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LETTER

A THEORY OF THE INTERACTION BETWEEN DC AND ELF ELECTROMAGNETIC FIELDS AND LIVING ORGANISMS

A recent report by the International Radiation Protection Association of the World Health Organization dealing with possible health effects of Extra Low Frequency (ELF) fields states, "At present, it is impossible to furnish any theory to predict the effects of exposure to these fields (1)." It is the opinion of this writer that an adequate data base exists from which it is possible to construct a testable theory of action of ELF fields on living organisms that has predictive value. The aim of this letter is to describe the theory, its derivation from known data, and its predictive value.

Classical concepts of the possible interaction between electromagnetic (EM) fields and living organisms are of little value in the ELF region, since the wave lengths preclude any resonance phenomena and the energy delivered is far less than kT of the living system. I wish, therefore, to propose a novel concept, albeit one with biological antecedents: a specific sensing mechanism or mechanisms evolutionarily developed to derive information of biological value from the normal magnetic field of the Earth.

The normal electromagnetic spectrum of the Earth (prior to the development of electromagnetic energy for power and communication facilities), was the result of electromagnetic radiation from the sun interacting with the ionosphere and the Earth's intrinsic magnetic field. This resulted in an EM spectrum consisting mainly of three parts: the DC magnetic field and associated micropulsation frequencies ranging from less than 1 Hz to approximately 100 Hz with major power density centered about 10 Hz (2); a band

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of frequencies centered in the 10 kHz region due to lightning strikes; and the narrow zone of visible light with its associated non-visible ultraviolet and infrared spectra derived from sunlight. Of these parameters, the magnetic field with its associated ELF spectrum and visible light may be considered quasi-static, in the sense that other than diurnal variations in intensity they are constant in occurrence. The lightning produced EM spectrum as well as the DC electric field at any point on the surface of the Earth are highly variable in intensity and occurrence and of no value as an environmental parameter from which information may be derived. As far as can be determined, this normal EM spectrum was constant throughout the period of the origin, development and evolution of life. It is self evident that during this period of time the vast majority of animal life forms developed specific sensing mechanisms of great sophistication to detect sunlight reflected off of physical objects as an imaging system providing information on the environment. It is worth noting that mechanisms involved in the detection, imaging and processing of the information contained in this portion of the EM spectrum are still incompletely understood. It is now also well known that many marine animals have developed specific sense organs for the detection of electrical fields (3), which provide information on the presence of other animals in their immediate environment and may, in some cases, provide direction sensing properties by detecting the fields produced by the movement of conducting sea water across magnetic field lines (4). It is therefore considered well within the realm of probability for living organisms to have developed specific sensing mechanisms, for the detection of the other quasi-static component of the normal EM spectrum, the DC magnetic field and its associated ELF components.

The information derived from such DC-ELF magnetic sensing organs would consist of a direction sense derived from the DC magnetic field vectors, and a timing signal, (zeitgeber) derived from the diurnal variation in both the DC and ELF components. At present several such candidate magnetic field sensing

organs have been described in a wide variety of living systems including humans.

The use of the Earth's magnetic field as a direction indicator was first firmly established by Keeton (5), and since then similar abilities have been described in other birds (6), mammals (7), and man (8). The biological substrate that provided for the detection and vector sensing of magnetic fields averaging 0.5 gauss was unknown until the discovery of biological magnetite by Blakemore in 1975 (9). While this initial description was in certain species of bacteria (where the magnetite provided an adaptive advantage to the bacteria by sensing the dip angle of the field), descriptions of similar deposits in homing pigeons (10), insects (11), fish (12), and humans (13), have been recorded. Recently, Frankel (14) has conclusively shown that the magnetic sensing ability of certain bacteria is due to their magnetite containing "magnetosome," and that the interaction with the Earth's field is via the linearly linked magnetite crystals exerting adequate torque to orient the bacterium along the field lines. This mechanism is inadequate to explain the presumptive orienting action of the magnetite crystals in larger organisms. However, in most instances the magnetite deposits in higher organisms are located in close association with elements of the central nervous system. In the most complete study to date, Walker (15) described magnetite deposits in the innervated dermethmoid sinus of the Yellowfin Tuna, as single domain crystals, partially free to rotate, capable of resolving direction of the magnetic field to a few seconds of arc, and with a sensitivity to differences in the field intensity of as small as 1 nanotesla. While the mechanism whereby this information is transferred to the neural elements in association with the magnetite has yet to be described (Walker suggests neural mechano-receptors), it appears quite feasible to postulate that the complex constitutes a sense organ for the DC components of the Earth's magnetic field. Should Walker's observation of the rotational freedom of the crystals be confirmed, it appears similarly possible to postulate some sensitivity to the ELF components of the field as well.

Brown was the first to postulate that the Earth's magnetic field acted as a zeitgeber for biological cycles. Most of his work was phenomonological in nature, describing alterations in the cycles produced by exposure to abnormally-oriented, Earth-strength, magnetic fields (16), and, lacking appropriate mechanisms or target organs, it was largely ignored. Within the past few years the pineal "gland" has been confirmed as the primary organ controlling cyclic activity via its secretion of a large number of specific hormone-like substances (i.e. melatonin, serotonin) that regulate the activity of the central nervous system and glands of internal secretion (17). It is of interest to note that the pineal, presently imbedded deep in the brain, was originally a "third eye" derived from neuroectroderm and therefore part of the central nervous system. It was not an image-forming structure but one that functioned to sense the intensity of natural light and accordingly adjusted the external coloration of the animal. In a few presently existing primitive organisms (lamprey eel, some lizards) the pineal third eye persists and serves the same function. Within the past few years the pineal has been shown to be very sensitive to magnetic fields, altering secretory levels (18) or electrical activity of pineal cells (19) when exposed to Earth strength, or less, fields with abnormal orientation. While the exact linkage mechanism between the field and the pineal has yet to be determined, this organ has been established as capable of sensing and responding to the diurnal fluctuation in the Earth's DC magnetic field. The possibility of a pineal sensitivity to ELF magnetic fields has not been directly investigated, however, Wever (20) has shown that the introduction of a 10 Hz signal restored synchronicity to multiple aspects of the human biocycle under null field conditions. While this data does not directly implicate the pineal as the target organ it now appears feasible to postulate this linkage.

Thus, it is evident that living organisms possess at least two specific "sense organs" with adequate sensitivity to the Earth's normal magnetic field components to derive information of both a directional and timing nature

therefrom. In the case of the bacterial "magnetosome" the interaction with the Earth's DC field is explicable by classical mechanisms. In higher organisms, while the interaction with the magnetite crystals is undoubtedly similar, the directional information must be transferred to neural elements and thence to the central nervous system itself, as demonstrated by magnetically produced behavioral responses (21). While this linkage is presently not understood, the evolutionary conservation of the "magnetosome" from bacteria to man indicates that it is of some adaptive advantage. The mechanism by which the cells of the pineal respond to the same low-strength magnetic field is presently unidentified. Candidates that should be considered include the well documented calcium flux changes in other neural cells demonstrated by Adey (22), the more recent ionic gyro-frequency theories of Liboff (23) and Blackman (24), the other resonance phenomena described by Jafary-Asl (25) and the possibility of innate magnetic sensitivity of biological macromolecules such as has been shown for collagen (26). At this point in time the possibility that the magnetosome and the pineal may have neural interconnections and may work in synchrony has not been evaluated.

The information derived from the Earth's natural magnetic field by these mechanisms is of a very basic nature, and is not directly referred to the conscious mind. However, the resultant alterations in function involve multiple organ systems. The pineal for example, regulates the activity of the cerebral neurones, the pituitary, thyroid and adrenal glands and the reproductive organs. The manifestations of biological cyclic behavior are mediated via tidal changes in all of these parameters induced by similar alterations in the output of pineal neurohumoral agents. Since the basic zeitgeber for the tidal rhythm of pineal function is the Earth's magnetic field, this then becomes a non-trivial aspect of the biological environment. The introduction of abnormal fields, both DC and ELF is postulated to result in abnormal function of the magnetic organs and resultant abnormal functioning

of the secondary target organs and pathological perturbations in general physiological functioning.

This theory has predictive value and lends itself to experimental verification. In general, whatever functional aspect is investigated, the sensitivity to magnetic fields should be several orders of magnitude greater than that to electric fields. ELF magnetic fields in the frequency range just outside of the normal, i.e. from 30 to 100 Hz, should be more effective in producing perturbations of the system than higher frequencies. However, envelope detection of ELF modulated high frequency fields remains a possibility. If the system's sensitivity is as presently described, then frequency becomes a more important parameter in any experiment than field strength. Since the Earth's normal magnetic field parameters are postulated to be non-trivial by this theory, then they must be considered as the operational substrate for any experiment and in this light, similar experiments may yield differing results when performed at different locations. Obviously, exposure to abnormal fields should result in diminution of orienting ability and disturbances in cyclic processes. These basic disturbances will have overt expression in pathology in many different organ systems ranging from disturbances in reproductive function to alterations in the operation of brain mechanisms. Since the central nervous system is intimately involved in the detection and resultant functional expression of these field parameters, abnormal field exposures may result in the production of disturbances ranging on the psychiatric. Should the details of this theory be verified and extended the bioeffects of the ubiquitous abnormal ELF fields in our environment will be better understood and realistic estimates of the biohazards of this technology can be made.

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