Scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences (26–27 October 1983)

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The joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the USSR Academy of Sciences was held on 26 and 27 October 1983 in the conference hall of the P. N. Lebedev Physics Institute of the USSR Academy of Sciences. The following papers were read.

26 October

1. *D. S. Chernavskiĭ.* Tunneling transport of electrons in biology.
2. *A. B. Rubin.* Molecular mechanisms for electron transport in biological systems.
3. *V. I. Gol'danskiĭ and Yu. F. Krupyanskiĭ.* Dynamics of biopolymers and the glass model of proteins and DNA.

27 October

4. *B. A. Volkov, V.A. Gorbatsevich, and Yu. V. Kopaev.* Anomalous diamagnetic properties of systems with spontaneous current.
5. *V. G. Veselago.* Photomagnetism.

A summary of the five papers is given below.

D. S. Chernavskiĭ. *Tunneling transport of electrons in biology.* Excited electrons are the primary carrier of energy in biological processes such as photosynthesis and the production of ATP in mitochondria (this is the so-called respiratory phosphorylation). The electron travels from one macromolecule to another (to distances of the order of $L \simeq 15$–20 Å) as a result of the tunnel effect. This process is accompanied by partial dissipation of the energy of the electron, but a considerable proportion is tranformed in other ways: a chemoosmotic potential gradient is produced and (or) energized protons are formed in local regions in the interior of the protein-membrane complex; in the end, the result is the synthesis of ATP.

One of the topical problems in biophysics is the elucidation of the transformation of the energy of the electron into other forms of energy, and the tunnel effect plays a leading role in this process.

The aim of this communication is to present existing ideas on the tunneling transport of electrons and the transformation of its energy in biology.

The experimental situation will be illuminated in A. B. Rubin's paper.

The specific character of tunneling transport in biology can be summarized as follows.

Normal oscillations of a charged group (or groups) in the protein molecule play the role of the acceptor mode (AM) which receives some of the energy of the electron.

Protein macromolecules differ from inanimate matter in that they are constructed expediently and adapted to perform a specific function (this is assured in the course of their synthesis on the basis of genetic information); their structure is heterogeneous, aperiodic, but not chaotic. It may be said that enzyme proteins are the structural units with a small number of degrees of freedom, which are responsible for performing this function.

In view of the foregoing, direct transfer of the results of theories developed for periodic or chaotic systems to biological objects is not always possible. It is better of use a physical model that is more suitable for a particular process.

A model of this kind is shown in the figure and was formulated and investigated in Ref. 1–5. The rectangular potential wells correspond to electrophilic groups of protein macromolecules. The curves marked in and fin represent the free Am energies (with allowance for the interaction with the electron) when the electron is localized in well I (prior to tunneling) and in well II (after tunneling). The transition of the electron is accompanied by the excitation of normal vibrations that are rapidly damped out and convert their energy into heat. The harmonic approximation (the parabolas marked in and fin in Fig. 1 and shown by the thick line) was used to consider the limiting cases of strong and weak coupling. In the latter case, the rate of the process is high only if the electron levels E_1 and E_2 are close to one another, i.e., $E_1 - E_2 = \delta E \simeq \hbar\omega \lesssim 0.1$ eV (this is the so-called "resonance" tunneling). This property means that transitions between levels that involve a high degree of dissipation during "resonance" tunneling are kinetically forbidden. This is possible only in the absence of a polar environment.

In either case, the theory is close to that of radiationless relaxation[6] and of processes occurring during electrolysis.[7]

The transformation of energy into another form is possible if (1) the acceptor mode is anharmonic, so that there are two minima (corresponding to stable and metastable states—thin lines in the figure) and (b) different states are stable in states marked in and fin. The transition takes place in stages: (I) tunneling of the electron from level E_1 to E_2, for which AM undergoes a transition from 1_{in} to 1_{fin} and (II)

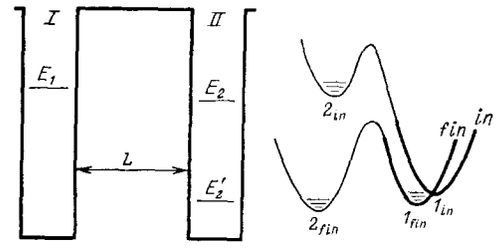

FIG. 1.

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transition of AM to state 2_{fin}, in which case the electron remains in well II, but its energy is reduced from E_2 to E_2'.

The second stage is a conformational transition in the macromolecule that involves a special and expediently organized "mechanical"[8] degree of freedom; it can also be looked upon as a phase transition in the structure.[9] The entire process is an electron-penformational transition (this designation was introduced by Vol'kenshteĭn[10]). The formation of a polaron is the analog of this process in physics.

In real macromolecules states 1_{fin}, 2_{fin}, etc., contain a large number of macro-states, and migration over these states is described within the framework of the "Brownian oscillator" model.[11] The transition between state 1_{fin} and 2_{fin} can also take place in stages (indented barrier), in which case its kinetics can be described within the framework of the restricted diffusion model.[11]

The energy transformation cycle can be completed if there is a third transporter of electrons (third well), in which the energy level E_3 lies below E_2', but is not too far from it. The following two stages will then take place: III—tunneling of the electron from E_2' to E_3, in which the AM will undergo a transition to a metastable (energized) state and IV—expenditure of the energy of the metastable state and return of the AM to the original state 1_{in} (this process is not connected with tunneling and must be considered separately).

The entire four-stage cycle is discussed in Refs. 2, 12, and 13. It is possible only under the conditions of "resonance" tunneling since, otherwise (strong coupling), state III will occur immediately after stage I (bypassing state II) and the entire energy will be dissipated. An application of this scheme to a particular proton energization process is described in Ref. 14.

An analogous cycle in the interior of one macromolecule containing two electrophilic groups, in which a photon can take an electron to an excited state, is discussed in Refs. 2 and 15. An application of this cycle to the energy transformation process in bacteriodopsin is discussed in Refs. 16 and 17.

Thus, the theory of tunneling transport of electrons in biology (with allowance for the specific character of the object) is now adequately developed and is being used to investigate specific processes.

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