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Lasers in Ophthalmology

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1. Introduction

Lasers emit electromagnetic waves of characteristic properties and energies (Gilmour, 2002; Krzeszewska & Zdybel, 2010; Podbielska et al., 2004; Sieroń et al., 1994; Ziętek, 2009). These specific features are used in the modern ophthalmology (Dick et al., 2010; Evans & Abrahamse, 2009; Gilmour, 2002; Schmidt-Erfurth, 2010; Seitz & Langenbucher, 2000; Soong & Malta, 2009). In this work we described theoretic problems of lasers as the quantum systems, the propagation of laser radiation, the lasers parameters and ranges of them. The historical data about laser apparatus and their applications are cited. The biophysical effects caused by laser radiation in biological structures during therapy are mentioned.

The applications of lasers in ophthalmology are widely taking to account. We described widely the two laser applications in ophthalmology which are connected with paramagnetic species and singlet oxygen. We chose these subjects, because of our experimental experience in spectroscopic studies of paramagnetic centers (Beberok et al., 2010; Buszman et al., 2003, 2005a, 2005b, 2006; Chodurek et al., 2003; Domagała et al., 2008; Latocha et al., 2004, 2005, 2006; Matuszczyk et al., 2004; Najder-Kozdrowska et al., 2009, 2010; Pilawa et al., 2002, 2003a, 2003b, 2005a, 2008c; Zdybel et al., 2009, 2010) and singlet oxygen O_2 with zero spin (Bartłomiejczyk et al., 2008; Latocha et al., 2008; Pilawa et al., 2005b, 2006, 2008a, 2008b). In this work the view of the information in scientific papers is done.

2. Lasers as the quantum systems – Basic theory

2.1 Energy levels

The quantum theory describes the energy levels of atoms and molecules (Glinkowski & Pokora, 1993; Sieroń et al., 1994; Ziętek, 2009). Electrons may move only between these levels, and these transitions are accompanied by emission or absorption of energy by the optical system. The emitted or the absorbed energies reveal the values related to the distances between the energy levels. The system will not absorb the energy, when the energy is lower or higher than the value of the energetic band between the levels. Energy levels of the optical active medium play an important role in laser irradiation. The energy levels of the materials used in laser construction determine the energy necessary to their excitation and the energy of emitted electromagnetic waves is dependent on these levels. The energy (E) of the electromagnetic waves produced by lasers is presented according to the formulas (Bartosz, 2006; Hatfield, 1976; Hewitt, 2001; Jaroszyk, 2008; Ziętek, 2009):

$$E = h\nu \quad (1)$$

$$E = hc/\lambda \quad (2)$$

where h is the Planck constant (h = 6,626 x 10^{-34} Js), c is the speed of the waves (c = 299 792 458 m/s), ν is the frequency of electromagnetic waves in Hertz, λ is the wavelength in meters. The frequency and wavelength determine the color of laser radiation.

The emitted energy is fitted to the biological structures treated by the individual lasers, so the reason of the majority of lasers used in ophthalmology is understandable. Summing up, the lasers produce electromagnetic waves with the given energy correspond to the energy levels of their optical systems, and it interact on the specific tissues or cells.

2.2 Optical pumping

Condition of absolute emission of radiation by laser is the previous excitation of its active optical system e.g. molecules formed in this system (Glinkowski & Pokora, 1993; Sieroń et al., 1994; Ziętek, 2009). This excitation is called the optical pumping. Excitation of molecules in laser may be done by electromagnetic waves emitted by lamps, by heating or by energy of electrical field (Podbielska et al., 2004; Sieroń et al., 1994).

2.3 Inversion of electron location on the energy levels

As the result of the optical pumping of the quantum molecular system, higher amount of electrons are located on the levels of the higher energy than those of the lower energy (Glinkowski & Pokora, 1993; Podbielska et al., 2004; Sieroń et al., 1994; Ziętek, 2009). The continuous propagation of energy to the system of electrons in molecules causes that the electrons upon absorption of this energy moves to the higher energy levels. Afterwards they return to the lower energy states via relaxation processes. The time of electron-lattice relaxation processes depends on the molecular structure of the optical system in lasers. Electron-lattice relaxation is the transition of the electrons from the excited energy levels to the ground energy levels via magnetic interactions with diamagnetic lattice molecules (Stankowski & Hilczer, 2005; Wertz & Bolton, 1986). The long time of interactions of electrons with the lattice causes the mentioned above inversion. The pumped electrons stay on the higher energetic level and the former irradiation of the molecular system in laser do not pump electrons to the higher levels, because of their absence in the lower energy levels (Ziętek, 2009). The inversion of electrons location on levels is useful to the former effective stimulation emission of radiation in laser apparatus (Glinkowski & Pokora, 1993).

2.4 Stimulated emission of radiation

The name of the **LASER** apparatus comes from the roles of its work as the "**L**ight **A**mplification of **S**timulated **E**mission of **R**adiation" (Maiman, 1960). Two types of emission of electromagnetic waves, the spontaneous and stimulated emissions, are known (Bartosz, 2006; Hatfield, 1976; Hewitt, 2001; Jaroszyk, 2008; Krzeszewska & Zdybel, 2010; Morrish, 1970; Sieroń et al., 1994). Spontaneous emission is the ordinary effect of energy loosening by the excited electrons at the non defined moment. Spontaneous emission is the result of the principle that the optimal state of the system is the state with the lowest energy (Glinkowski & Pokora, 1993; Jóźwiak & Bartosz, 2008; Sieroń et al., 1994; Ziętek, 2009). The stimulated emission is the most important effect to produce laser irradiation. The scheme of stimulated emission of radiation is shown in Figure 1, which was prepared according to the definition of this effect presented in (Sieroń et al., 1994). The stimulated emission of radiation is the controlled effect of energy loosening by the electrons. Before the proper effect of stimulated emission the electron is excited, for example by pumped photons, to the higher energy level. After this the stimulated photon is emitted to the system and at this moment two photons of the same energy are emitted. The energy of the individual emitted photon is equal to the difference between energy of the excited and ground state energy levels. The amplification of the energy of radiation is the effect of emission of these two photons after absorption of one exciting photon by electron. The radiation comes from stimulated emission consist of photons of the same energy so of the same frequency. It means that laser produce monochromatic electromagnetic waves. Monochromatic electromagnetic waves are the same frequency waves (Ziętek, 2009).

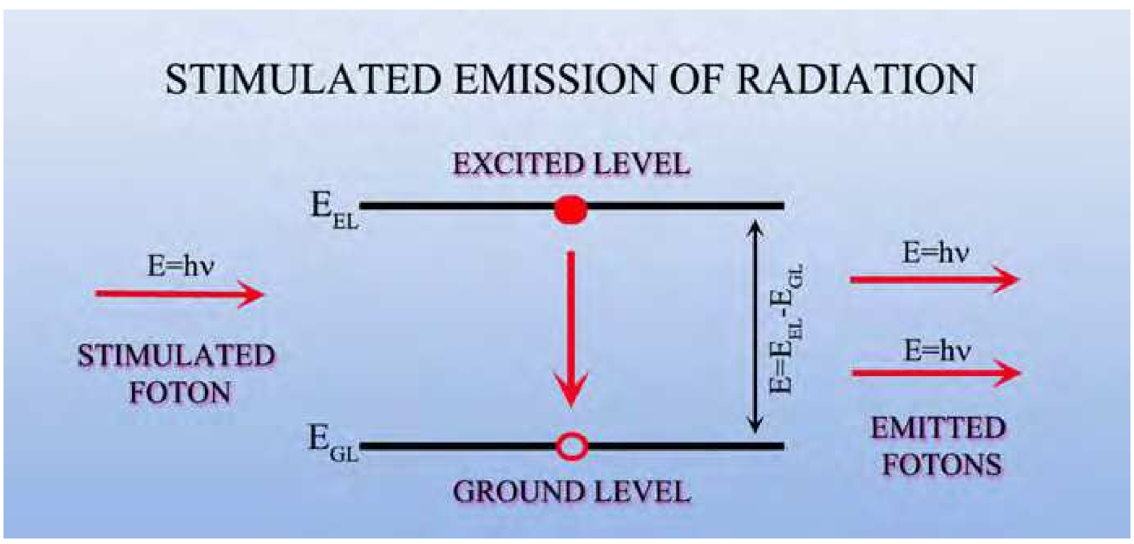

Fig. 1. The scheme of the stimulated emission of radiation prepared according to its definition in (Sieroń et al., 1994).

The exemplary way of the electrons between the three energy levels during laser action is described in work of Sieroń et al. (Sieroń et al., 1994). The main energy levels of electrons are the ground, non-stabile excited, and the quasi-stabile levels, respectively. Electrons are pumped by photons to the non-stabile level with the highest energy in this quantum system. Energy of the pumped photons is equal difference between energy of the non-stabile level and the ground level. Afterwards the electrons without radiation come to the quasi-stabile energy level located lower than the non-stabile level. During the optical pumping there is an increase in number of electrons on quasi-stabile level. At the moment dependent on the type of laser the effect of inversion of distribution of electrons in the energy levels occurs. The higher number of electrons stays on the quasi-stabile level than on the ground level with the lowest energy. The pumping is stopped then and the stimulating photons are sent to the electrons system. At the same time, at the moment of interactions of electrons with stimulated photons the stimulated emission appears. All the electrons located on the quasi-stabile energy level come to the ground energy level. The photons connected with the transition and the stimulated photons are irradiated. The emitted electromagnetic waves have properties of laser radiation, which are described in the next part of this chapter.

3. The properties of laser radiation

Laser radiation as electromagnetic waves differs from the light emitted by the ordinary lamp (Hewitt, 2001). The white light emitted from bulb is superposition of electromagnetic waves with frequencies and wavelengths corresponding to the background colors: red, orange, yellow, green, blue, and violet. The frequencies of the waves increase in the previously given order, and the wavelengths decreases in this manner. The summing of these electromagnetic waves of different colors gives the effect of white light. The component waves in the white light are not coherent. Coherent waves are the waves with the same phase shift (Ziętek, 2009). The component electromagnetic waves in the beam of white light are shown in Figure 2a constructed according to (Hewitt, 2001).

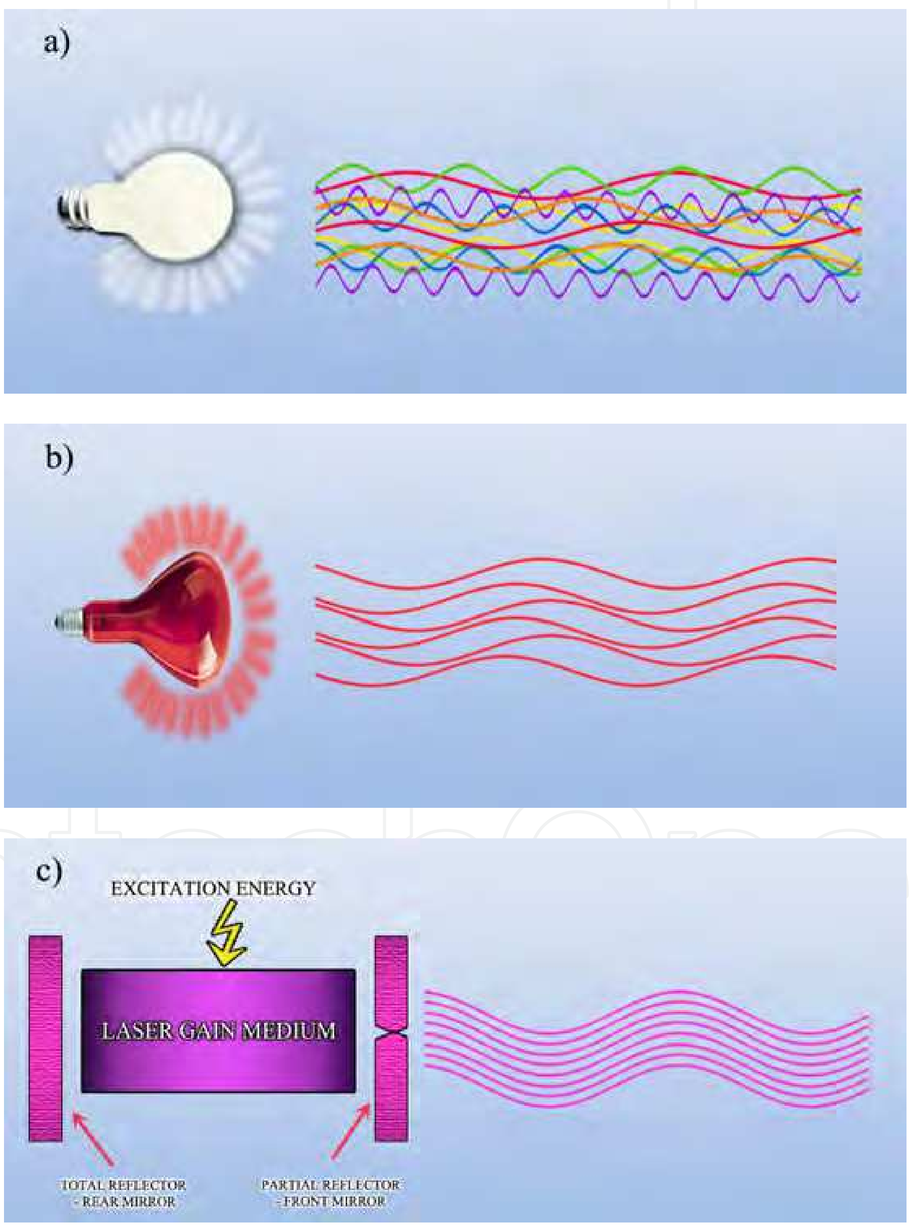

Fig. 2. The electromagnetic waves emitted by: the ordinary lamp produced the white light (a), the source of the monochromatic light (b), and laser (c). The scheme is prepared according to (Hewitt, 2001).

The monochromatic light from the lamp consists of electromagnetic waves of the same frequencies and the same wavelengths (Hewitt, 2001). The waves are not coherent. The electromagnetic waves in the beam of monochromatic light reveal different phases. The monochromatic and incoherent waves are presented in Figure 2b, which was prepared according to (Hewitt, 2001). The fine examples of monochromatic light are the red waves emitted by SOLLUX lamp (Hewitt, 2001).

Lasers produce monochromatic electromagnetic waves (Glinkowski & Pokora, 1993; Hewitt, 2001; Sieroń et al., 1994; Ziętek, 2009). The properties of laser radiation distinguish it from the ordinary white or monochromatic light (Figure 2c) (Hewitt, 2001). The laser waves are monochromatic and coherent. Contrary to white light, laser radiation is monochromatic and in the same phase.

Laser radiation differs from electromagnetic waves sending by the therapeutic BIOPTRON lamps (Straburzyńska-Lupa & Straburzyński, 2004). The BIOPTRON lamp produces electromagnetic waves of the same frequency, but they are incoherent (Figure 3) (Straburzyńska-Lupa & Straburzyński, 2004). The maxima and minima of energy appear on the area of the tissue exposed to coherent laser irradiation. The homogeneous distribution of energy on irradiated area is characteristic for BIOPTRON light.

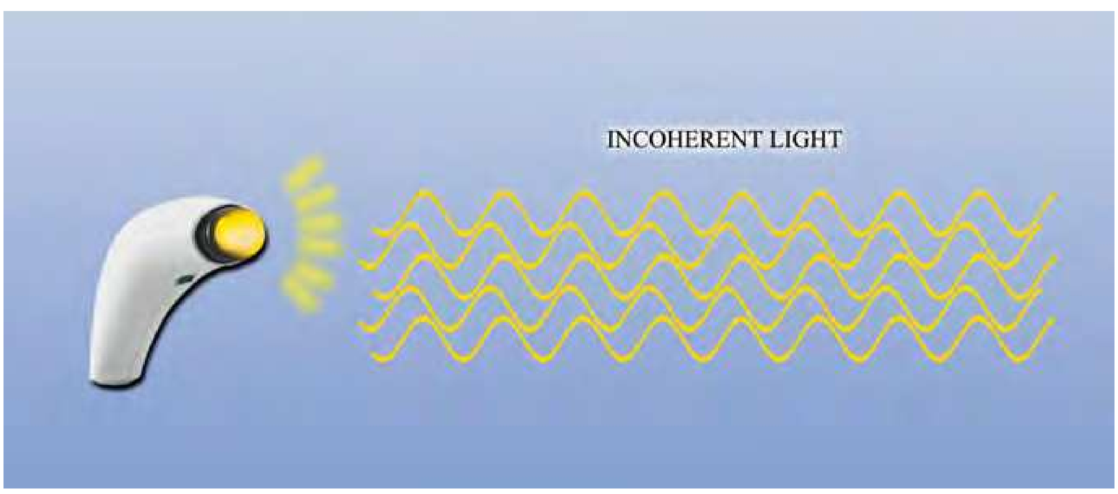

Fig. 3. The electromagnetic waves emitted by BIOPTRON lamps. Prepared according to (Straburzyńska-Lupa & Straburzyński, 2004).

Laser electromagnetic waves in the environment propagate as perpendicular electric and magnetic fields (Hewitt, 2001). The ranges of wavelength of electromagnetic waves emitted by lasers are showed on figure 4. The values of the wavelengths are cited from (Gilmour, 2002; Ziętek, 2009). The biophysical and biological effects on tissues depend on the energy and the wavelengths of electromagnetic waves (Gilmour, 2002; Jaroszyk, 2008).

There are three basic effects of lasers on biological tissues: photochemical (photoablation and photoradiation), thermal (photocoagulation and photovaporation), and ionizing (photodisruption) (L'Esperance, 1983; Podbielska et al., 2004). The photochemical effects are the result of absorption of energy of laser radiation by molecules in tissues without their destruction. During photoablation the absorption of laser energy causes the increase of temperature of the tissues. Practically the photoablation is caused by the short laser pulses of high energy. Photoradiation is the effect which appears after the transition of the excited by laser molecules in tissues to the ground or the lower energy levels with accompanied radiation of electromagnetic waves. These electromagnetic waves may be responsible for biostimulation effects and tissue temperature rise. Thermal effects interact mainly by the increase of temperature of the tissues after laser irradiation. Photocoagulation causes the increase of temperature in tissues up to 80-90°C via absorption of the laser energy.

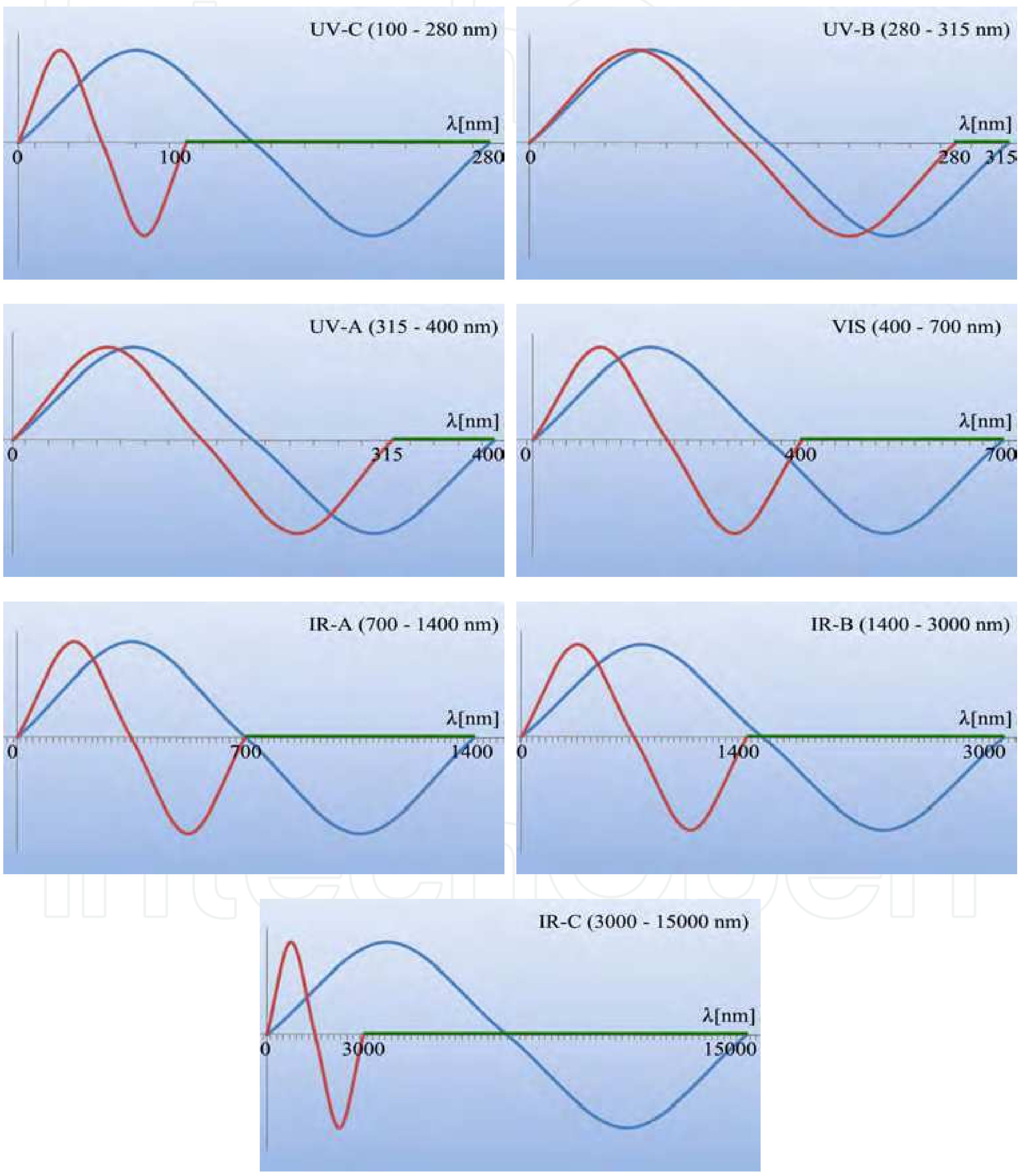

Fig. 4. The ranges of length of electromagnetic waves emitted by lasers. The values of the wavelengths (λ) are cited from (Gilmour, 2002; Ziętek, 2009).

The photocoagulation closes blood and lymphatic vessels, and causes of the necrosis of tissues. Photocoagulation denatures proteins and inactivates enzymes. The laser irradiation of high energy which causes the increase of temperature of the tissues up to 100-300°C is called as the photovaporation. The using of lasers with the high energy of pulse lead to photodisruption effects via ionization in tissues. The ionization is accompanied by the formation of shock waves. The photodisruption effects play an important role in the microsurgery of the front part of the eye.

UV-C and UV-B waves cause increase of pigmentation, burns and photokeratitis (Ziętek, 2009). UV-A waves cause burns, photosensitizing reactions, intensification of dark pigment production, and cataract (Ziętek, 2009). The visible light may destruct retina, lead to burn, and photosensitizing reaction. IR-A and IR-B waves may be responsible for burns and the others thermal destruction of epithelium and cataract. IR-B and IR-C waves may destruct cornea (Ziętek, 2009).

4. History of lasers application in ophthalmology

The history of lasers is connected with the basic theory of quantum radiation presented by Albert Einstein in 1916 (Wróblewski, 2006). This theory defines and characterizes spontaneous and stimulated emission of radiation by atoms. The method of optical pumping of atoms was discovered by Alfred Kastler and Jean Brossel in 1949 (Wróblewski, 2006) and in 1966 Kastler received the Nobel Prize. The inversion of electron localization on energy levels and the effect of stimulated emission of radiation were practically discovered by Edward Purcell and Robert Pound in 1950 (Wróblewski, 2006). In 1960 Theodore Harold Maiman constructed the ruby laser (Al_2O_3:Cr^{3+}) emitting light of 694 nm, which is still used in ophthalmology (Seitz & Langenbucher, 2000; Wróblewski, 2006; Ziętek, 2009). In Poland the first ruby laser was constructed by Zbigniew Puziewicz group from Military University of Technology in 1963 (Podbielska et al., 2004). The following types of lasers: helium-neon (He-Ne) (1150 nm), semiconducting, carbon dioxide (CO_2) (10600 nm), argon (476.5 nm, 488.0 nm, 514.5 nm), hydrogen (H_2) (102.5-123.9 nm), excimer (172 nm), and gallium nitride (GaN) (365 nm), were built in 1961, 1962, 1963, 1964, 1970, 1974, 1991, respectively (Ziętek, 2009). The krypton (647.1 nm, 568.2 nm, 530.8 nm) and neodymium: yttrium-aluminum-garnet (Nd:YAG) (1064 nm) lasers were introduced to clinical applications in 1972 and 1980, respectively (L'Esperance, 1983).

The ruby (694 nm) laser is used in the therapy of the following ocular structural defects: retinal tears, peripheral pigmentary degeneration and lattice degeneration of the retina (L'Esperance, 1983). Argon laser is used in the structural defects of the retina and choroid (L'Esperance, 1983). Krypton (647.1 nm) laser is mainly used in outer retinal structural diseases (L'Esperance, 1983). Krypton red laser photocoagulation is exemplary performed in retinal hemorrhagic diseases, retinal edematous diseases, pigment epithelial abnormalities (L'Esperance, 1983). Carbon dioxide laser is applied in operations with the high blood loss (L'Esperance, 1983).

In 1940 light was used in ophthalmology to coagulation of the retina by Gerd Meyer-Schwickerath (Seitz & Langenbucher, 2000). In Poland the first ruby (694 nm) laser coagulator to ophthalmology was constructed in 1965 (Podbielska et al., 2004). In 1961 Campbell applied confocal laser system to retinal coagulation. In 1971 argon laser was by the first used in eye surgery (Seitz & Langenbucher, 2000). In 1977 Nd:YAG (1064 nm) laser was used to microexplosion by Franz Fankhauser and Daniele Aron-Rosa. The history of lasers in ophthalmology is broadly described in the paper of Berthold Seitz (Seitz & Langenbucher, 2000).

5. Types of lasers using in ophthalmology

The group of lasers used in ophthalmology produces coherent electromagnetic radiation of different wavelengths (Dick et al., 2010; Evans & Abrahamse, 2009; Gilmour, 2002; Schmidt-Erfurth, 2010; Seitz & Langenbucher, 2000; Sieroń et al., 1994; Soong & Malta, 2009). Optical systems of ophthalmologic lasers are: CO_2, excimer, argon, tunable dye, Nd:YAG (Gilmour, 2002). Optical systems of excimer lasers contain molecules of dimmers of noble gases as argon fluoride (ArF), krypton fluoride (KrF) and xenon fluoride (XeF) (Ziętek, 2009).

The therapeutic effects as photocoagulation, photoablation, ablation via plasma, interact on eye structures. Photocoagulation is performed by the following lasers: blue-green (488-514 nm) and green (514 nm), argon, krypton red (647 nm), diode infrared (810 nm), Nd:YAG infrared (1064 nm) (Gilmour, 2002). Photoablation is carried on by lasers: excimer ultraviolet (193 nm), holmium: yttrium-aluminum-garnet (Ho:YAG) infrared (2060 nm), erbium: yttrium-aluminum-garnet (Er:YAG) infrared (2940 nm), and CO_2 infrared (10,600 nm). Ablation by plasma is done by pulsed infrared neodymium: yttrium lithium fluoride Nd:YLF (1053 nm) laser (Gilmour, 2002).

6. Parameters of lasers radiation using in ophthalmology

The power of laser is the energy emitted by laser during one second (L'Esperance, 1983; Sieroń et al., 1994). The lasers of low (4-5 mW), medium (6-500 mW), and high (above 500 mW) powers are used in medicine (Sieroń et al., 1994). The examples of lasers of low, medium and high powers are ruby, Nd:YAG, semiconducting (Podbielska et al., 2004; Ziętek, 2009). The lasers of low powers are called the soft lasers, and lasers which emit electromagnetic wave of high power are called hard lasers. The classification of lasers correspond to their irradiated power are shown in Figure 5 (Glinkowski & Pokora, 1993; Sieroń et al., 1994).

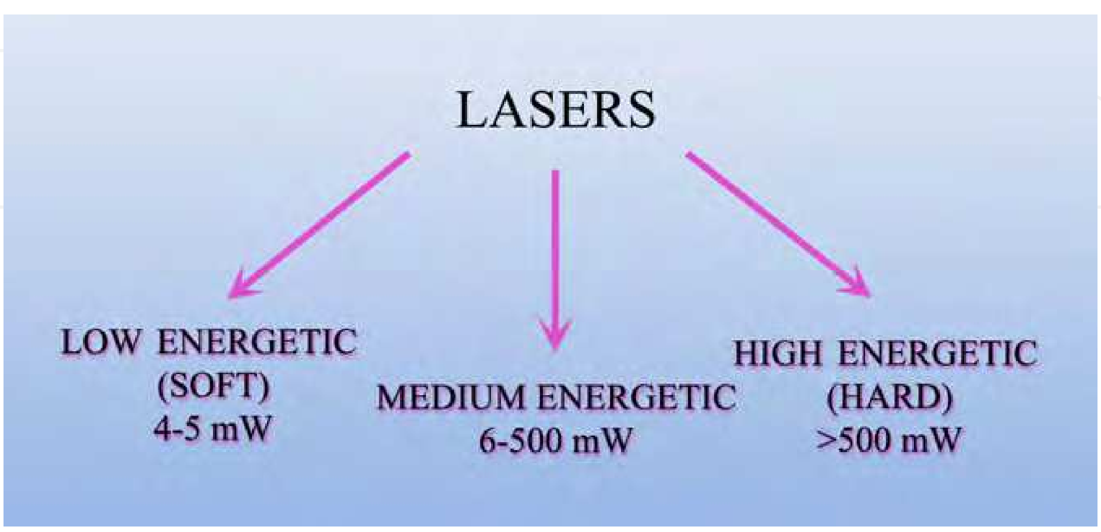

Fig. 5. Classification of lasers corresponds to power of radiation. The values of electromagnetic powers are sited from (Glinkowski & Pokora, 1993; Sieroń et al., 1994).

The biophysical effects in biological systems under laser irradiation are described by Sieroń et al. (Podbielska et al., 2004; Sieroń et al., 1994). Photochemical, thermal and acoustic effects appear during laser radiation propagation in biological samples. Photochemical reactions mainly exist in melanin biopolymers, enzymes, photosensitizers, and hemoglobin, which strongly absorb its energy. Thermal effects take place not only in the irradiated units, but they are also observed in the neighboring structures, because of thermal conductivity of the tissues. The lasers of the highest power cause heating, strong electric field, microplasma formation, increase of pressure, and as the result acoustic effects appear in the tissues.

The soft lasers with the low energy emitted to tissues during one second are used to biostimulation effects (Podbielska et al., 2004; Sieroń et al., 1994). The soft ruby lasers with low energy may be used to biostimulation (Podbielska et al., 2004). The light initiates and increases biochemical reactions. Lasers of medium power are applied in photodynamic therapy. Hard lasers are used to destruction of tissues mainly via thermal effects (Sieroń et al., 1994). Non-thermal effect of photo-destruction occurs in the irradiated structures, when the laser of high power interacts with biological system during the very short time (Podbielska et al., 2004; Sieroń et al., 1994). Free radicals may be produced by lasers of the three mentioned above ranges of power.

The power dose, time, methods, and pulse frequency should be taken to account during planning the laser therapy (Podbielska et al., 2004; Sieroń et al., 1994; Ziętek, 2009). The power, density of power, and density of energy should be correlated to the application of laser. Density of laser power I [W/m^2] is the power related to one square meter of the irradiated area. Density of laser energy H [J/m^2] is the power related to one square meter of the irradiated area (Podbielska et al., 2004; Sieroń et al., 1994; Ziętek, 2009).

7. Application of lasers in ophthalmology

The large amount of laser applications in ophthalmology is known. In that kind of medicine the excimer, argon, krypton, Er:YAG, Nd:YAG and semiconductor lasers are usually used (Dick et al., 2010; Evans & Abrahamse, 2009; Gilmour, 2002; Schmidt-Erfurth, 2010; Seitz & Langenbucher, 2000; Soong & Malta, 2009). The use of lasers in ophthalmology comes down to coagulate, cut and leads to photoablation. Laser radiation can reach the eyeball and focus on the retina and other locations within the eye without surgical intervention. The most common disease which are treated with laser light are glaucoma, cataract, retinal detachment, diabetic retinopathy (Fankhauser & Kwasniewska, 2003; Gilmour, 2002).

Glaucoma is an eye disease in which the optic nerve suffers damage (Chung & Guan, 2006; Eckert, 2010; Herdener & Pache, 2007; Hoffmann & Schulze, 2009; Juzych et al., 2004; Kanamori et al., 2006; Keicher & Stoffelns, 2010; Ngoi et al., 2005; Preußner et al., 2010; Schlote et al., 2008; Wilmsmeyer et al., 2006). It causes permanently decay of vision and if it is untreated it progresses to complete blindness. Glaucoma is often associated with increased pressure of the eye fluid (Gilmour, 2002). The cases in which there is constantly raise of intraocular pressure without any associated optic nerve damage are called ocular hypertension. In that case there is no glaucoma damage. The cases in which there is normal or low ocular pressure with typical for glaucoma visual field are called normal or low tension glaucoma. However, raised intraocular pressure is still the most significant risk factor for glaucoma progression. The permanent damage of the optic nerve and blindness are the effects of untreated glaucoma (Chung & Guan, 2006; Eckert, 2010; Herdener & Pache, 2007; Hoffmann & Schulze, 2009). There are two main categories of glaucoma - open or closed angle. First of them progresses much slower than the other and in this case patient can have any notice of vision lose. In the closed angle glaucoma, the symptoms of disease can appear rapidly (Chung & Guan, 2006). Gradual loss of vision occurs with open angle and chronic angle-closure glaucoma and with acute angle-closure glaucoma. That is why that kind of disorder it is recognized when the disease is quite advanced. In glaucoma once lost visual field cannot be recovered. There is about two percent chance of glaucoma progression in people with a family history of this eye disease. Both laser surgeries and conventional surgeries are performed to treat glaucoma. Selective laser trabeculoplasty (SLT) is one of the newest, efficient methods for the treatment of open angle glaucoma, pseudoexfoliative glaucoma and pigmentary glaucoma. In that kind of treatment Q switch Nd:YAG laser with a wavelength of 532 nm is usually used (Eckert, 2010; Gilmour, 2002). This laser affects on the cells of the trabecular meshwork but it does not cause any destruction or coagulation. The second method of laser treatment in glaucoma is argon laser trabeculoplasty (ALT). That method is focused on drainage correction of fluid from the eye. As a result the intraocular pressure is lower (Wilmsmeyer et al., 2006). In open angle glaucoma the drainage site of the eye does not function normally. In that disorder the iris is encircled by the trabecular meshwork of an eye. The increase of pressure is the result of difficult in drainage. In ALT therapy an argon laser beam is directed at the trabecular meshwork. As the effect the trabecular meshwork drain fluid more effectively (Eckert, 2010; Wilmsmeyer et al., 2006). Nd:YAG and argon lasers are used in iridotomy (L'Esperance, 1983). Argon lasers may be used in iridoplasty (L'Esperance, 1983).

Laser therapy is used in cataract too (Baratz et al., 2001; Çinal et al., 2007; Gilbert, 2011; Hille et al., 2001; Kanellopoulos & Group, 2001; Mahdavi, 2011; Shammas & Shammas, 2007; Verge´s & Llevat, 2003). The cataract is a disease that develops in the crystalline lens of an eye. It can block the passage of light and causes problems from slight to complete opacity. In age-related cataract the power of the lens may be increased, causing near-sightedness called myopia. The opacification of the lens may also reduce the perception of blue colors. Cataract typically progresses slowly and causes vision loss (Gilmour, 2002). That kind of disease potentially induces blinding if it is untreated. Cataract usually affects both eyes, but in most cases one eye is affected earlier than the other. A senile cataract which occurs in the elderly is characterized by an initial opacity and subsequent edema of the lens. One of the most popular cataract treatments nowadays is laser surgery, which uses light to dissolving cataract. The most popular method of cataract surgery is phacoemulsification. In that kind of treatment nucleus is cracking or chopping into smaller pieces. This fragmentation makes emulsification easier. Emulsification of the lens using the Er:YAG laser is very effective for performing small incision cataract surgery in eyes with soft and medium nuclei. The small ablation zones which are created during treatment can help prevent damage to surrounding ocular structures. The Er:YAG technique causes low ablation energy and does not result in thermal injury (Duran & Zato, 2001). Another method involves the removal of almost the entire natural lens while the elastic lens capsule is left intact to allow implantation of an intraocular lens. It is called conventional extracapsular cataract extraction (ECCE). That kind of treatment may be indicated for patients with very hard cataracts or other situations in which phacoemulsification is problematic. Increasingly to remove the pupillary membranes developed after ECCE is used Nd:YAG laser (Kozobolis et al., 1997). Intracapsular cataract extraction (ICCE) is rarely performed kind of cataract surgery, because of high rate of complications. It involves the removal of the lens and the surrounding lens capsule in one piece. After lens removal, an artificial plastic lens - implant is placed (Gilbert, 2011; Kanellopoulos & Group, 2001).

Lasers are also used in medical operations in the field of refractive eye surgery (Gilmour, 2002; Glinkowski & Pokora, 1993; Kim et al., 2011). The main aim of that kind of treatment is to achieve the correct relationship between the length of the eyeball and the power of its optical centers. This is possible by modifying the other shell knobs and intraocular tissues. Refractive surgery can eliminate the necessary of use the contact lenses or glass (Krzeszewska & Zdybel, 2010).

At the beginning of the development of refractive eye surgery procedures used CO_2 lasers (Glinkowski & Pokora, 1993; Kim et al., 2011). However, because of emerging adverse effects they were abandoned. Currently pulsed excimer laser emitting a beam with a wavelength of 193 nm is used during surgeries. The pulses from the beam which is transmitted last from 10 ns to 20 ns. This laser radiation penetrates the cornea to a depth of 1 μm leading to photoablation of the tissue (Krzeszewska & Zdybel, 2010). This is the most common refractive method nowadays. Excimer laser ablation is done under a partial-thickness lamellar corneal flap. While refractive surgery is becoming more affordable and safe, it may not be recommended for everybody. Patients that have medical conditions such as glaucoma, diabetes uncontrolled cardiovascular disease, autoimmune disease, pregnant women or people with certain eye disease are not good candidates for refractive surgery (Kim et al., 2011). Although the risk of complications is decreasing compared to the early days of refractive surgery, there is still a small chance for serious problems. It may appear vision problems such as double-vision, ghosting, halos, starbursts and dry-eye syndrome. Refractive surgery is used in myopia, hyperopia and astigmatism treatment (Gilmour, 2002; Seitz & Langenbucher, 2000).

Myopia is an eyes disease with a refractive defect (Gilmour, 2002). In that kind of disorder while accommodation relaxes, the collimated light produces image focus in front of retina. In other words it is a condition of the eye where the light that comes in does not directly focus on the retina. Because of that the image that one sees is out of focus when looking at a distant object but comes into focus when looking at a close object (Seitz & Langenbucher, 2000).

Hyperopia is a vision defect caused by an imperfection of an eye causing difficulty focusing on near objects and in extreme cases causing a sufferer to be unable to focus on objects at any distance. In that kind of disease power of the cornea and lens is insufficient and the image appears blurred (Gilmour, 2002).

Astigmatism is the visual defect, which is the result of an inability of the cornea to properly focus an image onto the retina. As the effect the image is blurred (Seitz & Langenbucher, 2000).

Laser subephithelial keratomileusis (LASEK) and laser in-situ keratomileusis (LASIK) processes are very common in laser surgery (Gilbert, 2011; Hille et al., 2001; Kanellopoulos & Group, 2001; Verge´s & Llevat, 2003). In LASEK which is the laser epithelial keratomileusis, the cornea's surface layer is treated with alcohol and peeled back to reshape the layer underneath. LASIK prevents most problems of postoperative pain, slow rehabilitation and corneal haze (Kanellopoulos & Group, 2001; Shammas & Shammas, 2007).

Lasers are also very useful tools in the management of malignant and benign intraocular lesions, nowadays. One of the most popular methods for small melanomas treatment is transpupillary thermotherepy (TTT) using 810 nm infrared laser. That kind of treatment can be used in medium and large melanomas as combination therapy with other treatment modalities (Gilmour, 2002).

The important application of lasers in the modern ophthalmology is their use in photodynamic therapy (PDT) (Podbielska et al., 2004). Photodynamic therapy was recently used to treat wet age-related macular degeneration (AMD). That kind of therapy was used for monitory of cases in AMD (Gilmour, 2002; Nakata et al., 2011). Now PDT is used in polypoidal choroidal vasculopathy (Akaza et al., 2007; Nakata et al., 2011; Podbielska et al., 2004). In PDT lasers with the medium range of electromagnetic radiation power are used (Podbielska et al., 2004). The molecules of photosensitizers and their excitation by laser play the most important role in this method. Laser radiation of the proper energy excites the photosensitizer molecules, which come to the next excited energy level, and after it comes to the lower energy level via sending the energy to the eye structures. The scheme of the processes in photodynamic therapy is presented in Figure 6. This scheme was prepared according to the work (Podbielska et al., 2004).

These optical processes form reactive free radicals and oxygen molecules O_2 in the singlet state in eye (Fig. 6) (Podbielska et al., 2004). Free radicals and oxygen molecules damage the pathologically changed structures in eye. Free radicals are the paramagnetic molecules containing unpaired electrons and the short lifetime characterize them, because of free radicals interactions with both dia- and paramagnetic molecules in tissues. Mainly the reactive oxygen species are formed upon laser irradiation during photodynamic therapy, especially hydroxyl radicals (OH) and superoxide radical anion (O_2^{-}) (Podbielska et al., 2004). Single oxygen molecules are diamagnetic, but this oxygen form is higher reactive than paramagnetic oxygen molecules in the ground state, because of the most molecules in the environment are diamagnetic, so the reactions between the similar units go easier (Bartosz, 2006; Podbielska et al., 2004).

Free radicals and singlet oxygen in the physiology are not expected, but their formation in the pathological state of organism during photodynamic therapy is the most important effect (Bartosz, 2006; Jóźwiak & Bartosz, 2008; Podbielska et al., 2004). Free radicals and singlet oxygen damage the pathologically changed tissue. The condition of laser irradiation should be fitted to the conditions of the highest formation of free radicals and singlet oxygen.

Free radicals ($S = 1/2$) may be directly detected by electron paramagnetic resonance (EPR) spectroscopy (Eaton et al., 1998; Jóźwiak & Bartosz, 2008; Kęcki, 1999; Kirmse & Stach, 1994; Morrish, 1970; Stankowski & Hilczer, 2005; Symons, 1987; Wertz & Bolton, 1986). Electron paramagnetic resonance effect is characteristic for unpaired electrons located in magnetic field of magnetic induction B (Stankowski & Hilczer, 2005; Symons, 1987; Wertz & Bolton, 1986). The electromagnet and the cavity of EPR spectrometer is presented in Figure 7. The Zeeman splitting of energy levels occurs in magnetic field. The spin magnetic moments orientations - parallel and anti-parallel to magnetic field are responsible for Zeeman Effect. Zeeman Effect is the effect of splitting of energy levels of unpaired electrons in the magnetic field as the result of parallel or non parallel electron magnetic moments orientations in this field (Stankowski & Hilczer, 2005; Wertz & Bolton, 1986). The quantization of magnetic moments of unpaired electrons with spin S in magnetic field results from the $2S + 1$ ($S, S-1, \ldots, -S$) possible values of magnetic spin quantum number M_S. Energy of these states is given by the following formula (Stankowski & Hilczer, 2005; Wertz & Bolton, 1986):

$$E(M_S) = g\ \mu_B\ B\ M_S \tag{3}$$

where: E – energy, M_S – magnetic spin number, g – spectroscopic factor, μ_B – Bohr magneton, B – induction of magnetic field.

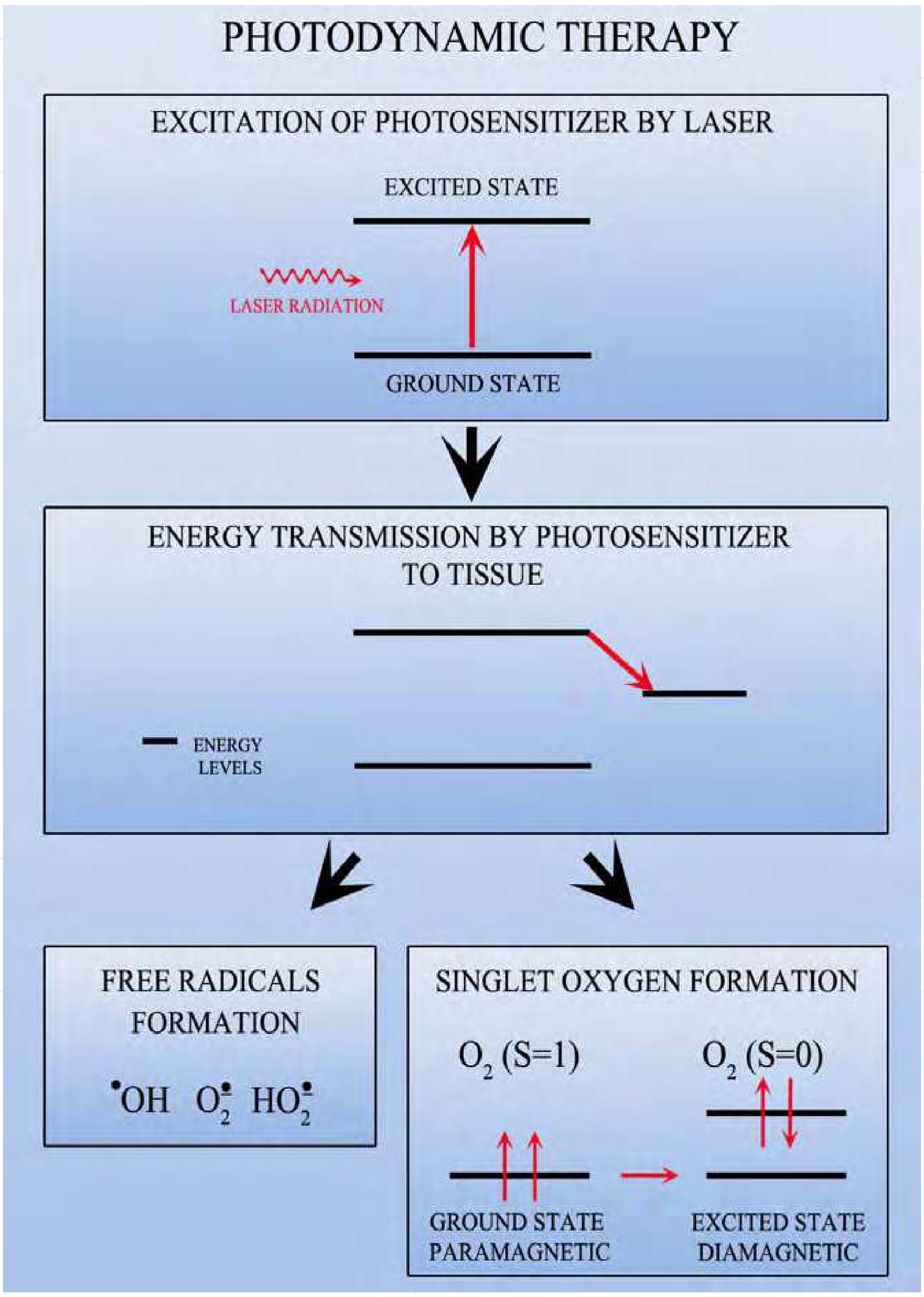

Fig. 6. Photodynamic therapy processes. Prepared according to (Podbielska et al., 2004).

Unpaired electrons are excited to the higher energy levels in magnetic field by microwaves (Stankowski & Hilczer, 2005; Symons, 1987; Wertz & Bolton, 1986). The energy of microwaves (hv) must be fitted to the distances between energy levels (ΔE) of unpaired electrons (Stankowski & Hilczer, 2005; Wertz & Bolton, 1986):

$$hv = \Delta E = g\, \mu_B\, B \quad (4)$$

where v is the frequency of microwaves.

The frequency of microwave from the basic X-band is 9.3 GHz. The equation (4) is called the electron paramagnetic resonance equation. The absorbed energy by unpaired electrons is presented in EPR spectroscopy as the resonance spectrum. The EPR spectra inform about the type and number of paramagnetic centers in the sample. The individual paramagnetic centers give EPR signals in characteristic magnetic field. The amplitude and integral intensity of EPR lines increase with the increasing of paramagnetic centers concentration in the sample. Multi-component EPR spectra as the superposition of several lines are measured for the samples with complex paramagnetic centers system consisting of different types of paramagnetic species (Stankowski & Hilczer, 2005; Wertz & Bolton, 1986).

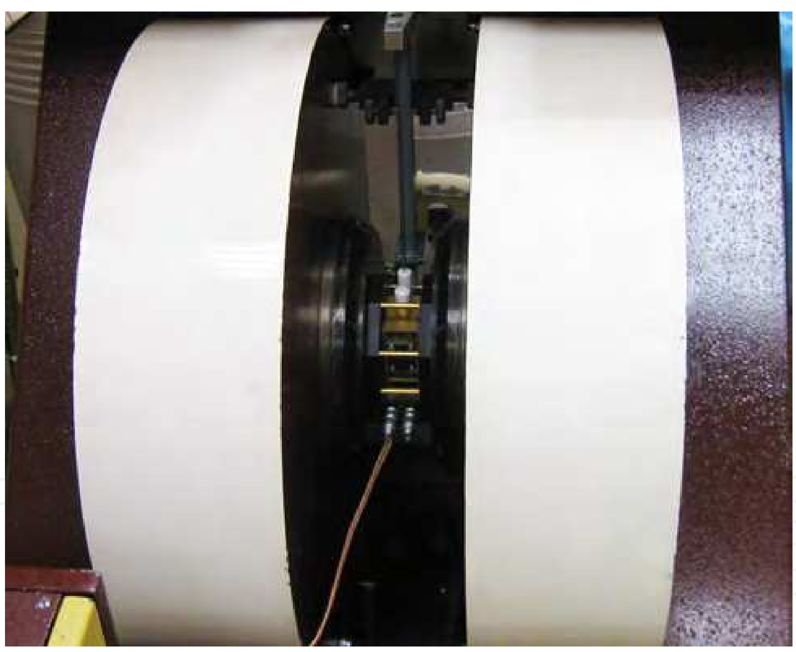

Fig. 7. The resonance cavity and electromagnet of EPR spectrometer.

Free radicals formation during laser irradiation of tumor cells with photosensitizers was studied by us earlier (Latocha et al., 2004, 2005, 2006). The observation of the changes of the amount of free radicals in eye structures irradiated by lasers is proposed in this work. The optimal conditions of PDT in ophthalmology may be search by EPR spectroscopy as the conditions with the highest free radical formation. Similar application was discussed by us for PDT of different tumor cells (Latocha et al., 2004, 2005, 2006).

The optimal conditions of photodynamic therapy are also accompanied by the highest formation of singlet oxygen. Singled oxygen as the diamagnetic molecule may be measured by EPR spectroscopy only by the use of oximetric probes. Oximetric probe is the paramagnetic sample which EPR spectrum strongly changes under changes of the concentration of singlet oxygen in its environment. Our previous results indicates that coal multi-ring aromatic samples may be used as the oximetric probes (Bartłomiejczyk et al., 2008; Latocha et al., 2008; Pilawa et al., 2005b, 2006, 2008a, 2008b). The coal oximetric probes were synthesized by Helena Wachowska group from Institute of Chemistry of Adam Mickiewicz University in Poznań (Poland). Scheme of the idea of application of EPR method and coal oximetric probe is shown in Figure 8. Coal paramagnetic probe contains chemical structures with unpaired electrons with the high probability of interactions with oxygen molecule O_2. Before laser irradiation paramagnetic molecules in the ground triplet state with spin of 1 mainly exist in the environment of the oximetric probe. Paramagnetic oxygen quenches EPR lines of coal probe. After laser irradiation the amount of paramagnetic oxygen molecules decreases, so the amplitudes of the EPR lines of coal probe increase. Under laser irradiation the paramagnetic oxygen molecules become diamagnetic, so the increase of the EPR line of coal probe is proportional to the singlet oxygen formation (Bartłomiejczyk et al., 2008; Latocha et al., 2008; Pilawa et al., 2005b, 2006, 2008a, 2008b). Such methods may be proposed in ophthalmology.

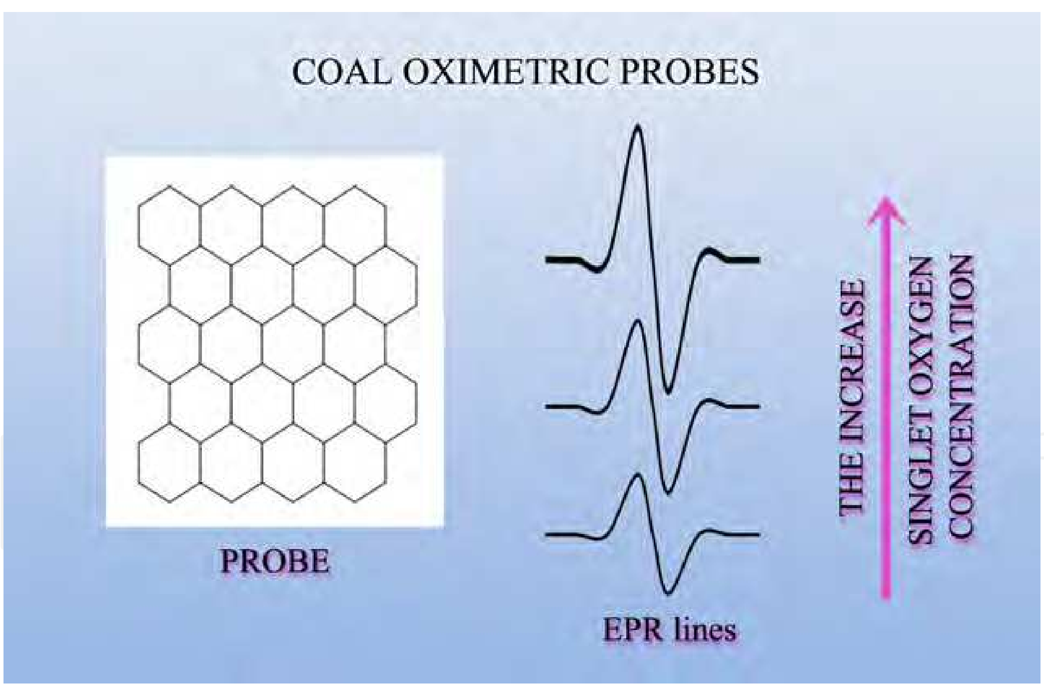

Fig. 8. Potential coal oximetric probe and the changes of its EPR line with increasing of singlet oxygen concentration in the environment.

Lasers in ophthalmology is used to the damage the eye structures via conducting of the energy from melanin biopolymer to them (Gilmour, 2002). Mainly eumelanins with the chemical structure presented in Figure 9 exist in eye (Bilińska et al., 2002; Pasenkiewicz-Gierula, 1990; Sarna, 1981; Zdybel, 2008).

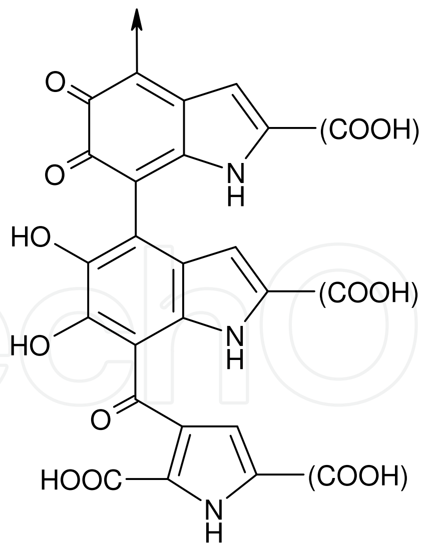

Fig. 9. The chemical structure of eumelanin polymer (Wakamatsu & Ito, 2002).

Melanins are the paramagnetic polymers with o-semiquinone free radicals with spin of 1/2 and biradicals with spin of 1 incorporated in their structure (Kozdrowska, 2006; Najder-Kozdrowska et al., 2009, 2010; Pilawa et al., 2004; Sarna, 1981; Zdybel, 2008). o-Semiquinone free radicals structure is presented in Figure 10 (Kozdrowska, 2006; Pasenkiewicz-Gierula, 1990; Sarna, 1981). Our earlier EPR studies of human retinal pigment epithelium melanosomes from young and old donors pointed out that the amount of free radicals depend on the age and method of irradiation (Bilińska et al., 2002). It seems that free radical reactions in melanin of eye influences on therapeutic effect of laser irradiation. This problem is the interesting proposition of the future electron paramagnetic resonance studies of free radicals and melanin biopolymer and laser application in ophthalmology.

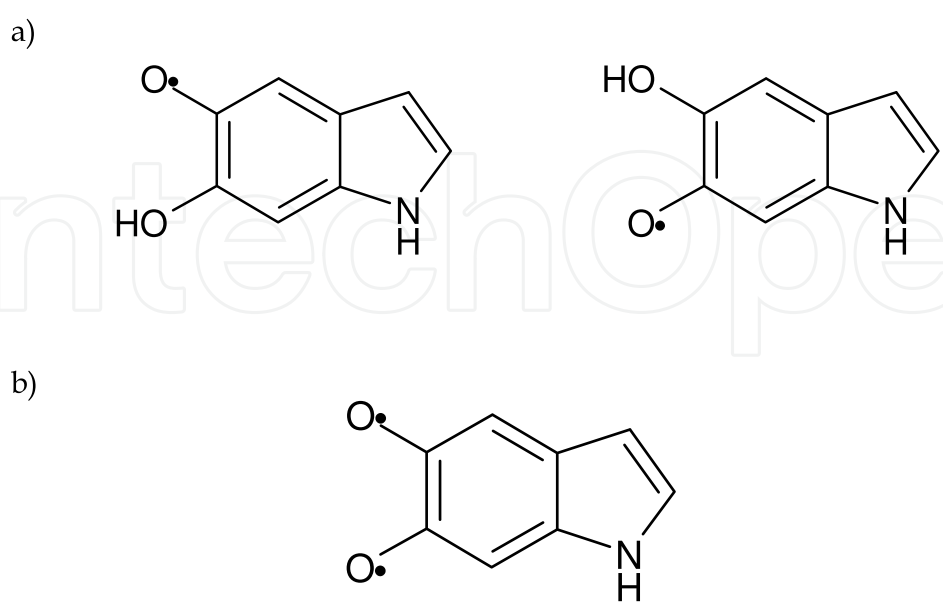

Fig. 10. o-Semiquinone free radicals (a) (Pasenkiewicz-Gierula, 1990; Sarna, 1981) and biradicals (b) (Kozdrowska, 2006) existing in melanin.

The second types of paramagnetic centers – biradicals in melanin were discovered in the last years (Kozdrowska, 2006; Najder-Kozdrowska et al., 2009, 2010; Pilawa et al., 2004; Zdybel, 2008). It is possible that biradicals of melanin could play the role in interactions of laser radiation with eye structures.

The free radicals and biradicals may be differentiated and detected by electron paramagnetic resonance spectroscopy (Kozdrowska, 2006; Najder-Kozdrowska et al., 2009, 2010; Pilawa et al., 2004; Zdybel, 2008). Integral intensities of EPR lines of free radicals and biradicals change differently with the increasing of the measuring temperature (Fig. 11) (Hatfield, 1976). Such dependences were obtained for melanin paramagnetic centers differ in spins (S: 1/2 and 1) (Hatfield, 1976; Kozdrowska, 2006; Najder-Kozdrowska et al., 2009, 2010; Pilawa et al., 2004; Zdybel, 2008).

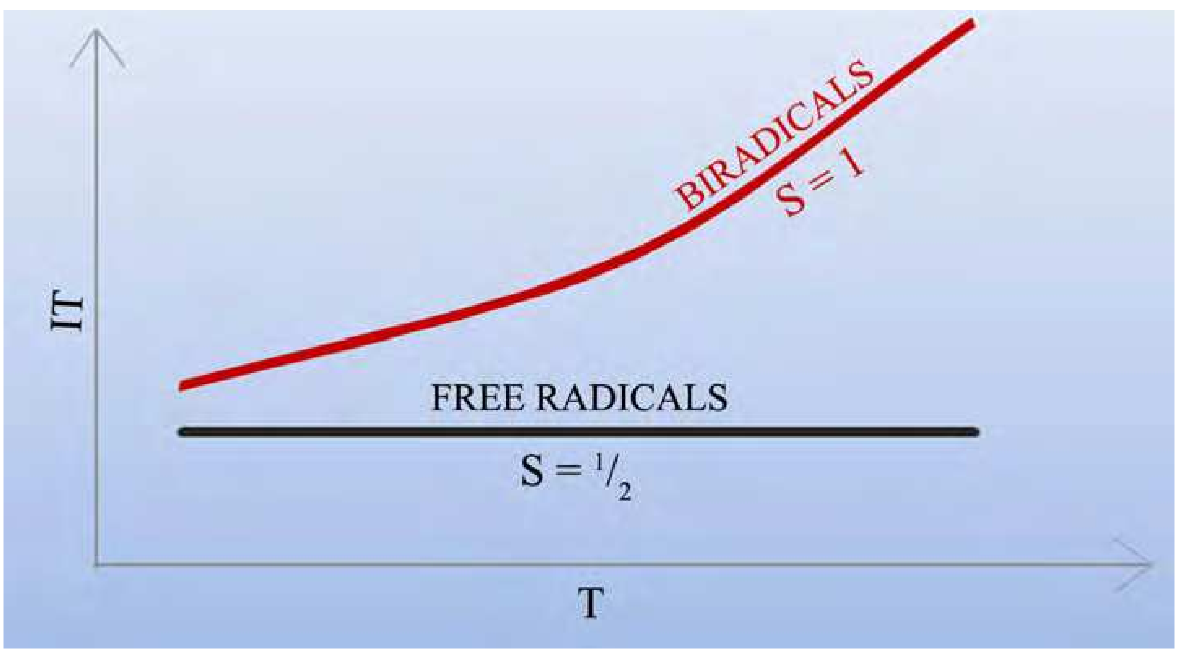

Fig. 11. Changes of integral intensity of EPR lines of free radicals (S = 1/2) and biradicals (S = 1) with the measuring temperature according to functions in (Hatfield, 1976).

The following theoretical functions for free radicals and biradicals in melanin were used (Hatfield, 1976; Kozdrowska, 2006; Zdybel, 2008):

$$IT = C \quad \text{for } S = 1/2 \tag{5}$$

$$IT = D/(3 + \exp(J/kT)) \quad \text{for } S = 1 \tag{6}$$

where: I – integral intensity of EPR lines, T – temperature, S – spin, k – Boltzmann constant, C, D, J – coefficients in the equations.

The electron paramagnetic resonance spectroscopy could be very useful in modern ophthalmology. EPR is the physical method of examination of paramagnetic species which does not damage the sample. The conditions of the laser therapy may be spectroscopically found and the reactions in the eye structures may be tested.

8. Acknowledgements

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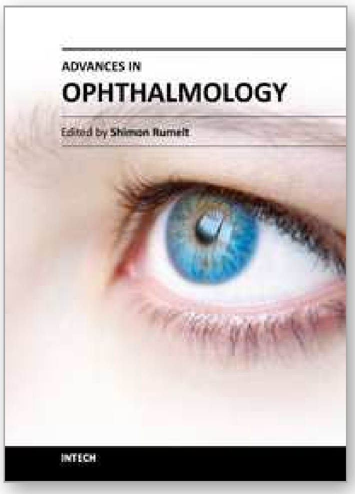

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This book focuses on the different aspects of ophthalmology - the medical science of diagnosis and treatment of eye disorders. Ophthalmology is divided into various clinical subspecialties, such as cornea, cataract, glaucoma, uveitis, retina, neuro-ophthalmology, pediatric ophthalmology, oncology, pathology, and oculoplastics. This book incorporates new developments as well as future perspectives in ophthalmology and is a balanced product between covering a wide range of diseases and expedited publication. It is intended to be the appetizer for other books to follow. Ophthalmologists, researchers, specialists, trainees, and general practitioners with an interest in ophthalmology will find this book interesting and useful.

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