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Nonlinear mechanism for weak photon emission from biosystems

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The nonlinear mechanism for the origin of the weak biophoton emission from biological systems is suggested. The mechanism is based on the properties of solitons that provide energy transfer and charge transport in metabolic processes. Such soliton states are formed in alpha-helical proteins. Account of the electron-phonon interaction in macromolecules results in the self-trapping of electrons in a localized soliton-like state, known as Davydov's solitons. The important role of the helical symmetry of macromolecules is elucidated for the formation, stability and dynamical properties of solitons. It is shown that the soliton with the lowest energy has an inner structure with the many-hump envelope. The total probability of the excitation in the helix is characterized by interspine oscillations with the frequency of oscillations, proportional to the soliton velocity. The radiative life-time of a soliton is calculated and shown to exceed the life-time of an excitation on an isolated peptide group by several orders of magnitude.

Keywords: Biophoton, Davydov's solition, Hybrid solition, Radiative life time

All living systems emit photons, although this emission is very weak due to which the reliable experimental registration became possible relatively recently. The pioneering role in the discovery of this phenomenon belongs to Alexander Gurwitsch in the beginning of the twentieth century[1,2]. The comprehensive experimental study of non thermal radiation of biophotons from living systems has been carried by Fritz-Albert Popp, who turned back to this problem not only himself, but has attracted a great deal of attention form many scientists all over the world after several decades of skepticism[3,4]. Up to now the question about the source of this emission remains open. Here we suggest that this emission can come from the radiative decay of solitons which are formed in macromolecules, such as polypeptides, DNA, microtubules, etc., and which participate in the energy, charge and information transfer in the living systems.

The concept of molecular solitons has been initially suggested by an outstanding Soviet scientist Alexander Davydov in 1980s to explain the mechanism for the energy storage and transfer in biological macromolecules[5]. Davydov's soliton is a self-trapped localized state of an electron or AMID-I excitation in a one-dimensional polypeptide molecular chain. Such soliton is a bound state of a quasiparticle and local chain deformation. It is formed in the result of the quasiparticle self-trapping by the local deformation created by a particle itself. The general properties of solitons as stable localized nonlinear solitary waves are discussed. Examples of solitons in physical systems (fiber optic communications, plasma, atmosphere, hydrodynamic tsunamis, crystal lattices, etc) are given to visualize these nonlinear objects and to give the clue about their very specific properties. An overview of the applications of the concept of solitons in biological systems is suggested. Among these applications there are molecular solitons and electrosolitons in alpha-helical proteins, nerve propagation in the form of solitons, solitons in DNA, soliton mechanism of muscle contraction, etc.

Special accent is given to the molecular solitons that provide the energy and charge transport during the metabolic processes. Such soliton states are formed, for instance, in alpha-helical proteins that participate in the photosynthesis, in such macromolocules like cytochrom c-oxidase in the redox chain in the respiration processes in mitochondria, etc. For the simplicity a one-

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dimensional molecular chain is considered and it is shown that the account of the interaction of a quasiparticle (it can be an electron or AMID-I excitation of the peptide group, excited by the quantum of energy that is released in the hydrolythis of the adenosine-triphosphate into the adenosine-diphosphate) with the local deformation of the polypeptide chain results in the self-trapping of a quasiparticle in a localized soliton-like state, known as Davydov's soliton. Such a soliton is exceptionally stable, it propagates along the macromolecule with the constant velocity together with the local deformation of the chain almost without the energy dissipation[6-8].

The important role of the helical symmetry of macromolecules in the formation, stability and dynamical properties of solitons is elucidated[8]. In particular, it is shown that the energy spectrum of quasiparticles in an alpha-helical macromolecule, stabilized by three polypeptide chains of hydrogen bonds, contains three energy bands. The upper band is a nondegenerate and has the minimum in the centre of the Brillouin zone. The lower band in the energy spectrum degenerates into two bands which have minima at nonzero values of wave-vectors, symmetrically shifted with respect to the centre of the Brillouin zone, by the values $\pm k_0 = \pm \frac{3\sqrt{3}L}{(18J+L)a}$. Here J and L are, respectively, intra- and inter-chain exchange energies, a is the hydrogen bond length. The corresponding system of nonlinear equations admits several types of soliton solutions, among which there is the hybrid soliton solution which is formed by the hybridization of the quasiparticle states from the two lowest degenerate energy bands. It is shown that this soliton has the lowest energy and possesses an inner structure with the many-hump envelope. The probability distribution, $P_j(n)$, of such a soliton on individual spines is shown in Fig. 1. It follows that such a soliton breaks spontaneously the local translational and helical symmetries of the macromolecule.

The total probability of the excitation on the j-th spine is given by the expression

$$P_j(t) = \sum_n P_{j,n}(t),$$

$$= \frac{1}{3}\left[1 - \frac{\pi k_0}{\kappa \sinh(\pi k_0/\kappa)} \cos(2k_0 V t - 2\pi j/3)\right] \quad \ldots (1)$$

where $\kappa = \frac{9\chi^2}{wa(18J+L)}$ is the localization parameter of a hybrid soliton, χ is the electron-phonon coupling, w is the elasticity coefficient, that is proportional to the elasticity of a hydrogen bond, and V is the soliton velocity. From (1) the probability of the excitation on a given spine is an oscillatory function of time with the period of oscillations, determined by the soliton velocity V:

$$T_h = \frac{\pi}{k_0 V}. \quad \ldots (2)$$

In particular, for the soliton velocity equal to *3/8* of the sound velocity[6] for an AMID-I excitation in alpha-helix (J=1.55 10^{-22} Jole, L=2.46 10^{-22} Jole, k_0a=0.422), we obtain the value T_h=2 10^{-12} s. Altogether, these results explain a soliton structure, interspine oscillations and their frequency, observed numerically by Scott[6].

These helical oscillations get mixed up with the oscillations that arise from the influence of the lattice discreetness on the soliton dynamics which leads to the appearance of the periodic Peierls-Nabarro potential. The period of these longitudinal oscillations is also determined by the soliton velocity[9].

$$T_l = \frac{a}{V}, \quad \ldots (3)$$

which is one order of magnitude smaller than T_h.

The oscillating character of the propagation of solitons and other specific properties of solitons can be responsible for some peculiar phenomena in the

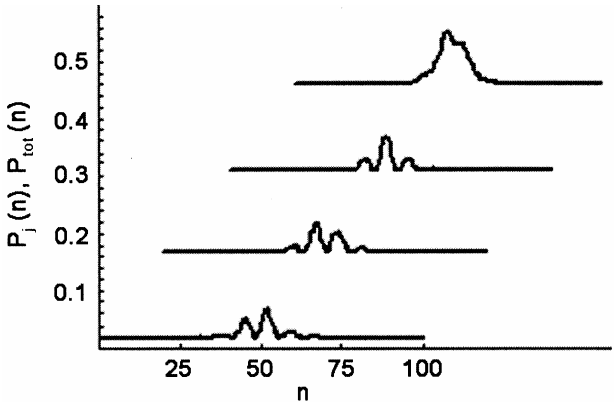

Fig. 1—Probability distributions, $P_j(n)$, of a hybrid solitons on the three individual spines of alpha-helix, j=1,2,3 (three lower curves). Upper curve corresponds to the total probability distribution, $P_{tot}(n)= P_1(n)+ P_2(n)+ P_3(n)$.

biological systems, which linear theories can not explain.

In particular, according to the analytical and numerical study[10], the influence of the external electromagnetic radiation on the dynamics of electrosolitons (i.e., solitons, that carry an electron charge), has a nonthermal resonant character with several characteristic frequencies. Such influence is characterized by two characteristic frequencies of electromagnetic fields $\omega_0 = \frac{2\mu V_a}{\pi}$ and $\omega_{dis} = \frac{\chi^4}{\mathrm{h}Jw^2}$, respectively, and is qualitatively different. Here μ and V_a are soliton width and velocity of the sound in the polypeptide chain. At low frequencies of the radiation, electrosoliton absorbing the energy from the field, generates the acoustic waves. This process is most intensive in the fields of frequencies $\omega \approx 1.3\omega_0$, determined by the characteristic time scale of the retardation effects, which is determined, in its turn, as the ratio of the soliton width to the sound velocity. The generation of acoustic waves in polypeptide chain can result not only in the local heating of the system, but also such sound waves can propagate along the alpha-helix as in the channel carrying some additional information. Moreover, the generation of the sound can change qualitatively some functioning processes connected with conformal states of macromolecules or their fragments, since electromagnetic radiation of the corresponding frequencies causes the oscillations of electrosolitons including the oscillations of the chain distortion.

When the frequency of electromagnetic radiation corresponds to the energy splitting of the electrosoliton level from the energy band bottom, the quantum transition of the electrosoliton into a delocalized band state occurs. Hence, the electromagnetic radiation of the frequencies ω; ω_{dis} can destroy an electrosoliton completely, making the coherent charge transport in the system far less effective, if possible. More precisely, the charge transport in biological systems is provided by bisolitons which are bond states of two electrosolitons with opposite spins[11], and one can expect the spectrum of bisoliton interaction with electromagnetic radiation to be richer than those of a single electrosoliton.

Due to the oscillating character of propagation, electrosolitons, according to Maxwell equations, emit electromagnetic radiation[12]:

$$\vec{E}_{rad}(r) = \frac{eV_0^2}{2a\varepsilon_0 c^2 r^3} \sum_{n=1}^{\infty} \frac{4nq^n}{1+q^{2n}} \sin(n\omega t)\vec{r} \times (\vec{r} \times \vec{l}) \quad \ldots (4)$$

$$\vec{B}_{rad}(r) = -\frac{eV_0^2}{2a\varepsilon_0 c^2 r^2} \sum_{n=1}^{\infty} \frac{4nq^n}{1+q^{2n}} \sin(n\omega t)\vec{l} \times \vec{r} \quad \ldots (5)$$

where the frequency of the main harmonic of oscillations,

$$\omega = \frac{2\pi V_0}{a} \quad \ldots (6)$$

is determined by the average soliton velocity, V_0. According to the numerical estimates, it is of the order $V_0 \sim 1.5\times10^3$ m/s, which gives the following estimate for the main harmonic frequency: $\nu = \omega/2\pi \sim 10^{12}\ \mathrm{s}^{-1}$.

This radiation constitutes the component of the endogenous electromagnetic field with characteristic resonant frequencies, which, according to (6), depend on the soliton velocity, which, in its turn, is determined by the metabolic activity of the system. The superposition of the longitudinal and helical oscillations of the electrosoliton results in a more complex spectral structure of this field with components of various polarization properties and radiation pattern. Namely, the longitudinal oscillations cause plane polarized radiation which can be described as the radiation of some effective dipoles, oriented along the helix axis[4]. Meanwhile, the component of the radiation due to the helical oscillations, has circular polarization. Altogether, this radiation can be responsible for the biocommunication in living systems[13,14]. Exchange by this radiation leads to synchronization of soliton motion[12]. Moreover, at different velocities solitons generate EMR of different noncommensurate frequencies and the total intensity of the EMR is proportional to the number of solitons, N, while in the case of their synchronized motion and emision it is proportional to N^2. The soliton model predicts the dependence of the intensity of bioelectromagnetic field on the functional state of a cell: the total radiation depends on the concentration of solitons which is determined by the metabolic activity of a system. The selfregulation of solitons via their

radiation can be stimulated by the external weak radiation of the corresponding frequencies. Indeed, some results of microwave resonance therapy indicate such weak irradiation stimulates the internal immune and self-regulating systems[11].

The life-time of solitons is determined by the relaxation processes in proteins and is inversely proportional to the probability of photon emission due to transition of a protein from an excited hybrid soliton state into the ground one. The radiative life-time of a hybrid soliton, τ_h, related to this transition, is given by the expression.

$$\tau_h = \frac{4\kappa a\,\tau_0}{3\pi^2 \sin^2\vartheta} \cosh^2\left[\frac{\pi(k_0 a + 2\pi/6)}{2\kappa a}\right] \qquad \ldots (7)$$

Here τ_0 is a lifetime of an isolated excitation of a peptide group, ϑ is an angle between the orientation of the dipole momentum of an excitation and helix axes. For the parameters of an AMID-I excitation in alpha-helix $\kappa a = 0.176$, $\vartheta = 30^o$ we get $\tau_h / \tau_0 = 5.8 \cdot 10^9$. Therefore, the radiation lifetime of a hybrid soliton in a helical structure is much bigger than the lifetime of an AMID-I soliton, τ_s, in a three-spine model with zero helicity[16]: $\tau_h / \tau_s = 2 \cdot 10^3$.

Therefore, the helicity of a protein significantly increases the radiative life-time of AMID excitations in proteins. This conclusion agrees with recent experiments of Austin *et al.*[17], which show that the life-time of an excitation in myoglobin, that is essentially alpha-helical protein, is much bigger than in isolated aminoacid such as L-alanine. Further, such an excitation in myoglobin has necessarily the nonlinear nature[17]. It is opined that, this nonlinear nature can originate from the electron-phonon interaction and anharmonicity of proteins, leading to the self-trapping of excitations and electrons in soliton-like states and in the significant increase of the life-time. Moreover, such solitons provide the complex endogenous electromagnetic radiation of characteristic frequencies with the resulting synchronization of charge transport processes, which, in its turn, provides the coherence of the guiding electromagnetic field and self-regulation of metabolism[9-11]. The electromagnetic radiation by solitons (4)-(5) by its properties coincides with the radiation from coherent dipoles, suggested by H. Froehlich[18]. The radiative decay of solitons contributes to the weak photon emission from biosystems, measured experimentally[3,4].

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