Ryazan state medical University
named by academician I. P. Pavlov

Lecture 1. Medbiophysics as a branch of applied physics. Mechanical vibrations in the medical applications.

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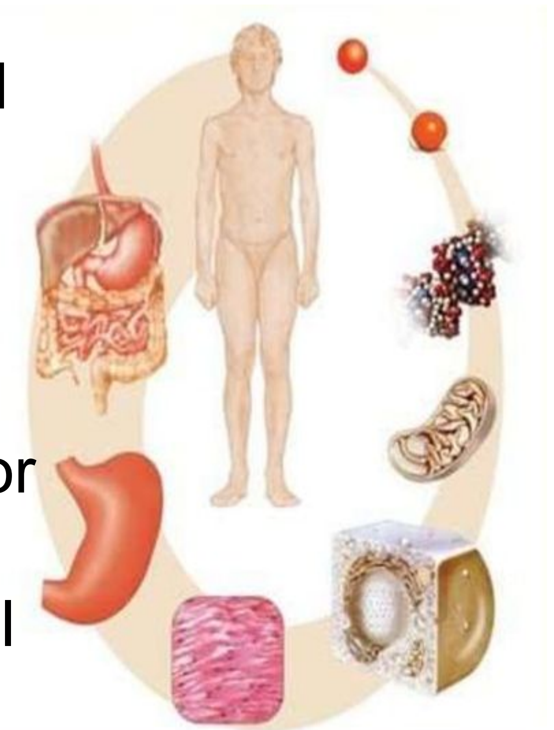
Medbiophysics is the science that studies the physical and physico-chemical processes that occur in biological systems at various levels of the organization and are the basis for physiological regulations.



Key tasks:

Identification of physical and physico-chemical parameters of the body, which could be used for object diagnostics;

The study of the physical and physico-chemical basis of pathological processes;

Deepening of knowledge of the mechanism of action on the organism of medicinal factors and environmental factors.

Biophysics is the basis of human physiology.

Many vital processes in the human body obey the laws of physics:

the movement of blood through the vessels is in accordance with the laws of hydrodynamics;

propagation of elastic waves through the vessels is the harmonic oscillations;

in the study of blood flow velocity using the laws of magnetic fields...

In medicine, the use of physical methods in diagnostics (temperature measurements, listening to the respiratory system (laws of acoustics), etc.).

Widely used methods of physical impact on the body UHF, inductothermy based on the laws of electrodynamics.

•Periodic mechanical processes in the living body

«Each person is a complex oscillatory system. "

N. Wiener

Oscillations are processes that repeat in time.

In this case, the system repeatedly deviates from its equilibrium state and returns to it again each time.

Depending on the physical nature of the repeating process, oscillations are distinguished: mechanical, electrical, etc.

In this lecture, mechanical vibrations are considered.

Repeating processes continuously occur inside any living organism.

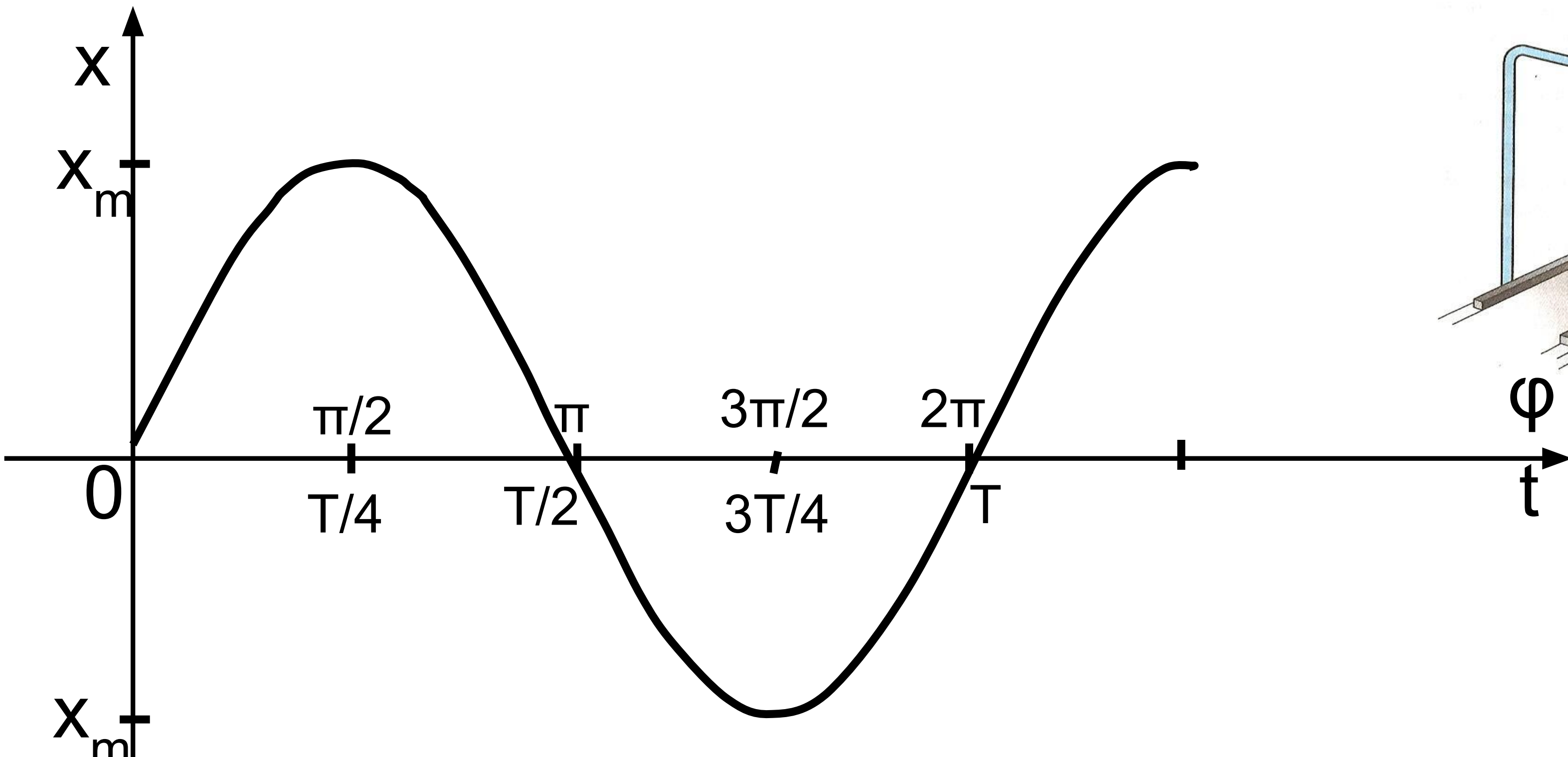
For example:

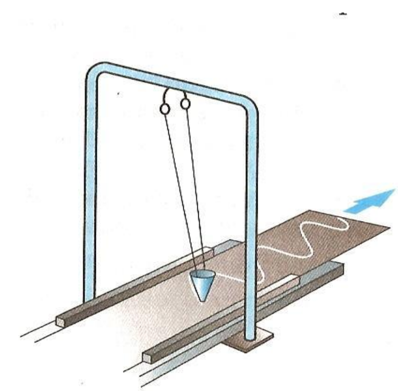
- **Дыхательные движения грудной клетки**;
- **Rhythmic contractions of the heart;**
- **Blood flow to the arteries (pulse);**
- **Breathing movements of the chest;**
- **we hear and talk due to fluctuations in the eardrums and vocal cords;**
- **when walking our feet make oscillatory movements.**
- **The atoms from which we are forming fluctuate.**

Examples of oscillatory systems

Among the various modes of vibration, the most simple form is **harmonic oscillation**, i.e. such that the oscillating quantity varies as a function of time according to the law of the sine or cosine.

Their significance is due to the following reasons. First, fluctuations in nature and in technology often have a character very close to the harmonic, and, secondly, periodic processes of a different form (with a different time dependence) can be represented as the imposition of several harmonic oscillations.





$$x = X_m \sin(\omega t + \varphi_0)$$
$$x = X_m \cos(\omega t + \varphi_0)$$

harmonic oscillation equation

MAIN CHARACTERISTICS OF VIBRATIONAL MOVEMENT

$$x = X_m \sin(\omega t + \varphi_0)$$

- **x** – **the displacement** of the point from the equilibrium position at a given time (instantaneous value).
- **A, X_m** – the module of the maximum displacement of a point from an equilibrium position is called **the amplitude**;
- $\boldsymbol{\varphi = \omega t + \varphi_0}$ – **phase of oscillation**, which determines the state of the oscillatory system at any time, φ = [radian]
- $\boldsymbol{\varphi_0}$ – **initial phase of oscillation**

MAIN CHARACTERISTICS OF VIBRATIONAL MOVEMENT

$$x = X_m \sin(\omega t + \varphi_0)$$

- **T** –the time of one complete oscillation is called **the period** **T = t/n,**

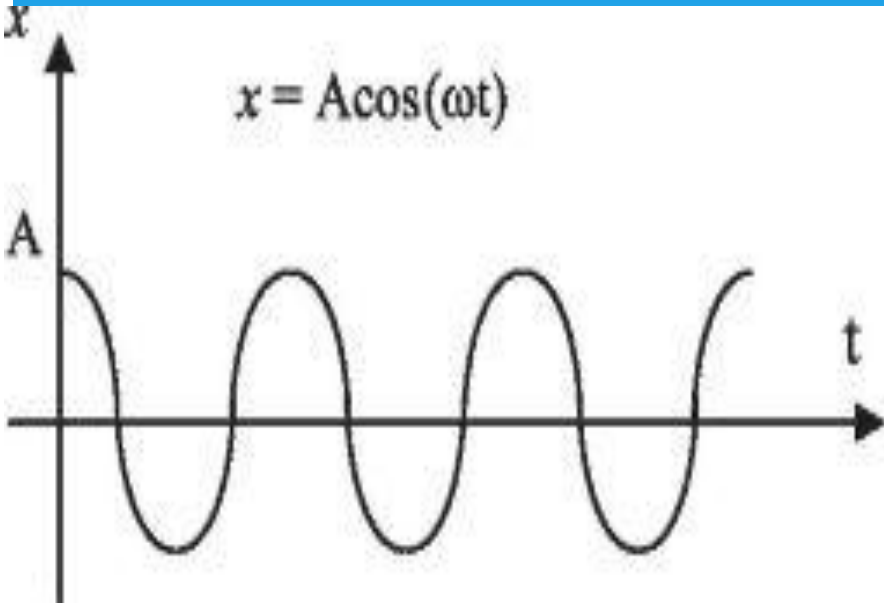
where **n** is the number of complete oscillations in time **t**

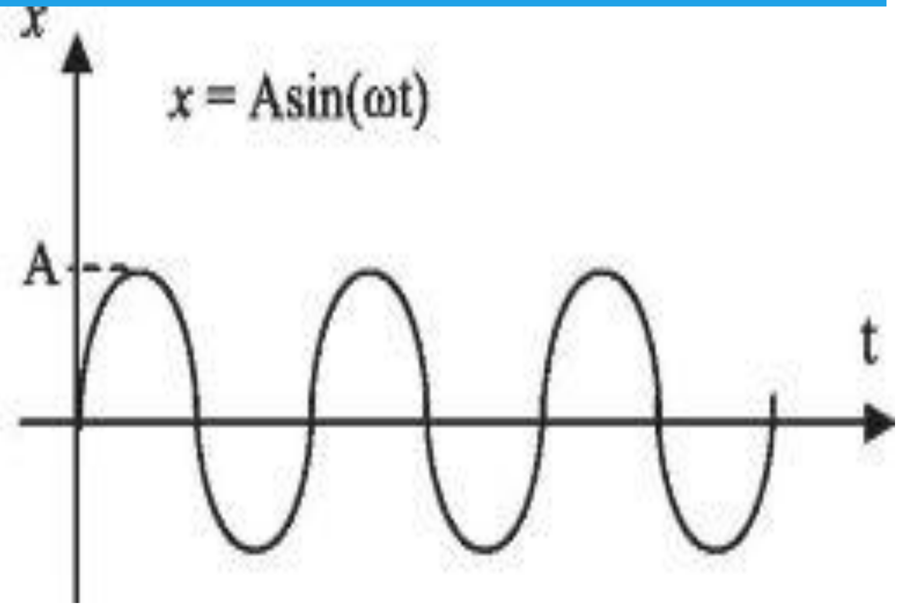
- **v** - the number of oscillations per unit time is called **the frequency**

V = 1/T – linear frequency **V = n/t** [1/s=Hz]

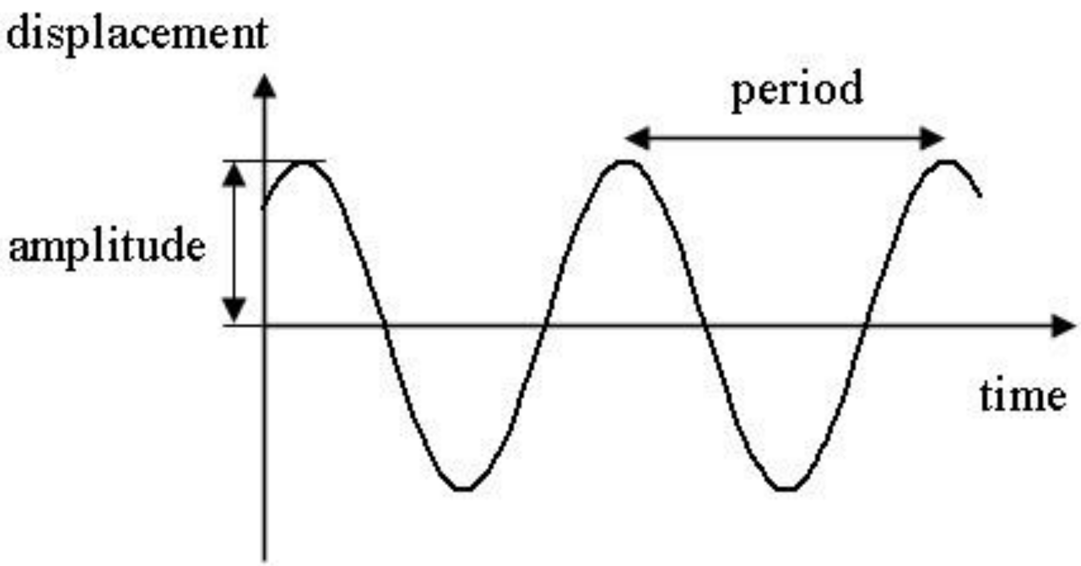
ω = 2π v – cyclic oscillation frequency [rad/s]

ω = 2π v = **2π/T** period and frequency relationship

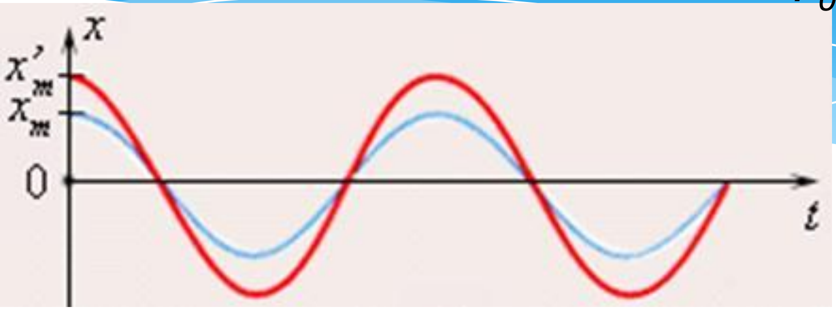




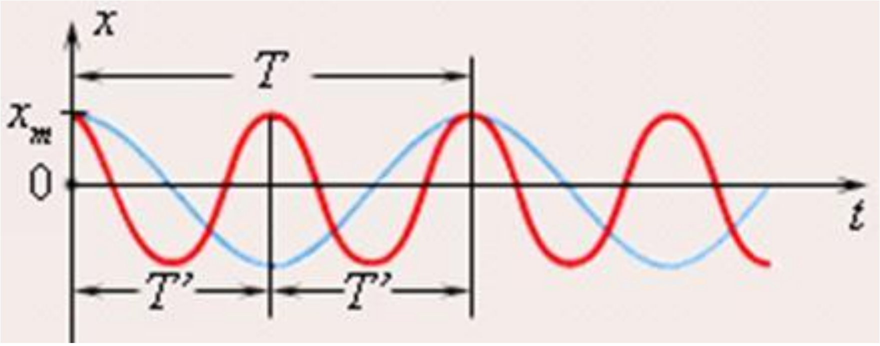
Graphs of the dependence of displacement on time for $x(0) = A$ и $x(0) = 0$



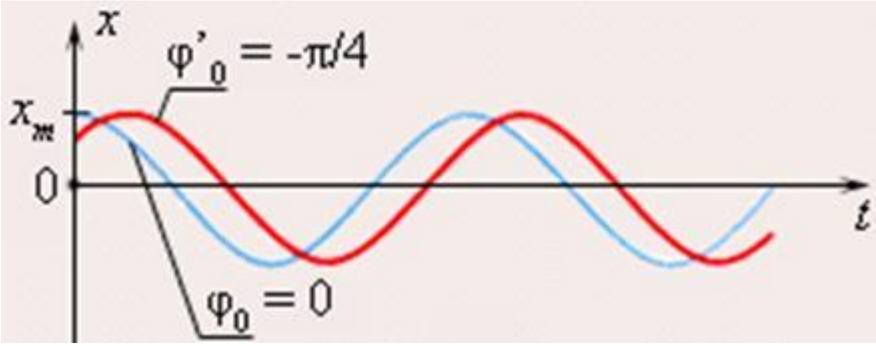
The harmonic oscillation graph is a sinusoidal or cosine wave.
In all three cases for blue curves $\varphi_0 = 0$:



The red curve differs from the blue **only by the larger amplitude**$(x'_m > x_m)$;



The red curve differs from the blue **only by the value of the period** $(T' = T / 2)$;



The red curve differs from blue **only in the value of the initial phase** (rad).

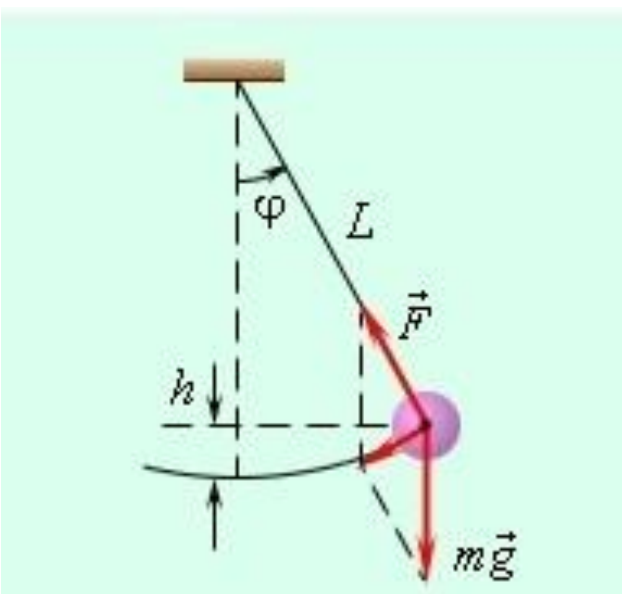
All fluctuations are divided into 3 groups:

1. Free undamped,
2. free decaying,
3. forced.

Free vibrations **are called such vibrations that occur in a system left to itself after it has been taken out of equilibrium.**

Example: oscillations of a ball suspended on a string. In order to cause fluctuations, you either need to push the ball, or, taking it aside, let it go. When the ball is shaken, the kinetic energy is reported, and in the case of a deviation, the potential energy is reported.

Mathematical pendulum



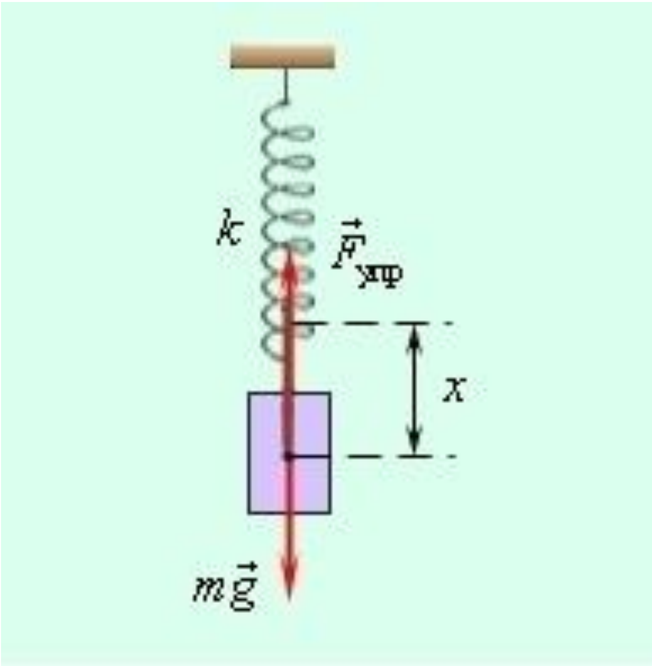
$$E_{пот} = mgh \qquad E_{кин} = \frac{m\upsilon^2}{2}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Free oscillations are made due to the initial energy reserve.

Free undamped oscillations

Free oscillations can be undamped only in the absence of frictional force.
Otherwise, the initial energy reserve will be spent on overcoming it, and the range of fluctuations will decrease.
As an example, consider the vibrations of a body suspended on a weightless spring, arising after the body was turned down, and then released.



$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$E_{кин} = \frac{m\upsilon^2}{2}$$

$$E_{пот} = \frac{kx^2}{2}$$

From the side of the stretched spring to the body acts the elastic force F, proportional to the magnitude of the displacement *x:*

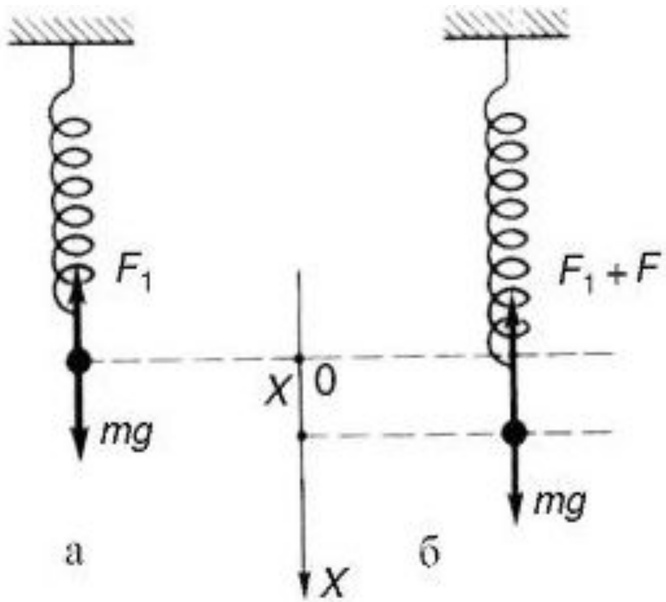


Рис. 1

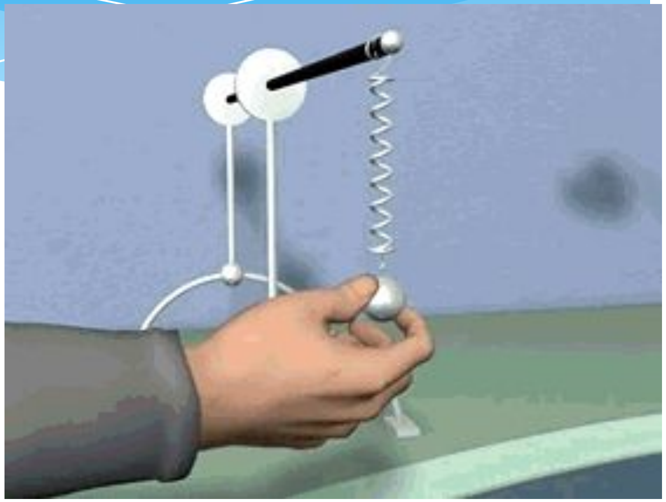
$$F = -kx.$$

k - spring rigidity and depends on its dimensions and material.
The sign "-" indicates that the force of elasticity is always directed in the direction opposite to the direction of displacement, to the equilibrium position.
In the absence of friction, the elastic force F is the only force acting on the body. According to Newton's second law (ma = F):

$$-kx = mx''$$

x'' - second derivative by time

After transferring all the terms to the left and dividing by the mass of the body (m), we obtain the differential equation of free oscillations in the absence of friction:



$$d^2x/dt^2 + \omega_0^2 x = 0,$$
$$\omega_0 = \sqrt{k/m}. \qquad (1.6)$$

The solution of this equation is the harmonic function

$$x = A\cos(\omega_0 t + \varphi_0), \quad \text{или} \quad x = A\sin(\omega_0 t + \varphi_0).$$

The value of ω_0 (1.6) turned out to be equal to the cyclic frequency. This frequency is called own.
Thus, free oscillations in the absence of friction are harmonic.

При выводе дифференциального уравнения гармонического колебания величина ω_0 была введена формально, однако она имеет большой физический смысл, так как определяет частоту колебаний системы и показывает от каких факторов эта частота зависит:

$$\nu = \frac{1}{T} = \frac{\omega_0}{2\pi}$$

упругости и массы пружинного маятника в одном примере,
длины нити и ускорения свободного падения – в случае математического маятника.
Период колебаний может быть найден из формулы:

$$T = \frac{2\pi}{\omega_0}$$

Таким образом, период колебаний пружинного маятника:

$$T = \frac{2\pi}{\sqrt{k/m}} = 2\pi\sqrt{\frac{m}{k}}$$

период колебаний математического маятника:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Скорость и ускорение колеблющегося тела:
Чтобы найти скорость материальной точки при гармоническом колебании, нужно взять производную по времени от выражения:

$$x = A \cdot \cos(\omega_0 t + \varphi_0)$$

$$\upsilon = \frac{dx}{dt} = -A \cdot \omega_0 \cdot \sin(\omega_0 t + \varphi_0) = -\upsilon_{max} \cdot \sin(\omega_0 t + \varphi_0) \;\_\_\_(*)$$

$$\upsilon_{max} = \left| A\omega_0 \right|$$

– максимальная скорость (амплитуда скорости).
На основании тригонометрических формул преобразуем (*):

$$\upsilon = \upsilon_{max} \cdot \cos\left|\frac{\pi}{2} + (\omega_0 t + \varphi_0)\right|$$

Замечаем, что фаза скорости на $\frac{\pi}{2}$

$$\frac{\pi}{2}$$

Скорость и ускорение колеблющегося тела:

Продифференцировав выражение для скорости, найдем ускорение:

$$a = \frac{d\upsilon}{dt} = -A \cdot \omega_0^2 \cdot \cos(\omega_0 t + \varphi_0) = -a_{\max} \cdot \cos(\omega_0 t + \varphi_0)$$

$$a_{\max} = \left| A\omega_0^2 \right|$$ – максимальное ускорение (амплитуда ускорения).

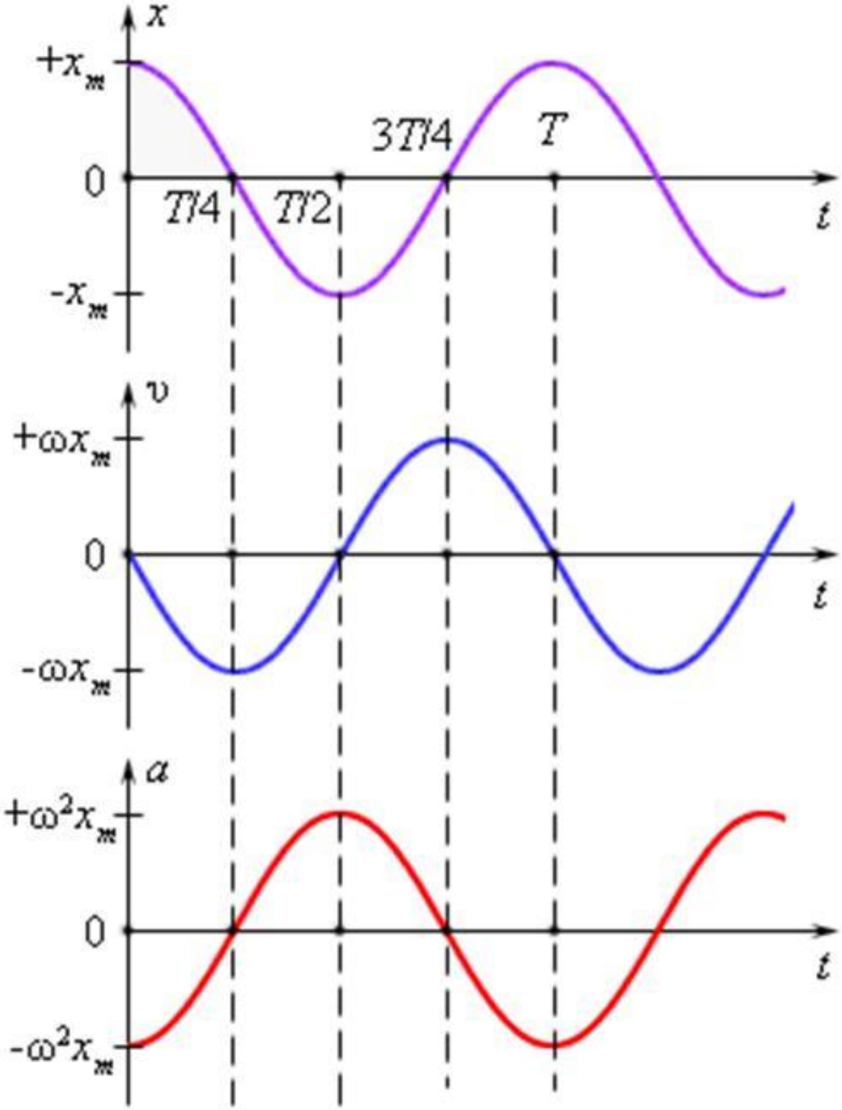
Можно переписать в виде:

$$a = a_{\max} \cdot \cos\left|\pi + (\omega_0 t + \varphi_0)\right|$$

Из сравнения выражений для ускорения и смещения следует, что фазы ускорения и смещения различаются на π, т.е. эти величины изменяются в противофазе.

Speed and acceleration of the oscillating body:

change according to the same law with a phase shift



Energy of harmonic oscillations.

The energy of the oscillating system consists of potential and kinetic energies.

$$E = E_{кин} + E_{пот}$$

$$E_{кин} = \frac{m\upsilon^2}{2}$$

$$E_{пот} = \frac{kx^2}{2}$$

$$E = \frac{m\upsilon^2}{2} + \frac{kx^2}{2}$$

$$x = A\cos(\omega_0 t + \varphi_0)$$

$$\upsilon = -A\omega_0 \sin(\omega_0 t + \varphi_0)$$

$$\omega_0^2 = \frac{k}{m}$$

$$E = \frac{m}{2} A^2 \omega_0^2 \sin^2(\omega_0 t + \varphi_0) + \frac{k}{2} A^2 \cos^2(\omega_0 t + \varphi_0)$$

$$m\omega_0^2 = k$$

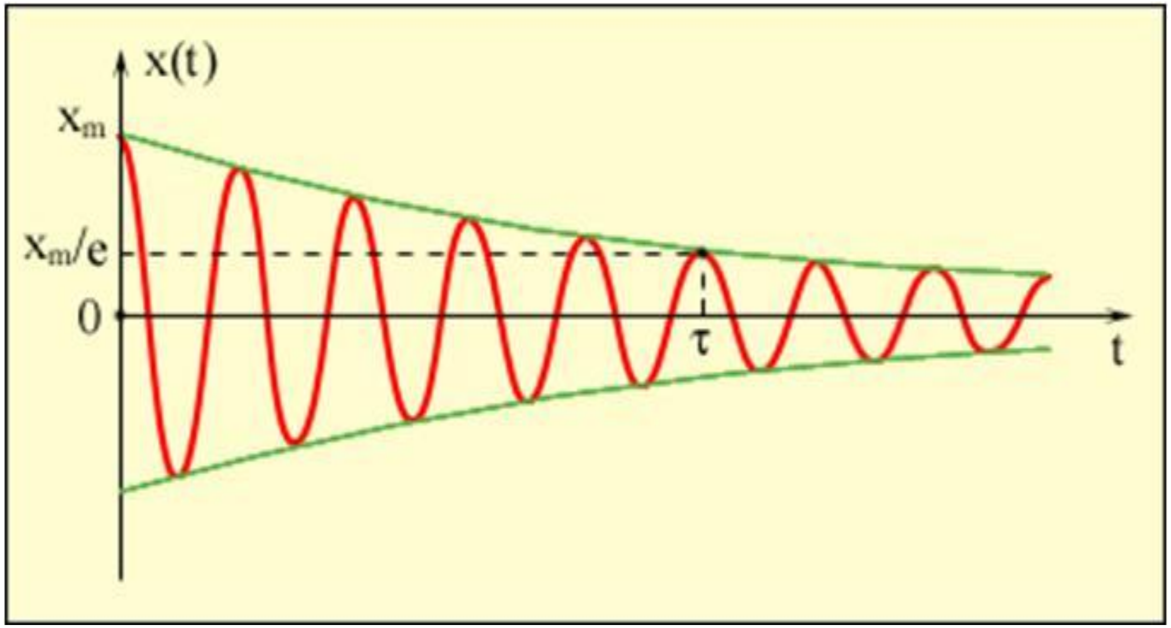
$$E = \frac{kA^2}{2}\left[\sin^2(\omega_0 t + \varphi_0) + \cos^2(\omega_0 t + \varphi_0)\right] = \frac{kA^2}{2}$$

$$E = \frac{kA^2}{2}$$ - the total energy remains constant = **const**

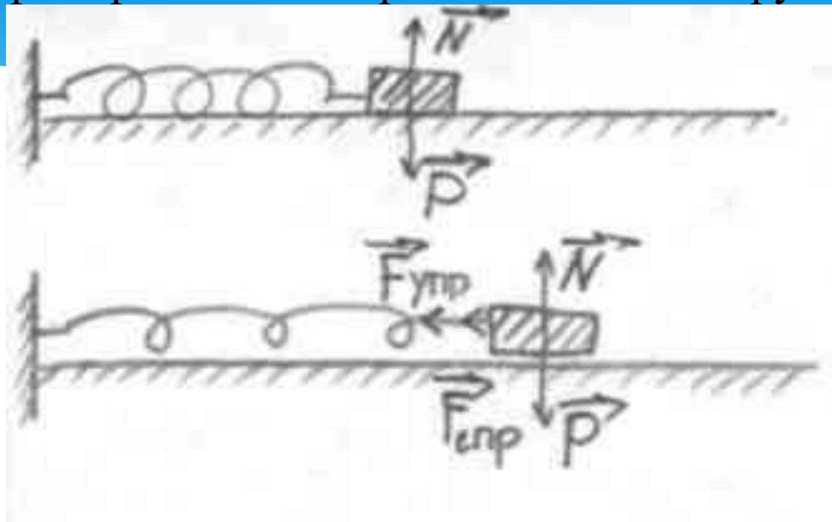
Damped oscillations

In real conditions, any oscillatory system is under the influence of frictional forces (resistance). At the same time, part of the mechanical energy is converted into internal energy of the thermal motion of atoms and molecules, and the oscillations become damped.

Damped are called oscillations whose amplitude decreases with time.



Рассмотрим на примере горизонтально расположенного пружинного маятника:



$$\vec{N} + \vec{P} + \overrightarrow{F_{conp}} + \overrightarrow{F_{ynp}} = m\vec{a}$$

Найдем проекцию на ось ОХ:

$$F_{conp} + F_{ynp} = ma$$

$$F_{ynp} = -kx \qquad F_{conp} = -r\upsilon$$

$$-r\upsilon - kx = ma$$

где r - коэффициент сопротивления среды; V - скорость тела.

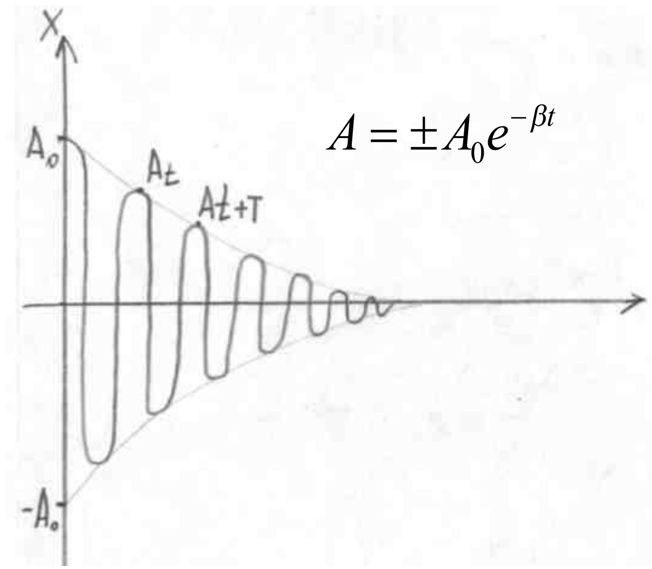
$$ma + r\upsilon + kx = 0 \qquad /:m;$$

$$\Rightarrow a + \frac{r}{m}\upsilon + \frac{k}{m}x = 0$$

Differential equation of damped oscillations

$$x''+2\beta x'+\omega_0^2 x = 0$$

where β is the attenuation coefficient.



The solution of this equation is:

$$x = A_0 \cdot e^{-\beta t} \cdot cos(\omega t + \varphi_0)$$

The ratio of two amplitudes separated from each other by a period T, are called the damping decrement:

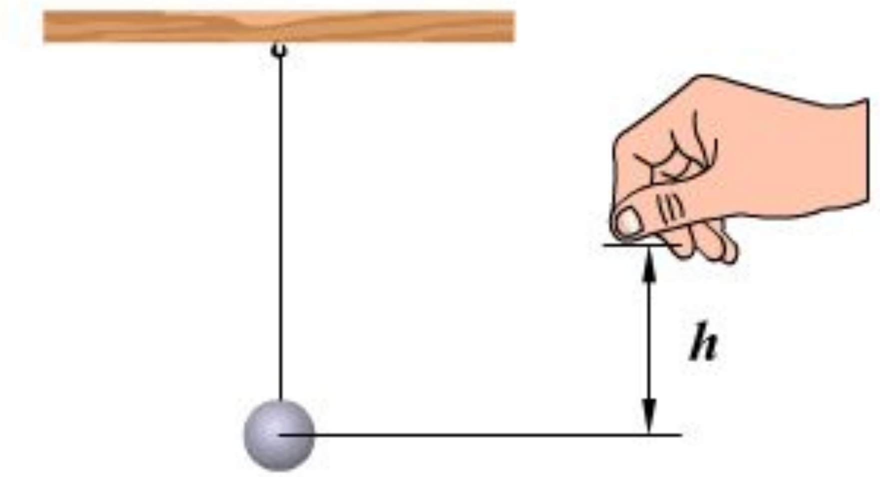
$$D = \frac{A_t}{A_{t+T}} = e^{\beta T}$$

$\lambda = \ln D = \beta T$ - logarithmic decrement decrement.

$\omega = \sqrt{\omega_0^2 - 2\beta^2}$ - frequency of damped oscillations

Forced oscillations. Resonance

In order for the oscillations not to decay, it is necessary to inform the system of additional energy, i.e. to act on the oscillating system by periodic force. Such oscillations are called forced. Forced oscillations are made with a frequency equal to the frequency of the change in the external force.



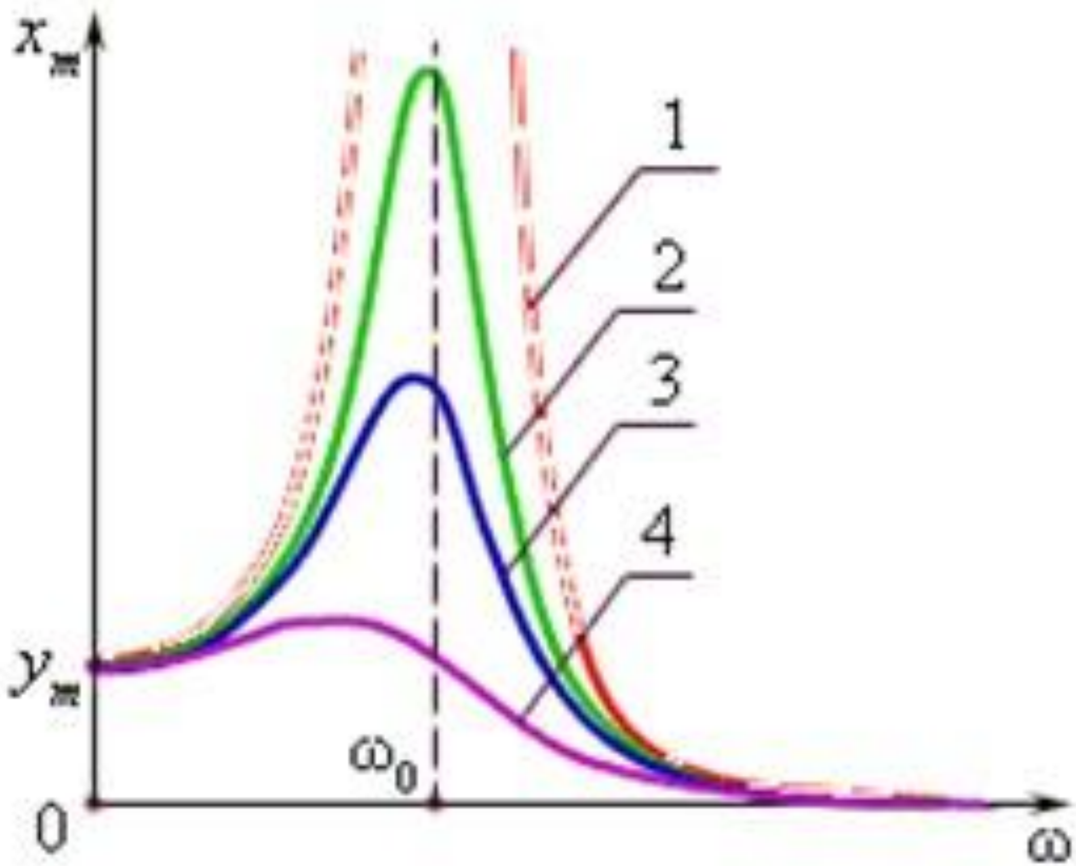
The amplitude of forced mechanical oscillations reaches its maximum value in the case when the frequency of the driving force coincides with the frequency of the oscillatory system.

This phenomenon is called **resonance.**

For example, if you periodically pull the cord in time with its own oscillations, we notice an increase in the amplitude of its oscillations.

$$\omega_{\text{рез}} = \sqrt{{\omega_0}^2 - 2\beta^2} \approx \omega_0$$

Зависимость амплитуды x_m вынужденных колебаний от частоты ω вынуждающей
силы называется **резонансной характеристикой** или **резонансной кривой**.



Резонансные кривые при различных уровнях затухания:
1 – колебательная система без трения;
при резонансе амплитуда x_m вынужденных колебаний неограниченно возрастает;
2, 3, 4 – реальные резонансные кривые
для колебательных систем с различным трением.

The phenomenon of resonance can be the cause of the destruction of machines, buildings, bridges, *if their own frequencies coincide with the frequency of the periodically acting force.*

So in the USA, a strong wind, whose frequency coincided with the frequency of oscillations of the bridge, led to its destruction.
Let's look at the video.

Positive resonance value

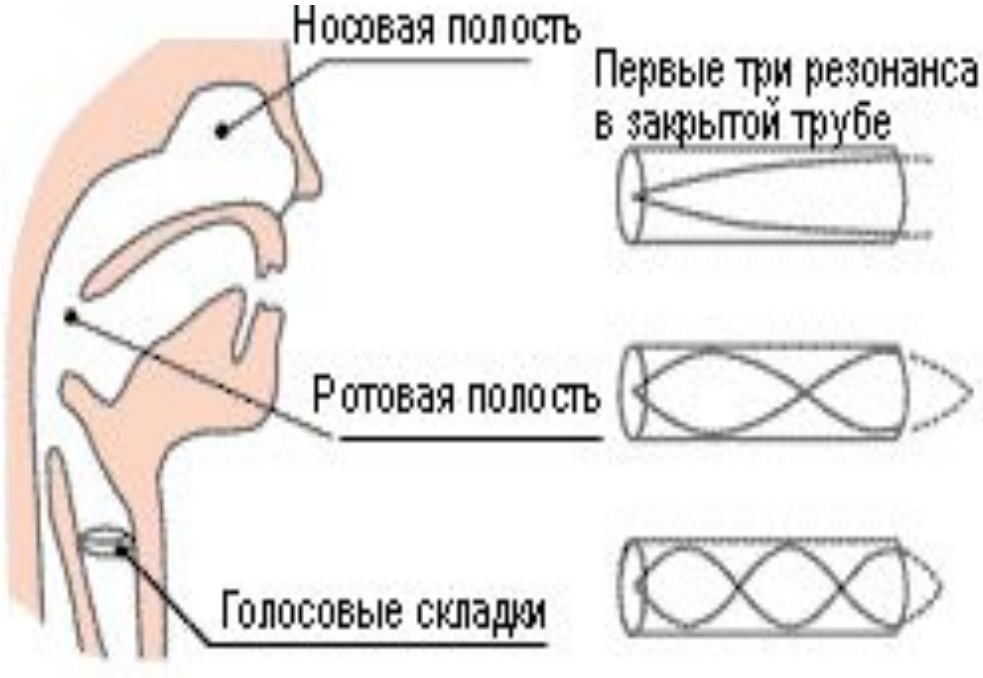
The resonance phenomenon is used in devices.

Frequency meter - a device for measuring the frequency of oscillations

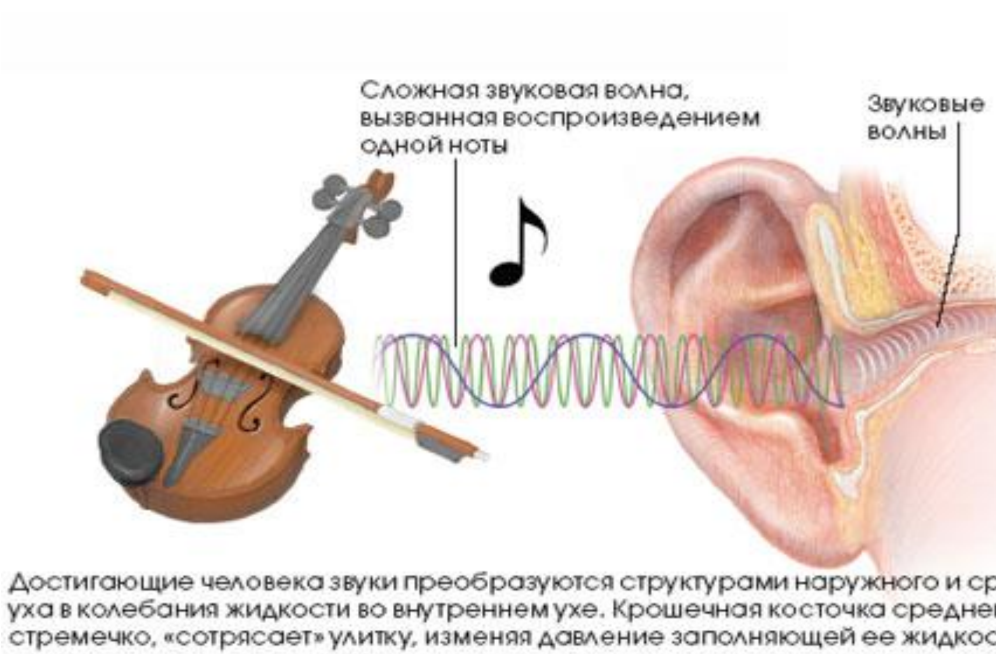
Positive resonance value

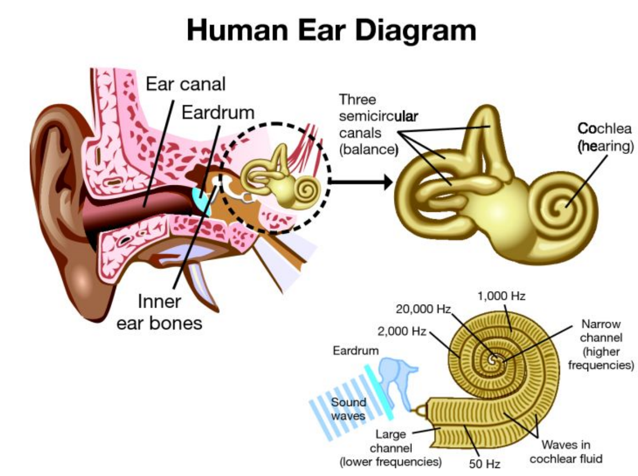
Wind musical instruments use this phenomenon

Resonance cavities of the vocal apparatus



The hearing is also based on resonance





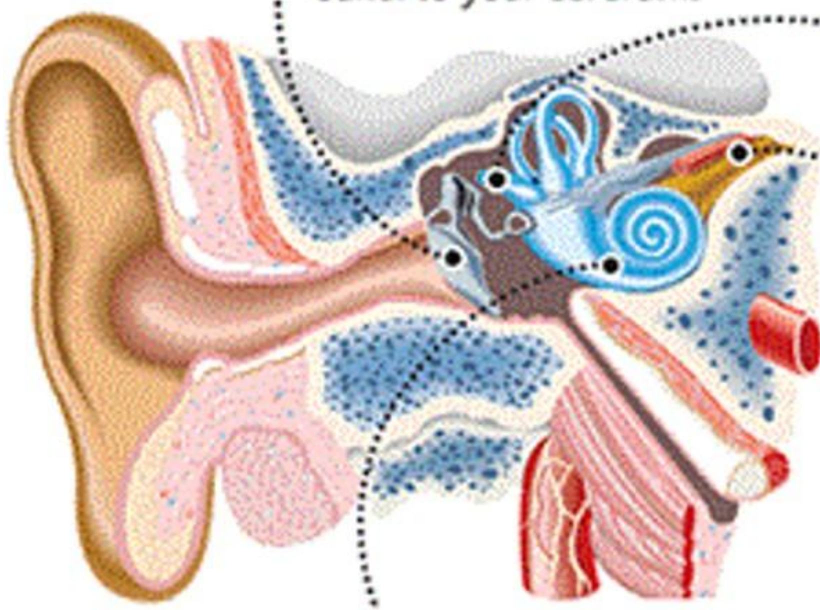
How We Hear

1.

Sound waves enter your outer ear and travel through the ear canal to your eardrum.

2.

Your eardrum vibrates with the incoming sound and sends the vibrations to three tiny bones in your middle ear.



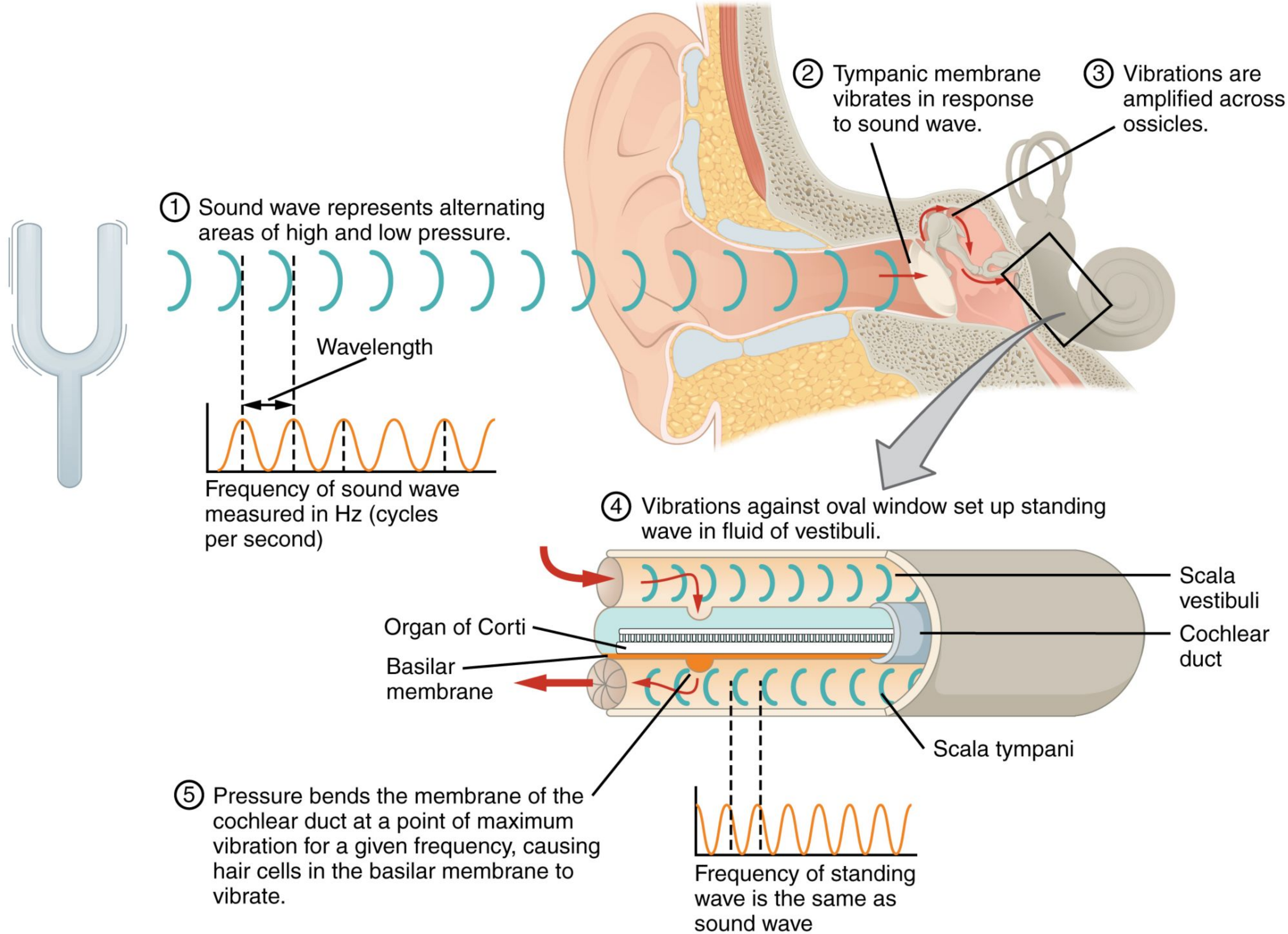
3.

The bones in your middle ear amplify the sound vibrations and send them to your inner ear, or cochlea. The sound vibrations activate tiny hair cells in the inner ear, which in turn release neurochemical messengers.

4.

Your auditory nerve carries this electrical signal to the brain, which translates it into a sound you can understand.

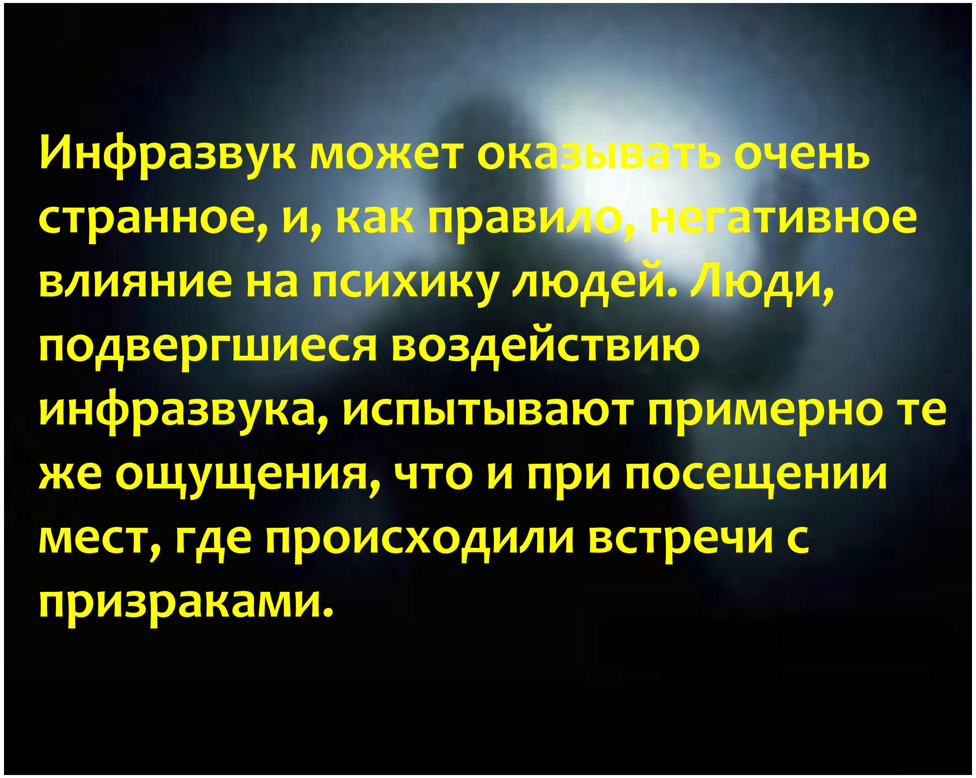
SwissMedicareGroup
Building A Healthy Nation



① Sound wave represents alternating areas of high and low pressure.
Wavelength
Frequency of sound wave measured in Hz (cycles per second)
② Tympanic membrane vibrates in response to sound wave.
③ Vibrations are amplified across ossicles.
④ Vibrations against oval window set up standing wave in fluid of vestibuli.
Scala vestibuli
Cochlear duct
Organ of Corti
Basilar membrane
Scala tympani
⑤ Pressure bends the membrane of the cochlear duct at a point of maximum vibration for a given frequency, causing hair cells in the basilar membrane to vibrate.
Frequency of standing wave is the same as sound wave

Резонанс и состояние человека

Привидения — это следствие воздействия инфразвука на психику человека



Инфразвук может оказывать очень странное, и, как правило, негативное влияние на психику людей. Люди, подвергшиеся воздействию инфразвука, испытывают примерно те же ощущения, что и при посещении мест, где происходили встречи с призраками.

Human body vibrations and their registration

The analysis of oscillations created by the human body or its individual parts is widely used in medical practice.

Walking is a complex, periodic locomotor process that occurs as a result of the coordinated activity of the skeletal muscles of the trunk and extremities. The analysis of the walking process gives many diagnostic signs.

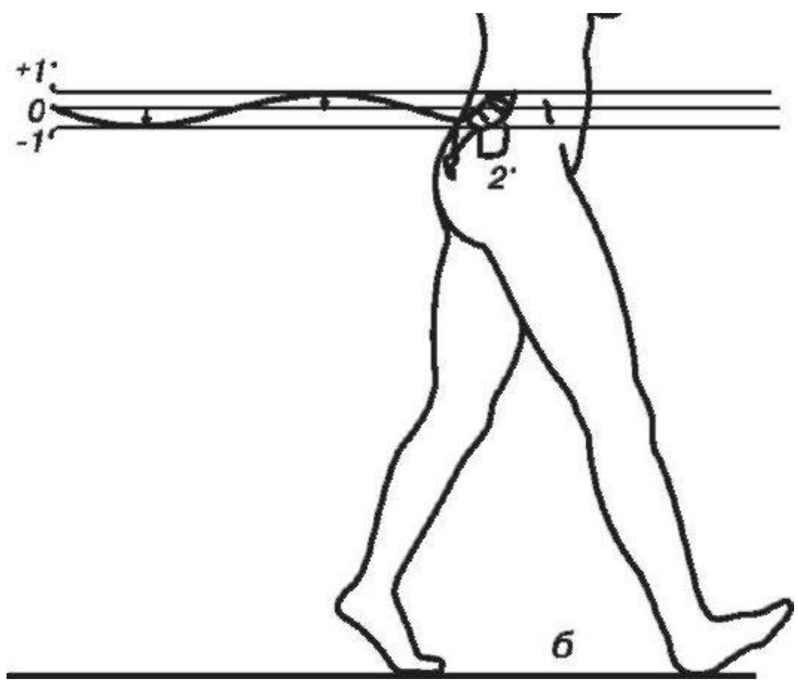


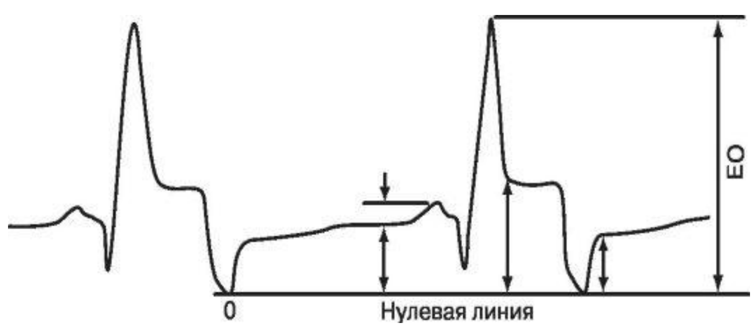
Рис. 1.8. Вертикальное смещение ЦМ тела человека во время ходьбы

Mechanical oscillations of the heart

There are various methods of heart research, which are based on mechanical periodic processes.

Ballistocardiography (BCG) is a method for studying the mechanical manifestations of cardiac activity, based on the recording of pulsed microscopic movements of the body, caused by the ejection of blood from the ventricles of the heart into large vessels.

Apekskardiography (AKG) - a method of graphical recording of low-frequency vibrations of the thorax in the region of apical stimulation caused by the work of the heart. Registration of an apekskardiogram is usually done on a multichannel electrocardiograph using a piezocrystalline sensor, which is a converter of mechanical vibrations into electrical oscillations.



Vibration

The work of many mechanisms is associated with the occurrence of **vibrations**, which are transmitted to a person and have a harmful effect on him.

Vibration - forced oscillations of the body, under which either the whole body vibrates as a single whole, or its individual parts oscillate with different amplitudes and frequencies.

Long-term exposure to vibrations causes persistent disturbances in normal physiological functions in the body.

Oscillations with a frequency of 3-5 Hz cause the reactions of the vestibular apparatus, vascular disorders. At frequencies of 3-15 Hz, there are disorders associated with resonance oscillations of individual organs (liver, stomach, head) and the body as a whole. Oscillations with frequencies of 11-45 Hz cause visual impairment, nausea, vomiting. At frequencies exceeding 45 Hz, cerebral vessels are damaged, blood circulation is disturbed, etc. At a frequency of 10,000 Hz there is heating of tissues, destruction of cells.

Vibration

At the same time, in a number of cases, vibrations are used in medicine. Using high-frequency vibrating apparatuses allows drilling a hole in a tooth in a complex shape.

Vibration is also used for massage. With manual massage, the massaged tissues are brought into oscillatory motion with the help of the hands of a massage therapist.