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CONTENTS

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THE BIOPHYSICAL BASIS OF BEHAVIOR

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There are certain basic characteristics of living organisms that differentiate them from other complex but non-living entities. These characteristics appear to arise from the "state of organization" of the organism, i.e., they are associated with the ultimate macro-molecular structure of the organism. Some of these basic functions appear to furnish the sub-strata for all biological activities, even including behavior. However, the majority of behavioral studies have been directed towards much more highly developed functions such as learning, and little attention has been given to these basic processes which underlie all behavior. During the past decade some advances in our knowledge of these basic characteristics have been made through the application of newer research tools and concepts. It is the thesis of this paper that the behavioral sciences would profit from a consideration of these factors.

Major advances have been made in the study of three of these primitive functions; the ability of self replication, the ability of self repair and biological cycles. The first property listed has been the subject of much work with determination of the DNA-RNA coding mechanisms for transfer of genetic information and much speculation on this furnishing the "key to the secrets of life." However, in any given individual organism loss of this mechanism does not result in immediate death but merely loss of the ability to transmit genetic information to second generation units (1). It is felt therefore that this is a second order phenomenon associated with life and that the original "living material" did not, in all probability, possess this sophisticated mechanism. The second and third basic properties listed, however, may well have appeared concurrent with the transition from non-living to living material. Both of these functions are preformed with a high degree of precision; self repair processes proceeding in an orderly fashion to maintain the integrity of the organism (2) and biological cycles demonstrating an astonishingly high degree of precise timing (3). Classical biology would have been content to describe and catalogue these activities; modern biology, on the other hand, has been increasingly concerned with the mechanisms and control systems operating to produce the observed functions. Electron microscopy, bioelectronics and bionics (application of control system theory and cybernetics to biological problems) have been powerful tools in this work. This new biological philosophy has resulted in one

fundamental conceptual change, the cell and protoplasm is no longer considered an amorphous fluid system withal chemical processes proceeding in solution, but rather a highly structured solid state system with many important processes occurring through electron transfer mechanisms (4). Over the past six years our laboratory has been involved in a study, originally begun on the problem of self repair mechanisms, which has led us to postulate the existence of such an electron transfer mechanism in the neural (or equivalent) structures of all animals. The characteristics of the system are such that it increases in complexity of organization as the evolutionary sequence results in organisms of increasing complexity. This mechanism has been found to function as a control system for self repair and biocyclic phenomena. It has been possible to determine the presence of this system in the human and to relate it to certain basic behavioral processes. I would like to present a broad over-view of this system and indicate some of its features. (It is not possible to present details of any of the experimental data and the interested reader is referred to the appropriate bibliographic listing.) Attention will be directed towards the behavioral aspects of the system although some evidence has been obtained of its functioning in self repair processes (5,6).

Representatives of all phyla examined so far from protozoa to man have demonstrated a measurable steady state, or d.c., electrical field pattern on their intact surfaces which was related to the over all organizational pattern of the organism. In metazoans, the development of a central nervous system was accompanied by complexities in the field pattern which mirrored the anatomical complexities of the central nervous system (7). It has been determined that this electrical field is quite likely produced by the continuous flow of a very small electrical current within the neural tissue and that this has many characteristics of a semiconduction mechanism (8). All neurons are electrically polarized in a specific fashion dependent upon the direction of the data transmission; that is, an axono-dendritic polarization with the dendritic or input side positive with respect to the axonic or output side. This polarization is associated with a constant electrical current flow axially, in some semiconducting element of the neurone (9). The anatomical arrangement of the individual neurons in the central nervous system results in a complex electrical circuit which in turn produce the electrical field pattern representative of the organization of the individual. Information may be impressed upon this current in an analog fashion, with increase or decrease of the steady current or with rhythmic fluctuation patterns in the current and polarity magnitudes. This system must be clearly differentiated from the action potential or nerve impulse system which is a digital type of data transmission system. The action potential

is basically a traveling wave of membrane depolarization and does not involve the transfer of electrical energy in an axial fashion. While the action potential system is capable of carrying much greater volumes of information in much shorter time periods than the semiconducting system, it is functionally dependent upon the latter system being in a “normal” state. In other words, the ability of a neurone to generate and transmit nerve impulses can be modulated or altered by changing the magnitude or direction of the semiconducting current (10). Since much of what we consider to be behavior is based upon the nerve impulses, then this behavior obviously can be influenced in subtle fashion by changes in the semiconduction system. If such behavioral alterations were viewed only from the level of the action potential, then there would be inexplicable changes in the type and rate of nerve impulse activity and the basic causative factor would remain unsuspected.

This can best be illustrated by considering in detail the functioning of the d.c. system in the vertebrate brain. In all animals demonstrating cephalization and a hierarchial organization of the central nervous system, a definite vector of electrical current can be demonstrated across the head. This vector is midline, unpaired and is characterized by a electrical polarity and current flow in an occipito-frontal direction, with the frontal region normally negative in respect to the occiput. We have tentatively located the site of this current in the brain stem region and have determined that it is intimately related to the level of general consciousness. Anesthesia (regardless of the nature of the agent used), sleep and hypnosis(11) are all accompanied by a decrease in the magnitude of this electrical vector, the degree of Joss of consciousness being directly related to the amplitude of potential drop. It was postulated that the basic action of anesthetic agents was to block or interfere with the semiconduction mechanism thereby producing a decrease in the current flow. One should be able therefore to produce anesthesia by simulating this action using properly oriented electric current alone. We found that the passage of small amounts of direct current (20 to 80μA in amphibia, 15mA in dogs) oriented in reversed polarity (frontal positive) and applied to the intact skin surface, resulted in a change in the EEG from an awake medium-high frequency pattern to a low frequency delta, sleep pattern. This was accompanied by a corresponding decrease in irritability, although since animals were utilized we cannot be certain that a true loss of consciousness occurred. However, the phenomenon does appear to be intimately related to the state of consciousness in that the converse experiment may be performed. An animal given an overdose of a chemical anesthetic agent will show: a drop in the occipito-frontal d.c. potential to zero, a low amplitude delta type EEG and depression of the respiratory center with

irregularity or loss of respiratory movements. Application of similar amounts of direct current in a normal polarity along the fronto-occipital axis then results in the appearance of a medium frequency EEG and the reappearance of rhythmic respiratory movements. It would appear therefore that one can produce gross changes in the level of consciousness, in either direction by manipulating this fronto-occipital current vector. Since this current flow was considered to be semiconducting in nature, solid state theory predicted a high order of interaction between it and a magnetic field imposed at 90° to the current axis. A field of sufficient strength should deviate enough of the electrical charge carriers to produce a measurable drop in the current delivered along the original vector. This should, if of large enough magnitude, result in a decrease in the level of consciousness. Experimentally in amphibians we have found that the application of a steady state 3500 gauss magnetic field results in a 50% drop in the d.c. vector magnitude, a shift of EEG pattern from fast alpha to slow delta waves, and behavior resembling sleep (12). While the strength of the magnetic field used in these experiments was many times that of the natural geomagnetic field, the behavioral changes produced were major changes in the level of consciousness. Could one not postulate that the smaller magnitude changes in the geomagnetic field were productive of more subtle alterations in behavior patterns? Biological cycles might be a case in point. The phenomenon appears to be universal in all living organisms and is characterized by rhythmic variations in the level of general activity with two major periodicities — circadian (about 24 hours) and lunar (about 28 days). The natural geomagnetic field has fluctuations in intensity with precisely the same periodicities and it has been postulated that the timing of biological cycles is exogenous to the organism being produced by some linkage with these geophysical periodicities (13). Brown has shown that the superposition of fields as low as 1 gauss in intensity will either completely alter the pattern of circadian activity or result in completely randomized behavior in vertebrates, depending upon the orientation of the field lines(14). Man, not demonstrating such clear cyclic behavior patterns, is not readily adaptable to such a study, however, correlations of equal subtlety have been made using natural changes in the geomagnetic field. In addition to the rhythmic 24 hour and 28 day fluctuations, the natural geomagnetic field is occasionally subjected to sudden major disturbances in intensity called magnetic storms. These are, in part, produced by the influx of charged particles into the magnetosphere from solar flares. They are completely unrelated to weather type storms and occur on bright sunny days or clear nights. We have recently reported (15) that statistically significant linear correlations can be made between the number of days of magnetic storms per month and the number of admissions to psychiatric hospitals during the same

period. The conclusions drawn are that a segment of the human population (most likely schizophrenic) is much more sensitive to changes in the magnetic environment due to unknown abnormalities in their neural semiconduction system. It would not appear too improbable that somewhat more subtle, but no less real, changes would take place in the normal human population under the same circumstances. One might venture to predict that even in the "normal" population major changes in magnetic environment would produce major behavioral changes (16).

While the physiological aspects of life are dependent upon the recognized environmental factors such as temperature, gas pressure, etc., it would appear that the basic psychological aspects of life are dependent upon complex interrelationships between environmental force fields and the electronic control system of the neural macro-molecular organization. Man, perhaps, is more a creature of his environment than has been previously guessed. These few examples may indicate that the concept of certain basic all pervading biological control systems is worthy of consideration by the behavioral scientist.

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