*The Possible Hazards of Human Exposure to Magnetic Fields**

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Within the past twenty-five years, the thesis that magnetic fields interact with biological organisms has become acceptable to most scientists. While our present knowledge is only fragmentary, enough is known to define certain areas of possible hazard to humans. At this time there would appear to be two paramount aspects to this problem. First, the fact that much is still unknown concerning this phenomenon indicates the desirability for a degree of caution in exploiting newer technologies that may involve exposing the population to new field conditions. Any such application should be preceded by a thorough study to determine possible undesirable side effects. Second, in view of the fact that most electronic devices are associated with some type of magnetic field, and considering the rapid rate of development in this area with the use of increasing power densities, it would appear desirable to determine as quickly as possible the exact mode (or modes) of interaction between magnetic fields and living organisms. This knowledge would permit the estimation of possible hazards with a much higher degree of certainty than is presently available.

Several recent bibliographies (1,2), selected reviews (3), and conference reports (4) indicate the extent of current interest in this field and are available for background material to those interested further. While many diverse effects are reported, ranging from growth suppression to alterations in the rate of enzyme activity, this paper will deal selectively with those known interactions which have been derived from human experimentation or those which appear to have overall biological significance and therefore are of importance to the human organism.

Each magnetic field has certain characteristics which permits its classification, these are: strength, direction, variation with time, and field configuration (i.e. uniform or non-uniform pattern of force). All of these aspects must be considered in any possible biological interaction. While not the most

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important, field strength is generally the primary variable in any experiment, and may be arbitrarily classified as high (in excess of 100 gauss), medium (10 to 100 gauss), and low (1 to 10 gauss). Added to these variables in the physical realm are certain biological variables such as the spatial relationship of the organism to the magnetic field, the duration of exposure, the species of organism, etc. Considering all of these variables, it is easy to understand why confusing and at times contradictory reports have appeared in the literature.

It would seem logical that the highest field strengths would be associated with the greatest detectable biological effects, however, the present literature does not support this thesis. While a host of relatively minor effects upon lower animals are reported, the most significant effect of high strength field exposure in mammals appears to be alterations in the electrical activity of the central nervous system (5,6), with possible associated pathological lesions in the brain (7). No associated behavioral alterations have been reported although most workers have not specifically searched for these effects. The primary difficulty in experiments of this type is the fact that high strength fields are difficult and expensive to produce and are limited to relatively small volumes. It has not been possible to expose larger animals to uniform configuration to high strength fields with controlled exposure for any considerable period of time. Nevertheless, the reported abnormalities in the electroencephalogram (EEG) of those animals that were exposed can be interpreted as indicating some disturbance in higher neural activity. It would at this time, therefore, appear desirable to avoid exposure of humans (either total body or head alone) to field strengths in excess of 1,000 gauss for anything other than short time periods. In particular, the suggestion to utilize magnetic shielding against radiation for space capsules, should be most carefully evaluated before being put to use. Another caution would be in the application of high strength fields modulated at certain frequencies. Since certain definite effects (to be discussed later) seem to be associated with low strength, low frequency (0.1–0.2 Hz) fields, human exposure to high strength similarly modulated fields should definitely be avoided except under controlled experimental conditions.

Magnetic fields of medium strength, when modulated at certain frequencies (25 to 90 Hz), are productive of a definite sensory effect in humans. This effect, the magnetophosphene, is the production of the sensation of light by the direct action of the magnetic field upon the human retina (8). The effect however is temporary, subsiding promptly upon removal of the organism from the magnetic field, and is not productive of any permanent biological effect. The magnetophosphene should, however, be taken into consideration in situations in which a human operator is required to make important command decisions based upon indicator lights or dial readings. The presence of a magnetic field with modulation appropriate to produce a phosphene could result in the misreading of an instrument panel with a resultant erroneous decision. This circumstance would again appear to be limited to such situations as on-board command decisions in space craft and possibly in the vicinity of equipment generating power by magnetohydrodynamic (MHD) equipment, or in attempts to control atomic fusion reactions by intense magnetic fields. Experiments on steady-state medium-strength fields have not been reported in sufficient numbers to reach any conclusion regarding their possible biological effects.

Low strength magnetic fields have been studied to a surprising degree. The stimulus to this seems to have been the well known relationship between biological cycles (the variations in activity or behavior of all organisms over twenty-four hours, twenty-eight days, and other time periods), and some similarly varying geophysical parameter. Such cyclic activities of organisms continue undisturbed even though the organisms are placed in an environment with no variations in temperature, light, barometric pressure, etc. This cyclic activity appears to be a basic function of living organisms, and disturbances in the cyclic pattern are considered to be functionally undesirable. For a general review of biological cycles and their geophysical relationships, the reader is referred to several recent reviews (9,10). In searching for a geophysical variable that would be all pervasive (in the same sense that its variations would be uniformly present and impossible or difficult to screen out), the magnetic field is evidently a prime choice. An extensive literature has been accumulated in this area, primarily through the efforts of Brown and his group at Northwestern. While they worked primarily with lower organisms where cyclic patterns are much more distinct than in humans, they have been able to demonstrate perturbations in biological cycles produced by fields as low as 1 gauss in strength (11). It has furthermore been possible to demonstrate cyclic alterations by merely altering the vector relationship between a photic (light) stimulus and the earth's normal field (12).

This brings us to a consideration of the biological role of the earth's magnetic field. Brown has concluded form his experiments that the driving force producing biological cycles is the cyclic variation in the earth's normal magnetic field. The earth's normal field however, is not a simple phenomenon; it is of low strength, averaging from ½ to 1 gauss, it displays cyclic variations in strength on twenty-four hour and twenty-eight day periods, it also contains certain frequency components with major strengths in the 0.1 Hz to 10 Hz ranges and it is furthermore subject to periodic disturbances related to the solar cycle known as magnetic storms. If the general field is of biological significance, then we must consider what role each of these factors has to play as well as what effects would be produced by removal of an organism from the earth's field or by the addition of new magnetic fields of low strength that would interact with the earth's field by virtue of their frequency of modulation etc. For many years, it has been postulated that the incidence of mental illnesses in the human population is related to the solar cycle or to associated magnetic field disturbances (13). Two recent statistical studies have appeared to further substantiate this thesis (14,15). One encounters some difficulty in attempting to logically explain this phenomenon. The magnetic storms are of relatively short duration and involve only a small increase in the overall magnetic field strength. It therefore seems quite unlikely that such modest factors could be productive of such major disturbances in the human. Based, however, on previous experimental studies (16,17), it was postulated that the frequency modulated components of the earth's field (which are also disturbed during magnetic storms) might be of more biological significance than the absolute field strength. Accordingly, an experimental study was performed involving the exposure of human volunteers to low strength magnetic fields modulated at 0.1 and 0.2 Hz. Using a relatively crude index (reaction time), definite statistically significant effects were detected (18). The exposures were of relatively short time duration and no statements can be made at this time regarding other possible psychological disturbances or whether the effects of exposures could be cumulative. At the present time, the frequency components of the magnetic field associated with magnetic storm activity are considered to be the most likely parameter producing disturbances in certain susceptible (? schizophrenic) individuals.

One other study involving human volunteers has been reported (19), this however, dealt with the effects of prolonged exposure (two weeks) to a magnetic field much reduced below the earth's normal. While a variety of tests performed demonstrated no significant alterations beyond normal, one (the critical flicker fusion test) demonstrated significant changes definitely related to the low field exposure. It should also be noted that the technique utilized to produce the abnormally low field was primarily effective in reducing the strength of the steady state field and that the frequency modulated components were not eliminated. The test subjects therefore still were exposed to what may be the more biologically important parameter of the earth's field.

To sum up at this time, there are definite biological effects of magnetic fields. Of these, the most important to humans accidentally exposed appear to be those related to central nervous system effects. It would appear desirable to limit human exposures to magnetic fields of very high strength (any configuration or frequency) to short periods of time only, and during such exposures to expect a possible deterioration in performance. Moderate strength fields of frequencies appropriate to produce magnetophosphenes should be avoided in any situation requiring the maximum performance relating to command or guidance decisions such as space craft cabins, supersonic transport pilot compartments, or hazardous experimental situations dealing with MHD power production. Any individual exposure to low strength fields modulated at very low frequencies (0.1 Hz etc.) should be avoided for similar situations as well as inadvertent exposures of larger population groups to similar fields. While it is evident that certain elements of the population are more sensitive to these physical parameters, it is not known whether long term exposures could be cumulative and involve larger segments of the population. It should be emphasized that certain industrial or communication techniques could result in the exposure of relatively large population groups to such fields entirely without the knowledge of the exposed individuals. For example, the present VLF transmitters in use, while operating at frequencies three orders of magnitude higher than those *so far* determined to be productive of biological effects, utilize quite large power densities. In allocating portions of the spectrum for this purpose, certainly the 0.1 Hz range should be avoided and probably the use of any frequencies below 100 Hz should be guarded. Finally, it should be considered possible that exposure to field strengths markedly reduced below earth's normal may result in performance deterioration that could be cumulative with time.

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