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EDE KAPUY

Albert Szent-Györgyi and the electronic structure of matter

Honoured Guests!

There have been few active workers in the natural sciences in this century able to exert a long-lasting influence on branches of science outside their own narrow specialities. Albert Szent-Györgyi was one of those few.

He was already an internationally known and recognized biochemist when, for years after receiving the Nobel Prize, he said in his famous Korányi lecture entitled "The Study of Energy Levels in Biochemistry":

> "Biochemistry is, at present, in a peculiar state. By means of our active substances we can produce the most astounding biological reactions, but we fail wherever a real explanation of molecular mechanisms is wanted. It looks as if some basic fact about life are still missing, without which any real understanding is impossible. It may be that the knowledge of common energy-levels will start a new period in biochemistry, taking science into the realm of quantum mechanics."

The essence of the lecture appeared in Nature in 1941 and owing to the high prestige and authority of that journal it attracted much attention.

At that time many experimental results requiring explanation became known. For instance, photosynthesis showed that several thousand chlorophyll molecules react as a single functional unit and collect four light quanta absorbed at different points for the reduction of one CO_2 molecule. From this it was concluded that the activated electrons move freely within the structure consisting of chlorophyll molecules. A similar conclusion was reached in connection with muscle contraction. At the splitting of ATP, energy is released at a single point, but along the muscle fibre it is transferred to a number of myosin molecules.

Szent-Györgyi supposed that the structures consisting of protein molecules behave as if they contained common, delocalized electronic orbitals in which the electrons can move easily, carrying electricity, that is energy. In other words, the proteins are, like some crystalline solid bodies, semiconductors. In the explanation of life phenomena we cannot stop at the molecular level, but have to go down to the submolecular level, where the laws of quantum mechanics apply.

The hypothesis concerning the electronic properties was a bold challenge to physicists. In spite of the war, it attracted great attention, and investigation was begun to prove the hypothesis experimentally and theoritically. Although Szent-Györgyi always stressed that he was not a physicist, that is he did not possess the technical knowledge what is indispensable for the cultivation of theoretical and experimental physics, he set forth his views so convincingly that he succeeded in drawing the attention of physicists to this problem.

The electrical resistance of the proteins was first measured by Baxter and Eley. The results seemed to prove Szent-Györgyi's hypothesis that they are semiconductors. The first theoretical studies were made by Evans and Gergely, who came to the same conclusion. Theoretical verification was difficult because there were no electronic computers at the time, and exact quantitative data, which are necessary for verification, can in this case be obtained only by a tremendous amount of calculation.

From the second half of the fifties, more and more workers began to deal with similar problems. This was largely attributable to Szent-Györgyi, who called attention again to the biological aspects of the electronic properties of the proteins in his monographs "Bioenergetics" (1957) and "Introduction to Submolecular Biology" (1960) published by the Academic Press.

The volume entitled "Horizons in Biochemistry", published also by the Academic Press in 1962, was already dedicated to him. The volume contained the papers of 28 illustrious authors reporting on the most recent results in this field.

By the beginning of the sixties, a new field of research had developed, the workers of which studied biochemistry like Szent-Györgyi, from the point of view of electronic structure. The main representatives of this trend besides Szent-Györgyi were Frenchmen (Daudel, Pullman), Englishmen (Coulson), Swedes (Löwdin), and Americans (Pauling, Kasha). At the end of the fifties, Ladik and coworkers started theoretical studies in our country along the lines of Szent-Györgyi's conception. Fortunately the saying that no one is a prophet in his own country did not prove true.

The workers in this field of research, who first called themselves quantum biochemists, then quantum biologists, have since 1968 been organizing annually the since then famous international symposia on quantum biology and quantum pharmacology at Sanibel Island, Florida. Szent-Györgyi regularly attended them until almost his death and gave several lectures on these occasions. The symposium of 1975 was dedicated to him, when 100 outstanding researchers from 20 countries celebrated him.

Rapid developments in the technique of measuring and of electronic computers has made it possible to examine his concept more closely. It has been found that electrical conduction in proteins and other organic substances is not necessarily based on the energy band mechanism, but occasionally other mechanisms, such as activated tuneling, the transport of protons and ions, solitons, charge density waves, etc. may also be responsible. Pure crystalline proteins are usually not semiconductors, but insulators, that is, their electronic energy levels are completely filled with electrons which can be put into empty free orbitals only by great energy expenditure. However, if they come into interaction with so-called electron acceptors, which extract electrons from the filled electronic energy levels, they become semiconductors. This conclusion has been proved by many experimental and theoretical studies. Szent-Györgyi took this fact as the basis of several hypotheses. A characteristic of the living state is regular cell division. According to Szent-Györgyi, the fact that the molecules become conductors due to the interaction with acceptors plays an essential role in regulation. If the interaction with the electron acceptors stops for some reason, the molecules become insulators and irregular cell proliferation occurs, which is the main feature of cancer. This is the electron theory of cancer. Although this hypothesis has been somewhat neglected since the discovery of oncogenes, nobody disputes its right of existence.

Szent-Györgyi upheld his basic idea to the end, declaring at the symposium on quantum biology and quantum pharmacology in Florida in 1977:

> "I am deeply convinced that these macromolecules are not really the actors in the drama of life. They are rather the stage in which this drama is enacted while the real actors are mobile electrons.
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> It will be your job to bring biology and quantum mechanics closer together."

In terms of physics this means that the behaviour of the molecules is determined by the electronic structure. The development has accelerated in the last decade. Fifth generation computers make more precise calculation of the constants of larger molecules possible, while after the appearance of computer graphic methods experimentation with molecules on the TV screen started.

The theoretical methods have a double advantage:

1. they help us to understand the phenomena;
2. they make it possible for us to calculate properties, which are very difficult to explore by measuring.

The research inspired by Szent-Györgyi by now has gone beyond biology. In the middle of the seventies it was found that there exist organic molecules which are not semiconductors, but as good conductors as metals. The perspectives are fantastic. It is thought probable that miniaturization of electronic devices leads to the molecular level, where the unit is a single organic molecule. These molecules can perhaps be put together to form a computer just as amino acids combine in the course of peptide synthesis. The "computer" thus formed has a much smaller capacity than the brain, but it calculates much more quickly. The aim has been set to develop a computer that can be connected "on line" with living organs.

The lesson that Hungarian researchers can learn from Szent-Györgyi's life work is that important results can be achieved only through intensive international interdisciplinary cooperation; thus biology, chemistry, physics, and computer technique must be coordinated or combined for the purposes of successful research. All the possibilities in our country should be used to this end. There should be cooperation between universities and academic institutes as well as between university departments. Another important lesson is that the "capital" gained by the results must be used to start new research, and we should not stop on reaching the first result. The third lesson to be taken seriously is that publication in an international journal of high circulation is essential to ensuring international recognition of important results.