CHARGE DISTRIBUTION

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The papers of this colloquium focus upon important characteristics of energy coupling:

(a) *Molecular mechanism of transmembrane charge separation.*

(b) *The relationship between membrane potentials and transport functions.*

(c) *The application of these principles to a physiological system.*

Considering the first topic, the pathway by which light energy is coupled to chemical reactions is the primary topic of photosynthesis and vision. In photosynthesis the coupling is expressed by a charge separation in the reaction center—a highly localized phenomenon which spreads via appropriate electron carriers through the membrane as a transmembrane potential. A hydrogen ion gradient is also established if one of the electron carriers is asymmetrically located and becomes protonated in the process of electron transfer (1–3).

Bacterial rhodopsin is also capable of establishing a transmembrane hydrogen ion gradient but does so in a way that appears vastly different from that of the photosynthetic system—photolysis results in the formation of a variety of intermediates which ultimately lead to the rupture of the retinylidine-lysine bond and the release of a hydrogen ion; apparently no electron carriers are involved. Depending upon the location of the bacterial rhodopsin molecule with respect to a membrane, a hydrogen ion may be released asymmetrically and a corresponding gradient formed (4).

Oxygen activated electron transport separates charge in a completely different way, namely, by protonation of the oxygen molecule reduced by electron transfer from an asymmetrically located heme protein.

The kinetic capability and efficiency of the respiratory and photosynthetic systems seems to outstrip that of the others largely because of the rapid chemical reactions involved. In addition, it is possible that the ion and potential gradients obtainable are higher due to the irreversible nature of the reactions.

Protons in addition to those directly linked to chemical reactions may also be involved and are in the general category of "Membrane Bohr effects" (2). These protons may arise directly from structural changes of the proteins involved in the primary events or from secondary changes in other proteins or membrane components linked to the primary energizing source. While the model for the "membrane Bohr effect" is soundly based upon the properties of hemoglobin itself, the identification of possible sources of Bohr protons in membrane systems is largely incomplete and much further work is needed in this study area.

A topic largely unexplored from the experimental standpoint and yet an essential key feature of a theory of energy coupling reactions is the control of electron flow through the respiratory chain. The hypothesis of respiratory control by concentrations of chemical intermediates fits well into the structure and function of enzyme and enzyme systems as we know them, with a particular example being glycolysis and the particular enzyme being phosphokinase. Similarly a variety of compounds are known to alter the electron flow rate through the respiratory chain, acting at any one or all of the three sites. The concept that a generalized membrane potential may accomplish the same effect and be responsible for the control of electron flow at the three sites of the respiratory chain and for the associated crossover of response crossover phenomena requires deep and thoughtful consideration and directed experimentation. A number of problems are involved and the first one to be considered is theoretical. The fraction of the membrane potential that would appear the distance through which the electron transfer occurs may be small. It would be maximal on the basis of electron tunneling over a distance of 30 Å at most and 5 or 10 Å at least. For outersphere electron transfer the distance would be several angstroms. Thus the fraction of the total membrane potential (assuming a uniform gradient) would be significantly under 100 mV and might be as low as 10 mV. The effect of such a potential upon the electron transfer between a pair of cytochromes, each highly charged due to their own protein structures, might be very small. The second possibility that the membrane potential might control lateral diffusion of electron carriers through the membrane under cases where the diffusion itself is rate-limiting is an interesting possibility but would require evidence that the membrane potential changes the microviscosity of the lipid phases of the membrane. Other possibilities need to be developed and considered.

In summary, a number of interesting questions are appropriate to this discussion, a number of experiments remain to be done, and some basic theoretical points of the interactions of potentials or charges with electron carriers remain to be considered from the experimental and theoretical standpoint.

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