NATIONAL UNIVERSITY OF PHARMACY
Department of Educational and Information Technologies

BIOPHYSICS, PHYSICAL METHODS OF ANALYSIS

Lecture 4

Biophysics of vision.
Biophysics of hearing.

Plan of the Lecture

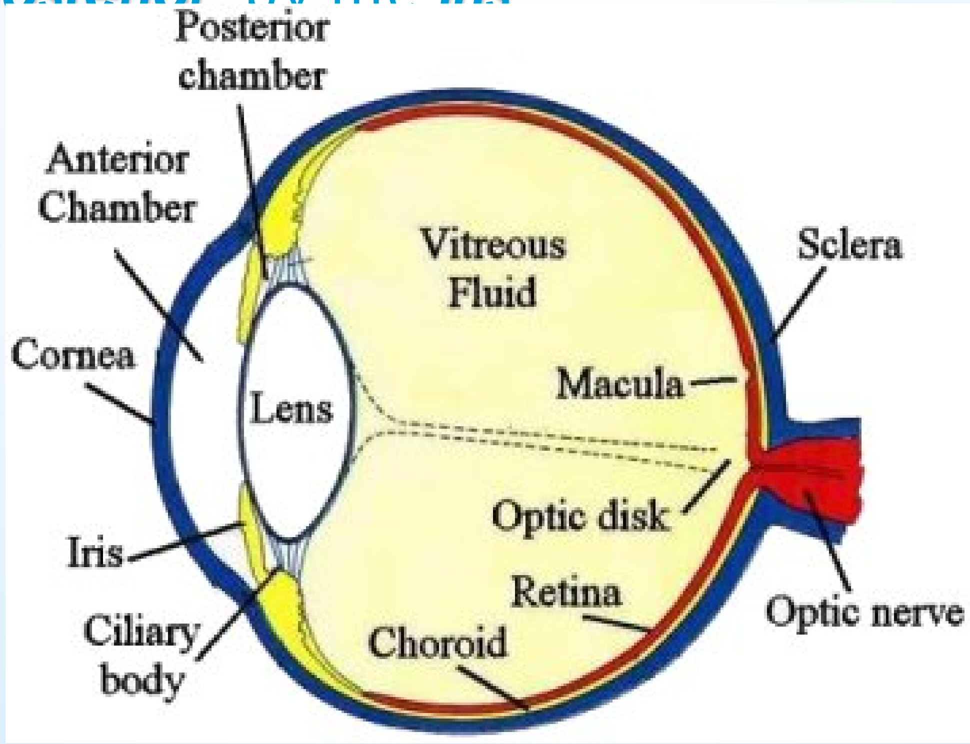
1. Light conducting and light perceiving systems of human eye.
2. Sensitivity of eye to color and light.
3. Human eye as an optical system.
4. Eye defects.
5. Light absorption.
6. Light scattering.
7. Local response (LR) and Action potential (AP).
8. Conversion function of receptors.
9. Biophysical relation between the stimulus and sensation.
10. Main characteristics of sound.
11. Mechanism of sound perception.

Purpose of the lecture is

- **to acquire knowledge about the physical structure of the eye and understand the basic physical properties of the light.**
- **to acquire knowledge about the physical structure of the ear and understand the basic physical properties of the sound.**

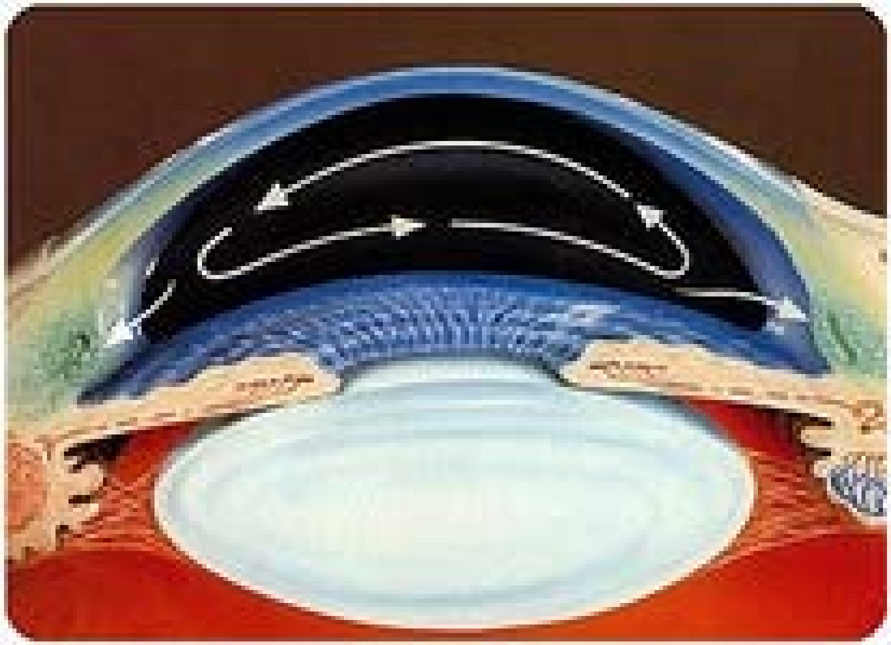
LIGHT CONDUCTING AND LIGHT PERCEIVING SYSTEMS OF HUMAN EYE

- The human eye structure is shown in Fig. A human eye has spherical form with diameter ***d≈24÷25 mm***. The eyeball contains three coats (or layers): outer, middle and internal, which are called ***sclera***, ***choroid***, and ***retina*** correspondingly. The eyeball is divided into ***two chambers, anterior*** and ***posterior***, by the ***iris***.

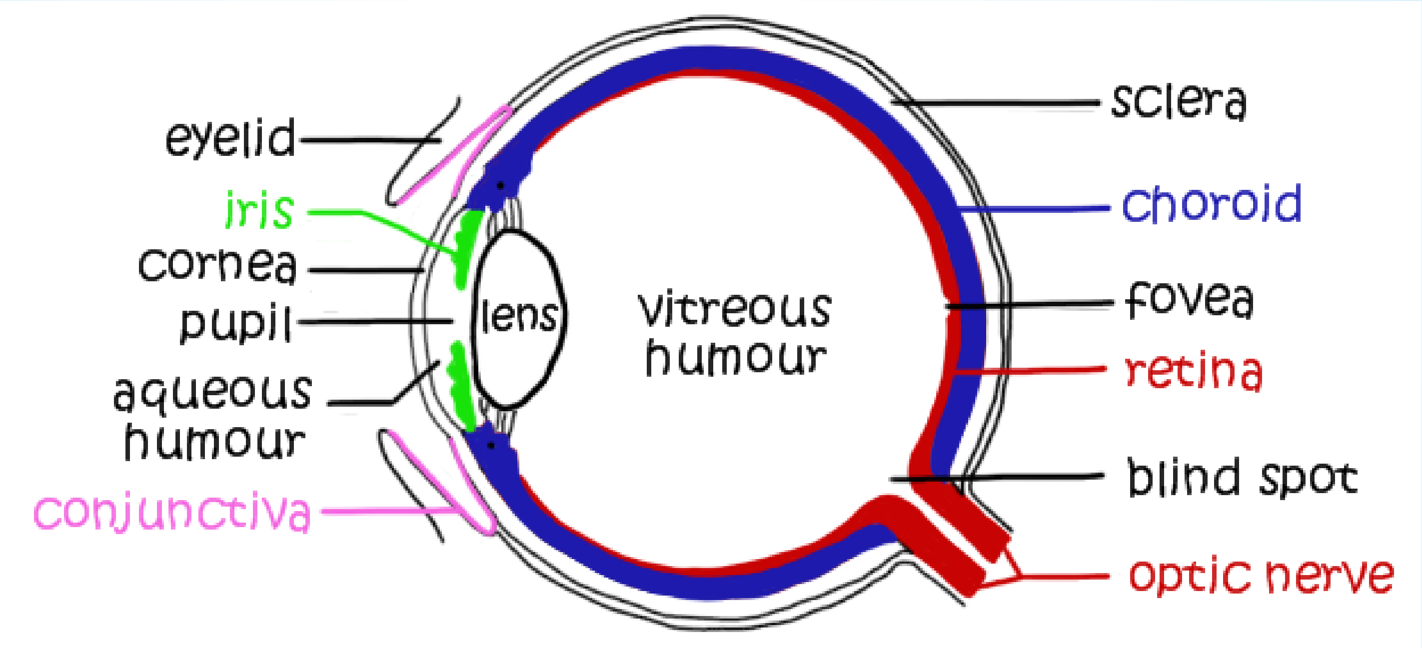


Eye’s Light Conducting System

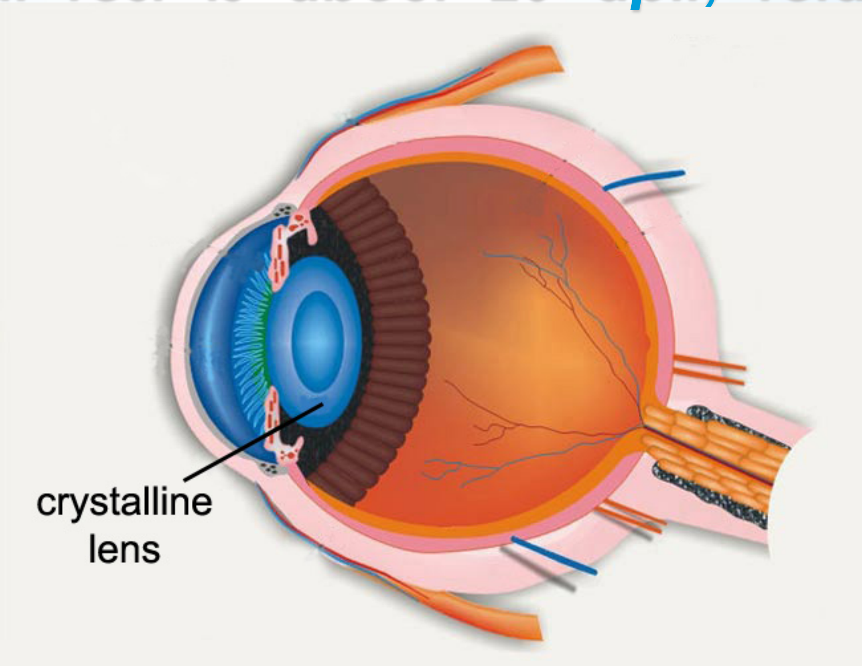
- Outer coat of the eyeball sclera (or fibrous coat) protects the eyeball and assists in maintaining its shape.
- The front part of the sclera is called the ***cornea***. Light enters the eye through the cornea. The cornea is transparent, and it has a bigger curvature and strength than the remaining part of the sclera. The relative index of refraction equals n=1.38; the focal power approximately equals to 40 dptr. Cornea is mostly a refracting part of the eye, so its external surface borders on air and its internal surface borders on ***aqueous humour*** (a watery fluid, which fills the anterior chamber of the eyeball). Aqueous humour is a transparent liquid with optical properties like those of water, n=1.33.



- ***The middle layer of the eyeball is the choroid.*** It contains numerous blood vessels. Its function is to absorb light to prevent internal reflection in the eyeball and to provide nourishment for the retina.
- The choroid is continuous with the iris in the front of the eye. There is a small aperture - the ***pupil*** - the opening in the centre of the iris. Light enters the eye through the pupil. The diameter of the pupil is changed from 2-3 mm at bright light to 7-8 mm at weak light. Thus, the quantity of light coming into the eye is regulated.
- ***The iris determines the colour of the eye***. There are muscle fibres regulated by the central nervous system. These fibres contract and change the diameter of a pupil.



- ***The space between the cornea and the iris is called the eye anterior chamber***. The anterior chamber is filled with a liquid whose index of refraction is almost equal to the index of refraction of water (n≈1.33). ***This liquid is called the anterior humour***.
- There is a ***crystalline lens*** (or just lens), which is situated immediately behind the pupil. The crystalline lens is a transparent elastic structure. The structure of the lens is very interesting. It consists of a number of transparent layers just like an onion.
- Crystalline lens has the shape of a biconvex (converging) lens. It refracts light onto the retina. ***The focal power of the crystalline lens at rest is about 20 dptr; relative index of refraction is 1.44***.



- ***The posterior camera of the eyeball is behind the crystalline lens. It is filled with a transparent jelly-like substance*** called ***vitreous humour***. Its relative index of refraction is 1.33. Vitreous humour helps maintain the shape of eyeball and assists in the refraction of light.

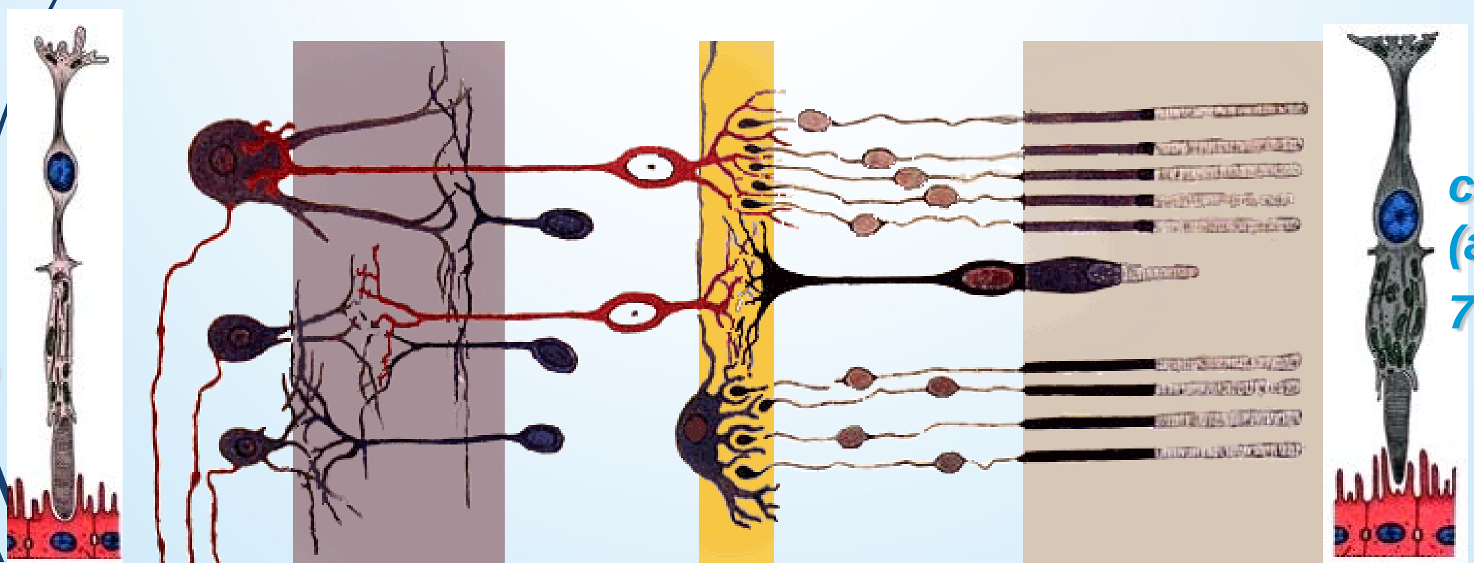
- All these parts of the human eye form a light conducting system of eye.

- ***The total focal power of the eye in rest (eye looks into infiniteness) is D_{eye}=63-65 dptr***. Thus, among all the parts of the light conducting system the cornea has the maximum focal power.

Eye’s Light Perceiving System

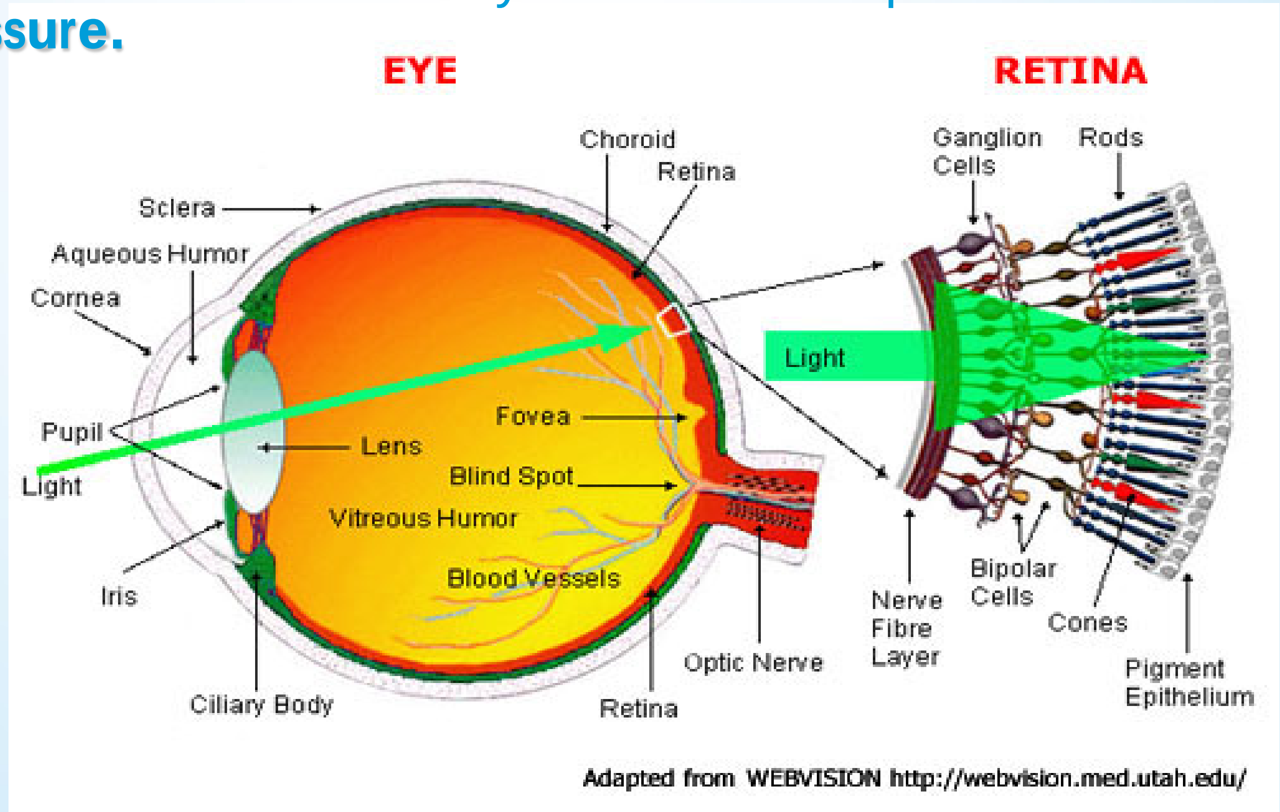
- The innermost layer lining the inside of the eyeball is retina. It is composed of nervous tissue and does not cover the front region of the eyeball. The retina contains ***photoreceptors*** (receptor cells sensitive to light), i.e. the retina serves as the light perceiving system of the eye.
- Man has two kinds of photoreceptor cells differing in form, which is reflected in their names, viz. ***rods*** and ***cones***.
- The number of rods on the retina is about 130 million, and that of cones is about 7 million.
- The rods and cones are irregularly distributed over the retina.

rod (about 130 million)



cone (about 7 million)

- Cones are mainly located in the ***macula lutea*** (or ***yellow spot***) – an oval area in the centre of the posterior part of the retina.
- The ***fovea centralis*** is situated at the centre of the macula lutea and contains numerous cones, but no rods. It is the region where light is mainly focused and where there is the greatest acuity of vision.
- Photoreceptors are only absent in that area of the retina where the *optic **nerve*** enters the eyeball. This area is called the ***blind spot*** (or ***optic disk***). At the blind spot there are neither rods nor cones, so light is not perceived at the area.
- All contents of the eye is under the pressure exceeding the ambient pressure by 18-26 mm of mercury column. This pressure is called an **intra-eye pressure.**



SENSITIVITY OF EYE TO COLOUR AND LIGHT

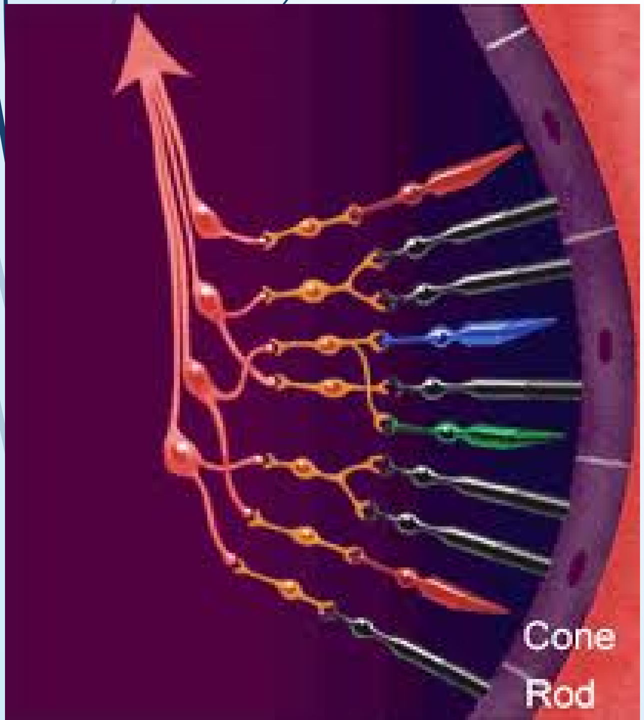
- One of the most striking phenomena of vision is the ***dark adaptation*** of the eye. The dark adaptation is the ability of the eye to adapt itself to different brightness due to following mechanisms:

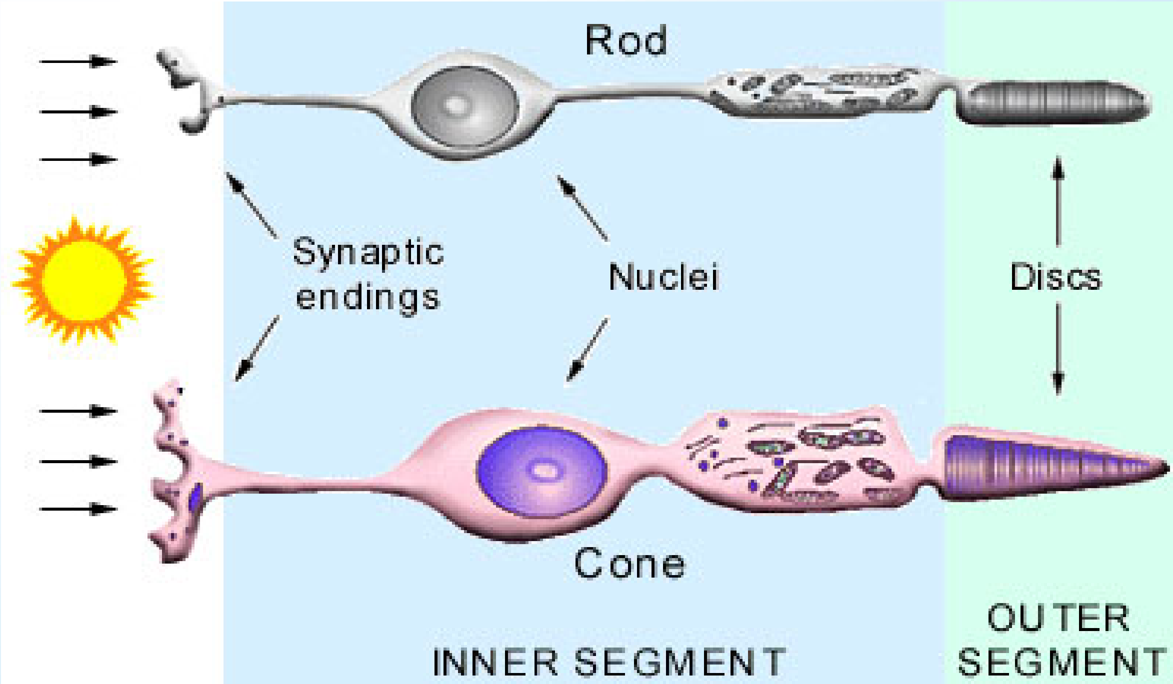
1) changing the pupil diameter; within 2 to 8 mm;
2) changing of concentration of the photosensitive substance contained in the photoreceptors, its decomposition causing receptor excitation;
3) screening of cones and rods with a dark pigment contained in the choroid, which is able to move toward the vitreous humor in the process of adaptation.

- By means of adaptation the eye perceives brightness (luminance) in the range from 10^{-7} to 10^{5} cd/m^{2} (candela per square metre), 1 cd/m^{2} = 1 nit.

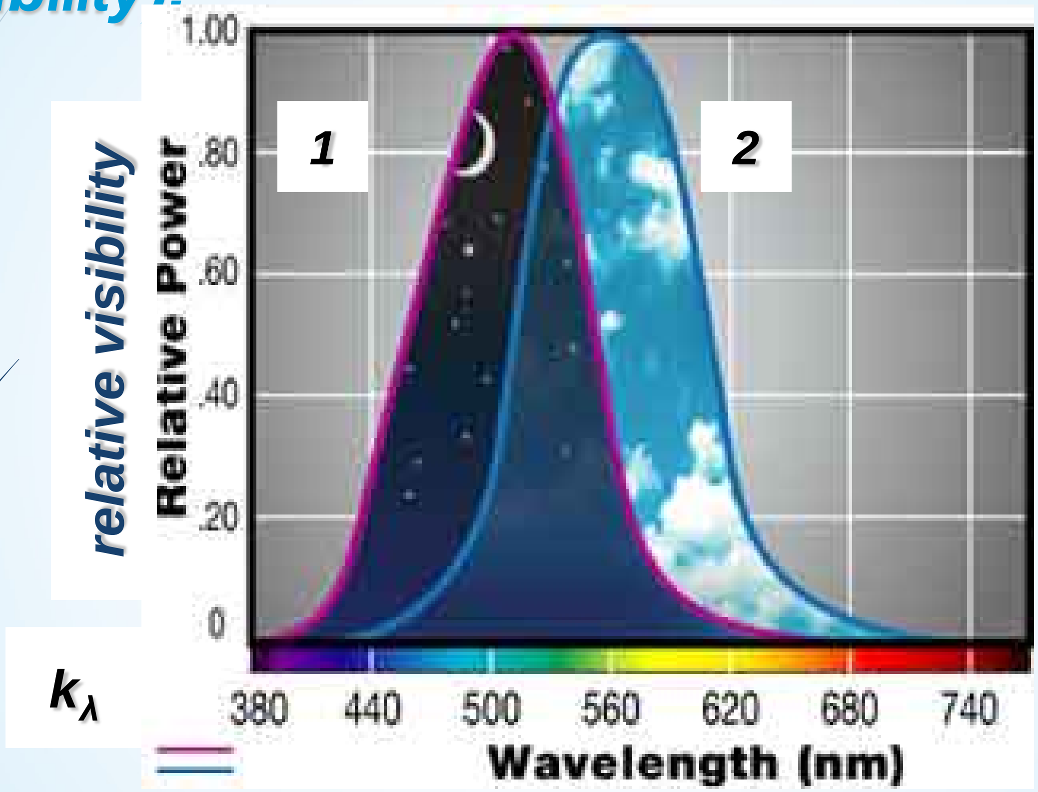
- Cones create the colour sensation; they make the human eye able to distinguish colours. Therefore they are called the apparatus of colour vision. But the cones lack very high photosensitivity and require sufficiently bright light for functioning. So, the ***cones form the apparatus of coloured daylight (bright) vision***.

- Rods cannot differentiate colours. Rods are called the apparatus of peripheral vision, or achromatic vision. But the rods possess very high photosensitivity. They function sufficiently well at twilight when lighting conditions are low, and the cone apparatus does not function. So, the ***rods form the apparatus of achromatic twilight vision***.





- Human eye perceives electromagnetic waves in the range from 380 to 760 nm ().
- Brightness curve is the spectral sensitivity of the eye. ***Quantity K is called the relative spectral sensitivity of the eye (or relative visibility).***



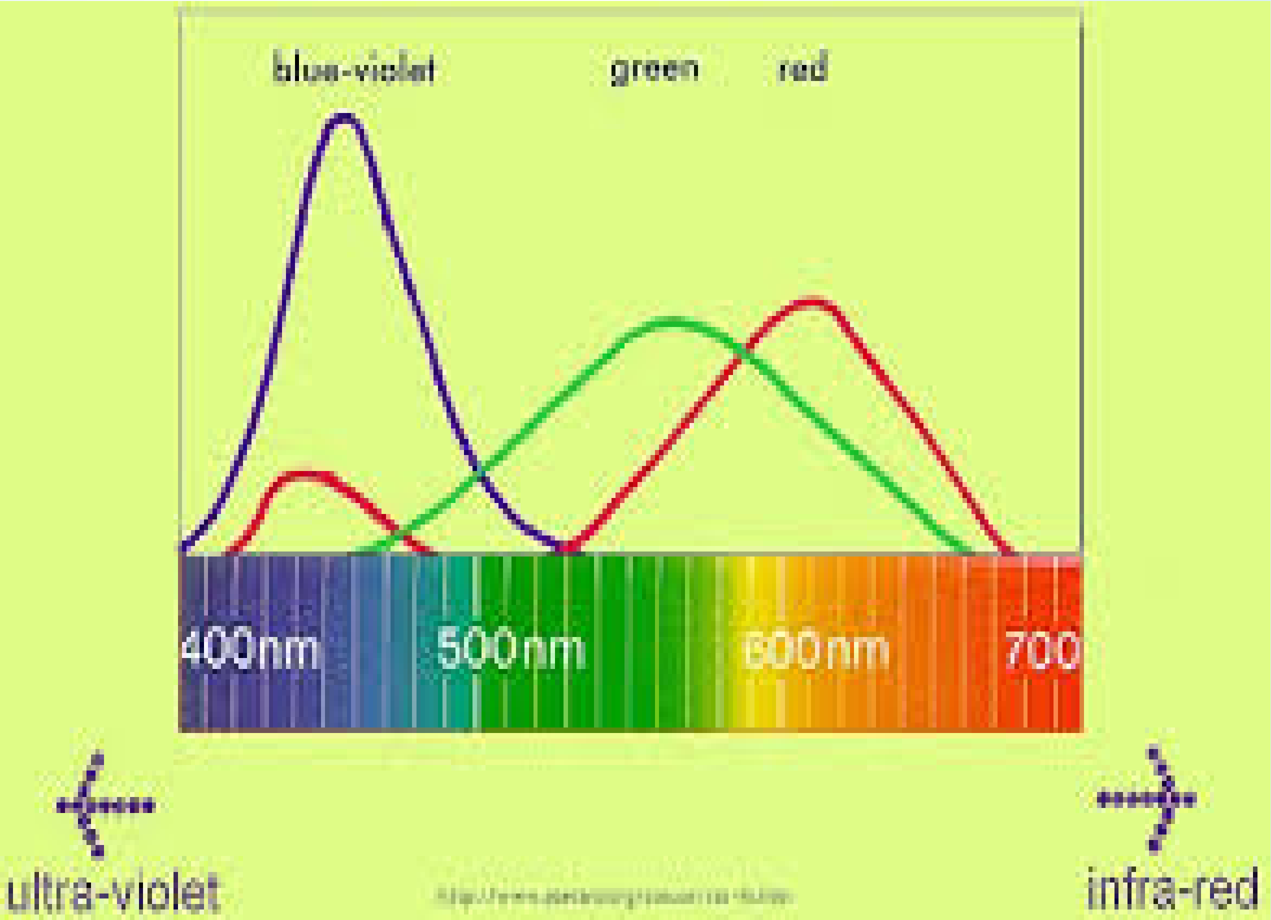
Rod (1) and cone (2) brightness curves

- In this figure there are two curves, one (1) represents the sensitivity of the eye in the dark (due to the rods); the other (2) for the eye in the light (the latter is the cone brightness curve).

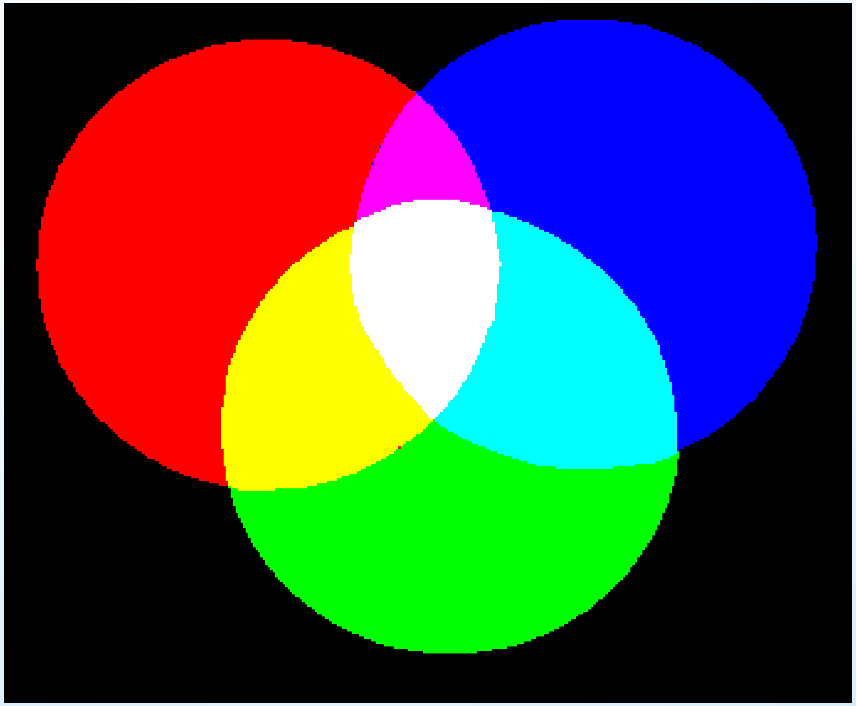
- ***For normal eye K=1 at λ=555 nm in the light, and K=1 at λ=510 nm in the dark.*** This means that ***the peak sensitivity of cones is in the yellow-green range of the spectrum (it corresponds to light with the wavelength of λ = 555 nm).*** This is because the spectrum of solar radiation incident on Earth also has a maximum in this wavelength range.

- ***The peak sensitivity of rods corresponds to green light with the wavelength of λ = 510 nm.*** This is because the rods function mainly in twilight, when lighting is provided by light scattered in the upper layers of the atmosphere. As will be shown further in detail, light is scattered more when its wavelength decreases.

- The simplest ***theory of colour vision in man*** is proposed by ***Young*** and ***Helmholtz*** and widely accepted. It supposes that in the eye there are three different pigments, which receive the light. These pigments have different absorption spectra. ***One pigment absorbs strongly in the red, another absorbs strongly in the blue, the other absorb in the green***.

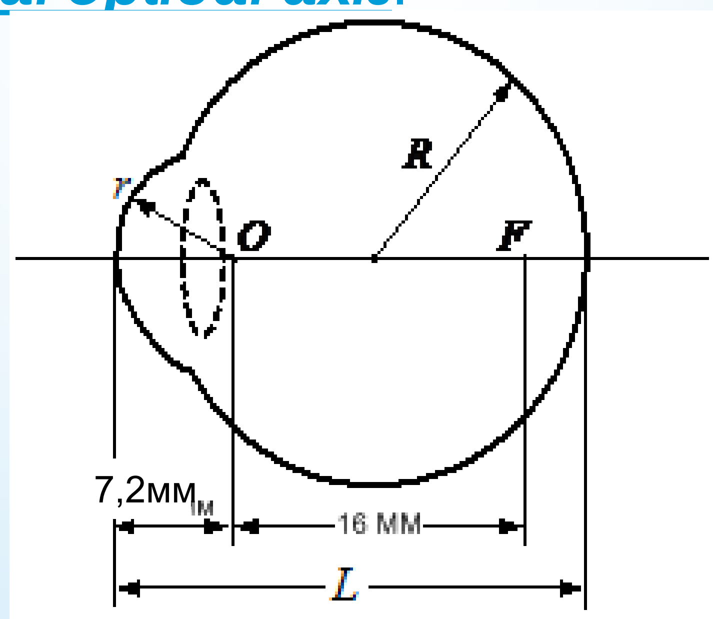


- Any light can be considered as a sum of various positive amounts of primary pure colours: red, green, and blue.
- Man's ability to distinguish colours is based on the normal eye having three types of cones in the retina, one type being sensitive to blue light, one type to green light, and one type to red light.
- The same degree of stimulation to all three gives the sensation of white light. Colours are sensed by differential stimulus of each of three types of cones.

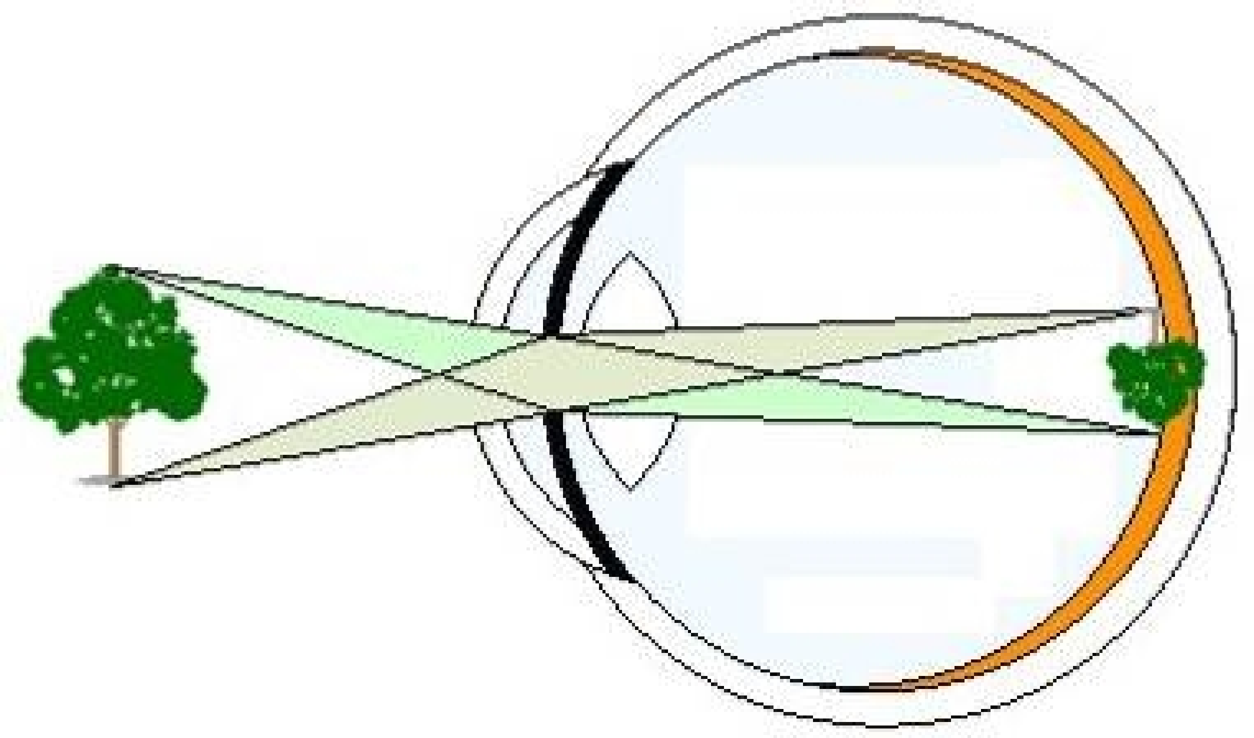


HUMAN EYE AS AN OPTICAL SYSTEM

- The human eye can be dealt with as a centered optical system. The principal axis of this system is the principal optical axis of the eye.
- ***The principal optical axis*** of the eye passes through the geometrical centers of cornea, pupil and crystalline lens.
- ***Eye optical center*** is at the distance of 7.2 mm from cornea and at the distance of 17 mm from retina.
- The line, which passes through the optical centre of the crystalline lens and the centre of the macula lutea, is called ***the vision axis***. ***<u>The vision axis forms an angle of approximately 5° with eye's principal optical axis</u>***.

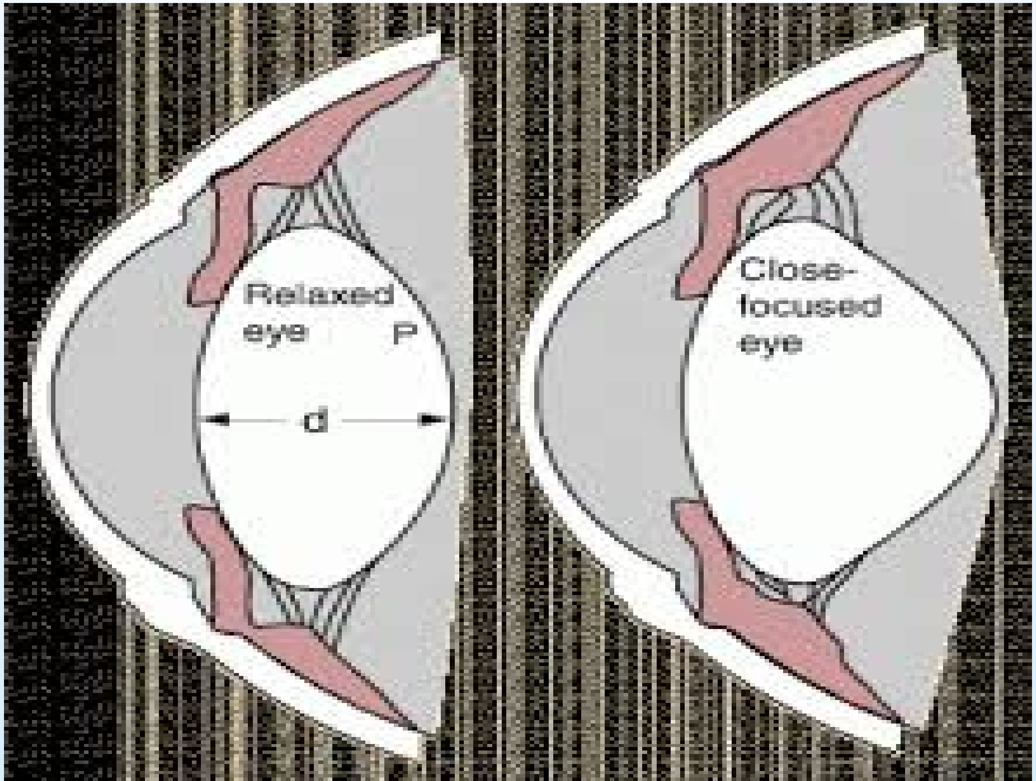


- In the process of forming the image a human eye is regarded as a uniform spherical lens surrounded by air from the side of object and by liquids (n=1.336) from the side of image,.
- The image in the eye is formed in accordance with the rules for a single converging lens. The object is usually placed in front of the eye at a distance of more than a double focal length (>2F), and its image is formed on the back surface of the eye.
- ***The image in the eye is reduced, inverted, and real.***



- ***The ability of the eye to focus on near or far objects (objects located at different distances) by changing the shape of the crystalline lens is called <u>accommodation</u>.***

- In the human eye the curvature of the crystalline lens automatically changes, and the focal power changes too. For an object to be viewed clearly its image must be precisely focused on the retina. Close objects can be seen when the lens takes up a more spherical shape, far objects when the lens is flattened.



- When an object is at infinity, its image is focused on retina for a normal eye. In this case the lens has a plane form and its focal power D is approximately ***60 dptr***. If an object approaches the eye, the focal power D increases to ***70 dptr*** (at this the focal power of the crystalline lens run up about 30 dptr).

- Accommodation is occurred without the stress of the eye if an object approaches the normal eye at a distance of ***25 cm***. This distance is called the ***<u>distance of the most distinct vision</u>*** (or ***distance of the best vision***).

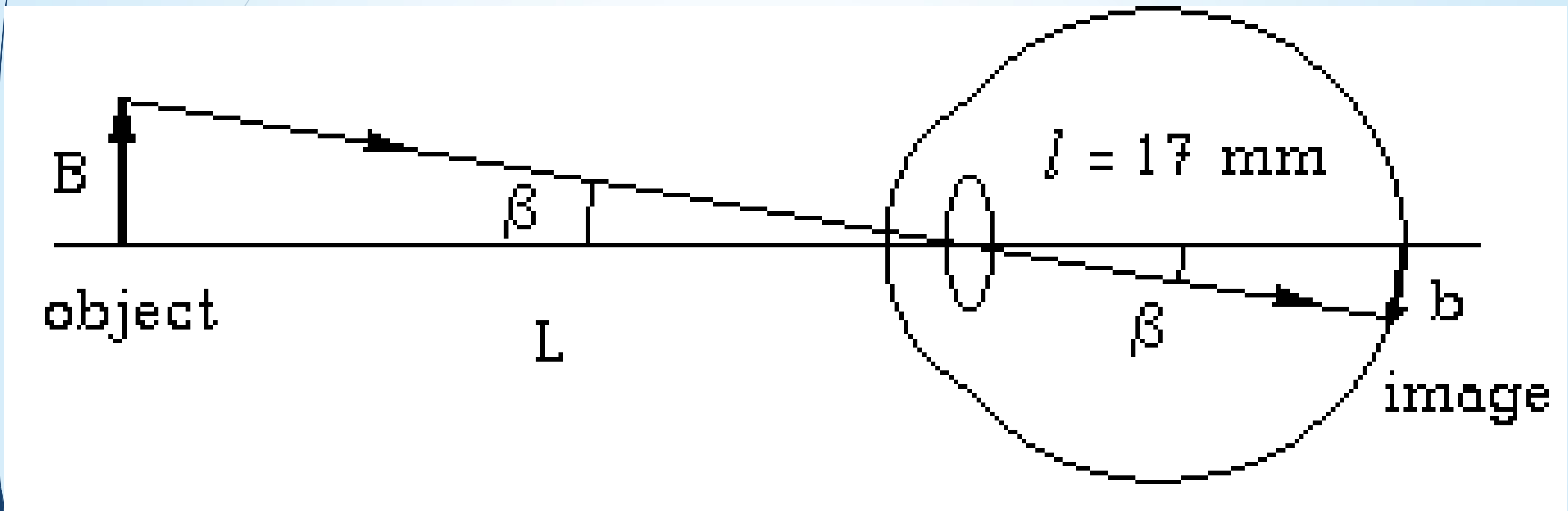
- ***The least distance from the eye to the object, at which one can get its clear image on the retina, is called <u>eye's nearest point</u>*** (or the *<u>nearest point of clear vision</u>*).

- The eye's ability to resolve different points of an object (see them as separate ones) is called ***resolving ability***.

- The eye distinguishes an object if its size is not less than a certain minimum value, because to distinguish two points of an object as two separate points, the rays from these points should arrive to two different cones in retina.

- Hence, there exists the minimum distance between two points, which can be distinguished by eye. This distance is called the ***eye-resolving power***.

- At the distance of the best vision (L=25 cm) eye-resolving power is equal to 70 μm (size of object B in Fig.). In this case the size of the image on the retina is b=5 μm. It corresponds to the mean distance between two cones in retina.



Angle of view (β)

- The size of the image obtained on retina depends both on the size of the object and the angle of vision.
- The ***angle of vision*** (β) is the angle at which rays from the extreme points of the object or its image converge in the optical centre of the eye.

- The ***limiting angle of vision*** of the human eye (β_{min}) is used to characterize the resolving power of the eye. The limiting angle of vision corresponds to the eye-resolving power at the distance of most distinct vision. It is minimal angle of vision; it is equal to β_{min} **= 1'** for the normal eye.

- In medicine the resolving power of the eye is appreciated by the ***acuity of vision***. The normal acuity of vision is equal to 1. In this case the limiting angle of vision β_{min} **= 1'**.

- If β_{min} for somebody differ from 1, his/her acuity of vision can be calculated by formula $1/\beta_{min}$. For instance, if β_{min} = 4' the acuity of vision is ¼=0.25.

EYE DEFECTS

- Eye defect is a structural defect of the eye causing a defect in vision.
- The main ***<u>defects of the light conducting system</u>*** of human eye are

myopia,

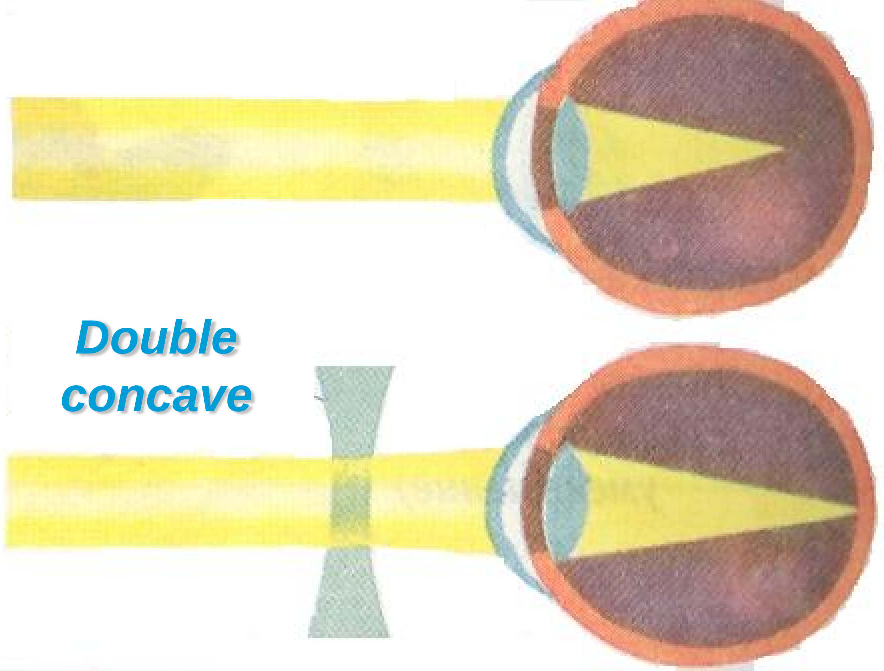
hypermetropia,

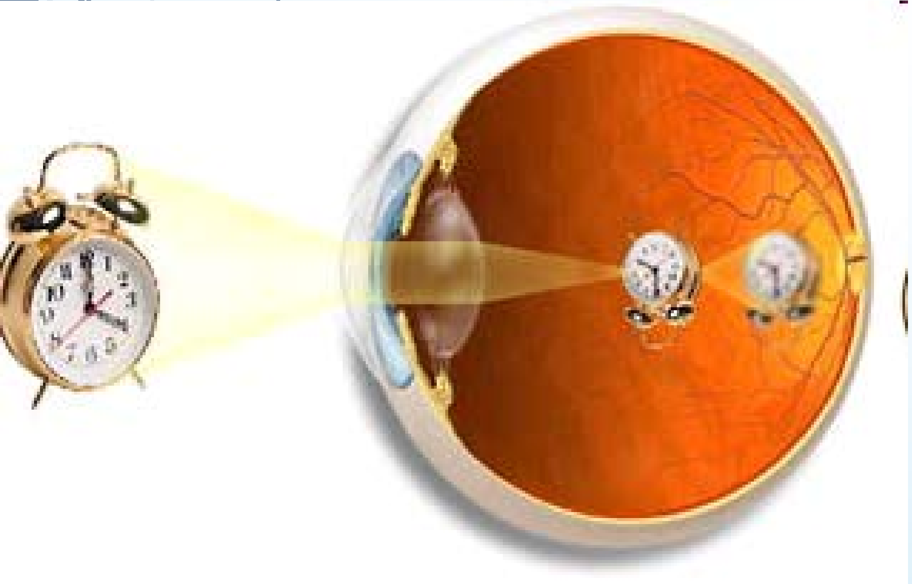
loss of accommodation, and ***astigmatism***.

- The main defect of ***<u>the light perceiving system</u>*** is

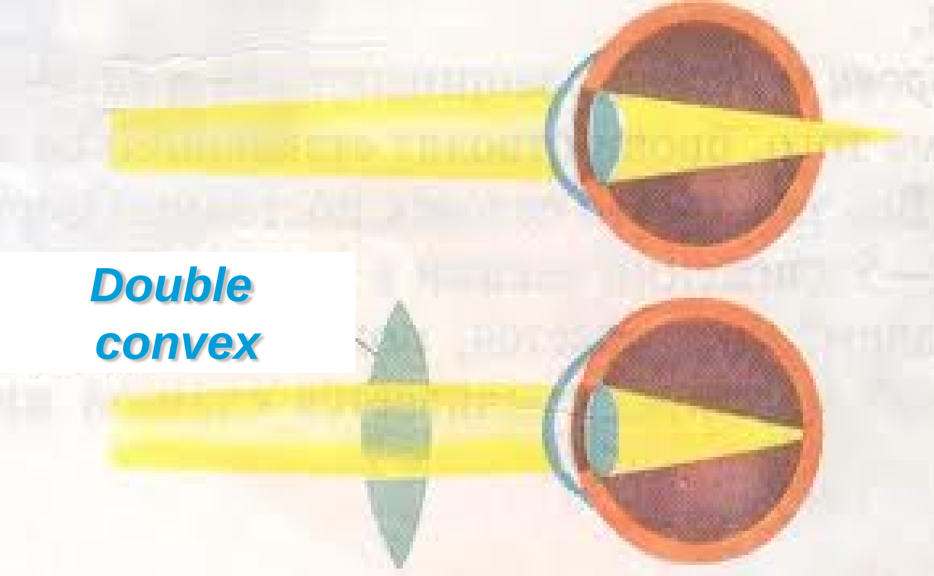
colour blindness.

- People can have ***congenital defects*** of the light conducting system, or those acquired due to age.





- ***At myopia (or short-sightedness) the light from a distant image is brought to a focus in front of the retina.*** Only near objects can be focussed sharply, distant objects are blurred.
- The most frequent cause of myopia is a prolonged form of the eyeball. Refractive myopia occurs less frequently. It is related to the excessive refracting ability (curvature) of different elements of the eye light conducting system.
- ***For myopia correction, it is necessary to decrease the eye's optical power***; ***for this,***



- ***At hypermetropia (or long-sightedness) the light from a near image is brought to a focus behind the retina.*** Only distant objects can be focussed sharply, near objects are blurred.
- Sometimes hypermetropia is related to the shortened size (oblate form) of the eyeball.
- ***To correct hypemetropia, it is necessary to increase the optical power of the eye; for this convex lenses in spectacles are used.***

- At ***loss of accommodation*** (or ***presbyopia***) ***the crystalline lens loses its elasticity***. The lens fails to change its form to a sufficient extent, thus disturbing the process of accommodation.

- Usually older people suffer from this. When the ciliary muscles contract and tension on the lens slackens, the lens no longer bulges and near objects are not focussed sharply on the retina. The effect is similar to that of hypermetropia, and corrected in the same way.

- ***At astigmatism, the curvature of the eye's refracting surfaces is unequal in different meridian planes, for example, in the vertical and horizontal ones.***

- Due to this, the rays, which are incident on the eye in different planes, are focused in different ways, and a blurred picture is received by the retina.

- ***To correct astigmatism, cylindrical lenses are used.*** They have a curvature only in one of the meridian planes, thereby providing equal refraction of the rays, which are incident on the eye in different planes.

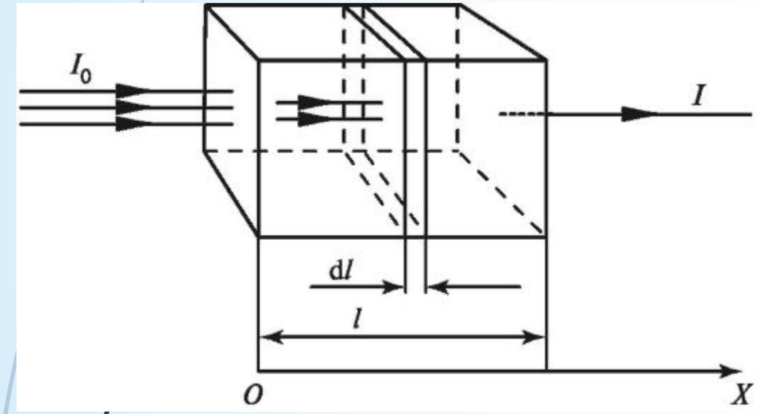
- ***Colour blindness is a defect in colour vision of man in which certain colours cannot be distinguished.***

- A common type is red-green colour blindness, when red and green are not distinguished. A totally colour blind person sees only black, white, and shades of grey.

- The defect is inherited and is genetically sex-linked.

Interaction of the light with subject
Light absorption

- ***Light absorption*** is decrease in intensity of light as it passes through a substance due to conversion of light energy into other kinds of energy.
- The absorption of light in a substance is described by ***Bouguer's law***:



$$I = I_0 e^{-k_\lambda \ell}$$

where ***I*** is an intensity of light past through the layer of absorbing substance with thickness ***l***; ***I_0*** is an intensity of incident light, and k_λ is the ***monochromatic natural absorption coefficient***.

- The monochromatic natural absorption coefficient is a characteristic of the absorbing medium that depends on light wavelength.

- Of practical importance is the case when ***a substance dissolved in a solvent absorbs light***, and light absorption by the solvent can be neglected. In this case, ***the intensity*** of light that has passed through the solution ***depends on the concentration of the solute.***

- This dependence for diluted (not too concentrated) solutions has the form

$$I = I_0 \cdot e^{-\chi_\lambda C\ell}$$

where c - is the ***molar concentration of the solution***, and χ_λ is the ***monochromatic natural molar absorption coefficient***. This formula is often called the ***Bouguer-Lambert-Beer law***.

It is often written in the form

$$I = I_0 \cdot 10^{-\chi'_\lambda C\ell}$$

where $ϰ'_\lambda$ is the *monochromatic molar absorption coefficient*. It is obvious that $ϰ'_\lambda = ϰ_\lambda \cdot lge \approx 0.43 \cdot ϰ_\lambda$

As characteristics of light absorption by a substance, the following values can also be used: ***light-transmission factor*** (***τ***) and ***optical density*** of the solution (***D***).

$$\tau = \frac{I}{I_0}$$

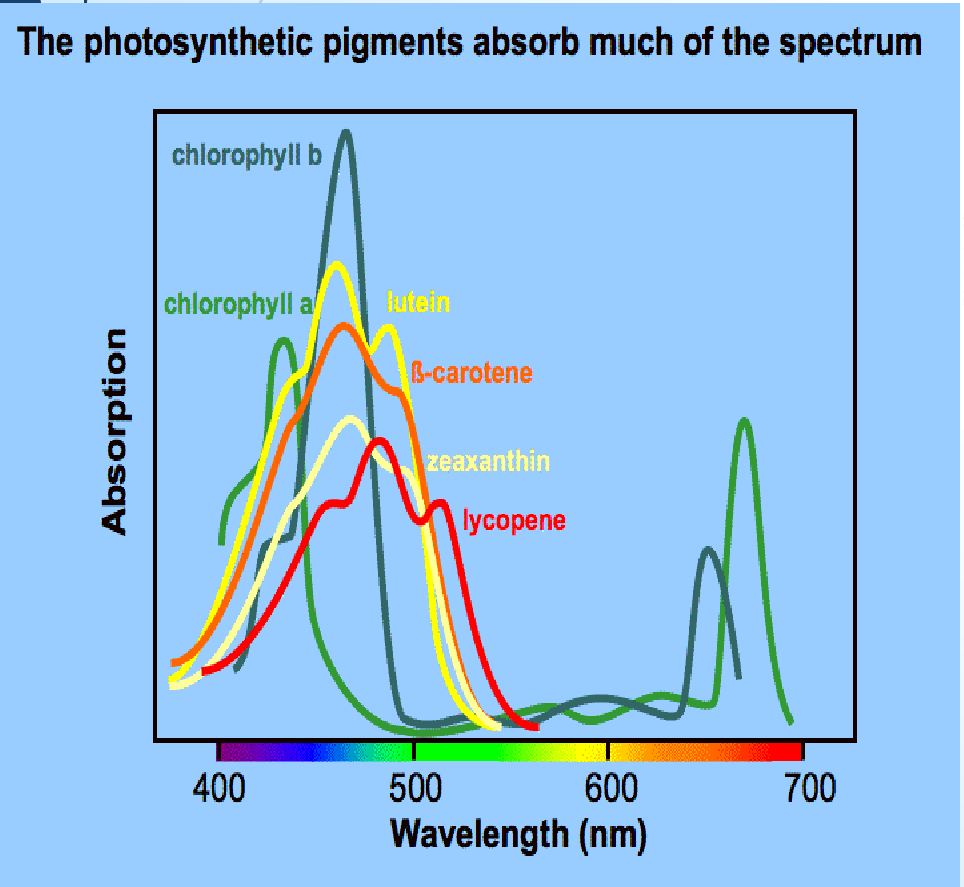
$$D = \lg\left(\frac{1}{\tau}\right) = \lg\left(\frac{I_0}{I}\right) = \chi c\ell$$

Hence, the Bouguer-Lambert-Beer law can be written in the form

$$I = I_0 \cdot 10^{-D}$$

- The optical density of the solution, similar to the absorption coefficients, depends on the light wavelength. The dependences of absorption coefficients of a substance, or the optical density of a substance solution, on the light wavelength are called ***the absorption spectra*** of this substance.

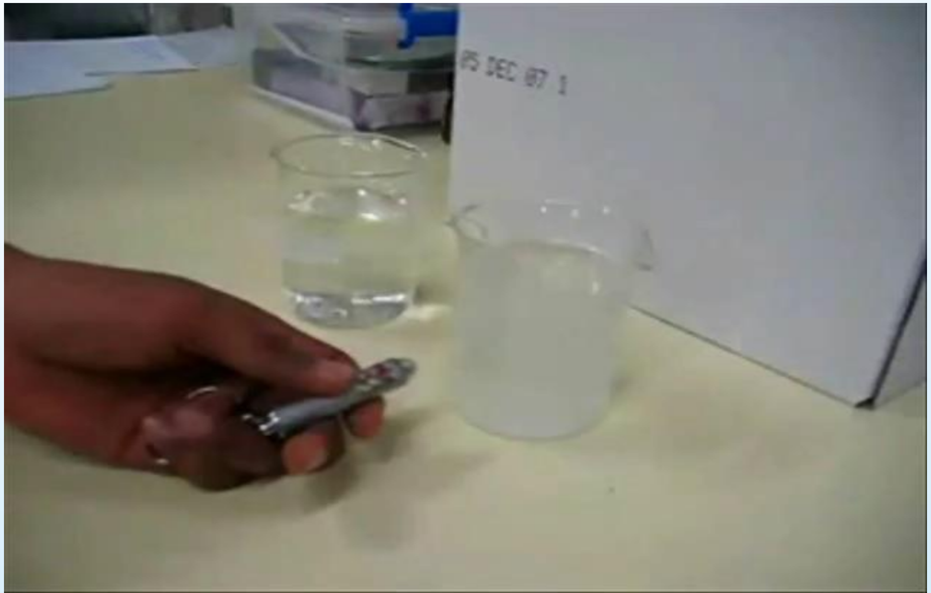
- Determination of the optical density is the basis of concentration colorimetry – a photometric method of substances concentration determination in painted solutions.



LIGHT SCATTERING

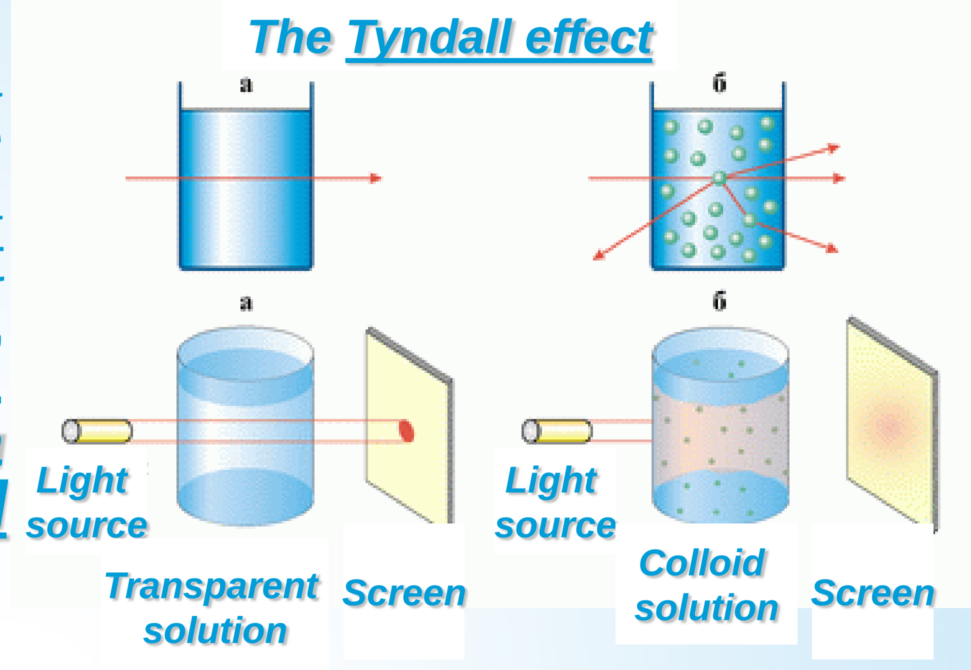
- ***Light scattering* is a process involving a change in the direction of propagation of a fraction of the light as it passes through a substance.** The cause of light scattering during its propagation in a medium is the presence of optical heterogeneities, i.e. areas in the medium, which have different index of refraction values.

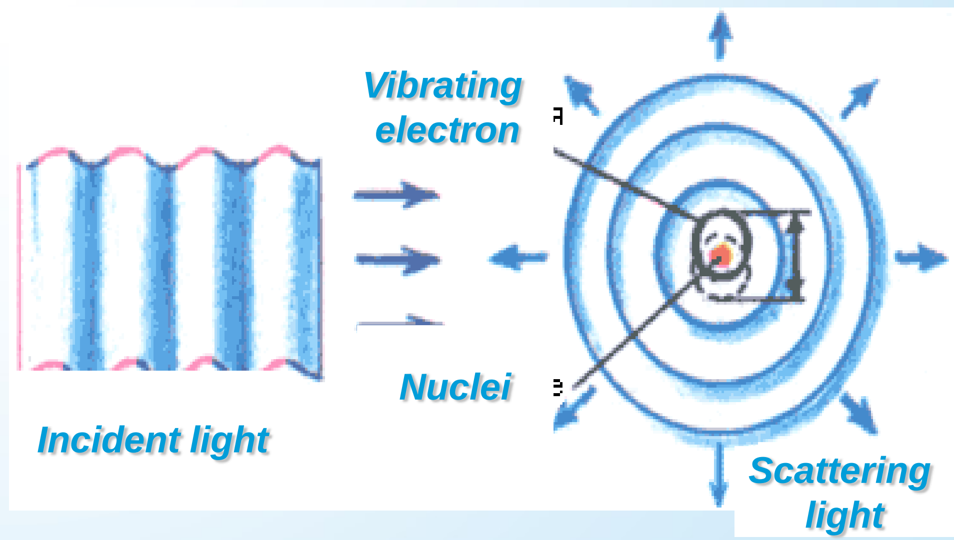
- There are two kinds of light scattering, viz. ***scattering in a turbid media*** and ***molecular scattering***.



- Scattering in a turbid media is scattering on minute foreign particles in a homogeneous transparent substance (for example, smoke, mist and others). ***Scattering in a turbid media is also called the <u>Tyndall effect</u>***.

- ***<u>Molecular scattering</u>*** is the result of continuously emerging and disappearing areas whose density is greater or less than the average substance density. These areas are formed in transparent media ***due to the chaotic motion of its constituent particles***.





Light scattering is described by a formula similar to ***Bouguer's law***:

$$I = I_0 \cdot 10^{-m\ell}$$

- where ***m*** is ***the scattering coefficient*** (more precisely, ***the natural scattering coefficient***).
- ***The light scattering coefficient depends on the wavelength***, viz. the less the wavelength the greater the light scattering. As a result, during scattering of ***white light, blue, dark blue and violet rays will scatter most***; and red and orange rays will pass best without scattering. That is why the sky is blue at daytime, and the sun is red at sunset.

- The technique of determining indices, which characterize light scattering, is called ***nephelometry***, and the measurement instruments used therefore are called ***nephelometers***.

Biophysics of vision and hearing.

This topic is a part of the topic “**Biophysics of sensory perception**”

Sensory perception – reception and perception of information from outer and inner medium.

- From outer medium: **Vision, hearing, smell, taste and sense of touch**
- From inner medium: information on **position, active and passive movement (**vestibular organ, nerve-endings in the musculoskeletal system). **Also: changes in composition of inner medium and pain.**
- **Complex feelings: hunger, thirst, fatigue etc.**

Local response (LR) and Action potential (AP)

Local electric response- takes local place, it does not spread to the vicinity, when its magnitude reaches more than 10 mV then, in turn AP is produced. This type of coding is so called „**AMPLITUDE**“. (i.e. the stronger is stimulus, the higher is amplitude of response (examples: receptor potential (generator potential)).

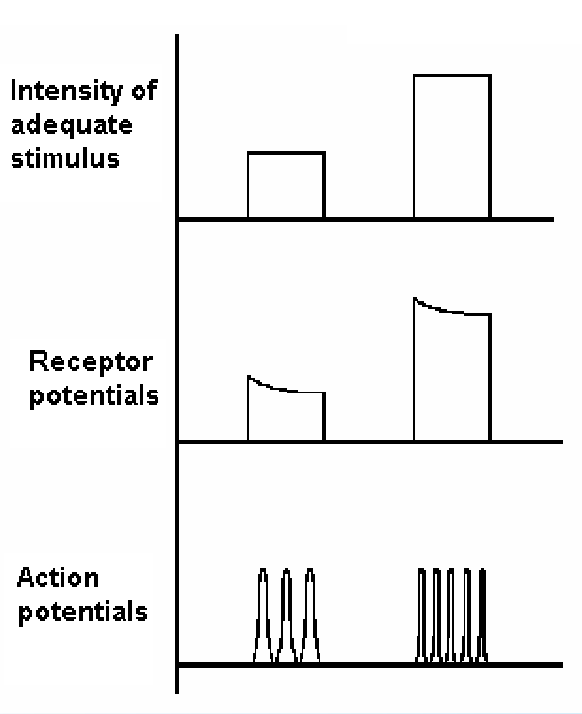
Action potential is a generally spreading electricity, being under the **Law All or None.** This type of coding is named „ **FREQUENCY**“. I.e.the stronger is stimulus the higher is a rate of APs from the receptors. The brain knows that a higher frequency of action potentials means a stronger stimulus (and vice versa)

Receptors- Definition and Properties

- Sensory Receptors are special nerve endings, distributed throughout the body (in the skin, muscles, vessels, bones and joints, in lungs, heart, and another organs).
- They Convert Different Forms of Energy into Electrical Signals. Thus they serve as *transducers*, changing the particular form of energy (e.g. mechanical, chemical, thermal, or electromagnetic) into the electrical signal.
- Our body contains 20 types of receptors that can detect e.g. heat, pressure, stretch, acceleration, sound, light, smells, taste, partial pressure, concentration of salts, hormons...and other forms of stimuli (Only receptors for ionizing radiation are missing)

Conversion function of receptors

- Primary response of sensory cell to the stimulus: **receptor potential** and **receptor current** are proportional to the intensity of stimulus. The receptor potential triggers the **action potential**.
- Transformation of amplitude modulated receptor potential into the frequency-modulated action potential.
- Increased intensity of stimulus, i.e. increased amplitude of receptor potential evokes an increase in action potential frequency.



Receptors - Classification

I. According to locality:

Exteroreceptors - are placed within the skin, like receptors for touch, pressure, heat, cold or pain

Proprioreceptors - are placed in muscles, in bones and joints -they inform about the lengt of muscles and ligaments

Interoreceptors – receptors within the organs (heart, lungs, kidney) They detect plasma osmolarity, partial pressure of O_2 blood pressure..

II. According to type of energy:

Mechanoreceptors - they transform mechanic energy into electric signal.E.g. exte-roreceptorś, baroreceptors, pulmonary stretch receptors).

Fotoreceptors - receptors containing photopigments (rods and cones at retina

Chemoreceptors – taste receptors in the tongue, smell receptors within a nose, osmoreceptors in hypothalamus,..

Nociceptors - pain receptors - in skin, in organs ...

III. According to complexity: simple receptors (skin) and complex ones (eye, ear)

Biophysical relation between the stimulus and sensation

- The intensity of sensation increases with stimulus intensity non-linearly. It was presumed earlier the sensation intensity is proportional to the logarithm of stimulus intensity **(Weber-Fechner law).** Intensity of sensation is $\mathbf{I_R}$, intensity of stimulus is $\mathbf{I_S}$, then:

$$\mathbf{I_R = k_1 \,.\, \log(I_S).}$$

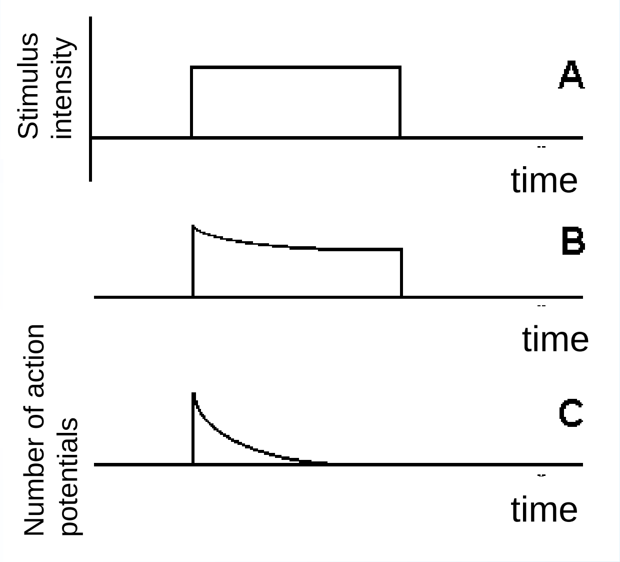
- Today is the relation expressed **exponentially** (so-called **Stevens law**):

$$\mathbf{I_R = k_2 \,.\, I_S^{\,a},}$$

- k_1, k_2 are the proportionality constants, ***a*** is an exponent specific for a sense modality (smaller than 1 for sensation of sound or light, greater for sensation of warmth or tactile stimuli). The Stevens law expresses better the relation between the stimulus and sensation at very low or high stimulus intensities.

Adaptation

- If the intensity of a stimulus is constant for long time, the excitability of most receptors decreases. This phenomenon is called **adaptation.** The adaptation degree is different for various receptors. It is low in pain sensation - protection mechanism.



Adaptation time-course. A - stimulus, B - receptor with slow adaptation, C - receptor with fast adaptation

Biophysics of sound perception

Physical properties of sound:

- **Sound - mechanical oscillations of elastic medium, f = 16 - 20 000 Hz.**
- It propagates through elastic medium as particle **oscillations around equilibrium positions**. In a **gas or a liquid**, they propagate as **longitudinal waves** (particles oscillate in direction of wave propagation - it is alternating compression and rarefaction of medium). In solids, it propagates also as transversal waves (particles oscillate normally to the direction of wave propagation).
- **Speed of sound - phase velocity (c)** depends on the physical properties of medium, mainly on the **elasticity and temperature**.
- The product $\rho.c$, where ρ is medium density, is **acoustic impedance**. It determines the size of acoustic energy reflection when the sound wave reaches the interface between two media of different acoustic impedance.
- **Sounds: simple (pure) or compound.** Compound sounds: musical (periodic character) and non-musical - noise (non-periodic character).

Main characteristics of sound: (tone) pitch, colour and intensity

- The **pitch** is given by **frequency**.
- The **colour** is given by the presence of **harmonic frequencies** in spectrum.
- **Intensity** - amount of energy passed in 1 s normally through an area of 1 m^2. It is the **specific acoustic power** [$W.m^{-2}$].
- The **intensity level** allows to compare intensities of two sounds.
- Instead of linear relation of the two intensities (interval of 10^{12}) logarithmic relation with the unit **bel (B)** has been introduced. In practice: **decibel (dB).** Intensity level *L* in dB:

$L = 10.\log(I/I_0)$ [dB]

- **Reference intensity of sound** (threshold intensity of 1 kHz tone) $\boldsymbol{I_0 = 10^{-12}}$ **$W.m^{-2}$** (reference acoustic pressure $p_0 = 2.10^{-5}$ Pa).

Loudness, hearing field

- **Loudness** is subjectively felt intensity approx. proportional to the logarithm of the physical intensity change of sound stimulus. The ear is most sensitive for frequencies of 1-5 kHz. The **loudness level** is expressed in **phones** (Ph). 1 phone corresponds with intensity level of 1 dB for the reference tone (1 kHz). For the other tones, the loudness level differs from the intensity level. **1 Ph is the smallest difference in loudness, which can be resolved by ear**. For 1 kHz tone, an increase of loudness by 1 Ph needs an increase of physical intensity by 26%.
- The unit of loudness is **son**. 1 son corresponds (when hearing by both ears) with the hearing sensation evoked by reference tone of 40 dB.
- Loudness is a threshold quantity.
- When connecting in a graph the threshold intensities of audible frequencies, we obtain the **zero loudness line (zero isophone).** For any frequency, it is possible to find an intensity at which the hearing sensation changes in pain - **pain threshold** line in a graph. The field of intensity levels between hearing threshold and pain threshold in frequency range of 16 - 20 000 Hz is the hearing field.

Biophysical function of the ear

The ear consists of outer, middle and inner ear.

- Transmission of sounds into inner ear is done by outer and middle ear.
- Outer ear: auricle (ear pinna) and external auditory canal. Optimally audible sounds come frontally under the angle of about 15° measured away the ear axis.
- **Auditory canal is a resonator.** It amplifies the frequencies 2-6 kHz with maximum in range of 3-4 kHz, (+12 dB). The canal closure impairs the hearing by 40 - 60 dB.
- Middle ear consists of the ear-drum (~ 60 mm^2) and the ossicles – *maleus (hammer)*, *incus (anvil)* and *stapes (stirrup)*. *Manubrium malei* is connected with drum, *stapes* with *foramen ovale* (3 mm^2). **Eustachian tube** equalises the pressures on both sides of the drum.
- A **large difference of acoustic impedance of the air** (3.9 kPa.s.m^{-1}) **and the liquid in inner ear** (15 700 kPa.s.m^{-1}) **would lead to large intensity loss** (about 30 dB). It is compensated by the ratio of mentioned areas and by the change of amplitude and pressure of acoustic waves (sound waves of the same intensity have large amplitudes and low pressure in the air, small amplitudes and high pressure in a liquid). Transmission of acoustic oscillations from the drum to the smaller area of oval foramen **increases pressure 20x**.

Mechanism of reception of acoustic signals

- The inner ear is inside the petrous bone and contains the receptors of auditory and vestibular analyser.
- The auditory part is formed by a spiral, 35 mm long bone canal **- *the cochlea*.** The basis of cochlea is separated from the middle ear cavity by a septum with two foramina.
- The oval foramen is connected with stapes, the circular one is free.
- Cochlea is divided into two parts by longitudinal osseous *lamina spiralis* and elastic *membrana basilaris*. *Lamina spiralis* is broadest at the basis of cochlea, where the basilar membrane is narrowest, about 0.04 mm (0.5 mm at the top of cochlea).
- The *helicotrema* connects the space above (*scala vestibuli*) and below the basilar membrane (*scala tympani)*.

Mechanism of sound perception: Békésy theory of travelling wave.

- Békésy theory of travelling wave: Sound brings the basilar membrane into oscillations, and the region of maximum oscillation shifts with increasing frequency from the top to the basis of cochlea.
- The receptor system in cochlea performs probably a preliminary frequency analysis. The further processing is done in cerebral auditory centres.
- **Sound comes to the receptors in three ways: air** (main), **bone** (the hearing threshold is by about 40 dB higher) and **through circular foramen** – small importance.

Electric phenomena in sound reception:

- Perilymph and endolymph differ in content of K^+ and Na^+. Endolymph content of K^+ is near to the intracellular content. The resting potential between endolymph and perilymph equals **+ 80 mV - endocochlear potential.**
- The big hair-cells of Corti's organ have a negative potential -80 mV against the periplymph. **The potential difference between the endolymph and hair-cells is about 160 mV.**
- The stimulation of Corti's organ leads to **cochlear microphone potential**, which can be measured directly on cochlea or in its close surroundings. At high frequencies, the maximum of microphone potential shifts to the basis of cochlea, what is in agreement with the theory of travelling wave.
- **Negative summation potential** is caused by stimulation of inner hair-cells of Corti's organ.
- The mechanism of the origin of final **action potential** led by auditory nerve is not yet fully explained. We suppose: The cochlear microphone potential and also the negative summation potential take place directly in action potential origin. This potential keeps the receptors in functional state.

Control Questions

1. The course of rays in the eye of man.
2. Absolute threshold of the eye.
3. Light absorption and photo conversion in the organs of vision.
4. The molecular mechanism of vision.
5. Eye defects.
6. Wave properties. Physical properties of sound.
7. Absolute threshold of hearing.
8. Intensity level.
9. Doppler Effect.
10. Electric phenomena in sound reception.

Recommended literature:

Basic:

1. Vladimir Timanyuk, Elena Zhivotova, Igor Storozhenko. Biophysics: Textbook for students of higher schools / Kh.: NUPh, Golden Pages, 2011.- 576p.
2. Vladimir Timaniuk, Marina Kaydash, Ella Romodanova. Physical methods of analysis / Manual for students of higher schools/– Kharkiv: NUPh: Golden Pages, 2012. – 192 p.
3. Philip Nelson. Biological Physics. – W. H. Freeman, 1st Edition, 2007. – 600 p.
4. Biophysics, physical methods of analysis. Workbook: Study guide for the students of higher pharmaceutical educational institutions / Pogorelov S. V., Krasovskyi I. V., Kaydash M. V., Sheykina N. V., Frolova N. O., Timaniuk V. O., Romodanova E.O., Kokodii M.H. – Kharkiv., – 2018. – 130 p.
5. Center for distance learning technologies of NPhaU. Access mode: http://nuph.edu.ua/centr-distancijjnih-tehnologijj-navcha/

Support:

1. Eduard Lychkovsky. Physical methods of analysis and metrology: tutorial / Eduard Lychkovsky, Zoryana Fedorovych. – Lviv, 2012. – 107 p.
2. Daniel Goldfarb. Biophysics DeMYSTiFied. – McGraw-Hill Professional, 1st Edition, 2010. – 400 p.


Thanks for
your attention