = c.T$$

Sound

- Infrasound - low frequency (16-20 Hz), inaudible to human ears
- Audible sound area (20-20 000 Hz;)
- Ultrasound - Frequencies higher than 20,000 Hz

Sound



Sound

- Sound
  - Tones - Musical sound, tones – dependence of intensity on time is a periodical function (Vowels)
    - Simple
      - harmonical, sinus function (sine wave)
    - Composited
      - Periodical; but not sine wave. Basic frequency + other hramonical frequencies
  - Noises - dependence of intensity on time is not a periodical function (consonant)
- Pitch – dependence on frequency
- Tone Timbre – dependence on partial tones intensity

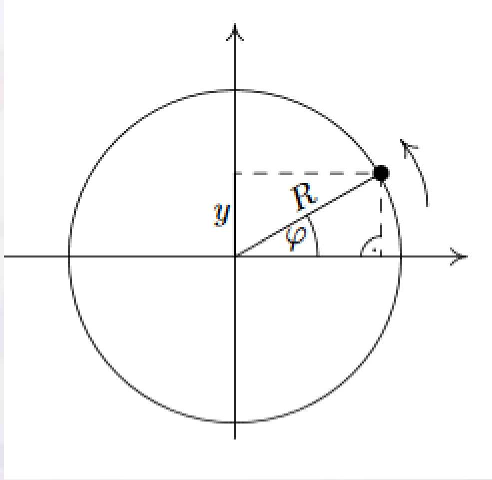
Acoustic displacement

- Acoustic displacement is deflection of a particle from its equilibrium position, it is caused by acoustic wave
- If a displacement meets following requirements:

$$a = a_{\max}.\sin(\omega.t) = a_{\max}.\sin(2\pi.f.t)$$

then the oscillation is harmonical

a_{max} = amplitude



- $\Delta\varphi = \omega\Delta t$
- $\omega = 2\pi f$

Acoustic velocity of oscillatory motion

- Immediate speed of oscillating particle:

$$v = v_{\max}.\cos(\omega.t) = v_{\max}.\cos(2\pi.f.t)$$

$$v_{\max} = a_{\max}.\omega = a_{\max}.2\pi.f$$

Acoustic pressure

- Movement of vibrating molecules is causing local pressure changes

$$p = p_{max}.\cos(2\pi.f.t)$$

$$p_{max} = \rho.c.v_{max}$$

Effective values

- at some calculations instantaneous values of acoustic velocity and sound pressure can be replaced with so called effective values
- For the harmonic pattern of oscillations effective pressure and speed can be determined by the relationship:

$$v_{ef} = \frac{v_{\max}}{\sqrt{2}} \qquad p_{ef} = \frac{p_{\max}}{\sqrt{2}}$$

Acoustic impedance

- **Acoustic impedance** - describes the acoustic properties of the environment. It is calculated as the ratio of the effective values of sound pressure and acoustic velocity

$$Z = \frac{p_{ef}}{v_{ef}} \qquad Z = c.\rho \qquad \text{Pa.s.m}^{-1}$$

- The impedance is characteristic for each environment; affects the size of the reflection at interfaces between environments
- By passing through the interface the propagation speed c is changed
- Passage through environment may result in partial absorption of energy (reduction in amplitude and acoustic velocity)

Intensity

- Intensity – the amount of energy that passes through an area perpendicular to the propagation direction of waves per time unit

$$I = \frac{P}{S} \qquad I = \frac{p_{ef}^2}{\rho . c}$$

(W.m^{-2})

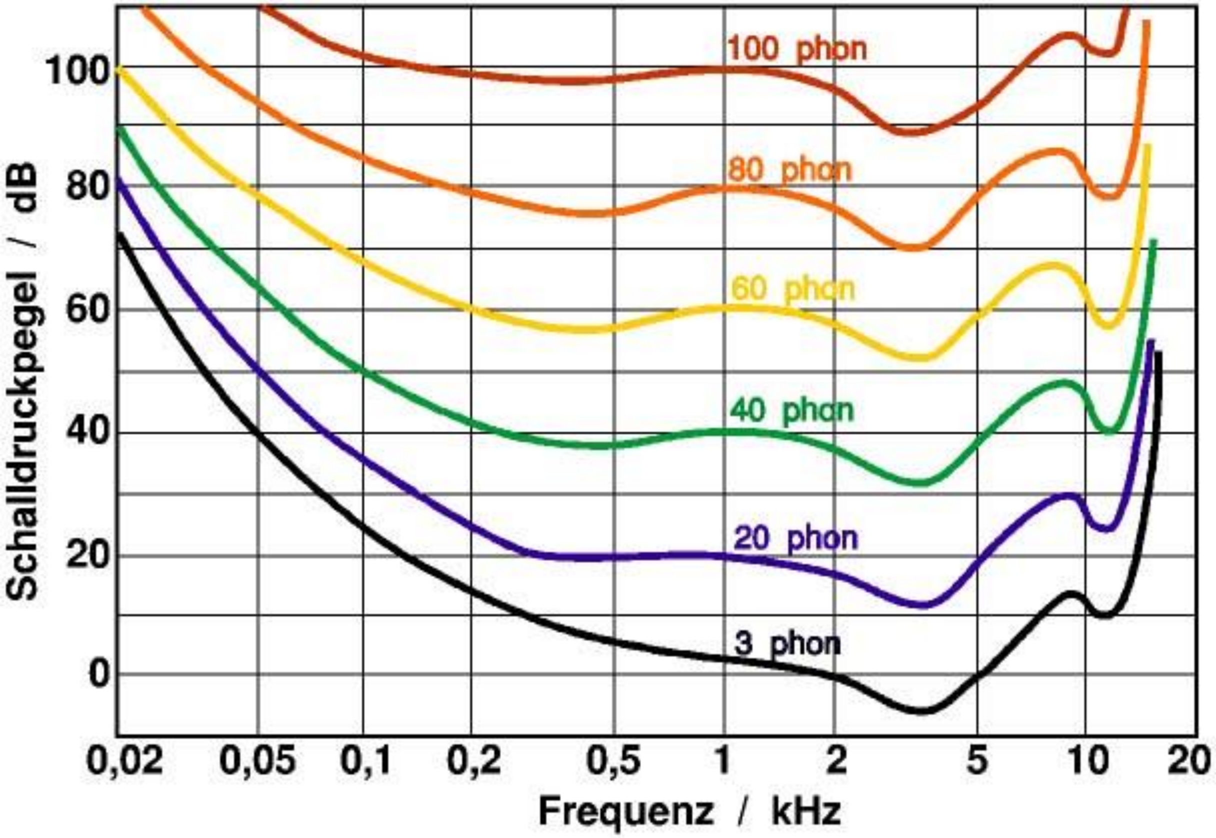
Loudness

- Level of intensity
  - Range of percepted intensity in $W.m^{-2} = 10^{12}$
  - Level of intensity creates more practical intensity description

$$L_{(dB)} = 10 \log \frac{I}{I_0}$$

- Loudness perception is subjective; Furthermore, the human ear differently sensitive to different frequencies
- Loudness level Λ (Ph – phon)
  - 1 phon corresponds to the intensity level of 1 dB for reference tone at a frequency of 1 kHz

Loudness



100 phon
80 phon
60 phon
40 phon
20 phon
3 phon
100
80
60
40
20
0
Schalldruckpegel / dB
0,02
0,05
0,1
0,2
0,5
1
2
5
10
20
Frequenz / kHz

Physiological acoustics

- Voice
  - Vocal cords: two ligaments stretched between the thyroid cartilage and vocal cord cartilage; during speaking, the vocal cords are stretched, thus changing the lumen Exhaled air vibrates => vibrating vocal cords rhythmically interrupt the flow of air going out of the trachea

Physiological acoustics

- Voice
  - larynx, oral cavity and nasopharynx = **voice tube** = gives human color to laryngeal voice
  - Great influence on the final form of sound has **resonance**
  - The final formulation into syllables is also possible due to upper respiratory pathways, mouth, tongue, lips, and teeth
  - Vocal strength increases with increasing the airflow through the glottis

Physiological acoustics

- Area of hearing **16 Hz to 20,000 Hz**
  - we perceive 1000-5000 Hz best
- Below 16 Hz **infrasound**
- Over 20,000 Hz **ultrasound**
- **Outer ear** - captures and maintains signal; auricle (pinna) and external ear canal; most audible sounds are sounds that are coming in an angle of 15 ° to the axis of both ears, external ear canal = resonator **(2000-6000 Hz)**

Physiological acoustics

Middle ear

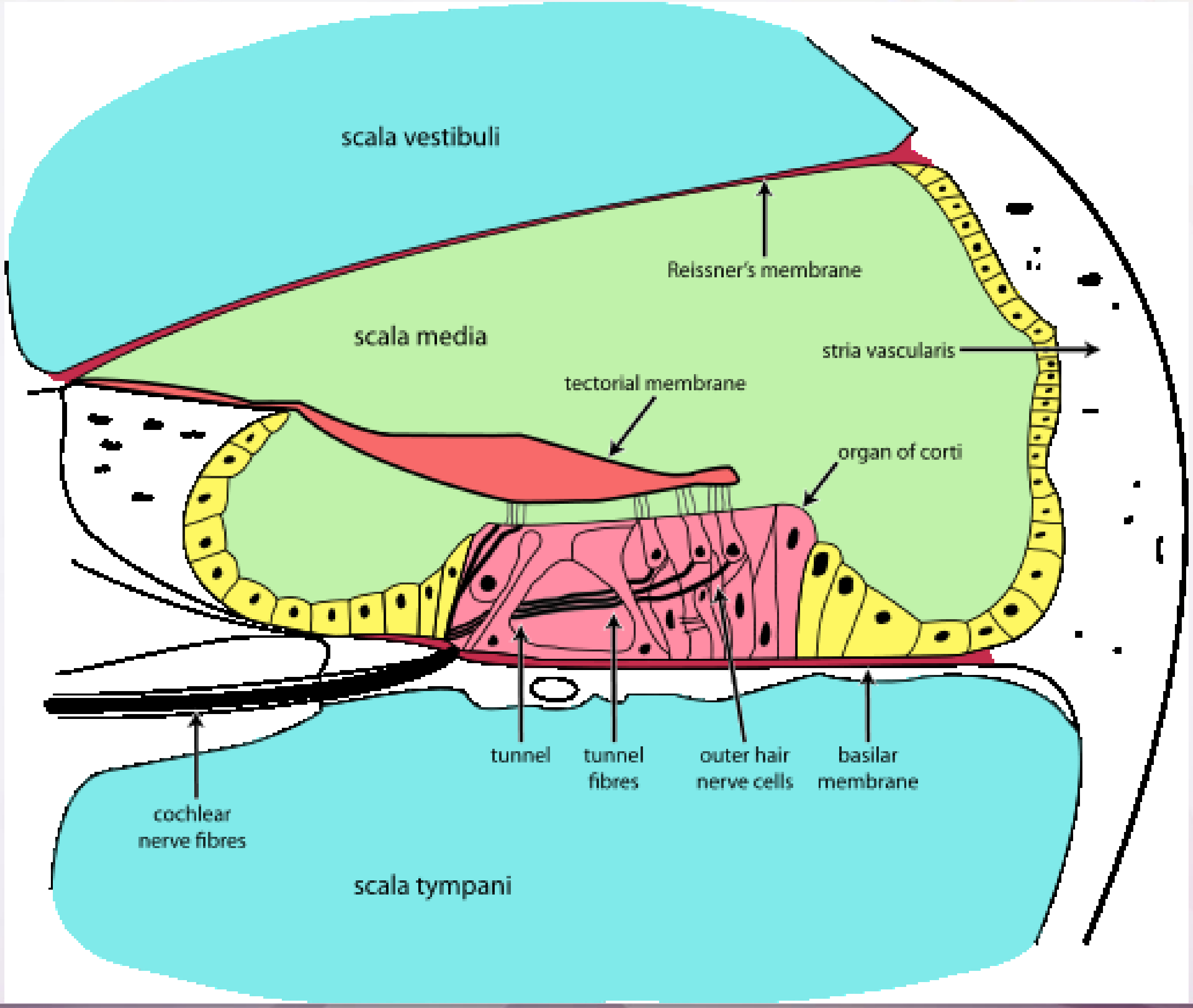
- Ear drum (connective pellicle) hammer, anvil, stirrup
- Transmission of the acoustic signal from the external environment to the inner ear fluid
- Transfer between environments means energy loss; compensation:
  Drum with a large flat area => oval window (20x)
  Hammer - Anvil: unequal lever; rotational motion

Physiological acoustics

Inner ear

- the Labyrinth: Cochlea
- the vibrations are transmitted through the bones to the perilymph
- transmission of vibrations on the basilar membrane
- the sensory organ - the organ of Corti - hair sensillas

Physiological acoustics



Physiological acoustics

- Outer hair cells (20 000) – the amplifier
- Inner hair cells (4000) – main neural output

- Pathway to receptors
  - **Conduction through middle ear** – most effective
  - Bone conduction – skull bones

Hearing examination

Audiometry - examination of the hearing threshold in the entire spectrum of acoustic frequencies

Audiometer - low frequency oscillator

- generation of the acoustic signal
- the examination is conducted in each ear separately
- in acoustically shielded space
- recording levels of intensity for each frequency

Hearing examination

Tuner tests - used to distinguish perception disorder and conduct disorder

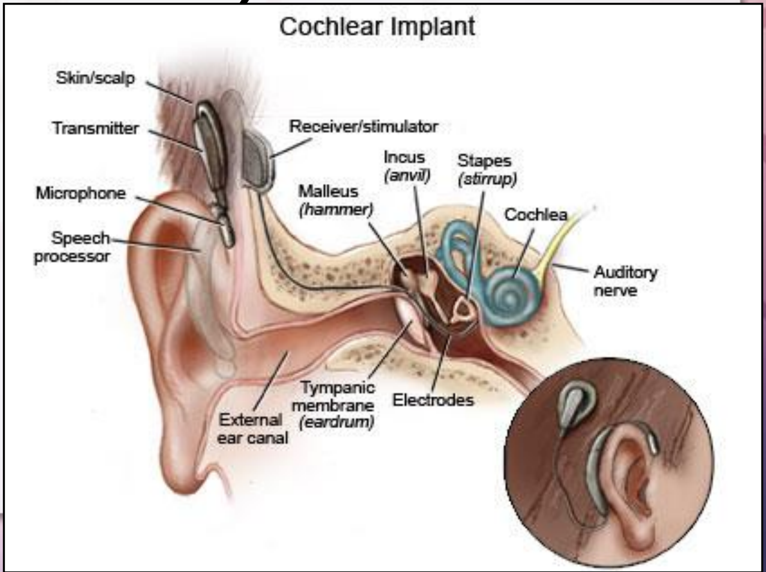
- Weber test - comparing the quality of audibility in each ear
- Rinne test - Comparison of middle ear and bone conduction
- Schwabach test - comparing the length of the bone hearings in patient and doctor (assuming that the doctor has a healthy sense of hearing)

Hearing examination

- Hearing disorders
  - **middle ear** sound conduction disorder (plug, mucus, inflammation); compensation by bone conduction
  - Perception disorders of the **inner ear** fatigue - system noise exposure, degeneration = bone conduction can not compensate for this type of disorder

Hearing examination

- Hearing aid – microphone, amplifier, speakers
- Cochlear implants– compensation for loss of or inadequacy of the inner ear (speech processor + receiver/stimulator)



Ultrasound and Ultrasound diagnostics

Ultrasound

- Ultrasound
- acoustic waves
- frequencies higher than 20000 Hz
- beyond hearing

Ultrasound

Creating ultrasound

- magnetostrictive generators
  - changing the volume of ferromagnetic materials due to the ambient magnetic field
  - the maximum frequency of 60 kHz
- piezoelectric generators
  - Indirect piezoelectric effect = material deformation due to voltage
    Usually, 1-20 MHz

Ultrasound effects

- **Mechanical** - sound particle vibration = alternating pressures = material degradation
- **Dispersion** - the preparation of fine emulsions and suspensions
- **Heat** - friction of vibrating particles; a large amount of heat is generated at the interface tissue with different acoustic resistance
- **Physical, chemical** - energy supply => excitation, speeding up chemical reactions; depolymerization, radical formation in an aqueous environment

Biological effects of ultrasound

- Enhancing membrane permeability
- lowering the nerve fibers conduction of
- Increasing the pH of tissues
- Analgesic, spasmolytic effect

- Intensity of 1.5 $W.cm^{-2}$ **positive** effect
- Intensity 3 $W.cm^{-2}$ **negative** effect **reversible**
- Above intensity 3 $W.cm^{-2}$ **irreversible** effect

Ultrasound diagnostics

- The ultrasonic detection devices use the piezoelectric effect

- The ability of crystal material deformation by a voltage (vibration source) and the ability of the crystal during its deformation to generate a voltage (detection)

- Ultrasonic transducer - silica crystals, ceramic materials

Ultrasound diagnostics

- At the interface of two environments that differ in acoustic impedance (resistance), there is a reflection of the ultrasonic waves
- The ratio of the former and the reflected intensity R
- $$R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2$$

R = 0: Homogeneous environment
R close to 0: Tissue with similar impedance
R closer to 1: Bone and soft tissue

Ultrasound diagnostics

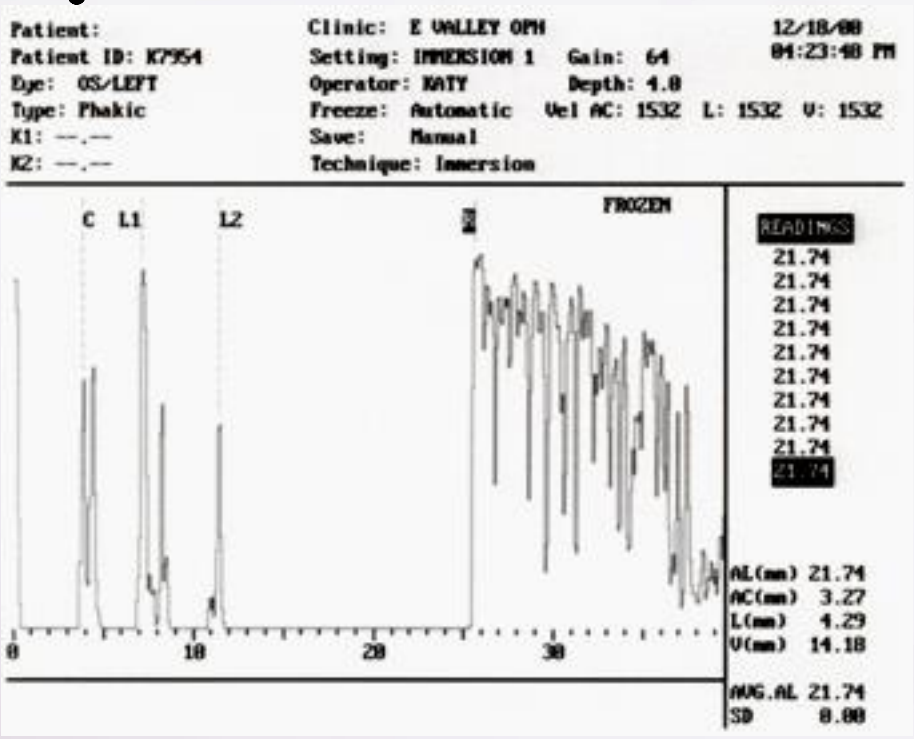
- Intensity decreases exponentially going through an environment:

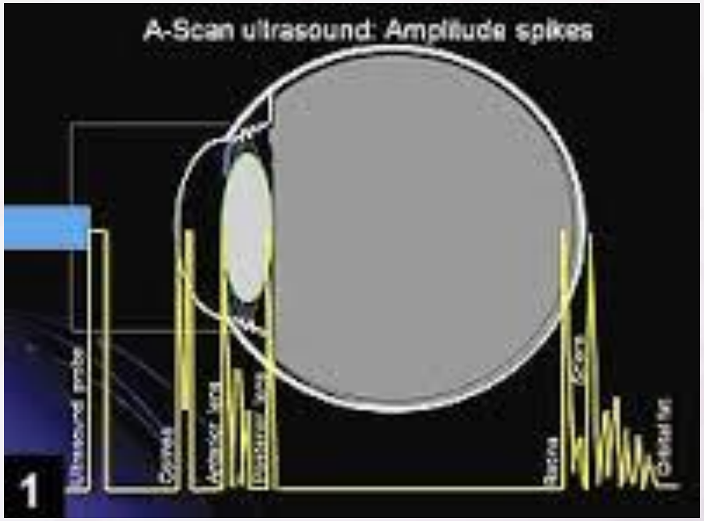
$$I = I_0 . e^{-\alpha d}$$

- d = length of the layer (m); α = absorption coefficient (m^{-1})

Ultrasound diagnostics

- Display Type A – signal as shown on the timeline as pulses
-



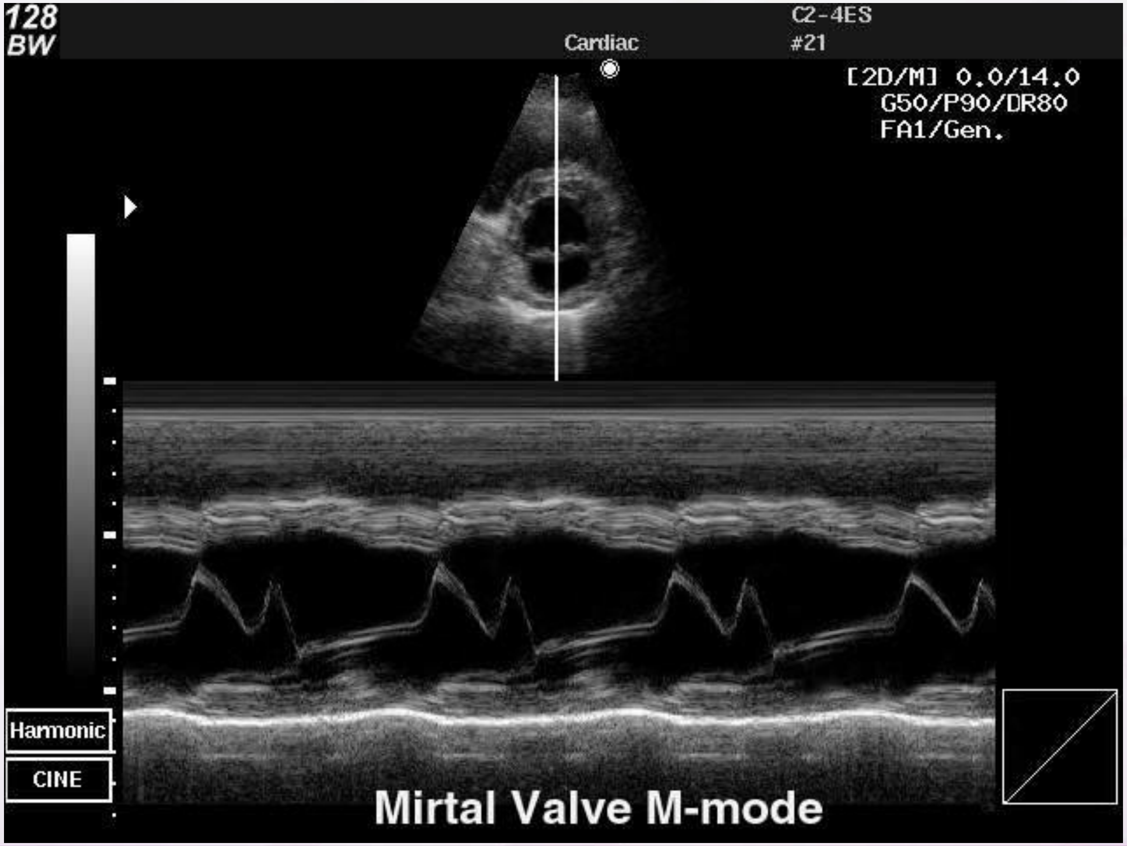


Ultrasound diagnostics

- Display Type B signal is displayed as dots on the screen with different brightness; tissues with higher levels of reflection are brighter (echogenic)

Ultrasound diagnostics

- M - display: subtype of type B display following the moving structure in relation to time



Ultrasound diagnostics

- 3D view – composed of high number 2D images

Ultrasound therapy

- Frequency 800 - 1000 kHz
  - Uses biological effects of ultrasound on the organism (increased permeability, increased pH, decreased neurotransmission)

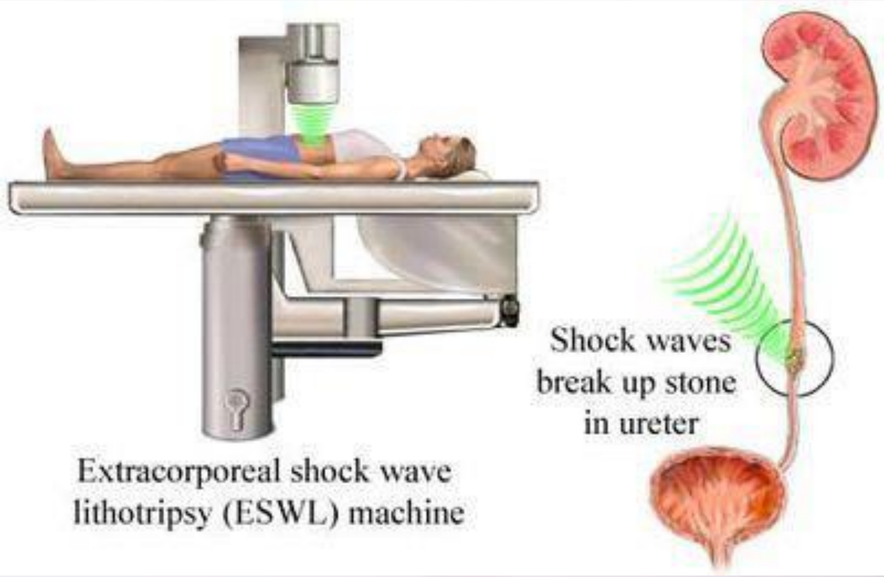
- This increases blood circulation, metabolism Spasm-analgetic effect

Ultrasound therapy

- Low-frequency ultrasound 20 to 30 kHz (magnetostrictive vibration source)
- Removal of tartar
- Uses the principle of cavitation

Ultrasound therapy

- Shockwaves
  - Unlike continuous ultrasound; here is just one wave (microseconds)
  - High sound pressure
  - Lithotripsy (ESWL)



Ultrasound therapy

- Shockwaves
  - 100-1000 shock waves to break the stone

- The need to ensure minimal damage to the surrounding tissue
  - Maximizing energy absorption at a given location
  - Focusing waves up to the point of stone position

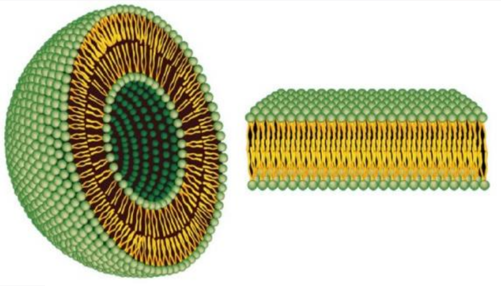
Ultrasound use in lab

Ultrasonic baths
Ultrasonic homogenizers

- cleaning
- degasing
- dissolvement
- homogenization
- emulsification

Liposomes preparation

- Composed of polar lipids - phospholipids (phosphoglycerides, sphingolipids) and cholesterol
- Size 25 - 2.500 nm



- Preparation

1. Drying the lipid solution in an organic solvent
2. **Dispersing lipids in an aqueous medium**
3. Purification
4. Analysis