comments. If it is true that contradictory conclusions have been drawn from the results of experiments concerned with the effects of electric shock, one might wonder why enough systematic studies have not been made to relate this variability to experimental parameters such as species, shock intensity, and previous history of the animal. Such a program has been largely neglected in favor of short, exciting theoretical studies which may be reinforcing to the experimenter but which seem to have added little to the store of communal knowledge about one of the great problems in contemporary behavioral science, that of aversive control.

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Quantum Mechanics and Biology

The molecular basis of energy transduction in biological systems has been excellently reviewed by Green and Hatefi (*1*). However, quantum mechanical contributions make it possible to relate these energy changes to more fundamental submolecular processes. Indeed, the application of quantum theory offers the most promising approach to as yet unanswered problems. This viewpoint has been eloquently expressed by Szent-Györgyi (*2*).

Green and Hatefi (*1*) quite correctly conclude that electron flow in transport systems is not a result of simple molecular collision. Quantum mechanics is more specific. The rapidity of electron flow stems from the redistribution—a practically instantaneous process—of molecular orbital energies. Energy transduction based on such redistributions need not contemplate any appreciable linear movement of the electrons. The quantum-mechanically derived π-electron system fully satisfies the requirements for a catalytically functioning mechanism. This is particularly true for the unsaturated conjugated structures in which the electrons are coupled resonators. This completely allows for both instantaneous and distant site transfer of energy. The known facts concerning biologically active compounds (purines and pyrimidines) are in accord with these concepts. They are predominantly unsaturated, conjugated structures.

As pointed out by Green and Hatefi (*1*), the mitochondrial lipids are characterized by fatty acid residues with a high degree of unsaturation. This unsaturation is quite consistent with the ability of lipids to provide a high degree of stereospecificity combined with participation in the π-electron system of associated proteins. Thus, the role of lipid in electron transport instead of being "far from clear," as indicated by these authors, is, on the contrary, a very distinct one when based on quantum-mechanical considerations.

The respiratory coenzymes have been shown by Green and Hatefi (*1*) to play a predominant role in electron transport. The redox mechanism of these coenzymes has also been specifically related to the molecular orbital energies of their π electrons. Employing LCAO (linear combination of atomic orbitals) calculations, Pullman and Pullman (*3*) have obtained resonance integral coefficients for the enzymes which explain their redox function. The coefficient for the homo (highest occupied molecular orbital) of reduced flavin mononucleotide ($FMNH_2$) turns out to be negative. Since this is quantum-mechanically indicative of antibonding character, the finding is in remarkable accord with the known fact that this compound is autoxidizable. While similar calculations have not as yet been reported for the cytochrome components of the transport system, evidence is not lacking on which to predict that some will be found with negative homo coefficients. Dixon *et al.* (*4*) have reported on an irreversible autoxidation of cytochrome *c* reductase. Armstrong *et al.* (*5*) have reported a similar autoxidation of cytochrome b_2 lactate dehydrogenase. Both autoxidations involve flavin dissociation.

The findings reported above are not without potential application to medical problems. Dehydrogenase deficiencies have been implicated in genetically transmitted and sex-linked transmitted diseases (see *6*). Theoretical quantum mechanical calculations involving π electrons have also been applied to the study of carcinogenesis (see *7*). The ability to theoretically predetermine those particular components of an enzyme system which may be the ultimate source of a distorted metabolism offers exciting frontiers for the biological scientist. A great deal of ground work has been done by the physicist, and if the quantum guideposts are read correctly, this ability could be within the realm of realization.

No doubt, as Szent-Györgyi (*2*) has emphasized, the mastering of a new discipline like quantum mechanics is a Herculean task for the biologist, but it is a road that must be traveled. Nor is it necessarily a one-way street. It is of interest to note the increasing application of biological phenomena to the solution of electronic and engineering problems. Simulation of neurons, memory tracks, and retinas has become the basis of the entirely new field of bionics (see *8*). It is not unlikely that new and revolutionary concepts for physics will have their origins in biology. Knowledge gained in the study of photosynthetic and bioluminescent systems is today providing answers to questions concerned with the storage of solar energy. Such answers may, in the future, provide the means of sustaining life in outer space. All of which points up the basic unity and universality of the various disciplines of science.

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