

FIG. 1

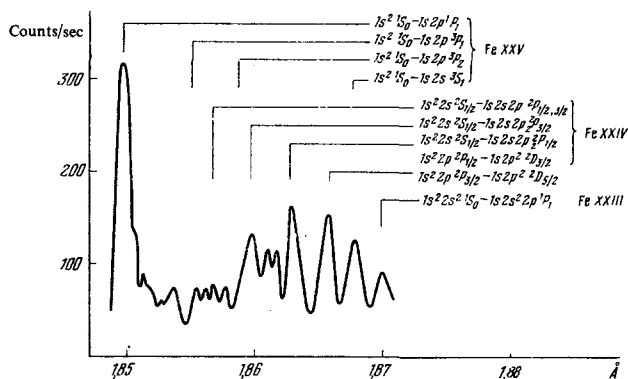
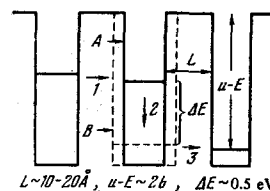


FIG. 2



- 1) Physical aspects of biochemical processes.
- 2) Mathematical modeling (more precisely, mathematical models of the kinetics of biological processes). We cite a few examples.

The first pertains to electron transport, which is the basis of the supply of energy to the cell, i.e., the formation of ATP. It consists in the following. An electron is excited in a certain molecule (in plants, this is the chlorophyll molecule, and excitation is by a quantum of light). The electron is then transferred to other, transferror molecules; its level is lowered. In some molecule, the lowering of level is accompanied by transformation of energy to other forms (in the final analysis, to chemical form—formation of ATP). The transferrors are macromolecules with dimensions in the tens of Angstrom units; they are situated in the membrane and fit tightly into one another. A diagram illustrating the process appears in the figure.

The physical aspect of the question is that of how the electron is transferred—by jumping over the barrier or tunnelling through it. Tunneling appears more likely for a number of reasons, but two objections have been raised to this: 1) it was assumed that the rate of tunneling should not depend on temperature (a dependence with activation energy on the order of 0.14 eV has been observed experimentally<sup>[1]</sup>); 2) extremely precise (practically unattainable) coincidence of the levels is necessary for tunneling.

It was shown in<sup>[2]</sup> that both of these objections are answered when the binding of the electron with a small number of normal oscillations is considered: the level difference may reach 0.1 eV (the characteristic magnitude of the normal-oscillation energy); the rate of the process depends on the presence of normal oscillations and, consequently, on temperature (the activation energy is of the same order, 0.1 eV).

A physical model of the chief event—transformation of energy—was examined in<sup>[3]</sup>. The molecule of the transformer-transferror may be in either of two forms: A—an equilibrium form in the absence of the electron and B—an equilibrium form in its presence; the level of the electron is higher in A than in B.

The energy-transformation process consists of the following stages (see Figure): (1) an electron from a preceding transferror tunnels into the transformer molecule:  $A + e \rightarrow Ae$ . (2) The state  $Ae$  relaxes to equilibrium:  $Ae \rightarrow B$ ; the change in the form of the molecule is accompanied by a lowering of the level. (3) The electron tunnels into the next transferror, whose level is close to the level B. The state B contains an excess of energy, since its form (and the disposition of its active groups) are nonequilibrium; this form of the energy may be transformed to chemical, as happens in (4): the relaxation  $B - e \rightarrow A$ . Thus, the energy goes from the form of electronic excitation to deformation energy and thence to chemical bonding energy.

tions of the line wavelengths (calculations performed by U. I. Safronova).

The electron temperature of the flare region was determined at  $T_e \approx 20 \times 10^6$  K from the relative intensity of the lines of Fe XXV at  $\lambda = 1.850$  Å and Fe XXIV at  $\lambda = 1.886$  Å, and according to the Doppler broadening of the lines of Mg XII at  $\lambda = 8.418$  Å and Fe XXV at  $\lambda = 1.850$  Å, the ion temperature  $T_i \approx 16 \times 10^6$  K.

X-ray flare regions have a drawn-out filamentary structure with bright nodes that changes rapidly in time; the filament length  $\approx 100''$ , the diameter  $\leq 10-20''$ , and the electron density  $\approx 10^{10}-10^{11}$  electron/cm<sup>3</sup>. The height and structure of the x-ray-flare regions were found to be very close to those of optical flares, indicating an intimate relation between x-ray and optical flares.

#### D. S. Chernavskii. Modeling of Certain Biological Processes.

The paper is concerned with the application of methods of theoretical physics to solution of certain biological problems. There are currently several aspects of this effort. We shall examine two of them:

The deformation-energy segment is apparently characteristic for a broad class of enzymatic reactions (and not only for electron transport). To resort to simile, the enzyme works like a mechanical engine. These considerations and the related estimates are given in<sup>[4]</sup>. Many problems in this trend (such as the relation of the macromolecule's deformation energy to its polarization, etc.) still await solution.

Essentially, the quantum theory of solids is used to solve these biological problems. They are specific in that the dimensions of the objects (the macromolecules) are intermediate: they are not large enough for the body to be considered infinite, but they are too large to confine the treatment to quantum-chemical calculations (details on the properties will be found in<sup>[5]</sup>). Thus, much depends on a fortunate selection of an adequate model.

The second trend—mathematical modeling—involves the writing and investigation of kinetic-equation systems<sup>[6]</sup>. Its purpose is to describe the regulatory properties of living systems and bring out effects that are unexpected at first glance. Trigger-type models are used to investigate the development of complex organisms (tissue differentiation and formation of organs). In the higher organism, the cells of different organs perform different functions and differ greatly from one another. At the same time, they all carry identical genetic information and originate from the same fertilized ovum. The process of development unfolds in highly coordinated fashion; each organ is formed at the necessary moment and at the proper place.

The question arises: can this process advance "by itself," governed by the regulatory properties of the proteins, or is a special development-correcting organ necessary? Investigation of a number of trigger models has shown that spontaneous development without a special correcting organ is quite possible and even favored. (In<sup>[7]</sup>, the problem was discussed on the basis of abstract models, while the scheme of Jacob and Monod was used as a basis in<sup>[8]</sup>).

Models of self-oscillatory processes describe periodic variations that are quite commonly encountered in biological systems (concerning oscillations in glycolysis, see<sup>[9]</sup>, in photosynthesis<sup>[10]</sup>; the life cycle of the cell can also be regarded conventionally as a self-

oscillatory process). Self-oscillatory models have practical application, since they make it possible to determine the optimum phase for external interference.

When there is a set of "oscillators" with different phases, it is first necessary to synchronize the system. An example of successful use of this method to treat leukemia was described in<sup>[11]</sup>.

The process of microoscillator synchronization requires further study, both experimental and theoretical (certain theoretical problems of synchronia are set forth in<sup>[12]</sup>).

<sup>1</sup>D. de Vault and B. Chance, *Biophys. J.* **6**, 825 (1966).

<sup>2</sup>L. N. Grigorov and D. S. Chernavskii, *Biofizika* **17**, 195 (1972); L. N. Grigorov, Candidate's dissertation (Moscow, 1970).

<sup>3</sup>L. A. Blyumenfel'd and A. I. Kol'tover, *Mol. biol.* **6**, 161 (1972); N. M. Chernavskaya et al., *On the Possible Role of a Tunneled Effect in the Electronic Transport*, P. N. Lebedev Phys. Institute Preprint No. 168 (1970).

<sup>4</sup>D. S. Chernavskii, et al., *Mol. biol.* **1**, 419 (1967).

<sup>5</sup>M. V. Vol'kenshtein, *Fizika fermentov (The Physics of Enzymes)*, Nauka, 1967.

<sup>6</sup>Transactions of Symposium on "Kolebatel'nye protsessy v biologicheskikh i khimicheskikh sistemakh" (Oscillatory Processes in Biological and Chemical Systems), Nauka, 1967; Yu. M. Romanovskii, N. V. Stepanova, and D. S. Chernavskii, *Chto takoe matematicheskaya biofizika (What is Mathematical Biophysics?)*, Prosveshchenie, 1971.

<sup>7</sup>N. Rashevsky, *Bull. Math. Biophys.* **3**, 93 (1941); A. M. Tühring, *Phil. Trans. Roy. Soc.* **B237**, 37 (1952).

<sup>8</sup>L. N. Grigorov, et al., *Mol. biol.* **1**, 410 (1967).

<sup>9</sup>E. E. Sel'kov, *ibid.* **2**, 252 (1968).

<sup>10</sup>N. M. Chernavskaya and D. S. Chernavskii, *Usp. Fiz. Nauk* **72**, 627 (1960) [*Sov. Phys.-Usp.* **3**, 850 (1961)].

<sup>11</sup>B. C. Lambkin, et al., *Nature* **222**, 1275 (1969).

<sup>12</sup>I. G. Minkevich and D. S. Chernavskii, *Biofizika* **14**, 564 (1969); *Tsiklicheskaya vozrastnaya sinkhronizatsiya protochnykh kul'tur mikroorganizmov (Cyclical Synchronia in Continuous-Flow Microorganism Cultures)*. Deposited Paper No. 3111-71 of July 22, 1971.