Relationship of Geomagnetic Environment to Human Biology

THE MAGNETIC FIELD *of the earth is an important physiologic factor for living organisms. It appears that behavioral changes of an undesirable nature, either quite evident or subtle, may result from exposure to environments having lower or higher field strengths than "normal" or those having either no fluctuation or cyclic fluctuation at frequencies other than those to which we are adjusted. Magnetic factors beyond eight earth radii distance must be investigated thoroughly before exposing human beings to such environments.*

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ALL LIFE on this planet is the result of an evolutionary process extending over many millions of years. In the course of this process the anatomic and physiologic characteristics of the living tissue have been shaped and molded by the environmental factors existing on the planetary surface. Today we exist in equilibrium with very narrow ranges of temperature, pressure, radiation intensity, and atmospheric gas composition. Now that the possibility has arisen for man to transport himself out of this, his embryonic environment, attention is being directed toward finding ways for him to duplicate and carry with him those physiologically important environmental factors that may be lacking or altered in the exotic environments to be encountered and that are absolutely necessary for minimum survival.

There is, however, another factor, perhaps more subtle than those listed but nevertheless all-pervading and one that has been present since the onset of the life processes on this planet, and that is the magnetic environment. The magnetic field of the earth has a particular configuration, intensity, and mode of behavior that are peculiar to it. In man's future ventures into interplanetary space or landings on other planets, he will be exposed to entirely different magnetic environments than the one which has been his constant companion through his evolutionary development.

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To characterize briefly the earth's fields: It has the well-known dipole configuration; is quite weak, averaging about 0.5 gauss; and is subject to certain fluctuations. Of the latter, there are rhythmic circadian (about 24 hours) variations and longer-period (approximately 1 lunar month) variations. In addition, there are random fluctuations, occasionally of rather high intensity, that are known as magnetic storms and are apparently related in part to solar phenomena. The magnetic field in interplanetary space (beyond eight earth radii) is uniform and much lower in magnitude than that of the earth. While it is subjected to storm fluctuations of solar origin, these may have larger magnitudes and more rapid rates of change compared to magnetic storms on earth. In addition, the circadian and long-period rhythmic fluctuations are absent in this area. Little is known about the magnetic fields of the other planets in the solar system. However, certain stars are known to have very intense fields of their own.

Therefore one may hypothesize that man in his lunar and interplanetary journeys will be exposed to magnetic environments generally much lower and occasionally much greater in magnitude than those existing here. While certain of them may exhibit rhythmic variations, these will have frequencies different from those of the earth's field. In addition, the suggestion has been made that space vehicle crews could be protected against certain ionizing radiation by the generation of strong magnetic fields about the vehicle. This procedure would expose the occupants to a field density considerably higher than the earth's for long periods of time.

Physiologic effects of changes in magnetic field strength

To determine whether any of these variations would be of physiologic significance we must know the effects of exposure of organisms to increased and decreased field strengths as well as what effects the naturally occurring earth's fields have on the normal organism. To interpret these data in a rational fashion it is further necessary to know the physiologic mechanisms that are involved in causing the effects.

Some work has already been done on the physiologic effects of exposure of organisms to high-strength fields. Most of these studies have involved simple living systems or exposure of larger organisms in a random orientation to the field direction. The majority of the reports have noted growth disturbances of some type.[1-4] The exposure of fruit flies to very intense fields resulted in death.[5] Speculation on the possible mechanism of these actions of high-strength fields is generally based on the differential action of a magnetic field on various molecules, depending on whether they are para- or diamagnetic. One objection to this thesis is that the thermal agitation of the molecules in the cellular material would have a greater range than any separation or displacement produced by the differential action of the field. This objection no longer appears valid in view of the findings of the electron microscopists. Protoplasm is no longer regarded as a disorganized soup with random molecular structure but as a well-ordered complex with important functions being performed by structures with very tight molecular tolerances. It is not too difficult, therefore, to conceive of a differential effect producing a spatial separation in a multimolecular system, the functioning of which is a factor of spatial arrangements. The differential effects on dia- and paramagnetic molecules should be greater with very nonuniform fields or fields having

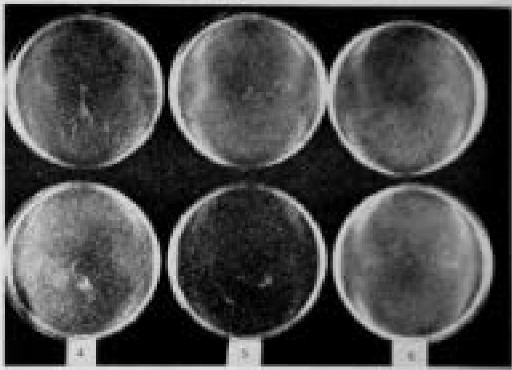

FIGURE 1. Culture dishes of Staph. aureus after seventy-two hour incubation. The top row of cultures were exposed to a reduced magnetic environment. The bottom row of cultures were grown simultaneously under similar conditions of light, temperature, and humidity but with normal-strength magnetic field. The numbers refer to dilution factors from the original broth culture.

steep gradients. That this is precisely the observation that has been made appears to lend support to the initial hypothesis.

We find that little experimentation has been done on the effects of fields lower than the earth's normal. Tchijevsky,[6] who was primarily interested in air ionization and cosmic radiation, probably produced in his experimental procedure a decrease in the natural magnetic field. He reported a rather rapid onset of inanition and death in rats under these conditions. In our laboratory we became interested in this problem, and using magnetic shielding materials we have exposed cultures of Staphylococcus aureus to a reduced magnetic environment. This was actually a "resistive" reduction, and the remaining field inside the enclosure was both detectable and varied with the same frequency as did the natural field. However, both average field strength and magnitude of fluctuation were reduced by a factor of 10. The cultures were introduced four hours after plating from a previous broth culture. The organisms grew well at room temperature, and the exposure time of seventy-two hours covered the major exponential growth period.

The experimental cultures in all dilutions showed a 15-fold reduction in number of colonies as well as some reduction in size of colonies as compared to the control cultures (Fig. 1). These were actually preliminary experiments, and while they were performed on Staph. aureus several times with uniform results, no other organisms have been tested. It is manifestly impossible to explain these results on any differential, para- or diamagnetic action. However, a possible clue to the mechanism of action may be in a consideration of the physiologic significance of the earth's natural magnetic field.

It has long been noted that certain cyclic phenomena in living organisms have periods closely approximating the major geophysical cycles (circadian and lunar month). These biologic cycles have been shown to continue in regular rhythmic fashion even in the total absence of environmental cues of light, temperature, barometric pressure, and so forth. How can one explain the persistence of a circadian rhythm of activity in an organism that is exposed to absolutely constant environmental factors? Two major hypotheses have been advanced. One suggests that the organism possesses an internal autonomous clock or oscillator that regulates the cyclic behavior.[7] However, despite extensive work, the exact nature of this master clock remains unknown. The alternative hypothesis advanced is that the biologic rhythms are dependent for their timing on subtle geophysical rhythms.[8] Some evidence has been obtained indicating that the magnetic field with its rhythmic fluctuations is the geophysical parameter of significance. Marked disturbances in cyclic behavior of organisms have been produced by exposure to magnetic fields as low as a few gauss.[9–11] The human organism also exhibits biologic cyclic behavior, demonstrating a time relationship to the variations in the magnetic field.[12] If cyclic behavior can be viewed as a rhythmic variation in the level of irritability of the organism, would the naturally occurring magnetic storms produce any demonstrable variation in irritability level?

Previous work indicated a statistical relationship between magnetic storms and suicides in the human population.[13] In a preliminary statistical study of the relationship between the average daily magnetic field variations and the incidence of hospital admissions for neuropsychiatric disturbances, we obtained a coefficient of correlation of + 0.26.[14] The probability of obtaining this result by chance alone is less than 1 in 10,000. At present, this work is continuing with much larger volumes of data and automatic processing equipment. It therefore appears that the variations in the earth's magnetic field may be in part responsible for driving the cyclic activity of living organisms. Again, the strength of this field is far too low to permit any serious consideration of dia- or paramagnetic effects in this relationship.

There is, however another class of phenomena worth consideration. The galvanomagnetic effects are the result of interaction between the flow of direct current electricity and steady or pulsating magnetic fields. These effects are normally quite small in ordinary electrical equipment and can be disregarded. However, for certain reasons they are increased over a million times in magnitude in semiconductors and other similar solid-state electronic systems.[15] Work in the author's laboratory over the past few years has indicated that such an electronic phenomenon is an important characteristic of the nervous system.[16] This solid-state electronic current appears to be a prime factor in determining the level of irritability of the neurones, as judged by their threshold and action potential activity. Further, in all the vertebrates examined, including man, it appeared that some midline structure or structures in the brain, possibly brain stem reticular formation, demonstrated this activity to a high degree and that the magnitude and perhaps polarity of this electronic current flow directly determined the level of consciousness. Considering that in the vertebrates activity of the brain determines the over-all behavior of the organism, it is not difficult to conceive of a galvanomagnetic effect between the fluctuations in the magnetic environment and this solid-state electronic system in the brain stem producing the subtle behavioral alterations of biologic cycles. In this regard, it is interesting to note that the latest observations on the earth's magnetic field indicate that it is subject to continuous pulsations of low magnitude, with a frequency ranging from 0.1 to 100 cycles per second. The major components of the phenomenon appear to be centered around 8 to 16 cycles per second. The suggestion has been made that this phenomenon may be related to the average frequencies of the electroencephalogram.[17]

Since this current system in the brain has a definite vector orientation (midline, fronto-

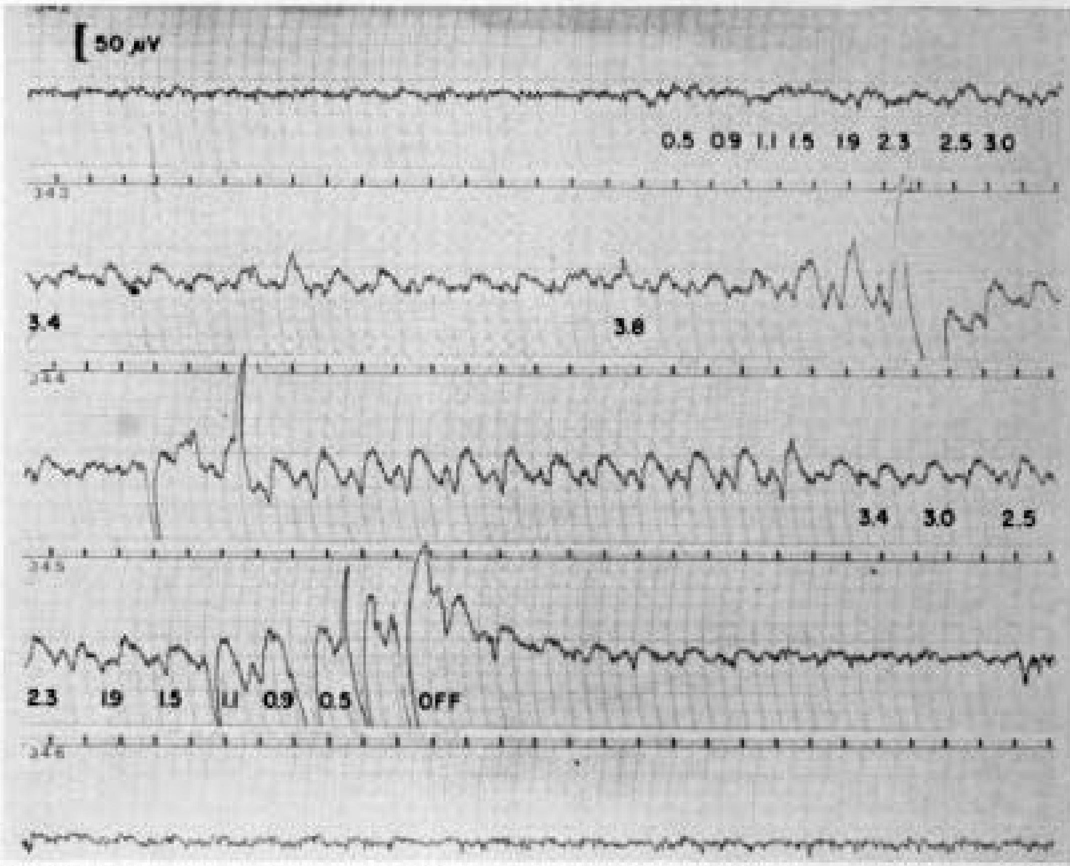

FIGURE 2. Electroencephalogram of lightly tranquilized amphibian during exposure to a magnetic field. The field was oriented at 90 degrees to the cranial neuraxis and was generated by a well-stabilized electromagnet (Varian V–4007–1). The tracings from the top down are a consecutive series and were made in sequence. The numbers beneath the tracing refer to the field strength in kilogauss. The time markers at the top of each record indicate one-second intervals. In the top tracing no field was applied until just prior to 0.5 kilogauss (500 gauss). Before the field application, a typical 8–10 alpha pattern can be seen. Starting at 0.5 kilogauss and proceeding to 3.8 kilogauss on the second record from the top, the field was smoothly increased in strength. During this time the appearance of large 1 per second delta waves may be noted. From the 3.8 kilogauss point on the second record to 1 second before the 3.4 point on the third record the field was uniform and was maintained at 3.8 kilogauss. A sustained 50 microvolt amplitude 1 per second delta wave accompanied by diminution in the superimposed alpha frequency can be seen. The field was reduced smoothly until the OFF point on the fourth record. The larger fluctuations between 1.1 kilogauss and off are presumably due to some induced current from the changing field. The delta wave forms subsided over the following ten to twelve seconds and were followed by a return to the original alpha pattern, shown in the last recording. The delta wave forms produced by the exposure to the magnetic field are typical of moderate to deep surgical anesthesia in this animal.

occipital) and can be measured on the exterior surface of the head, it can be subjected to experimentation under varying circumstances. In theory, the imposition of a steady magnetic field at right angles to the direction of this current flow should produce a deviation in the path of some of the charges flowing. If these can find new circuit paths at this new vector, then the amount of current to be delivered along the original vector will be decreased. From our experiments on the effects of increasing or decreasing the total electrical current flow along the path by the addition of externally generated current,[13] we know that a relative diminution in this amount of current will cause a decrease in the level of consciousness. Therefore the imposition of a magnetic field oriented at right angles to the brain stem should alter the electroencephalographic pattern in a fashion to indicate a decrease in the level of consciousness. In addition, a rough linearity should exist between the field strength applied and the magnitude of the change induced.

Such experiments have been done, and in every case when field strengths of from 2,500 gauss or more were applied (Fig. 2), the electroencephalographic pattern has changed from that of a moderate amplitude alpha to a high amplitude delta type, which is typical of moderate to deep anesthesia. The behavior of the experimental animal is also appropriate; he remains immobilized within the field of the magnet. It was further noted that no change could be produced in the electroencephalographic patterns of heavily anesthetized animals. Since our other data indicate that this state is associated with a maximal reduction in current flow, no effect was anticipated. These results clearly indicate that a magnetic field of proper magnitude and orientation can reduce consciousness to levels approximating general anesthesia, as judged by the electroencephalogram. It seems quite likely that fields of much lower magnitudes would also be capable of changing the level of irritability sufficiently to produce a deterioration in the performance of complex tasks. Other work with alteration of consciousness induced by application of externally generated direct currents has indicated that modulation of these currents by low frequencies (0.1 to 10 cycles per second) enhanced the physiologic effect. While it has not yet been possible to evaluate the effect of magnetic fields varying at these same frequencies, the inference would be that similar potentiation would occur.

Conclusions

It is concluded that the magnetic field of the earth is an important physiologic factor for living organisms and that life as we know it is adjusted to be in equilibrium with its characteristics. It would appear that behavioral changes of an undesirable nature may result from exposure to environments having lower or higher field strengths than "normal" or those having either no fluctuations or cyclic fluctuation at frequencies other than those to which we are adjusted. These behavioral alterations may be quite evident, in the case of high field strengths, or they may be subtle, representing only a deterioration in performance level.

Man's ventures into space thus far have been in areas where the magnetic environment approximates that of the earth's surface. In addition, these flights have been of relatively brief duration, insufficient to observe any cumulative effects. The factors discussed in this paper become operative on journeys of long duration beyond eight earth radii distance. Before exposing crews to such environments, it would appear desirable to investigate these factors thoroughly.

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