Bioelectronics and Cancer
Albert Szent-Györgyi

Marine Biological Laboratory, Woods Hole, Mass.

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Abstract

The appearance of oxygen on our globe induced profound changes in the nature of living systems which started to differentiate and build complex structures with complex functions. Oxidation was added to fermentation and unbridled proliferation was subjected to regulation. Fermentation demanded no structure, being the result of the action of a series of single molecules. Oxidation, with its electron flow, demanded structure and electronic mobility. To produce meaningful structures and complex functions the action of the single molecules had to be integrated. The question is: how could oxygen bring about these transformations?

These changes are not limited to the distant past because in every division the cell has to revert, to some extent, to the undifferentiated, fermentative, proliferative state of its earlier anaerobic period. After having completed its division, it has to find its way back to its oxidative resting state. If this road of return is deranged the cell has to go on dividing as it does in cancer. By elucidating the details of these processes we can hope to be able to control them. We can control only what we understand (Bernal).

That oxygen can induce profound changes in cell life can be demonstrated even in the acute experiment. L. Pasteur showed that fermentation is inhibited by the admission of oxygen ("Pasteur Reaction"), and H. G. Crabtree demonstrated the opposite effect. The intimate relation of cancer and oxygen was made evident by H. Goldblatt and G. Cameron who provoked malignant transformation in their tissue culture by periodically limiting their oxygen supply.

O. Warburg attributed the changes, induced by O₂, to a wealth of energy it produced. Undoubtedly, without a new and rich source of energy these changes could not have occurred. Energy made them possible, but energy offers no mechanism. The chemical mechanism underlying these transformations will be the main topic of this paper and it will be shown that charge transfer is one of the central biological reactions. A biologist trying to understand life without electronic mobility is comparable to a Martian trying to understand our civilization without knowing about electricity.

This paper will chiefly be concerned with principles. The chemical methods employed will be discussed in a subsequent paper by Dr. L. Egyud.
Introduction

Biology is dominated by the molecular concept, and the protein molecules are recognized as the main bearers of life. But life is not brought about by the single molecules; it is the result of their integrated function, as a symphony is the product of the concerted action of many separate instruments. This shifts the emphasis from the units to their integration.

To connect the macromolecules to a harmonious whole, smaller and more mobile particles are needed. The smallest units of biological systems are the electrons. To be mobile they need conductors. More than 30 years ago [41] I proposed with my young pupil and friend, K. Laki [28] that proteins may be semiconductors. Our proposition was rejected and at the state of our knowledge, at that time, I was unable to defend it. The knowledge accumulated since allows to rescind the problem.

Proteins are, essentially, chains of peptide links, held together, partly, by hydrogen bonds, that is, by H atoms belonging, simultaneously, to two different peptide links. According to our present knowledge, in such a system the energy levels of the single units can unite to continuous energy bands (M. G. Evans, J. Gergely, J. Ladik and A. Pullman), as the sidewalks before single houses confluence to a street. Whether the electrons, within such a band, are mobile or not, depends on their number. According to the exclusion principle, only two electrons (of opposite spin) can have the same energy in such a system. So, if every unit contributed two electrons to the band, then every allowed place is filled, and the situation becomes similar to that in a box completely filled with marbles: there is no mobility. To create mobility we have to take out some of the pieces.

Many of the dielectrics which we use as electric insulators have such continuous energy bands which, being filled, have their electrons immobilized. To make such systems conductant, we would have to desaturate them, take electrons out of them. The simplest way to do this is to "excite" electrons from the highest filled band to the next higher empty one. If this latter band is so close to the former that even the energy of heat agitation is sufficient for this excitation, then the substance is a "semi-conductor".

L. Brillouin pointed out that proteins could be made conductant by "acceptor impurities", that is, substances which can take up