Lecture 4

Methods of processing biomedical information based on acoustic (sound) research methods.

Plan of the Lecture

1. Sound. Propagation of sound in various media
2. Standing waves, the conditions of emergence. The resonance phenomenon
3. The physical and physiological characteristics of sound, their interrelation
4. Weber's law, Weber-Fechner
5. Infrasound and ultrasound
7. Sound research methods in clinic.

Learning outcomes:

- study of regularities of sound in air
- examine the relationship of physical and physiological characteristics of sound

Under acoustics understand the doctrine of sound, of elastic vibrations and waves in gases, liquids and solids, perceived by the human ear. Acoustics - this is an area of physics which investigates elastic vibrations and waves from the lowest frequency to extremely high (1012-1013 Hz). Modern Acoustics covers a wide range of issues, it identifies a number of sections: physical acoustics, which studies the characteristics of elastic wave propagation in various media, physiological acoustics, studying the structure and operation of sound images and organs in humans and animals, and others. The human an organism there set of periodic oscillatory processes. The sound emitted by the internal organs, characterized their physiological state. In the clinic sound research methods are widely used for the diagnosis. Many processes in an organism for example breathing, heart function, etc. accompanied by sound phenomena. Directly listening of sounds occurring inside the organism, is one of the most important clinical research methods and is called auscultation. The simplest devices used for this purpose, a phonendoscope.

Sound represents waves with a frequency of 16 to 20,000 Hz, propagating in an elastic medium. Energy characteristic of sound is a intensity. Sounds are divided into tones, noise and sonic booms. There are simple and complex tones.

A simple tone - is sound vibrations occurring harmonically. Its main characteristic is the frequency. If the tone is a non-harmonic oscillation, it is called complex.

Simple tone gives a tuning fork, a complex - musical instruments or vocal apparatus.

The intensity or power of sound is called the energy flux density of the sound wave. Units - $1W/m^2$, and $1\mu W/cm^2$.

Sound or *acoustic pressure* $I = \frac{\Delta p}{\rho C}$ called the effective value of the additional pressure (excess over average ambient pressure), forming in areas condensations particles in the sound wave.

The speed of sound propagation (m / s) depends on the physical parameters of the medium. For some environments, it is: rubber - 40-60; air - 343; water - 1500; tree - 2500-3500; brick - 3500; steel - 5000. (m \ s).

The range of sound pressure distinguished by the human hearing organs, its minimum value felt by the human hearing organs, is called *the hearing threshold.* The average value of the threshold pressure is at the level of $P = 2 * 10^{-5}$ Pa (at a frequency of 1000 Hz), and the corresponding sound intensity is $I = 10^{-12}$ W \ m2.

The value of sound pressure at which a painful sensation of the human hearing organs begins to appear is called *the pain threshold*, and for a person it is $P = 2 * 10^2$ Pa and intensity $I = 10^2$ W \ m2.

Noise called to a variety of sounds, representing a combination of a plurality of different tones, frequency, shape, intensity and duration which vary randomly. Noise can be a short-term (knock, wheezing) or long-term, such as the noise of the various machines and mechanisms. Noise is also found in nature, accompanying atmospheric phenomena (wind, turbulent water flow, etc.). The auditory sensation subjectively differs the height, volume and timbre. These characteristics of the auditory

sensations are connected with the objective characteristics of the sound wave - oscillation frequency, the intensity of the wave and harmonic spectrum. Complex tones with the same fundamental frequency may differ on form fluctuations and, accordingly, harmonic spectrum. This difference is perceived by the ear as a timbre sound. For example, on the same basic frequency vowel sounds of speech in different people are different in timbre.

Sound, freely distributed in the environment, is a traveling wave. In the limited areas of the environment formed standing sound waves. When the coincidence the frequency vibrations of the sound wave and natural frequency of the portion of the medium oscillation amplitude dramatically increases, this phenomenon is called sound resonance and used to amplify the sound.

Standing waves, its nodes and antinodes

For wave motion is characteristic the phenomenon of interference. Consider the case of the interference of two opposing waves - forward and reverse, reflected from obstacles, resulting in a standing wave.

In physics, a standing wave – also known as a stationary wave – is a wave in a medium in which each point on the axis of the wave has an associated constant amplitude. The locations at which the amplitude is minimum are called nodes, and the locations where the amplitude is maximum are called antinodes. Distance λ_{cm} between two adjacent nodes and antinodes of the standing wave is equal to half the length λ traveling waves $\lambda_{cm} = \frac{\lambda}{2}$.

The energy in the standing wave is not transferred. Maxima energy correspond to the antinodes, the nodes energy is zero.

Standing waves are formed and transverse and longitudinal waves of any physical nature.

The volume of sound. The volume sound describes the level of auditory sensation over his threshold.

The volume sound depends on the intensity of the sound. This dependency have a complicated character, conditioned sensitivity of the ear to the sound wave action. Sensitivity - a physiological property of the ear, which depends on the physical characteristics of the acoustic wave: frequency of oscillation and wave intensity (sound power). The first relates to the very nature of sound is percipient ear device, the second is a property common to all the senses, and is called adaptation the power to irritation. Adaptation of the ear sensitivity decreases, and vice versa. So, the ear perceives sounds in extremely wide range of intensity, but, between the volume and intensity of the sound is no direct proportionality even if the same oscillation frequency. Experience shows that in connection with the adaptation of the increment of irritation strengt ΔI, causing the least perceptible change in the level of sensation on ΔI, It depends on the initial force irritation I so that $\Delta I / I$ It remains constant throughout the range of irritation (***Weber's law***).

Applying this condition to the case and expressing it in a differential form, we get

$$dL = kdI/I,$$

where dL - elementary increment of volume level, I - the initial intensity and dI – causing to change volume level dL, k – coefficient of proportionality.

Then the volume level dL for a given intensity of sound determined by integration of this expression is in the range of the zero level I_0 to a predetermined level I intensities:

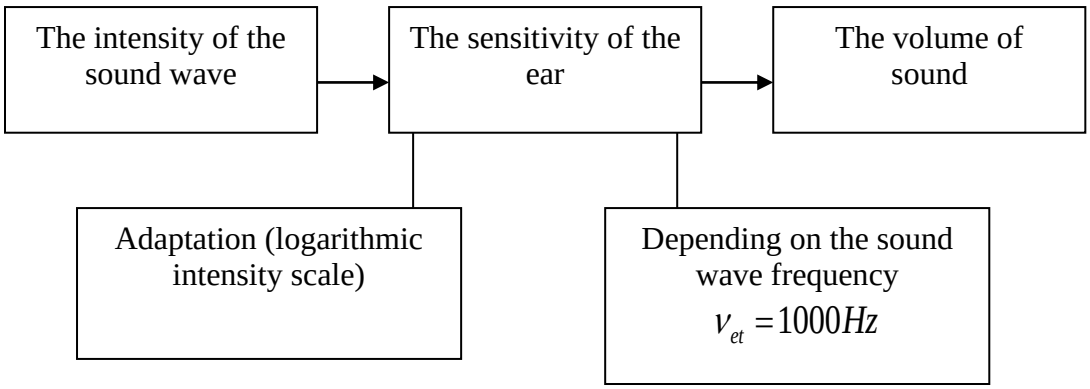
$$\Delta L = \int_{I_0}^{I} kdI/I = k \ln I/I_0 .$$

of the volume level (with the same frequency of oscillation) is directly proportional to the logarithm of the ratio of its intensity to a value corresponding to the threshold of hearing ***(Law Weber - Fechner***).

Sound methods of research in clinic

Many processes in an organism for example breathing, heart function, etc. accompanied by sound phenomena. Directly listening of sounds occurring inside the organism, is one of the most important clinical research methods and is called auscultation. The simplest devices used for this purpose, is a

phonendoscope. ***Percussion*** performed by tapping on the body surface and analyzing the sounds arising with sound. The character of these sounds depends on the mechanical properties (elasticity, density, etc.) Tissue directly under the place in which there is the tapping. Tapping is performed using a special rubber hammer head and plate of an elastic material, called plessimetrom which impact is applied to the body surface. uses also simply tapping the tips of the bent fingers of one hand on the phalanx of a finger of the other hand, imposed on the patient's body. The method of measuring the severity of hearing loss is called audiometry. Usually determine the point of the curve threshold of hearing at different frequencies. Hearing loss is defined as the difference between the received data and the norm. A graph showing the difference in decibels depending on the vibration frequency, called audiogram. Audiometry performed using an apparatus called audiometer base which is thin with a sound generator and independent adjustment of frequency and intensity of the sound level over the entire range of sound frequencies.



Scheme 1. The relationship between the intensity and volume sound caused by the sensitivity

Infrasound and ultrasound

Elastic waves propagating in the medium in the form of longitudinal waves at a frequency of less than 16 Hz (practically in the range of a hertz up to 20-25 Hz) are called infrasound. Infrasound is a part of various noise, both production and naturally occurring . The air infrasound quickly fades, but well communicated by elastic media and, in particular, on the water. The action of infrasound on tissue of organism is perceived tactile and bone - muscular nerve receptors, causing the sensation of vibration.

Elastic Waves with a frequency above 20 kHz (the upper limit is not limited, produced oscillations with a frequency greater than 200 MHz) are called ultrasound (US). Ultrasound low frequencies (60-80 kHz) is formed organs of certain animals (dolphins, bats), as well as a part of natural and industrial noise. Ultrasound of higher frequency is obtained from artificial sources. This device, which is based on the oscillator (generator) frequency electrical oscillations corresponding frequencies. Converting them to ultrasonic oscillations occur with the use of magnetostrictive phenomenon (low frequency) or inverse piezoelectric effect (if to higher).

Ultrasound has a substance complex action: mechanical, physical and chemical and the thermal. In the complex action of mechanical, thermal and chemical factors based biological action of ultrasound that can cause the death of viruses, bacteria, fungi, etc., and even when large capacity and small animals. At low capacities ultrasound, for example, increases the permeability of cell membranes, activates processes of tissue volume, etc..

Ultrasound is used in the investigation of internal organs difficult, and to detect pathological formations in the body (in particular tumors in the brain). It uses two methods: translucency ultrasound and ultrasound location. The first is based on the different absorption of ultrasound with tissues different acoustic properties (density, elasticity). In the study through an object in its various points of the ultrasonic beam passes a certain intensity, which is perceived by the sensor located on the other side of the object. Changing the intensity of the beam is produced shadow picture of the internal structure of the object.

When ultrasound locating registered pulses reflected from the boundaries of media with different acoustic properties, which the beam meets during the passage of through the object. The distance between the pulses makes it possible to judge the depth of the location of the required education, while moving the sensor - its shape and location. The device for the diagnosis of brain tumors called *echoencephalography*.

In surgery a narrow ultrasonic beam is sufficiently high intensity, focused on a small area of tissue is used, for example, for cutting bone or formation of holes in them, what is going on without adverse accompanying phenomena (destruction of adjacent tissues, vibration, heating, etc.) inherent in the use of conventional metal instruments. Exposure to 800 kHz ultrasonic frequency of low intensity (of a watt per square centimeter) is used in physical therapy with curative intent. The method is based on the fact that the complex mechanical and physico-chemical action of ultrasound on the site of its application is a complex physiological reaction in organism, which causes the therapeutic effect in the respective diseases. Ability ultrasound crush bodies placed in the liquid and create an emulsion used in the pharmaceutical industry in the manufacture of drugs. In the treatment of diseases such as tuberculosis, asthma, aerosols apply different drug substances obtained by ultrasound.

The questions for self - control:

1) What is sound?
2) Range of sound waves
3) Physical sound settings
4) The wave properties of sound waves
5) Acoustics
6) Ultrasound
7) Methods for obtaining ultrasound
8) Using of ultrasound in medicine

Recommended readings:

1. The German OF, Hoffman Y.F. Handbook of nuclear physics .- Kiev, 1975.
2. Suzanne A.K. Introduction to physics in modern medicine. USA: Taylor@Francis Group, 2009.
3. An Introduction by Roland Glaser. Biophysics. Second edition. Springer. 2012
4. Patrick F.Dillon. Biophysics. Cambridge University Press. 2012
5. Daniel Goldfarb. Biophysics DeMystified. 2011 by the McGraw-Hill Company. USA
6. Philip Nelson. Biological Physics. 2004.