LABORATORY WORK
DETERMINATION OF THE SPECTRAL CHARACTERISTICS OF HEARING AT THE THRESHOLD OF HEARING

GOAL OF THE WORK:
1. Get acquainted with the operation of the audiometer.
2. To master the method of determining the hearing threshold using an audiometer.
3. Construct an air conduction audiogram for the left and right ear.

EQUIPMENT:
audiometer, headphones for determining air conductivity.

RELEVANCE OF THE METHOD
Determination of the spectral characteristics of hearing is of great importance both in assessing the functional capabilities of the organ of hearing and hearing in diagnosing the type of impairment in a patient. A quantitative study is carried out using a medical device - an audiometer.

THEORETICAL PART

Sound – the longitudinal elastic waves perceived by a human ear. Sound waves can travel in air, liquids, solids and do not exist in a vacuum. Let's note the main objective (physical) characteristics of sound waves.

Elastic waves. To imagine what elastic waves, you can, throwing a stone into the water. The circles appearing as a consequence of it - alternating depressions and ridges are an example of mechanical waves.

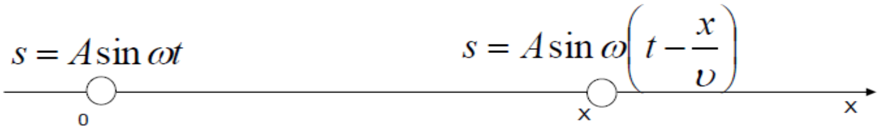
Mechanical waves are the process of propagation of vibrations in elastic media.

Well-cited examples of wave propagation in different media include, for instance, the transmission of sound in air (eardrum), the propagation of a seismic disturbance in the earth, ultrasonic sounding, among others. An elastic wave course the mechanical perturbations propagating in space and carrying energy.

Two main types of elastic waves are distinguished: elastic waves - propagation of elastic deformations - and waves on the surface of the liquid - surface waves.

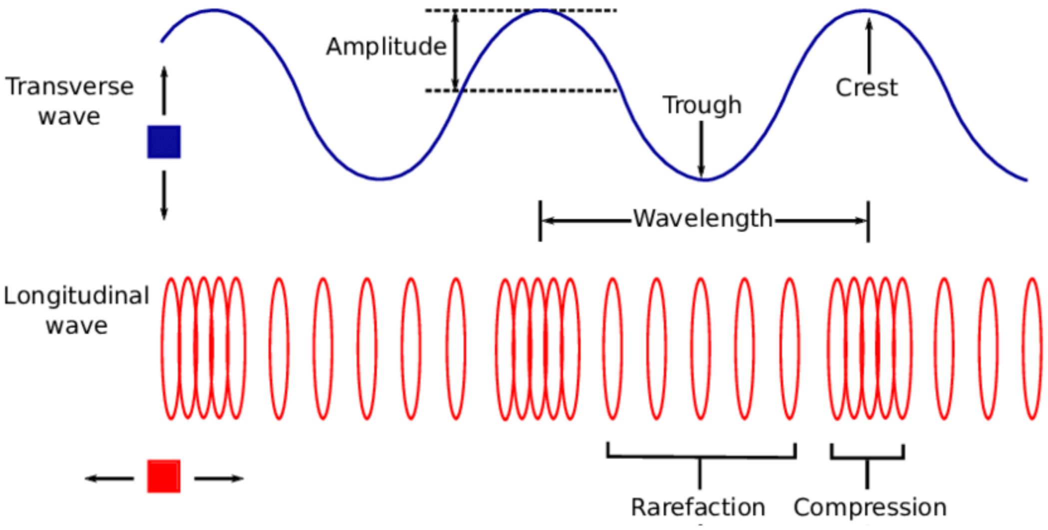
Shock waves - is a type of propagating disturbance that moves faster than the local speed of sound in the medium.

Scheme of the wave distribution



A- initial deviation, s - displacement, *x* - coordinate, *u* - wave velocity, w - cyclic (angular) frequency [rad/s].

If s and x are directed along one line, then the wave is ***longitudinal***, if they are mutually perpendicular, then the wave is ***transverse***:



Phase velocity

The propagation velocity of the oscillations fixed phase called ***phase velocity***:

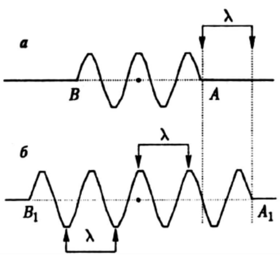
$$\varphi = \omega\left(t - \frac{x}{\upsilon}\right) = const \qquad 0 = \omega\left(dt - \frac{dx}{\upsilon}\right)$$

It'equal to

$$\upsilon = \frac{dx}{dt}$$

Wavelength (λ)

Distance between two points, which phases are similar the same time:



$$\lambda = T\upsilon$$

$$T = \frac{1}{\nu} \qquad \lambda = \frac{\upsilon}{\nu}$$

T – wave period [s],
ν – frequency [Hz]

Energy characteristics of waves:

The **flow of energy** (ϕ)

Volumetric energy density (ω_p)

The wave intensity (density of energy flux of the waves) (**I**)

The **flow of wave energy** is equal to the ratio of the energy carried by the waves through some surface to the time during which this energy is transferred:

$$\Phi = \frac{dE}{dt} \text{ [Watt]}$$

The **wave intensity** (average power, transported across unit area perpendicular to the direction of energy flow) – I:

$$I = \frac{\Phi}{S} \text{ [Watt/m}^2\text{]}$$

$$\Phi = \omega_\rho \cdot S \cdot \upsilon$$

$$I = \omega_\rho \cdot \upsilon$$

When a wave propagates in the areas of concentration of particles of the medium, an additional acoustic pressure P is formed, which is associated with the intensity I sound:

$$I = \frac{P^2}{2\rho\upsilon},$$

moreover, the acoustic pressure P depends on the density ρ medium, amplitude A, and circular frequency ω vibrations of particles of the medium, as well as the wave speed υ in a given environment:

$$P = \rho \cdot A \cdot \omega \cdot \upsilon.$$

Sound is the oscillation of medium particles propagating as longitudinal mechanical waves at a frequency of **16 Hz to 20,000 Hz** (20 kHz).

Sound characteristics:

1. Frequency – ν, ω.

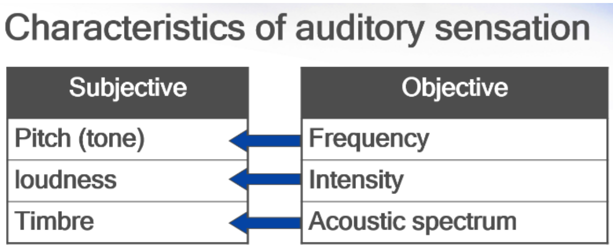
2. Sound intensity - I

3. Sound pressure - p

4. Acoustic spectrum.

Types of sounds:

- **Tone -** sound, which is a periodic process.
- **Noise** is a sound characterized by a complex non-repeating time dependence.
- **Sonic boom** – short-term sound influence.



Subjective characteristics of sound:

- **pitch** – the sound quality determined by the pitch frequency
- **timbre** - determined by the spectral composition of the sound and the distribution of energy between different frequencies
- **volume** - the level of auditory sensation determined by the intensity of the sound and its frequency

Sound Volume

$$L = \lg \frac{I}{I_0} [bel] \qquad L = 10 \cdot \lg \frac{I}{I_0} [decibel]$$

The intensity level is measured in bels (B) or decibels (dB) - values 10 times less. Therefore, for a frequency of 1 kHz, the minimum intensity level (hearing threshold) for a person is:

$$\mathrm{L}_{\min} = \lg \frac{10^{-12}}{10^{-12}} = \lg 1 = 0(\text{Б}),$$

and the maximum intensity level (pain threshold) is:

$$\mathrm{L}_{\max} = \lg \frac{10}{10^{-12}} = \lg 10^{13} = 13\text{Б} = 130\text{дБ}$$

The Law of Weber – Fechner (1858г)

As the intensity of a sound increases exponentially, the sensation of loudness of that sound increases arithmetically:

$$E = \kappa \lg \frac{I}{I_0}$$

k – a coefficient of proportionality depending on frequency and intensity.

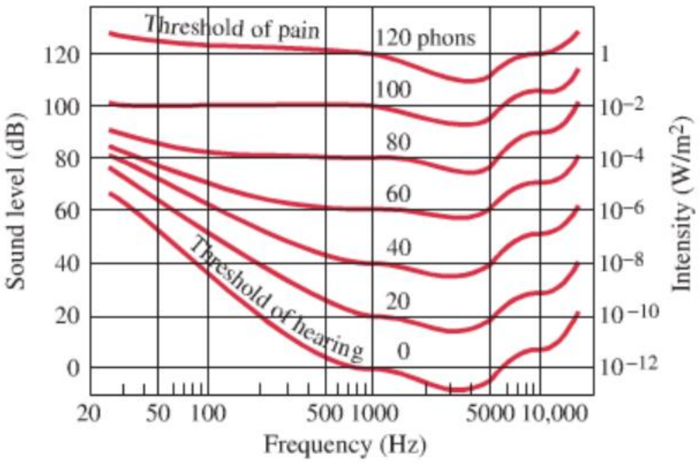
Sound Volume E

The physiological characteristic of sound - is the level of sound volume that is measured in the fones.

At 1 kHz, the volume and intensity scales are the same:

$$E = 10 \cdot \lg \frac{I}{I_0}$$

Equal loudness curves:



The approximate character of the sound	Sound intensity (W/m^2)	pressure (Pa)	sound intensity level (Db)
Hearing threshold	10^{-12}	0,00002	0
Whisper	10^{-10}	0,0002	20
A conversation in a normal voice	10^{-7}	0,0064	50
Talking in a loud voice	10^{-6}	0,02	60
Noise on a busy street	10^{-5}	0,64	80
Scream	10^{-4}	0,2	80
Threshold of pain	10	64	130

Pitch of the sound depends on the vibration frequency of the sound wave: *the higher the vibration frequency, the higher the sound is perceived.*

Sound waves are divided into tones and noises. Tone is a sound with a periodic process of oscillations of particles of the medium. If the oscillations occur according to a harmonic law, then the tone is called simple (obtained using a tuning fork or sound generator). A complex tone consists of a fundamental tone (harmonic vibration with the highest amplitude) and multiples of it in frequency, but smaller in amplitude, overtones or harmonics.

Noise - sound with a complex, non-repeating time dependence (creak, surf noise, gas burner flame, etc.).

Sound waves are described quite clearly using the acoustic spectrum, which indicates a set of frequenciesvand the corresponding amplitudes (or intensities) of vibrations that form a given sound wave. In fig. 1 shows examples of acoustic spectra of noise and some sound waves with the same pitch frequency. It is easy to see that the spectrum of a complex tone is linear, while the spectrum of noise is continuous.

Complex tones with the same fundamental frequency can have different acoustic spectra, which means that they will differ from each other in the form of vibrations (Fig. 2).

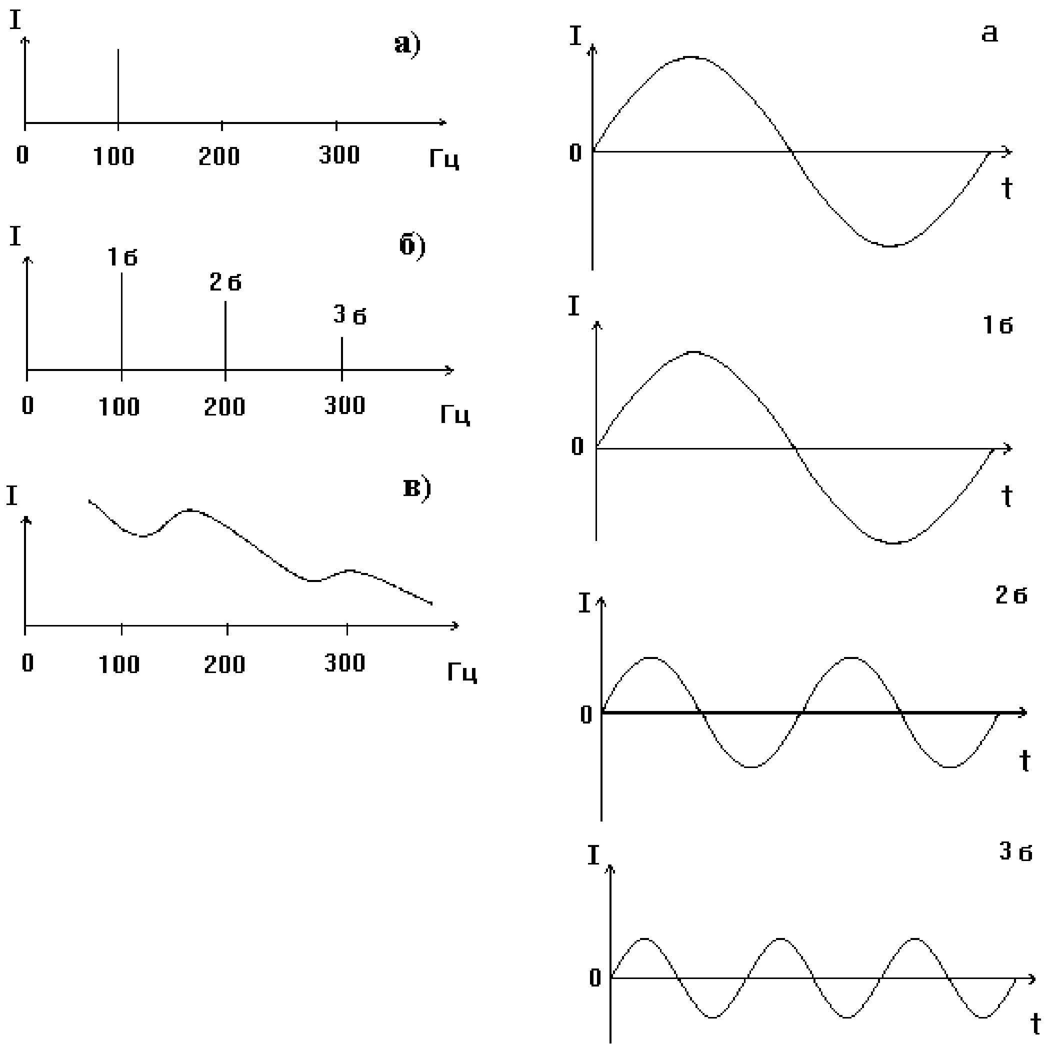


Figure: 1. Acoustic spectrum of simple (а), complex (б) tones and (в) noise (graphs of harmonic vibrations forming a given tone are given on the right side of the figure).

The difference between sounds of the same key produced by different sources (sound coloration) is determined by the timbre. Timbre depends on the acoustic spectrum of sound - from the frequencies of overtones and their intensities (Fig. 2).

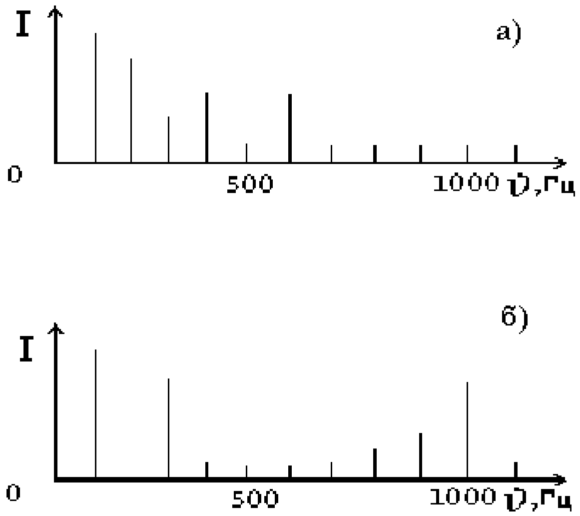


Figure: 2. Acoustic spectra of the same note played on the piano (a) and on the clarinet (b), the fundamental frequency of the tone is 100 Hz.

Sound research methods in medicine

Auscultation (listening) – with a stethoscope or phonendoscope.

Percussion - listening to the sound of individual parts of the body when tapping them.

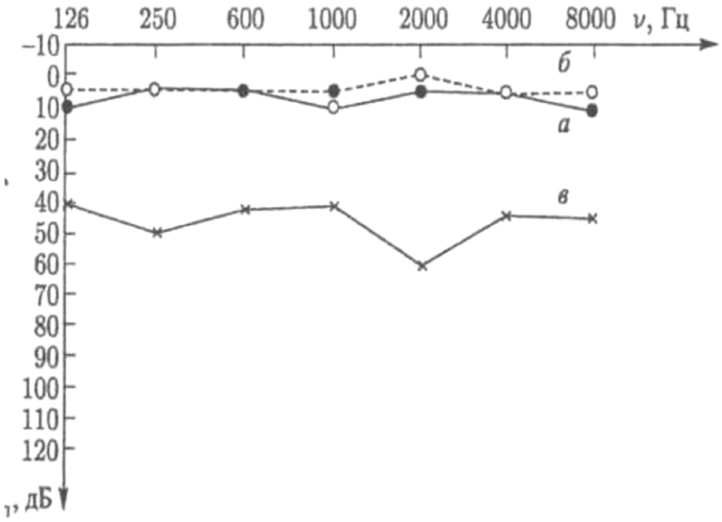
Phonocardiography (PCG) – graphic registration of heart tones and noises.

The method of measuring hearing acuity is called ***audiometry***.

A special device (audiometer) determines the threshold of auditory sensation at different frequencies.

Audiograms

- curves reflecting the dependence of the threshold of perception on the frequency of the tone, that is, it is the spectral characteristic of the ear at the threshold of audibility.



PRACTICAL PART

To obtain an audiogram, the audiometer is used. The main unit of the device is a sound generator that generates discrete frequencies in the range from 125 to 8000 Hz.

Exercise 1. Prepare the audiometer for operation.
1. Connect the headphones, Put on.
2. Set the horizontal band of the frequency switch to 1000 Hz.
3. Set the computer's intensity level scale to a position where a normally hearing ear senses a minimum intensity signal.

Task 2. Determine the hearing threshold.
1. Decrease the sound intensity level to the level at which you hear the least sound, changing the frequency of the signal, according to the tables proposed.
2. Place a mark on the audiogram at the intersection of the planks through the hole in the plank.
3. Take measurements at all frequencies for the right and left ear, enter the measurement results in the table.

ν, Hz	125	250	500	1000	2000	3000	4000	6000	8000
L (left ear), dB									
L (right ear), dB									

4. Based on the data obtained, construct audiograms for the right and left ear.
5. Mark the normal line on the audiogram.
6. Compare the audiogram of both ears with the norm
7. Make a conclusion.

CONTROL QUESTIONS

1. What is sound? Classification of sounds.
2. Indicate the objective characteristics of the audio tone.
3. Name the subjective characteristics of the sound tone and indicate their relationship with the objective characteristics.
4. Sound intensity level scale. Units.
5. Volume scale. Units. Curves of equal loudness.
6. What is hearing threshold and pain threshold?
7. Sound research methods in the clinic.
8. Influence of infrasound on biological objects.
9. Noise, fight against it.

SITUATIONAL TASKS

1. The rupture of the tympanic membrane occurs at a sound intensity level of 150 dB. Determine the intensity, the amplitude value of the sound pressure for sound with a frequency of 1 kHz, at which it can occur.

2. Outdoor noise, which corresponds to the sound intensity level at L_1 = 50 dB, is heard in the room in the same way as noise at L_2 = 30 dB. Find the ratio of the intensities of sound in the street and in the room.
3. The intensities of two sounds with the same frequency of 1 kHz differ 1000 times, how much their volume differs.
4. The intensity of heart sounds perceived through a stethoscope is 10^{-9} μW/cm^2. Determine the intensity level of heart sounds.
5. Find the value of the acoustic pressure in the body tissue at a depth of 2 cm when it is irradiated with ultrasound with an intensity of 2 W/cm^2. The absorption coefficient of the fabric is considered equal to 0.19 cm^{-1}, and its density is 1.06 g / cm^3, v = 15.5 cm / s.
6. The sound of the whistle of the locomotive creates an additional pressure of 90 Pa. Calculate the intensity of the sound in the air.
7. Determine the intensity of a sound wave with an amplitude of 10 cm and a frequency of 50 Hz, if the acoustic impedance of the brain is $1.6 \cdot 10^6$ kg/m^{2}s.
8. Determine the amplitude value of the sound pressure of a sound wave with an amplitude of 10 cm and a frequency of 50 Hz, if the acoustic impedance of the liver is $1.7 \cdot 10^6$ kg/m^{2}s.
9. What is the intensity of a sound wave with a frequency of 50 Hz in human adipose tissue (sound speed –1460 m / s; tissue density - 0.86 g / cm^3) at an amplitude of 50 cm?
10. Determine the intensity, the amplitude value of the sound pressure in air for a sound with a frequency of 1 kHz, and an intensity level of 120 dB.
11. The intensity level of the sound of peals of thunder is 120 dB, and of a conversation in a normal voice - 50 dB. How many times do the intensities of these sounds differ at a frequency of 1000 Hz?
12. Determine the force acting on the human eardrum (area S = 66 mm^2) for two cases: 1) hearing threshold, 2) pain threshold. The frequency is 1 kHz.
13. Two sounds with a frequency of 1000 Hz differ in volume by 10 phon. Find the ratio of the intensities of these sounds.
14. It is known that the human ear perceives elastic waves in the frequency range from 20 Hz to 20 kHz. What wavelengths does this interval correspond to in air? In water? The speeds of sound in air and water are 340 m/s and 1400 m/s, respectively.

LITERATURE

1. Remizov A.N. Medical and biological physics. - M .: Higher school, 1999 .-- S. 127-142.
2. Fedorova V.N., Stepanova L.A. A short course in medical and biological physics with elements of rehabilitation. Lectures and seminars. -M .: FIZMATLIT, 2005.- S. 97-123, 581-588.
3. http://www.krasgmu.ru.