Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

It is approved
on meeting of department of
medical informatics, medical and biological physics
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Head of department _____O.V Silkova

Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	1. Fundamentals of higher mathematics and biological physics
Theme of lecture:	**Biophysics of hearing organ. Audiometry.**
Year	1
Faculty	Medical
Speciality	Medicine

Poltava - 2020

The topic significance:
Hearing is one of base channels of information reseiveing for humen organism; sound and other mechanical vawes surround us and influe on human body directly; mechanical vawes are widespread technological instruments. Topic is very important for future doctors in their professional activity, positively influences the students in their attitude to the future profession, forms professional skills and experience as well as taking as a principle the knowledge of the subject learnt.

Specific targets:

To have general knowledge of the topic studied;
To understand, to remember and to use the knowledge received;
To form the professional experience by reviewing, training and authorizing it;
To be able to carry out laboratory and experimental work.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	Obtainable skills
Previous (providing disciplines): physics, biology, anatomy	To know basic parameters of the oscillatory motion; structure of the organ of hearing
The subsequent disciplines: Normal physiology	To know role of mechanical processes in organism, sound characteristics; acoustic measures; mechanism of hearing; analysis of sound intensity and frequency in human hearing analyzer.

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

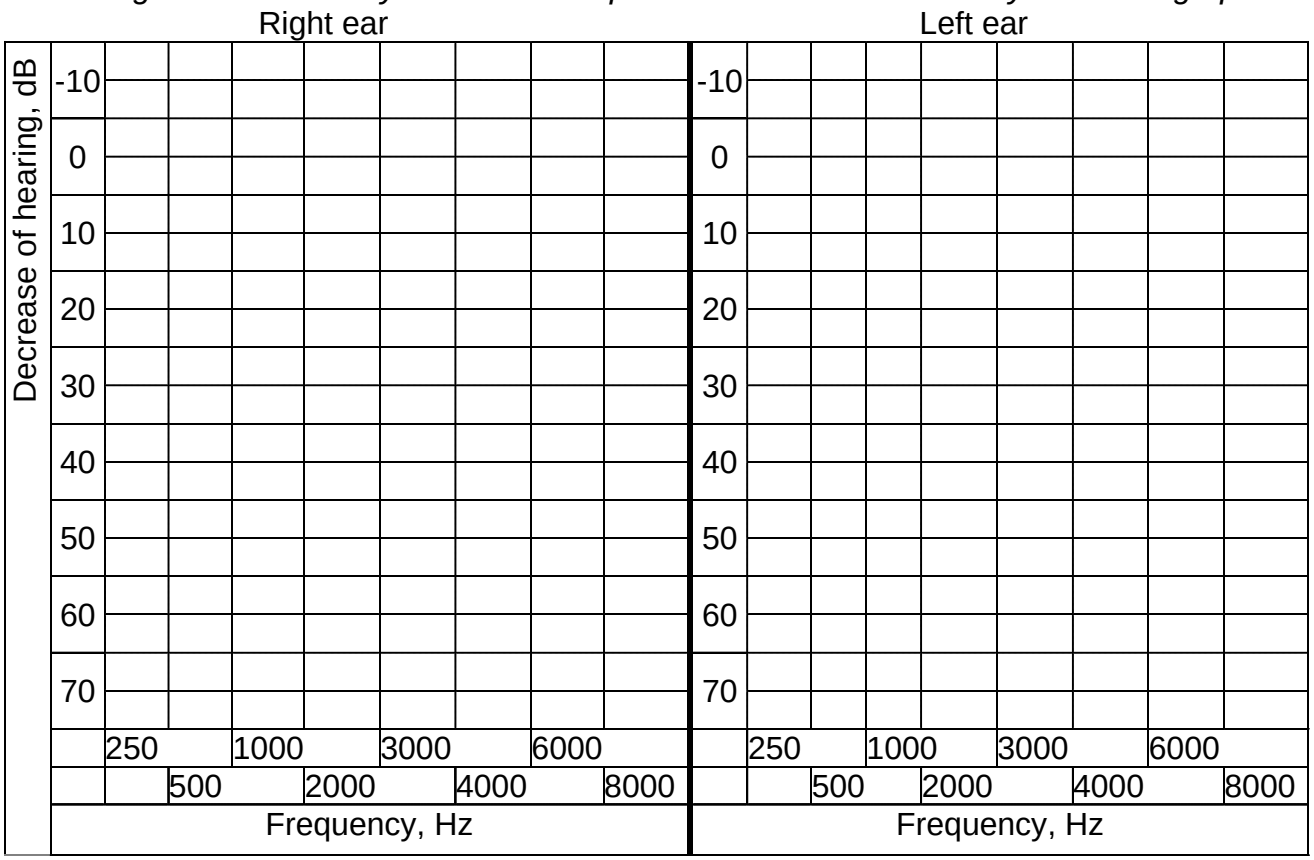
Term	Definition
Loudness level	It is the level of auditory sensation depending, in the first place, on intensity, and on sound frequency also.
Hearing threshold	It is the smallest intensity of sound I_0, at which sound is still perceived by the human ear. The hearing threshold depends on the sound frequency. The standard hearing threshold is taken to be $I_0=10^{-12}W\cdot m^{-2}$ at the sound frequency of v=1000 Hz.
Threshold of pain	The highest intensity of sound, at which sound is perceived by the ear without any sensation of pain yet.
Audiometry	Measurement of hearing acuity at different frequencies.

Theoretical questions to class:

1. Structure of human ear. Outer, medium and inner ear.
2. Amplification of sounds in ear.
3. Cochlea. Determination of frequencies in ear.
4. Sound sensitivity. Threshold of audibility. Threshold of pain.
5. Physiological characteristics of auditory sensations, and their relation to physical characteristics of sound.
6. The Weber-Fechner law.
7. Units of sound intensity and loudness measurement .
8. Audiometry.

Practice work executed at class:

The audiogram form to fill by measurement points and to create audibility threshold graph:



Record the frequency dependence of hearing threshold for a tested person.

- To fix the form of audiogram in the audio-frequency oscillator;
- put the stereo headphones on a tested person;
- turn on the minimum frequency of sound oscillation;

- set the signal that is heard by the tested person well;
- make the signal lower step by step till the tested person can't heart it;
- mark with the point the place where the rulers of the audio-frequency oscillator cross;
- do the same measurements for higher frequencies;
- unite these points with the help of a line.

Draw conclusions.

The contents of the topic:

Auditory sensation characteristics. Weber-Fechner law

As sound is an object of auditory sensations, so human evaluates it also subjectively. ***Physiological (subjective)*** characteristics for describing the auditory sensation of sound are used. These characteristics are as follows: *loudness* (or *loudness level), pitch* and *timbre of sound.*

The ***loudness level*** of sound is the level of auditory sensation depending, in the first place, on *intensity.* But since the sound perception capacity of the auditory apparatus depends on its frequency, the loudness also depends on *frequency.* In spite of this subjectivity, the loudness level can be quantitatively evaluated by comparing the auditory sensations from two sources.

At a fixed sound frequency, the auditory sensations obey the ***Weber-Fechner law:*** *with increase of irritation in geometric progression (i.e. in an equal number of times), the sensation of this irritation increases in arithmetical progression (i.e. in equal value).*

As applied to sound, this means that if sound intensity takes a number of successive values, e.g. aI_0, a^2I_0, a^3I_0 (a is a coefficient greater than 1), the respective loudness of sound sensations will be L_0, $2L_0$, $3L_0$.

According to the Weber-Fechner law, at a fixed sound frequency, the loudness (L) has a linear dependence on the level of sound intensity, i.e.

$$L = k \lg \frac{I}{I_0}$$

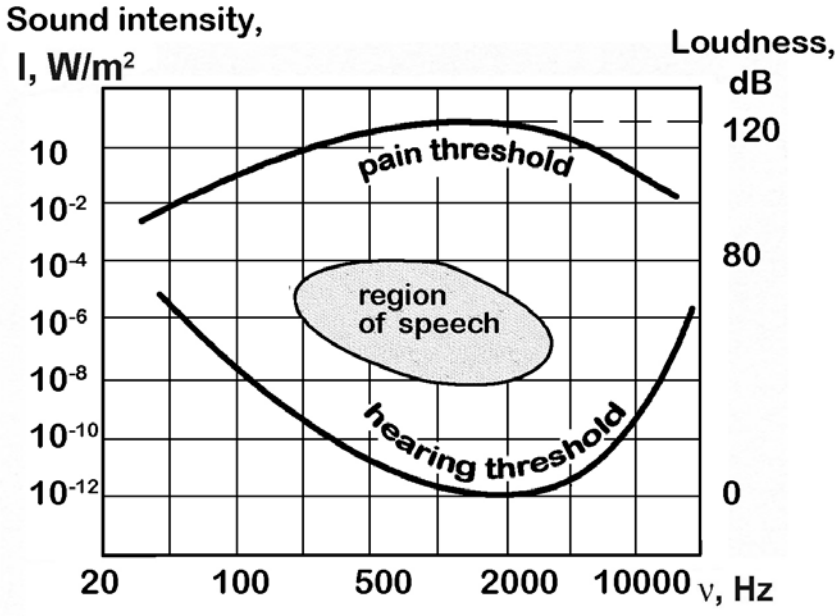


Fig.2. Dependence of audibility and pain thresholds on sound frequency.

In this formula I_0 is the minimum sound intensity perceived by human ear, the value depending on the sound frequency. Coefficient ***k*** depends on frequency, intensity and on the selected unit of loudness. Unit of loudness level is ***phon.***

If the sound frequency is 1000 Hz (the standard frequency of sound measurements), and loudness is measured in phons, ***k=1***. Therefore, at the frequency of 1000 Hz, the notions of loudness and intensity level, phon and decibel coincide.

Besides phon, the unit of loudness is ***sone.*** Sone is a unit of the scale of sound loudness, which expresses the direct

subjective evaluation of the relative loudness of a simple tone. One sone corresponds to the loudness level of 40 phons at the sound frequency of 1000 Hz. At every increase of loudness by 1 phon, the number of sones doubles.

The ***threshold of audibility*** (or ***hearing threshold)*** (Fig.2) is the smallest intensity of sound I_0, at which sound is still perceived by the human ear. The hearing threshold depends on the sound frequency. The standard hearing threshold is taken to be $I_0=10^{-12} W\cdot m^{-2}$ at the sound frequency of ν=1000 Hz.

The ***threshold of pain*** (or ***threshold of feeling)*** is called the highest intensity of sound, at which sound is perceived by the ear without any sensation of pain yet. If the sound intensity exceeds this value, normal sound perception becomes impossible. The threshold of pain also depends on the sound frequency. At the frequency of ν=1000 Hz, the threshold of feeling is $I_{max} = \frac{10W}{m^2}$.

At frequencies differing from 1000 Hz, to determine the loudness by the level of intensity, or vice versa, diagrams are used, which are obtained experimentally and which relate these quantities at different frequencies. The curves making up these diagrams are called the ***curves of equal loudness*** (Fig.3).

As evident, the *human ear is most sensitive to sounds with the frequencies of 2.5 to 3.5 kHz,* and at the auditory range limits (16 Hz and 20 kHz) the sensitivity of the human ear is significantly worse.

Sounds in limits from 150 Hz (a deep voice) up to 2500 Hz (a high voice) are used in speech.

The upper frequency limit of audition declines with the years . At children it attains 30000 Hz sometimes, and in 35 years it is only 15000 Hz.

Hearing thresholds of speech variate with the years also. The least quantity of hearing thresholds, that is the greatest sensory acuity, is detected by 14-19 years and after 20 years it decreases.

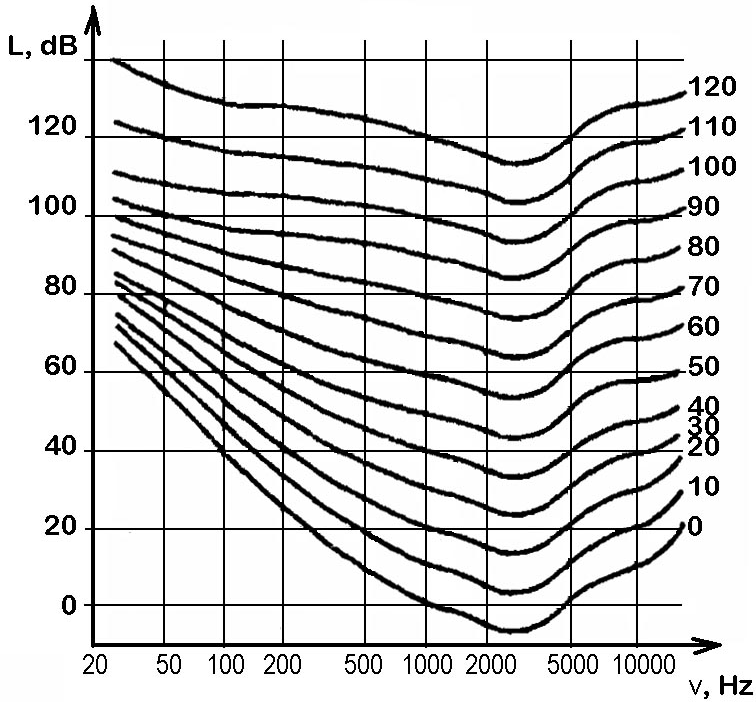


Fig.3. Curves of equal loudness.

The ability of using the curves of equal loudness is in the list of obligatory practical skills to be acquired by the students when studying the course of medical and biological physics. Consider some examples of using the tables of curves of equal loudness.

Let ν=100 **Hz,** and L=60 dB. Determine the level of sound loudness. We find the point with coordinates (100 Hz, 60 dB).

The next physiological characteristic of sound is its pitch. The ***pitch of sound*** is determined mainly by its frequency, viz. the higher the frequency the higher the sound, and the lower the frequency the lower the sound.

The pitch depends on tone complexity and its intensity to a much lesser extent, viz. a sound of higher intensity is perceived as a sound of lower tone.

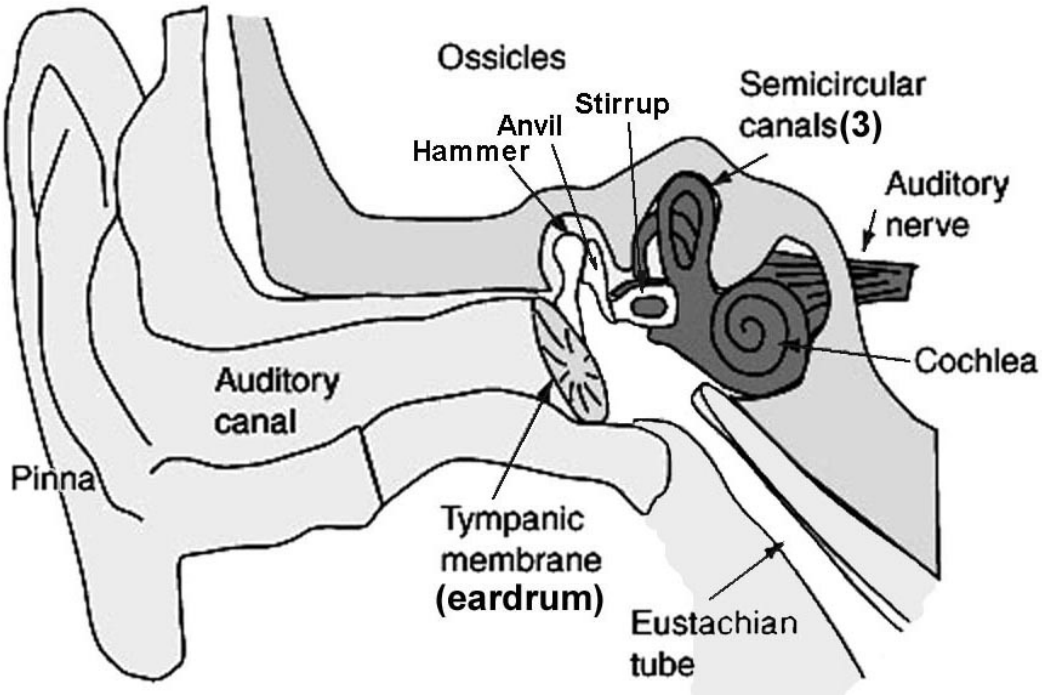


Fig.6. Human ear.

The third physiological characteristic of sound is its timbre. ***Timbre*** is determined by the sound harmonic spectrum. The notion of timbre is usually used to characterise complex (musical) tones.

Man is able to distinguish the sound of the same note reproduced by different instruments. This is due to that these sounds coincide in the main tone, but they differ in the quantity and amplitude of overtones, which gives the peculiar “coloration” to the sound.

The human auditory apparatus

The human auditory apparatus provides reception of acoustic signals (sound waves) and their conversion to electric signals. Here, an electric signal is meant to be a train of electric pulses created by receptor cells and transmitted to the brain by nerve fibres.

Based on its morphological peculiarities and functional role, the human auditory apparatus comprises the auricle, middle ear and internal ear (Fig. 6).

The auricle and middle ear comprise the ***sound-conducting system.*** The internal ear comprises the ***sound-perceiving system.***

The ***auricle*** consists of the *helix* and the *external acoustic duct.* The human helix is not essential for hearing. It helps to locate the sound source when it is in the sagittal plane. Person has two ears allowing to evaluate the location of the sound source in the horizontal plane with a precision to 3° due to the *binaural effect.*

The ***middle ear*** (Fig.7) contains the *eardrum (tympanum)* (4) and the *auditory ossicles.* The eardrum is of irregular form and has different tension in its different parts. It has no natural oscillation period and always oscillates with the frequency of sound oscillations. The auditory ossicles (*malleus* – 1*, anvil* – 2 and *stirrup* – 3 *bones*) serve for transmission of oscillations from the eardrum, whereto the malleus is fixed, to the membrane of the *oval window of the cochlea* (5)*,* which is the beginning of the internal

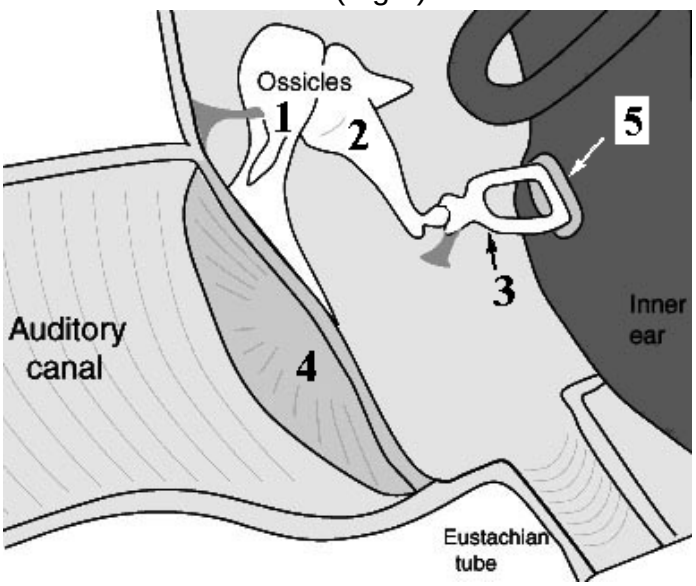


Fig.7. The middle ear.

ear. The stirrup is fixed to the oval window membrane.

The system “ear-drum – auditory ossicles – oval window membrane” acts as a signal amplifier. The sound pressure amplitude increases due to two effects:

1) an increase in pressure force amplitude owing to a system of levers formed by ossicles, and

2) a decrease in area affected by this force (the ear-drum area exceeds that of the oval window by more than 20 times).

The total signal amplification provided by the middle ear is about 28 *dB*. At an excessively high sound intensity at the level of sensation of pain, this mechanism is partially blocked due to a reflexive decrease in mobility of the auditory ossicles system.

The main part of the ***internal ear*** (Fig.8) is the *cochlea,* which converts mechanical oscillations to electric signals. The cochlea is a bone formation in the form of a conical spiral.

The *cochlea cavity* (Fig.9) is divided by two membranes (the *vestibular* and *main*, or *basilar* ones) into three passages, or channels, viz. the vestibular, cochlear and tympanic ones).

The *vestibular* and *tympanic channels* are connected in the zone of the cochlea cupola with a small orifice (*helicotrema*), and they are filled with the *perylymph*.

The cochlear channel, which is located between the *vestibular* and *main membranes*, is filled with the *endolymph*. The receptor hair cells are located on the main membrane in the cochlear channel. These cells, along with *tectorial membrane*, form *Corti's organ* (fig.10).

When the sound wave propagates along the cochlea channels, the main membrane gets involved in the process of oscillation. In so doing, the hairs of the receptor cells contact the tectorial membrane, and their deformation causes excitation of the cells. The electric pulses so generated are transmitted to the brain by the auditory nerve.

Depending on the wave frequency, different sections of the main membrane are involved in the process of oscillation, this leading to excitation of different sections of Corti’s organ (different groups of receptor cells). This allows the brain to identify the frequency of the acoustic signals (subjectively, the pitch) received.

Changing sound wave intensity causes a change in the amplitude of oscillations of the main membrane, i.e. the degree of excitation of receptor cells. This allows the brain to identify the sound intensity (subjectively, the loudness).

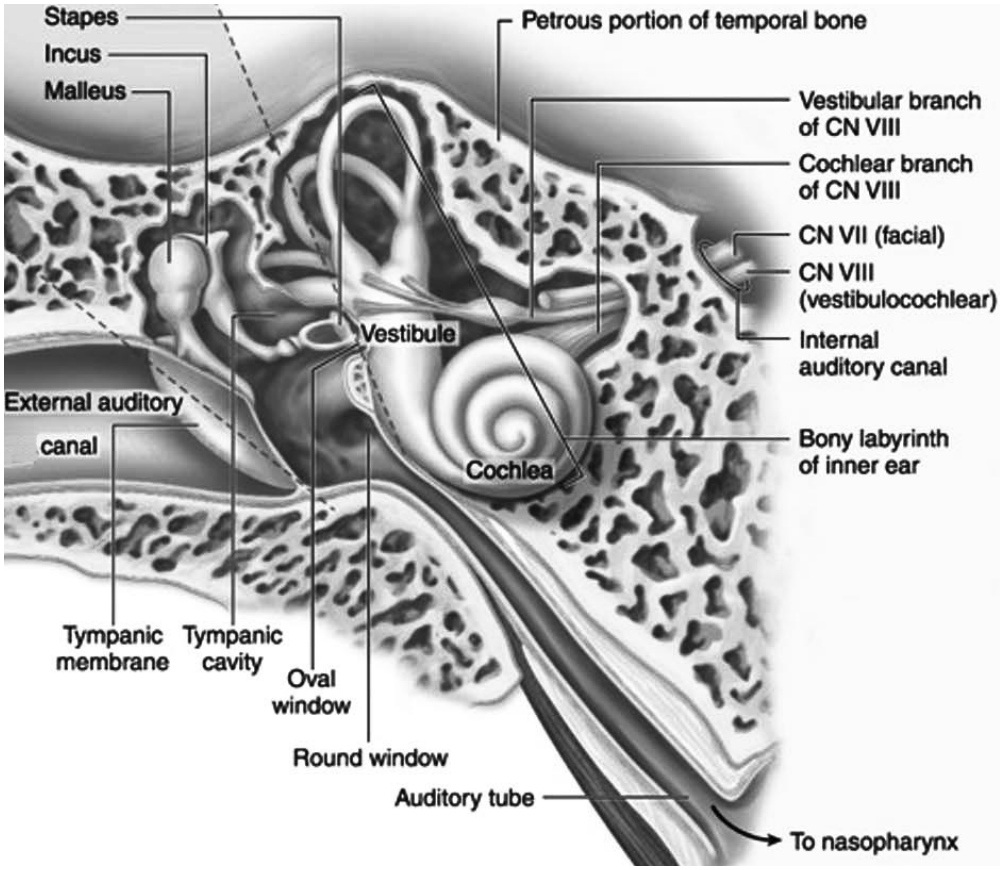


Fig.8. General overview ear structure.

Some forms of deafness are related to with affection of the cochlea receptor apparatus. In this case, the cochlea fails to generate electric signals under the affect of mechanical oscillations. These patients can be cured by prosthesis of the cochlea main function (cochlear prosthesis).

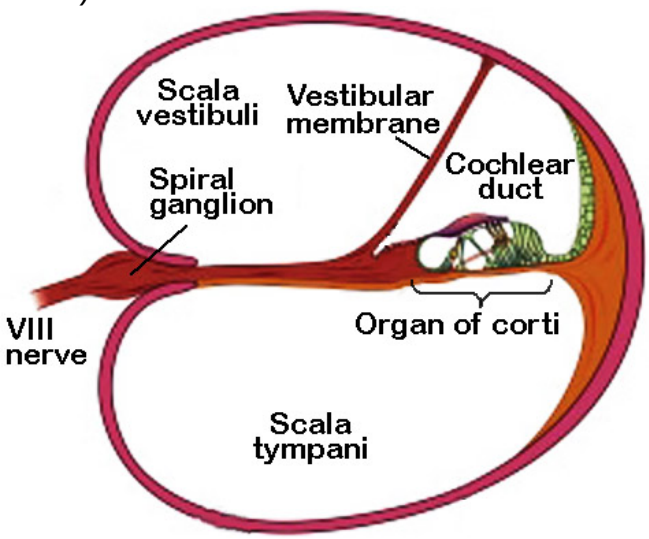


Fig.9. Cochlea cross-section.

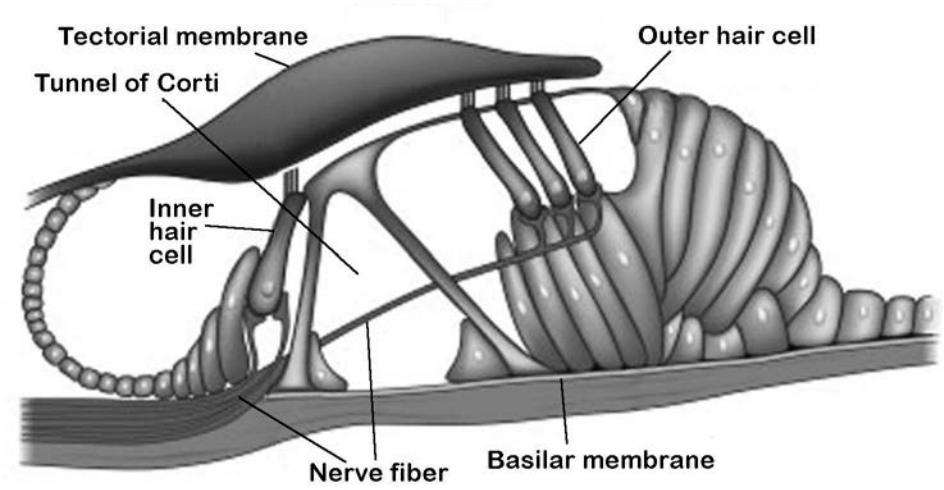


Fig.10. Corti organ cross-section.

Self-control material.

Theoretical questions:

1. What are constituents of a human middle ear?
2. What are isophones?
3. What is a false feature of infrasound propagation?
4. What is a false feature of ultrasound interaction with substance?
5. What is a part (are parts) of the human internal ear?
6. What is acoustic pressure?
7. What is an auscultation?
8. What is an infrasound radiant?
9. What is an ultrasound source usable in technology?
10. What is an ultrasound source using in medical devices?
11. What is audiometry?
12. What is infrasound influence on biological objects?
13. What is necessary for acoustic wave occurrence and propagation in medium?
14. What is peculiar to ultrasound?
15. What is peculiar to ultrasound?
16. What is percussion?
17. What is percussion?
18. What is phonocardiography?
19. What is provided by binaural hearing?
20. What is purpose of vibrations uses?
21. What is the audiogram?
22. What is the least intensity of a sound which is perceived by an ear?
23. What of the listed acoustic values can has a measurement unit 1Bel?
24. What of the listed acoustic values has a measurement unit 1Bel?
25. What of the listed acoustic values has a measurement unit 1phon?
26. What of the listed acoustic values have a measurement unit of 1 dBel?
27. What of the named devices can be used for hearing check?
28. What role is carried out by the Eustachian tube?
29. What should be intensity of a sound wave 1kHz frequency that mechanical oscillations have caused sensation of a sound in the person with normal hearing?
30. What values there are need to know to calculate specific ultrasonic resistance of medium?
31. What waves do not concern to the acoustic?
32. Where in medicine ultrasound location is used?
33. Where there is a Corti's organ?

34. Where there is a transformation of sound oscillations of air into sound oscillations of a liquid?
35. Which of the listed acoustic values don't concern to physiological characteristics of a sound?
36. Which of the listed acoustic values is a psychophysiological characteristic of a sound?
37. Why at ultrasound therapy it is necessary to avoid an aerial layer between a source of radiation and a site of a body which is irradiated?
38. Why ears are blocked at plane launch and landing?
39. Why it is expedient to use paraffin oil or water as the intermediate conducting medium between a radiant of ultrasounds and a site of a body which is irradiated?
40. At which conditions velocity of sound spreading is maximal? Minimal?
41. At which conditions can refraction of sound waves be observed?

Test tasks :

1. What are physical parameters of oscillations?
   а) frequency;
   б) period;
   в) intensity;
   г) vawelength;
   д) amplitude.
2. What are physical parameters of vawes?
   а) frequency;
   б) velocity;
   в) intensity;
   г) vawelength;
3. How ultrasound oscillation are created?
   а) piezoeffect;
   б) thermoelectric effect;
   в) magnetostriction;
   г) Peltye effect.
4. What is effect of ultrasound on biological ogranisms?
   а) termal;
   б) electrical;
   в) mechanical;
   г) chemical.
5. Whar aqoustic diagnostic methods are?

а) phonocardiography;
б) electrocardiography;
в) rheography;
г) auscultation;
д) percussion.

6. In what medium sound oscillation can spread?
   а) air;
   б) water;
   в) vacuum;
   г) solid bodu.

Literature recommended

Main sources.

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Additional sources*:*

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