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Methods of using Laser Radiation and Devices in Eliminating Eye Defects

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Abstract: This article presents the physical and biological rationale for the use of laser radiation in the correction of the most common defects of the human eye, nearsightedness (myopia) and farsightedness (hyperopia). The technologies of excimer lasers and femtosecond lasers used in these diseases are highlighted, and their differences from previously used methods are shown.

Keywords: optical quantum generators, laser technology, laser physics, nanotechnology, pedagogy, didactics, competence, interactive.

Laser radiation (LASER – Light Amplification by Stimulated Emission radiation) is a stream of monochromatic light (electromagnetic waves) radiation that is amplified by a forced method [1].

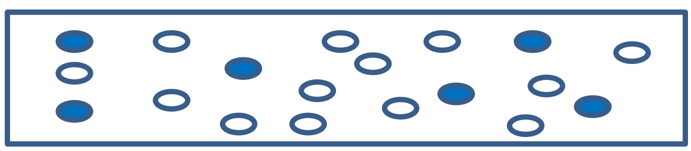
Let us dwell on the mechanism of light amplification by forced excitation. Since light is an electromagnetic wave, it is produced by the transition of particles from a higher energy state to a ground or lower energy state. An atom, molecule, or particle in the ground energy state is excited to a higher energy state by absorbing radiation (Figure 1).

Figure 1. The transition of an atom to an excited energy state

Here E_0 is the ground energy state of the atom (particle). E_1 is the excited energy state. Even if there is no influence on the atom that has passed into the excited state, after a certain time it will return to its initial ground energy state. In this case, the absorbed energy is re-radiated in a probable direction. Usually this radiation occurs spontaneously after 10^{-8} s. This radiation is called spontaneous emission [2].

$E_1 - E_0 = h\nu$ (1).

A transparent medium is a medium. The medium can be in the form of a gas, a liquid, or a solid (Figure 2).



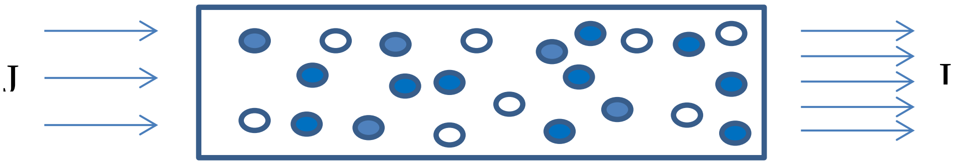
2. States of matter (gas, liquid, solid)

medium . Let the number of particles that have passed into the excited state as a result of light absorption be N_2. The number of particles in the ground state is $\mathbf{N - N_2 = N_1}$. If we assume that the medium is in thermodynamic equilibrium, the ratio of excited to ground state particles obeys the Boltzmann distribution.

$$\mathbf{N_2/N_1 = \exp[-(E_1 - E_0)/kT]} \quad \mathbf{(2).}$$

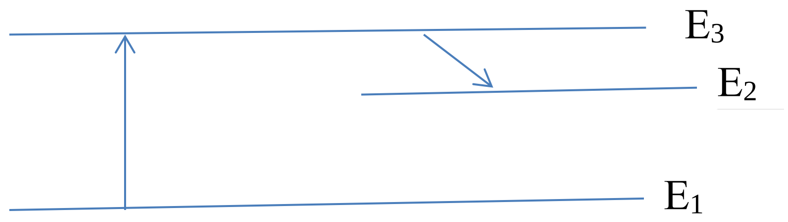
Here **k** is the Boltzmann constant, **T is** the absolute temperature.

Let the intensity of light incident on the medium be $\mathbf{I_0}$**, and** the intensity of light emerging from the medium be **I.** For the intensity of light emerging from the medium to be greater than the intensity of light incident on the medium, $\mathbf{N_2 > N_1}$ The condition must be met (Figure 3).



3. Intensity of light entering and leaving the environment ($\mathbf{N_2 > N_1}$)

$\mathbf{N2 > N1}$ The state that satisfies the condition is called the inverse filled state, and the inverse filled environment is called the active environment. To create the inverse filled state, there is a metastable energy state, consisting of at least 3 energy levels. systems are needed [3], (Fig. 4). The residence time in the metastable state is about 10^{-3} s.



4. Inverse filled state

3 energy levels is exposed to high-energy light radiation, the transition $\mathbf{E_1 \rightarrow E_3}$ occurs. When some of the atoms do not radiate energy, $\mathbf{E_2}$ The transition to a metastable level. External radiation $\mathbf{E_2 \rightarrow E_1}$ Since the probability of transitions is much lower, inverse filling conditions arise. The inverse filling process is called doping. The following types of doping are used in modern laser devices.

1. Optical fiber – uses a light pulse.
2. Electric discharge nozzle – used in gas laser devices.
3. Injection nozzle - used in semiconductor laser devices.
4. Chemical radiation – uses radiation from chemical reactions.

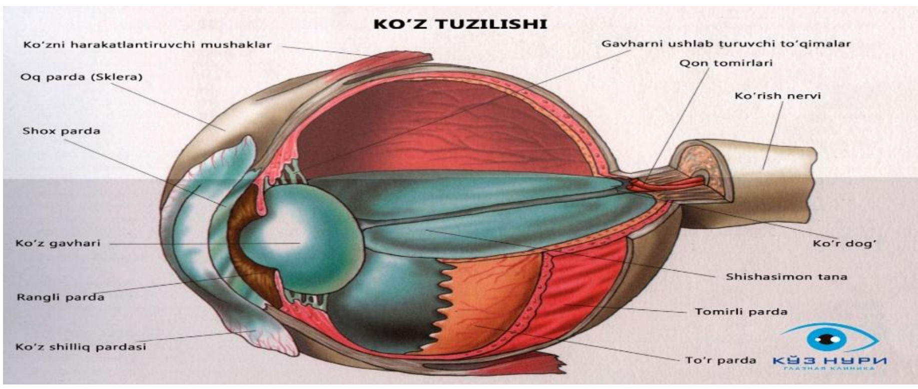
Let's get acquainted with the functional diagram of laser devices in a generalized form (Figure 5).

5. Functional diagram of laser devices

The working body (active medium) is a long thin cylinder, the edges of which are closed by 2 mirrors. One of the mirrors (mirror 1) is semi-transparent and is designed for the emission of laser beams. The mirrors act as optical resonators. In the active medium $\mathbf{E}_2 \rightarrow \mathbf{E}_1$ In the transitions, the part of the emitted photons that makes an angle with the resonator axis leaves the system and does not participate in the amplification process. Photons directed along the resonator axis undergo the forced $\mathbf{E}_2 \rightarrow \mathbf{E}_1$ **process when returning** from the mirrors . makes transitions and produces amplified light (laser radiation). Laser radiation exits a semi-transparent mirror. Depending on the nature of the working medium, 1. Gas lasers, 2. Solid-state lasers, 3. Liquid lasers, 4. Semiconductor lasers have been developed. Laser radiation has the following properties. A) coherent, B) collinear, C) monochromatic. Laser devices operate in continuous and pulsed modes.

We will examine the physical and biological foundations of the use of laser radiation in medicine (ophthalmology) to correct nearsightedness (myopia) and farsightedness (hyperopia), two of the most common defects in the human eye.

The human eye is an optical system (Fig. 6), consisting of light-transmitting and light-receiving parts. The light -receiving part consists of cells sensitive to the intensity of light quanta - rods, and cells sensitive to the wavelength of light quanta - cones, forming the retina. The light-transmitting part of the eye includes the cornea, the aqueous humor of the anterior chamber, the lens, and the vitreous body. Each component of the light-transmitting part of the eye is considered a lens.



6. Eye structure

The converging lens is a collecting lens with an optical power of +(42-45) diopters. It is about 0.6 - 1 mm thick and has a refractive index of 1.38 .

The anterior chamber fluid has an optical power of +(2 - 4) diopters, and its refractive index is the same as water.

The eye is a naturally elastic, biconvex, collecting lens with a diameter of 8-10 mm and an optical power of +(20 - 30) diopters. The refractive index is 1.48.

The object is a transparent material, a jelly, and is like a diffusing lens with an optical power of -(5 - 6) diopters.

The eye is a central optical system. In the normal state (when the eye muscles are not strained), the optical power of the eye is about + 60 diopters and the image is formed on the retina . The optical power of the eye is equal to the sum of the optical powers of the parts that make up the eye. That is,

$\mathbf{D}_{\text{eye}} = \mathbf{D}_{\text{cornea}} + \mathbf{D}_{\text{anterior chamber fluid.}} + \mathbf{D}_{\text{cornea}} + \mathbf{D}_{\text{vitreous humor}}$ (3).

A decrease in the radius of curvature of the eyeball causes the optical power of the eye to be higher than normal (nearsightedness - myopia), and an increase in the radius of curvature causes the optical power of the eye to be lower than normal (farsightedness - hypermetropia). We believe that it is more convenient to use converging and diverging lenses for small differences. The image formation and use of lenses, depending on the difference in the optical power of the eye from the norm, are presented in the table below (Table 1).

Optical power of the eye	$\mathbf{D}_{\text{eye}} = \mathbf{D}_{\text{norm}}$	$\mathbf{D}_{\text{eye}} > \mathbf{D}_{\text{norm}}$	$\mathbf{D}_{\text{eye}} < \mathbf{D}_{\text{norm}}$
Image creation	The image is formed on the retina.	The image is formed in front of the retina.	The image is formed behind the retina.
Using lenses	Not used	A diffusing lens is used.	A collecting lens is used.

The optical power of lenses depends on the refractive index of the material from which the lens is made and the radius of curvature.

$\mathbf{D = (n-1) (\pm 1/R_1 \pm 1/R_2)}$ (4).

Here **n is** the refractive index of the medium, $\mathbf{R_1}$ and $\mathbf{R_2}$ are the radii of curvature. (+) is used for a converging lens, (-) is used for a diverging lens. If we assume that $R_1 = R_2 = R$ and $n = 1.5$ in formula (4), we get a simple representation.

$\mathbf{D = \pm 0.5/R}$ (5).

It can be seen that an increase in **R leads to a decrease in D** , and a decrease in **R leads to an increase in D.** In order to normalize the optical power of the eye, it is possible to use the method of changing the optical powers of the cornea, which performs the functions of the lens that organizes and collects it, or the lens.

Currently, the method of changing the optical power of the cornea is widely used in medicine. This uses excimer lasers (operating in a pulsed mode), which belong to the class of gas lasers operating in the ultraviolet radiation range. Here we will dwell on the processes that occur as a result of an increase in tissue temperature during the exposure of laser radiation to biological tissue. The processes that occur in the tissues depend on the mode of generation of laser radiation (continuous, pulsed) and the exposure time. The table below shows the processes that occur as a result of the exposure of tissues to high-power laser radiation in continuous mode, depending on the exposure time of the radiation and the values of the tissue temperature (Table 2).

Table 2. Processes that occur depending on the exposure time of laser radiation and tissue temperature

Temperature (^{0}C)	37-100	100	100-150	150-300	300
The process that takes place	Heating - heating	evaporation	Heating and carbonization	Heating and carbonization	Evaporation – evaporation
Exposure time	⟶				

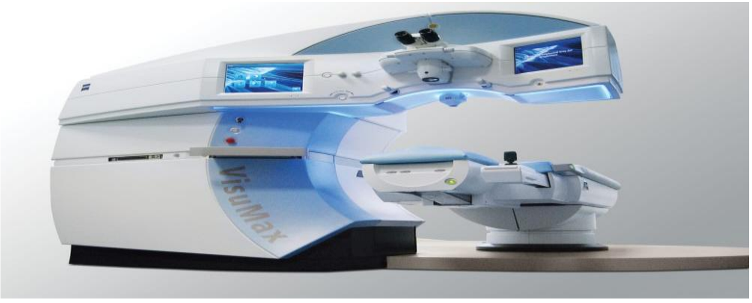
The word excimer means an excited dimer (a molecule consisting of two atoms). Under the influence of an electric discharge, inert gas atoms, hydrogen or halogen atoms combine to form a molecule (dimer). The excited bound molecules automatically form an inversely charged state. Dimers spontaneously or as a result of forced radiation go to the ground energy state. After that, they disintegrate into their constituent atoms in a very short time (about a picosecond). The wavelength of excimer laser radiation depends on the composition of the gases used and lies in the ultraviolet range (Table 3).

Table 3. Excimer lasers

Excimer	F_2	ArF	KrF	XeBr	XeCl	XeF
Wavelength (nm)	157	193	248	282	308	351

Ultraviolet radiation does not pass through glassy materials. The human cornea can also be considered organic glass. Therefore , when the eye is exposed to laser radiation in the ultraviolet range, the elements inside the cornea are not affected. To change the optical power of the cornea , its thickness is changed. When changing the thickness of the cornea using excimer laser radiation, its upper layer is vaporized with great precision without contacting the cornea. The first operation using this method was performed in 1985 by Marshall and his co-authors. The operation was called photorefractive keratectomy (PRK). The rehabilitation process for patients after the operation is quite unpleasant (2-4 days), and adaptation lasts 3-4 weeks. FRC is considered the optimal method for correcting mild to moderate myopia. Residual myopia is about 10%.

Currently, the FRK method is being replaced by the more common LASIK (LASIK – Laser Assisted in Situ Keratomileusis, laser keratomileusis). The LASIK method uses two different principles: excimer and femtosecond lasers (Figure 7).



7. Femto-Lasik device

Initially, a 100-150 μm layer (flap) is cut off from the surface of the cornea using a femtosecond laser. Femtosecond lasers operate in a pulsed mode. The pulse duration is about 10^{-15} s (1 femtosecond). Depending on the need, femtosecond lasers in the frequency range of 1-100 Hz are used. The accuracy of absorption of femtosecond laser radiation into the tissue is achieved with an accuracy of one tenth of a micron.

After the flap is separated, the inner layer of the cornea is irradiated with excimer laser radiation, changing the thickness of the cornea, that is, giving the cornea the desired shape. When performing these operations, the eye parameters, measured with high accuracy individually for each patient, are entered into the computer program. The eye parameters include: deviation of the optical power of the eye from the norm, the actual thickness of the cornea, the thickness of the separated flap, the thickness of the cornea that needs to be removed, etc. It is clear that the process is completely controlled by computer programs. The window of sizes entered into the computer program is shown in Figure 10.

After the s h o x membrane is treated, the flap is closed. Since the collagen in the s h o x membrane has the property of adhesion , the flap fuses well with the remaining part within a few minutes. The rehabilitation process is accelerated. The patient almost does not need to take a sick leave.

Along with the advances in the use of LASIK technology in correcting vision defects, there are also indications for its non-use:

- For those under 18,
- When the thickness of the membrane is less than 450-440 μm ,
- Glaucoma , cataracts, and others.

s h o x film on the optical power can be determined by the following calculations.

L = D $_{\text{king curtain}}$ **/ h** $_{\text{king curtain}}$ **(6)**

Here **L is** the thickness of the cornea corresponding to an optical power of 1 diopter. **D** $_{\text{cornea}}$ **is** the normal optical power of the cornea **. h** $_{\text{cornea}}$ – thickness of the cornea.

LASIK technologies currently used in medicine are evolving due to changes in software.

The conclusion is that, **firstly , in the absence of** contraindications , the use of excimer and femtosecond laser radiation increases the quality of operations performed to eliminate the most common diseases of the human eye - myopia and hyperopia, and accelerates the rehabilitation process. **Secondly , the use of** pulsed excimer laser radiation to change the shape of the cornea does not adversely affect other components of the optical system of the eye. **Thirdly, the accuracy and comprehensiveness of the computer software that controls the operations performed using** laser radiation is a measure of the perfection of the LASIK method.

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