

Import of Radiation Phenomena of Electrons and Therapeutic Low-Level Laser in Regard to the Mitochondrial Energy Transfer

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Abstract

The process of the cellular energy transfer is taking place in the mitochondria. In the theoretic model of this mitochondrial process, the electrons are considered as energy carriers. The model is based on the classical corpuscular aspect of electrons. Taking this into consideration, however, it is not possible to explain some of the intermediate steps of this complex energy transfer, yet even contradicts sometimes the corpuscular model. Because of the wave-particle dualism of electrons, it is evident to regard radiation phenomena in order to explain the mitochondrial energy transfer. This includes especially the electron flow in this process. Examination of the energy range, which is relevant by the energy transfer from the nutrients into the high energy adenosine triphosphate (ATP) in the cell, shows also the influence of electromagnetic radiation in the form of visible light (laser of low reactive-level). This range corresponds obviously to the metabolic energy as far as the energy intake and energy release systems of the whole process are concerned. The aim of this issue is to draw up a consistent theoretical model of the cellular energy transfer by taking into consideration radiation phenomena.

Introduction

Every living cell needs energy. The energy necessary for the complex functions of the cell comes from foodstuffs respectively nutrients absorbed by the organism. In its primary form, however, the chemical energy of the nutritive compounds is not directly useable for the cell, but has first to be converted biochemically into a cellularly useable form. The highly most important cellularly useable form is the highly energetic ATP system. The cellular energy transfer takes place in the mitochondria, and therefore these organelles have a key function for the eucaryotic cell. Biochemical models of the energy transfer describe the energy transporting electrons as responsible for the intermediated steps of this conversion. It begins, via the citric acid cycle, with the generation of high energy electrons, which subsequently loose their initial energy in the electron transport chain of the inner mitochondrial membrane (respiratory chain) and disappear again as soon as oxygen (O_2) is reduced to water (H_2O). According to the classical corpuscular idea of electrons, the transfer of energy originating from foodstuffs to cellular energy in the mitochondrial structures of the inner membrane is a flow process of high-energy electrons (electron flow). Several processes in this assumed flow of electrons can only be insufficiently explained with regard to the particle idea of electrons. Furthermore, the energy transport is not consistently explained until now.

What characterizes an Electron?

Electrons belong to the elementary particles (leptons) and are therefore a constituent part of the fundamentals that all matter is made of. The corpuscular model qualities (mass, charge) of electrons discovered by J. J. Thomson (Nobel prize 1906) still hold today. This furnished a basic explanation of the structure of matter. 30 years later, his son G. P. Thomson (Nobel prize 1937) demonstrated the wave-particle dualism of electrons by means of electron interferences that occurred during the transillumination of polycrystalline metal foils. The wave-particle-dualism is described by the Einstein - de Broglie relations for the wavelength and frequency of corpuscular radiation [1]. These relations represent the connection between the particle and wave qualities of both electrons and other objects such as photons (the quantum units of electromagnetic energy) without hurting the classical corpuscular mechanics. The striking proof of the wave-particle dualism of photons arises from the fact that electrons are energetically stimulated by electromagnetic rays. Furthermore electromagnetic radiation can transfer its energy to electrons. In order to describe atomic processes involving electrons and electromagnetic radiation, it is possible to apply as well the wave as the particle concept. The wave and particle qualities of electrons are complementary. Their diffusion is primarily characterized by their wave qualities, their interaction with atomic systems by their particle qualities. These physical facts will take into special consideration by looking to the following examination of the mitochondrial energy transfer.

The classical model of the mitochondrial energy transfer

In the biochemistry the electron transport linked with the mitochondrial energy transfer is defined by the particle idea of the electron. The function of electrons in the system of the mitochondrial energy transfer is to operate the real power plant of the mitochondria as energy carriers. That is the oxidative phosphorylation, which produces ATP. The oxidative phosphorylation can only work in connection with an electron donor and an electron acceptor. The most important electron donors in this regard are the nicotinamide adenine dinucleotide (NADH/NAD⁺) and the flavin adenine dinucleotide (FADH₂/FAD) system. The catabolism of foodstuffs in the citric acid cycle generates high-energy electrons, which pass via NADH and FADH₂ to the respiratory chain. These electrons flow in the system of the ATP-producing oxidative phosphorylation and loose their energy in doing so. Finally they are reducing molecular oxygen (O_2) to water (H_2O). This mitochondrial electron flow is biochemically described as hydrodynamic, electrochemical and biomechanical model.

The hydrodynamical model

The hydrodynamical model illustrates the aspect of the mitochondrial electron flow by means of defined potential levels, where electrons are either picked up or delivered. In this connection, the cellular electron flow can be compared to a watercourse with several waterfalls like an artificial garden. The waterfalls owe their existence to several water reservoirs, which are linked to each other and situated at different heights. The height of these water reservoirs corresponds with the oxidation-reduction potential (redox-potential) of the involved redox-pairs (donator/acceptor). However not every waterfall (electron flow) must be connected to a power station, respectively energy conversion system (oxidative phosphorylation). If, however, there are such transfer systems in the electron flow, nature tries to establish as many as possible intermediate steps in the whole system. These intermediate steps are comparable to cascade in the watercourse /2/.

The electrochemical model

The electrochemical model explains the mitochondrial energy transfer and electron flow as follows. The energy, which is released during the transfer of electrons from a high-energy to a low-energy state, is used to operate proton pumps as part of an elaborate electron-transport process in the mitochondrial membrane. The mechanism is basically analogic to an electric cell driving a current through a set of electric motors. However in biological systems, electrons are carried between one site and another not by conducting wires but by diffusible molecules (electron carriers) that can pick up electrons at one location (donator) and deliver them to another (acceptor) /3/.

The biomechanical model

The corpuscular based concept of the cellular electron flow demands the realisation of a complex electrons transporting biomechanism, which yet present cannot be explained consistently. Thereby, the mitochondrial electron-transport starts with the generation of high-energy electrons in the citrate cycle. In the course of four oxidation-reduction reactions three electron-pairs are transferred to the oxidized form of NAD⁺, while one pair to the oxidized form of FAD. These electron acceptors, which in their reduced forms (NADH/FADH₂) are very highly energetic, are regenerated again when they deliver their electrons to the respiratory chain in the inner mitochondrial membrane. Reduced NADH gives its electrons to membrane-bound proteins of the respiratory chain due to random collisions. Reduced FADH, because of sitting on the inner membrane, hands its electrons directly to the respiratory chain. In the course of this transfer, the electrons loose their energy due to the high redox potential in the regard to molecular oxygen (O₂). This energy is used cellularly to install a proton gradient and so, this energy will be transferred by the means of the oxidative phosphorylation to produce ATP. In aerobic organism, this process is the main source of ATP. The features of this process are characterized by:

1) The oxidative phosphorylation takes place in the respiratory chain that is located on the inner mitochondrial membrane as one of its integral parts. The NADH reduced by means of the extramitochondrial glycolysis cannot penetrate the mitochondrial membrane, and the same applies to energy suppliers like pyruvate and fatty acids. The mitochondrial membrane is a structural obstacle to transportation. This is why NADH, the main source of electrons, depends on the help of membrane-transport systems (shuttles) to get into the mitochondria. As far as quantity is concerned, the malate-aspartate shuttle (malate cycle) is the most important transport system of the cytoplasmic NADH /4/.

2) The arrangement of the respiratory chain contains numerous electron carriers such as cytochromes, flavins etc. The transfer of electrons from NADH or FADH₂ to O₂ by means of these electron carriers consists of several intermediate steps. In addition to this, proton pumps generate a membrane potential (proton-motor force) in the mitochondrial matrix. According to the partial concept of the electron flow, the high-energy electrons flow through the respiratory chain via a set of electron carriers (flavins, iron-sulphur complexes, chinones and cytochromes) until

they finally reduce O₂ to water. With the exception of the quinones, these electron carriers are prosthetic groups of proteins. The reaction centers of these proteins are almost exclusively equipped with reactive transition metals like for example iron and copper. The model of the electron transport shows that the electrons mainly flow from one metal to another by means of rotation and translation of the electron carrier /2/. The electrons are thus brought down to the lowest energy level, that is, oxygen, and emit their energy. But although each NADH donates two electrons, for example, each O₂ molecule must receive four electrons to produce water. This is why a corpuscular conception of the electron flow quantitatively demands the existence of different electron-collect and dispersing points along the electron-transport chain, where these differences in the number of electrons compensated /3/.

3) The driving force of the oxidative phosphorylation in the model is the membrane potential of the inner mitochondrial membrane and the electron transfer potential of 1,14 V, which is created between the NADH/FADH₂ and O₂. The free energy of the oxidation of NADH via O₂ amounts to 220 kJ/mol. The electron-transfer feeds three oxidative phosphorylation units until the electrons are finally delivered to O₂. Therefore most of the energy released can be converted into a storage form instead of being lost to the environment as heat. The particular model explains this with an indirect way of reaction, where hydrogen atoms are first separated into protons and electrons (creation of hydrid ions, that is hydrogen atoms with additional electrons and H⁺). At several steps along the way, protons and electrons are transiently recombined, but only when the electrons reach the end of this electron-transport chain are the protons permanently returned to neutralize the negative charges created by the final addition of electrons to the oxygen molecule /3/.

The model of the mitochondrial electron flow with regard to radiation phenomena

Regarding the prevailing classical particle idea of electrons, the energy-transfer from nutritive molecules such as pyruvate to the molecular mitochondrial structures of the respiratory chain is described as a flow of high-energy electrons. But as has already been said, there are no consistent explanations for some intermediate steps involved in this electron flow. These include the transport and diffusion of electrons and the interaction between electrons and other components of the mitochondrial energy transfer. Furthermore, the question of the coordination in this process taking part on all levels is answered insufficiently with the random principle. According to the molecular particle concept of biochemistry, the intermediate steps of the energy-transfer are regarded as chaotic occurrences without any synergetic precision /5/. For example, NADH emit its electrons to the respiratory chain in the course of random collisions. The particle concept think this as well-aimed vibratory and rotary motions of the components up to quantum mechanical tunneling of electrons through molecular barriers /6/. The reason for this is, amongst others, the correspondence between the real observed rapidity of the electron transfer and the frequency of random collisions between diffusible electron carriers and the enzyme complexes (rate: each complex donates and receives an electron about once every 5 - 20 milliseconds). This assumed randomness of collisions is linked with the observation, however, that there is no need to postulate a structurally ordered chain of electron-transfer proteins in the lipid bilayer, and that the ordered transfer of electrons is due entirely to the specivity of the functional interactions among the components of the respiratory chain /3/.

From the particle aspect to radiation phenomena

Because radiation phenomena, in consequence of the wave-particle dualism, belong to the fundamental nature of electrons, the electron flow linked with the mitochondrial energy transfer can also be described as radiation process. Contrary to the above-mentioned chaotic randomness in the classical particle concept, functional movements and changes in the cell take place in a highly ordered way /7/. The cellular order and the whole human organism couldn't exist otherwise. Order principles only work, if high-structured processes are dependend on long range interactions between the components involved. These interactions have a greater radius of action as that of chemical forces, for example of chemical bonds. This means to leave the exclusively

molecular point of view and turn to the radiation aspect of matter instead /5/. Therefore, the classical particle concept of the mitochondrial electron flow can be regarded theoretically as well as a wave. The connection between energy transport in the space (radiation) and order (molecular structure) reveals itself then, when in structural form bound energy is released during the breakdown of structures respectively, if circumstances are reversed, is structurally bound again. This can explain some of the above mentioned aspect of the mitochondrial energy transfer, which so far cannot be explained consistently.

The import of electromagnetic radiation

Chemical reactions are made basically of splittings or combinations of the reaction partners. Cellular examples for this are the oxidation of foodstuffs in the citric acid cycle and the ATP-production in the respiratory chain. To realise a chemical reaction in the cell, the involved partners need receive enough energy of motion to meet. Besides usually at least one of the reactant partners must be stimulated - at least at a short time - in order to change its electric charge distribution for instance, before new units can be formed /5/. These essential regulations in the team-work of the components are triggered off by electromagnetic radiation phenomena /7/. In other words, the presence or absence of radiation of a special frequency, wavelength, intensity, diffusion or polarisation in the cell is the deciding factor whether reactions take place or not. The following will discuss the import of electromagnetic radiation on the systems and components involved in the mitochondrial energy transfer. Basis for this view is the energy range which plays a role for the energy carriers of the mitochondrial energy transfer. This cellular energy range can, for example, be shown by means of the following components, which are primarily involved in the energy transfer.

1) Starting point of the examination are the bond energies of different kinds of chemical bonds in the cellular catabolism of nutrients in the citric acid cycle. Table 1 shows typical energy ranges for the bond energies of chemical bonds (van der Waals, hydrogen, covalent and ionic bonds). These energies can also be expressed in units of wavelengths of electromagnetic radiation. To present chemical bond energies as energies of electro,magnetic radiation the following fundamental formula by Einstein (equation 1) is used. Electromagnetic radiation of the wavelength λ is inversely proportional to the energy E of the electromagnetic radiation:

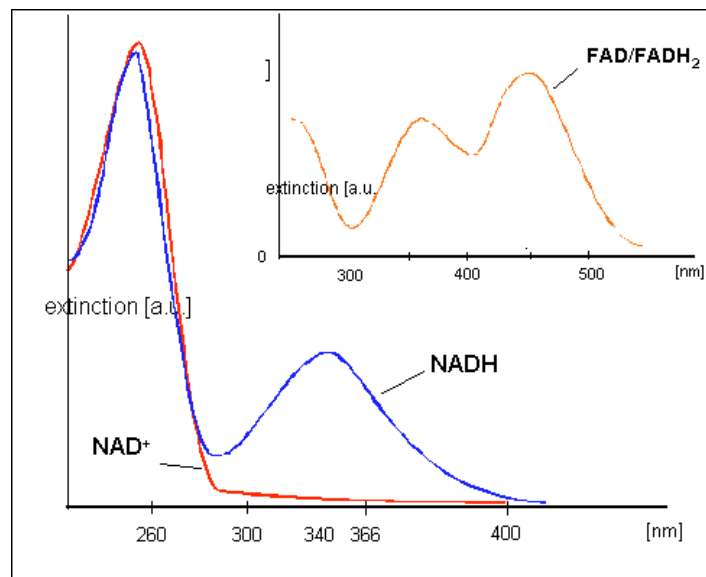
$$E = h \cdot \frac{c}{\lambda} \text{ (J) (equation 1)}$$

with E = energy of electromagnetic radiation in Joule (J), ($= 6,6256...10^{-34}$ J...s), c = velocity of light ($= 2,9979...10^8$ (m/s) and λ = wavelength of electromagnetic radiation in meter (m).

CHEMISCHE BINDUNG	BINDUNGSENERGIE (J)	ENERGIE elektromagnetischer Strahlung in Wellenlänge (nm)
Van-der-Waals-Bindung	$6,4 \cdot 10^{-21} - 1,3 \cdot 10^{-20}$	31100 — 15300 (Infrarot)
Hydrogenbindung	$2,1 - 4,8 \cdot 10^{-19}$	950 — 410 (JR, sichtbares Licht)
Ionische Bindung	$3,2 - 6,4 \cdot 10^{-19}$	620 — 310 (sichtbares Licht, UVA)
Kovalente Bindung	$3,5 \cdot 10^{-19} - 1,2 \cdot 10^{-18}$	560 — 160 (sichtbares Licht, UVA, UVB, UVC)

To illuminate the energy values shown in Table 1, the wavelength of the range of electromagnetic radiation that is visible to the human eye measures ca. 400 - 800 nm. The energies of these chemical bonds mentioned above correspond more or less with the energy range of visible light. Some partly reach into the near infrared and ultraviolet (UV-A, UV-B and UV-C) range of electromagnetic radiation. For example, the bond energies of hydrogen bonds are nearly the same as the wavelengths of the low energetic range of visible light and reach from yellow over red to the near infrared.

2) As shown above, the chemical energy of the different kinds of bonds is first released during the breakdown of bonds in the cellular metabolism and then converted into cellularly useable energy by corresponding molecular structures of the mitochondria. These molecular structures consist of the electron-donor and acceptor systems and, in addition to this, of the components of the respiratory chain. The characteristic energy ranges that apply to these systems can also be specified. One corresponding functional structure on the molecular side of the energy transfer is the nicotinamide adenine dinucleotide system (NADH/ NAD⁺). Its photoabsorption (UV-visible) spectrum is shown in Figure 1. The FADH₂/FAD system, which in the corpuscular model of the electron transfer also yields as a donor of high-energy electrons, shows an photoabsorption behaviour similar to that of NADH/NAD⁺ (Figure 1, inset).



Due to its physical origin (electronic configuration, specific molecule orbital structure), the photo(UV-visible)absorption spectrum is a characteristic fingerprint of the systems in question. Absorption maxima (absorption bands) of the spectrum marks the range where the observed system resonances, that means absorbs the most energy in the form of electromagnetic radiation (visible light). What happens with the absorbed energy depends on the physical nature of the specific systems and their own original electronic structure. Whether energy is released or not, is depending on factors such as relaxation, fluorescence, heat conversion or dynamical changes of the system. In comparison to the energies of chemical bonds (Table 1), there is a remarkably good correspondence between the energy-value ranges of the both already mentioned components of the mitochondrial energy transfer. The chemical bond energies (expressed in wavelengths of electromagnetic radiation), which are released in the citric acid cycle from covalent carbon bonds and hydrogen bonds, correspond well to the absorption bands of the NADH/NAD⁺ and FADH₂/FAD systems (compare Figure 1 and Table 1).

3) Another energy range to be examined more closely arises from the key structures in the respiratory chain, the electron carriers. These electron carriers are mostly metal proteins with iron-sulphur centres, heme groups and copper atoms as prosthetic groups. The most known are the flavins and heme components. The three main enzyme complexes of the respiratory chain with such metal proteins are the NADH dehydrogenase complex, the cytochrome bc1 complex and the cytochrome oxidase complex (cytochrome aa3). In general, each electron carrier has an absorption spectrum and reactivity that is distinct enough to allow its behaviour to be traced even in crude mixtures [3]. They absorb electromagnetic radiation in the range of the visible light and change their absorption bands (colour) when they are oxidized or reduced. Table 2 shows some of the essential electron carriers and their range of their absorption bands. For example, flavins constitute an astonishing class of green and yellow pigments that derive from riboflavin or vitamin B2, while hemes (iron-porphyrines) combine with proteins to form a whole range of coloured molecules with hues from blood-red to peagreen. The position of the absorption bands can vary dependent on the coordination of the prosthetic groups in the holoprotein.

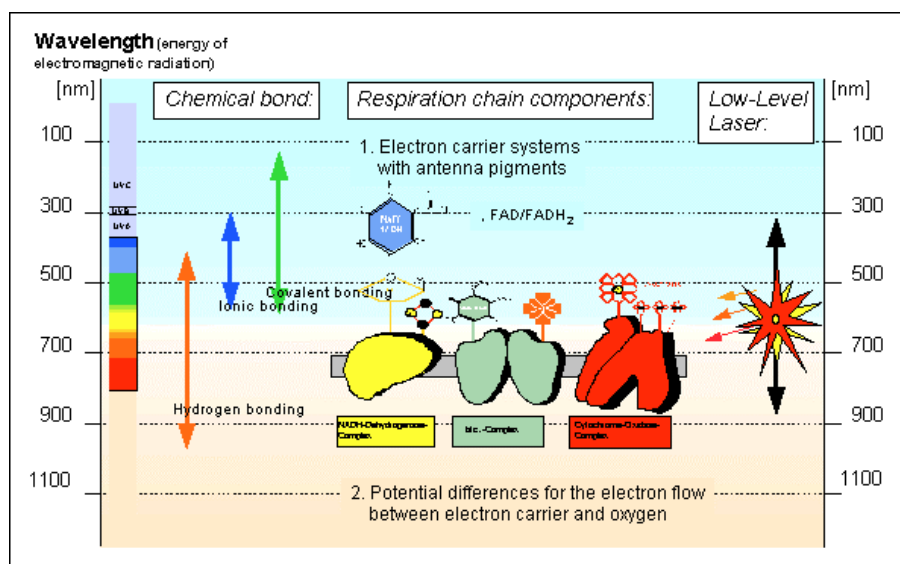
COMPONENT	ABSORPTION BAND (nm)		
	Soret-band	β -band	α -band
NADH/NAD	300 - 340		
Flavoproteins	350 - 490	470 - 490	580 - 630
Ubichinon Q	270 - 410		
Cytochrom b	450 - 465	520 - 530	558 - 562
Cytochrome a	370 - 380	530	555
Cytochrom c	410 - 415	521 - 528	551 - 557
Cytochrome a	420 - 450	520 - 540	603 - 605
Cu A			830
Cu B	UV-band of the protein in the range of 220-290 nm		760
Cytochrom a ₃		520 - 540	806

As mentioned above, these components of the respiratory chain are clearly distinguishable by means of their absorption spectra. The shortwave absorption bands in the region of 280 nm (UV range of the electromagnetic radiation) are derived from amino acids of the protein like tryptophan or tyrosine. The longer wave absorption region mostly originates from the prosthetic (metal) group of the particular electron carrier (for example, Soret-, a-, b-bands of heme). These energy ranges correspond well too with both the energies of released chemical bonds (table 1) and the photoabsorption spectra of the electron-donor and acceptor systems (figure 1). Therefore, electromagnetic radiation entering in the mitochondrial respiratory chain can be directly absorbed by the electron carriers through their so-called antenna pigments. The effective radiation scale (expressed in frequency or wavelength) extends from UV over the visible region to Infrared (IR).

Furthermore, the oxidative phosphorylation is enabled by the close link between electron carriers and protein molecules. These proteins control the electrons through the respiratory chain, so that they can pass from one enzyme complex to another in the right order and effectively. This electron control occurs by allosteric rearrangements in the proteins involved. Both the control system and the provision of energy for such dynamical conformation changes in proteins or vibratory motions in macromolecules can be explained with the aid of radiation phenomena /5/. The import of radiation phenomena in the context of the mitochondrial energy transfer and electron flow, enables to understand the process of the energy finally released from the catabolism and its absorption by the structures of the inner mitochondrial membrane. Hence follows an explanation of the import of electromagnetic radiation in form of light on the mitochondrial energy transfer. Depending on its wavelength, light (photons as quant) can, for instance, stimulate macromolecules to change the geometry of molecules as well as to transfer energy to electrons. As a matter of fact light has a directly stimulating effect on cellular structures, as has been shown by several experiments /13, 14/. On this cellular level there still remains yet a lot of research to be done, concerning the biostimulative effect of electromagnetic radiation (e. g. in the region of visible, natural solar light). The relevant issues of this research arise from the location of cellular stimulation points and from the explanation of the directly stimulating effect of electromagnetic radiation in connection with the components of the respiratory chain.

Low level laser light

The stimulative effect of electromagnetic radiation in the form of low level laser light in medicine is already used today /15, 16, 17/. Its known that the effect of low level laser light does not derive from heat /18/. Variations of the energy of electromagnetic radiation show that the effect of laser light is limited to certain spectral regions. The wavelength (energy range) between 600 and 700 nm (red region) seems to be especially effective /19/. Low level laser light from the red region and the near infrared region corresponds definitely with the characteristic energy and absorption levels relevant for the respiratory chain. This hences at the reaction center of low level laser light in this way that the electromagnetic energy stimulates the components of the so-called antenna pigments of the respiratory chain and thus vitalizes the cell by increasing the mitochondrial ATP-production. This kind of stimulation can be interpreted as a biological resonance effect /18/. Therefore, the components of these antenna pigments are resonators of different sizes and forms, which resonate with a specific stimulation, that means energy of radiation. They are capable to transfer the stimulation functionally for various regulation processes in the cell. The energy range which plays the role by the different processes and components of the cell involved in the mitochondrial respiratory chain, is shown in Figure 2.



One characteristic energy range is represented by the chemical bonds, which are released by the cellular catabolism. On the other hand, the absorption bands of the components of the mitochondrial respiratory chain (particularly the electron carriers with their antenna pigments) are in a comparable energy range (see Figure 1 and Table 2). These both relevant energy range correspond remarkably with the energy range of the electromagnetic radiation of low level laser light therapeutically used.

Conclusion

In the mitochondria, the chemical energy contained in foodstuffs is converted into a cellularly usable form. Biochemical models of this energy transfer regard electrons as responsible energy carriers for the different transfer processes. After gained in the citric acid cycle, high energy electrons effectively pass the electron transport chain (respiratory chain) by delivering their initial energy to the cellular energy transfer and finally reduce oxygen to water. The classical particle idea of electrons describes the mitochondrial energy transfer as a flow process of high energy electrons (electron flow). Intermediate steps in this model of electron flow are inconsistent with the particular idea of electrons. Because the inherent wave-particle dualism of the electrons, it is obvious to regard radiation phenomena in order to explain the mitochondrial energy transfer. The connection between energy transport by radiation and order in structural form may be understood, if, for instance, structurally bound energy is released during the dissolution of structures (oxidation of foodstuffs) or is again manifested (reduction of oxygen to water). Regarding the energy values relevant for the respiratory chain, the import of electromagnetic radiation of characteristic ranges of wavelengths on the mitochondrial energy transfer becomes evident. Depending on its wavelength, electromagnetic radiation in the form of light can for example stimulate macromolecules, initiate conformation changes in proteins or can transfer energy to electrons. Therefore, with regard to radiation phenomena in the mitochondrial energy transfer and its induced electron flow in the respiratory chain it is possible to explain the experimentally found increase of ATP-production by means of low level laser light on a cellular level. Furthermore, it must be emphasized, that this theoretical model mentioned above and the biostimulative effect of radiation phenomena require intense researches.

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