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THE BIOLOGICAL EFFECTS OF MAGNETIC FIELDS—A SURVEY*

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Abstract—The literature relevant to the biological effects of applied magnetic fields has been reviewed. Reported effects vary with the type of field applied and the duration of application.

The production of magneto phosphenes by the application of alternating fields (of certain frequencies) is a well accepted phenomenon. The major question, at this time, seems to be the mode of action responsible.

Medium to high strength, non-uniform, steady-state fields have well documented effects upon rapidly growing tissues.

Steady-state fields with strengths approximating the natural geomagnetic field are reported to produce alterations in the pattern of biological cycles.

1. INTRODUCTION

To review the literature pertinent to possible biological effects of magnetic fields is a frustrating task. Many reports in the scientific literature are based upon insufficient data and experimentation of the crudest nature. Frequently diametrically opposite results are reported under what appear to be identical conditions. In order to reach even tentative conclusions, some type of critical, organized review is necessary. It is hoped that this paper will at least in part fulfill this criterion.

Papers reviewed are, for the most part, limited to those published or presented subsequent to the turn of the century. In each case the original or an authenticated translation has been read personally by the reviewer. Papers that could not be verified or for which translations could not be obtained have been omitted. Those based upon grossly inadequate techniques, and those which fail to specify in sufficient detail the techniques utilized have been likewise omitted. Publications dealing with technical applications of magnetic fields for measurement purposes (electromagnetic blood flow meters, magnetoelectrophoresis) are considered to be non-pertinent to the subject. A rather rigid classification, based upon the type of field applied (field strengths have been quoted in the units employed by the original investigators), has been used for purposes of clarity and organization. Some repetition is unavoidable under these circumstances, since the same material may be applicable to more than one section. Considerable effort has been expended to make the review as complete as possible; over eighty papers were carefully appraised. The omission of any worthwhile papers is completely unintentional.

2. HISTORICAL BACKGROUND

It is unfortunate that any discussion of the historical antecedents of biomagnetism must begin with Mesmer. While we cannot deny his contributions in regard to hypnosis, he succeeded in completely confusing this phenomenon with "animal magnetism", a concept completely lacking in scientific validity. Despite repeated refutations of his thesis, his erroneous concepts still have appeal for certain segments of the population, a fact affording considerable embarrassment to any one scientifically interested in the possible biological effects of magnetic fields. It must be emphasized, however, that while Mesmer earlier experimented with magnets, he attributed the resulting "cures" to animal magnetism and not to any property of the magnetic fields themselves. It is obvious

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that the substitution of the word "suggestion" for "animal magnetism" restores validity to this statement. In spite of the complete rejection of mesmerism by the scientific community, the practice continued and became even more confused with the increased use of magnetic fields. In 1888 HERMANN recorded in "Pflüger's Archives" the first series of experiments specifically designed to determine whether or not the magnetic field had any physiological action. While he is regrettably vague about his experimental conditions, he reported no evident physiological or morphological effects in a variety of animals exposed to steady-state fields. He also stated that no subjective symptoms were produced in human subjects who placed their heads in the field. The conclusion reached by HERMANN was that any reported effects of magnetic fields upon humans were due to suggestion and not to any property of the magnetic field. Four years later, PETERSON and KENNELLY (1892) reported on an extensive series of experiments using the very large electromagnets available to them in the Thomas Edison Laboratory. One such magnet with a field strength of 5,000 cgs lines/cm^2 was quoted as being capable of producing "visible distortion" of a drop of water placed between the poles. Nevertheless, no visible effects were produced by it on a drop of blood or a fragment of ciliated epithelium whether the magnet was energized continuously or turned on and off repeatedly. In retrospect, it seems unusual that a magnet of this strength did not induce sufficient current on "make or break" to produce some observable effect on the ciliated epithelium. In other, more spectacular experiments, a dog was placed in a non-uniform field (1,000–2,000 cgs lines/cm^2) for 5 hr with no obvious discomfort, and no subjective sensations were reported by five volunteers who placed their heads within a 2,500 cgs lines/cm^2 field, whether the field was on continuously or repeatedly turned off and on. This latter observation is particularly interesting in the light of the next paper of note. d'ARSONVAL (1896) reported that the application of changing fields to the human head produced a subjective sensation of light. This finding was substantiated by BEER (1902), and since then this so-called "magnetic phosphene" has been studied at length. Its existence is unquestioned, and it is difficult to explain why PETERSON and KENNELLY failed to experience it since some of their experiments were practically identical with later ones which produced the effect. Despite the rather obvious technical limitations and inadequate experimental series, the papers of HERMANN (1888), and PETERSON and KENNELLY (1892) are still frequently referred to as evidence for the non-existence of any biological effects ascribable to magnetic fields.

3. ALTERNATING AND INTERRUPTED FIELDS

The primary biological effect associated with this type of field application is the production of magnetic phosphenes (by definition: phosphene, a sensation of light produced by physical stimuli other than visible light). The magnetic phosphenes are uniformly described as colourless or occasionally light blue tinted, shimmering luminosities appearing in the borders of the visual fields. They are reported to be produced by the application of 10 to 100 cps alternating fields to the temporal areas of the human head. MAGNUSSON and STEVENS (1914) noted that the intensity as well as the character of the sensation is strongly frequency-dependent. The intensity is greatest (for any given field strength) between 20 and 30 cps. Below 25 cps the individual flashes of the phosphene are seen to be synchronized with the field frequency, while above 30 cps interference and standing wave patterns are present. Above 90 cps the phenomenon becomes much less evident, and field strengths many times over threshold values produce only minimal increases in luminosity. The minimum field strength necessary to induce phosphenes, therefore, varies with the frequency of the field as well as the background illumination to which the subject is exposed. As the intensity of the phosphene is increased by either field strength or frequency adjustments, the luminosity appears to involve more and more of the visual field, but never the fixation point. (BARLOW, KOHN and

WALSH, 1947). These same authors also compared the magnetic phosphene with electrical phosphenes produced by the passage of alternating current longitudinally through the head. At the same frequencies, the phenomena were subjectively the same. However, closing the eyes raised the threshold for electrical phosphenes but not for magnetic phosphenes. The ability of steady-state fields to produce phosphenes was evaluated by MAGNUSSON and STEVENS (1911, 1914). They employed a large solenoid-type coil which could be placed over the subject's head, producing a vertical field. No subjective sensations of any type were noted during steady field applications, but phosphenes were experienced during "make" and "break" of the coil current. The sensation was more pronounced on closing the circuit, consisting at that time of a horizontal band of luminosity moving rapidly downward. The weaker phosphene produced by opening the circuit was also a horizontal band, but moved rapidly upward. The authors reported that changing the direction of the lines of flux in the solenoid did not change the direction of movement of the phosphene wave on "make" or "break".

The major problems associated with magnetic phosphenes have been questions regarding the site and mode of production of the phenomenon. Suggested sites have been the retina (FLEISHMANN, 1922), optic nerve and optic cortex (DUNLAP, 1911). However, since the studies by BARLOW, KOHN and WALSH, there appears to be little doubt that the retina is the affected tissue. They noted that pressure on the eyeball completely obliterated the phenomena, while intense stimulation of the optic cortex was completely ineffective in producing the phosphene. By using pointed pole pieces they were able to produce relatively narrow beam fields which could be limited to certain areas of the retina. In all cases, sensations aroused were referred to the opposite quadrant of the visual field. While we can thus confine the site of action to the retina, the mode of action is still debatable. The original postulated mechanism was stimulation of irritable tissues by the induced currents (DUNLAP, 1911). Most recently, VALENTINUZZI (1962) has analyzed this possibility mathematically. He postulated that each retinal cell constituted a microscopic circuit capable of having an induced current generated in it. His calculations, based on this assumption, agreed well with the observed dependence of the phosphene persistence on the intensity of the applied field (BARLOW, KOHN and WALSH, 1947).

LIBERMAN (1958) however, claimed that the induced e.m.f. was at least 10^8 times too small to cause retinal stimulation. He proposed that the phosphene was produced by Hall or photomagnetic effects upon a light-activated electron transfer system functioning within the retina. While there is some evidence for such semiconduction systems in retinal elements (ROSENBERG, 1961), LIBERMAN's thesis requires that phosphenes be produced only in the light-stimulated retina. However, both BARLOW, KOHN and WALSH, and MAGNUSSON and STEVENS (1911), noted that the phosphenes were easiest to see in the dark. While the best available evidence indicates a primary action on the retina, the nature of the mechanism of action is still open to question.

LENZI (1940), reported on the only adequate experimental series dealing with another effect of alternating fields. Since this work is most closely related to growth inhibition effects of steady-state gradient fields, it is discussed in that section.

4. STEADY-STATE FIELDS

The reported biological effects of steady-state magnetic fields vary greatly, depending upon the degree of field homogeneity and the orientation of the biological specimen with respect to the applied field. BARNOTHY (1961), correctly stated that magnetic fields and gradients are vector quantities, and proper experimentation must provide for a constant relationship between the biological test object and the field vectors.

4.1. *Homogeneous fields*

DRINKER (1921) exposed dancing mice to a homogeneous field of 2,800 cgs lines/cm^2 for 12 hr, every day, for three months. He reported that the colony carried on its normal activities with no observable abnormalities and that several pregnancies were carried to term with the production of normal young. He and his co-workers also placed their heads within the field of the same magnet with no subjective symptoms. In both experiments the orientation of the field with respect to the test object is unclear.

SSAWASTIN (1930) stated that he was able to markedly increase the growth rate of plants by exposure to supposedly uniform fields of 200 to 2,150 G strength, with no alteration in the direction of growth. While he does not specify the orientation of the field lines with respect to the growth axis, he does report that no growth effects are obtained when the field lines are parallel to the axis. One other interesting observation, unfortunately reported in very little detail, relates the magnitude of the growth acceleration to the time of day during which the experiment was conducted. The possible relationship between this observation and BROWN'S experiments dealing with biological cycles (see *Natural Geomagnetic Field* Section) should be noted. Subsequent experimentation on plant growth in magnetic fields has been directed primarily towards differential growth in non-homogeneous fields. There are no further reports of plant growth acceleration with either homogeneous or inhomogeneous fields, and SSAWASTIN'S observations remain unsupported.

JENNISON (1937) exposed various types of bacteria, yeast and fungi to a 3,000 G homogeneous steady-state field for 48-hr periods, with no observable effects upon growth rate or morphology. The following year KIMBALL (1938), working with both homogeneous and inhomogeneous fields, reported no growth effects with exposure of yeast cultures to 11,000 G homogeneous fields.

BARNOTHY (1956) reported that adult mice exposed to 4,200 G homogeneous fields demonstrated a drop in numbers of circulating polymorphonuclear white blood cells. Following removal from the field, the count of these cells transiently rose to values considerably above normal.

Later (1958), the same author attempted to utilize this phenomenon to minimize the leukopenia following exposure to lethal ionizing radiation. Some success was claimed in the low lethal dose range, but no favourable responses were obtained in any high radiation dosage ranges. In 1960 he reported, in narrative form, on several types of experiments involving both homogeneous and non-homogeneous fields. While experimental techniques are not given in detail, homogeneous fields of 5,500 G and inhomogeneous fields of 4,500 G maximum strength were said to produce growth arrest and death in adult mice during 10 days exposure. Pre-puberty mice exposed to the same fields apparently could "adapt" to the field and survive without serious damage. A variety of other effects were claimed, including inhibition of the oestrus cycle in females and slowing of the normal aging process.

GROSS (1961) presented some evidence for a delay in wound healing and antibody formation in mice exposed to uniform fields of 4,000 G. The quantitation of wound healing in this case was subject to the usual difficulties.

BEISCHER (1962) reported some experiments utilizing field strengths much greater than those previously available. Adult mice and fruit flies survived 1-hr exposures to homogeneous fields of 120,000 G strength. However, sea urchin eggs demonstrated great disturbances in developmental pattern under the same circumstances.

In all of these studies, except possibly JENNISON'S, KIMBALL'S, and BEISCHER'S, it seems probable that the homogeneity of the field was not complete. Excluding BEISCHER'S work involving very high field strengths, it should be noted that the two other studies in which a truly homogeneous field was most closely approximated reported no biological effect. Except for some of the rather unusual findings of BARNOTHY, the majority of other reports indicate an inhibitory effect upon rapidly growing cells or tissues. This is so similar to the reported effects of inhomogeneous fields that it appears questionable whether it can be realistically ascribed to homogeneous fields.

4.2. *Inhomogeneous fields*

KIMBALL, as mentioned above, noted no effect from a 11,000 G uniform field on yeast cultures. The majority of her paper, however, is devoted to effects produced by non-uniform fields of 4 G or less. Using small permanent magnets and young yeast cultures, she obtained statistically significant decreases in growth rates in the areas of the culture exposed to the maximum gradient of field strength. The exact area on the culture dish influenced was dependent upon the shape of the magnet and its position relative to the culture dish, and in each case coincided with maximum field gradients. The effects were produced only in cultures less than 2 hr old. Older cultures exhibited no inhibition and presumably the effect is upon the earliest growth phases of the cells. While there are no subsequent reports in the literature specifically refuting KIMBALL'S work, the criticism has frequently been raised that the field strength utilized was entirely insufficient to produce any biological effect. However, BROWN'S reports (see *Natural Geomagnetic Field* Section) in which definite alterations in biological cycles are produced by fields of less than 1 G would appear to technically support KIMBALL'S assertions.

In 1940 LENZI reported on an extensive series of experiments involving both steady-state and alternating fields. While not specifically stated, the experimental conditions would indicate that the fields were probably inhomogeneous. He claimed significant effects of steady-state fields on the healing rate of skin wounds and growth of implanted tumors. In the latter instance the number of experiments were quite adequate, and the conclusions would appear to be valid. Ehrlich's adenocarcinoma was injected into mice, and the animals were immediately exposed to steady fields of 1,500–1,700 G. During field exposures the percentage of tumor "takes" was much lower than with the control growth. After removal from the field, the delayed tumors began their normal growth rate. In a significant number of the animals exposed to alternating fields (42 cps) of the same maximum strength, the tumors failed to develop after removal from the field. If the injected tumors were permitted to "take" and develop to palpable size, before exposure to either steady or alternating fields, no growth inhibition was noted.

Inhomogeneous fields were applied to the problem of plant growth by MAGROU and MANIGAULT (1946), and AUDUS (1960). The former group worked with the abnormal growth, crown gall tumor (*Phytomonas tumefaciens*). Exact gradients per cm were not recorded; however, the data given on the pole face geometry indicates high gradient values. Field strengths at sites of specimen placement are given and ranged from 1×10^6 to 22×10^6 cgs units. Exposure times were up to 3 months. Development of these tumors was almost completely inhibited by the highest fields, while lower field strengths produced correspondingly less growth inhibition. Comparison with control plants is shown and is quite remarkable. Histological examination of the exposed tumors presented a picture of exaggerated proliferation of poorly undifferentiated cells, typical of tumor formation. However, "the sections presented a picture of tumors much delayed in their development in comparison with the tumors in control plants". No statements were made concerning the growth of the tumor subsequent to removal of the host plant from the magnetic field. The authors did not report any effect upon the normal tissues of the host plant, although these were adult specimens and slowly growing. AUDUS was concerned with the possibility of field gradients influencing the direction of normal growth. Permanent magnets with sharp triangular pole pieces producing a maximum field of 4,000 G with a gradient of 5,600 G/cm were used, the test object being the growing root tip of *Lepidium* seedlings. Light, gravitational and other trophic stimuli were appropriately nulled out by the experimental conditions. In all but a very few instances, marked growth curvatures appeared, away from the gap and down the field gradient. Reaction times were estimated to be 30–45 min (compared with 4–8 min reaction time for gravitational stimulus). AUDUS postulated that the effect was primarily upon the diamagnetic starch granules, and attempted to demonstrate histologically a non-random distribution of the granules in the experimental plants. The results, however, were inconclusive.

In 1961 MULAY and MULAY worked with tissue cultures and small organisms using permanent magnets of 4,000 to 8,000 oersteds. While no specific indication of field homogeneity is made, it would appear probable that some field inhomogeneity was present. Normal tissue (embryonic mouse and chick heart) showed no changes after 18 hr of field exposure, whereas mouse acites tumor cells (Sarcoma 37) were completely destroyed. Lower intensity fields had no effect upon either normal or abnormal tissues. *Drosophilia* were exposed to 600 to 8,000 oersted fields continuously for 3 generations. In the last generation some non-specific external deformities appeared in a high percentage of the organisms. The authors theorized that the field effect is only upon certain cells (or cells in certain states) and not upon the entire organism.

GERENCSER (1961) reported that high gradient (3,000 G/cm), high strength (16,000 G), fields produced a statistically significant decrease in the growth rate of *Serratia marcescens* cultures. Apparently actively growing fluid cultures were used and were continuously exposed; with aliquot samples removed hourly. No significant differences between control and experimental cultures were noted until the 7th hour of exposure, at which time there were significantly less experimental organisms. This period was followed by an increase in the growth rate which was insufficient, however, to restore the total population; the experimental cultures required a "few" more hours of incubation to reach the population plateau than did the controls. The authors failed to mention the age of the culture at the onset of the experiment, a factor that KIMBALL (see above) felt was important.

BEISCHER exposed mice to very high gradients 7,000 G/cm) in fields of 45,000 G maximum strength for periods of 1 hr without fatalities or obvious manifestations of difficulty. The same field, however, produced 100% mortality in *Drosophilia* and again sea urchin eggs were markedly influenced (as they were by the high-strength uniform fields).

The reports on highly inhomogeneous fields appear to uniformly indicate an inhibitory effect upon rapidly growing cells or tissues. Some of the reported inconsistencies may be removed by consideration of such factors as length of exposure and normal life cycle time of experimental organism. BEISCHER'S finding that adult mice survived 1-hr exposure to 45,000 G non-uniform fields may not be inconsistent with the fatalities reported by BARNOTHY with 4,500 G non-uniform fields and 10 days exposure. *Drosophilia*, with its short life cycle, succumbed to BEISCHER'S inhomogeneous fields, while sea urchin eggs in early development stages were inhibited by both inhomogeneous and uniform fields of high strength.

The reports of growth inhibition produced by homogeneous fields would appear to require re-evaluation in the light of the much better substantiated effects of inhomogeneous fields. The factors rendering rapidly growing tissues particularly susceptible to magnetic field effects are as yet speculative. Generally magnetic susceptibility differences of cellular constituents (AUDUS, 1960; MULAY and MULAY, 1961), are suggested, but as yet firm evidence has not been forthcoming.

5. FIELD EFFECTS ON NEURAL PHYSIOLOGY

Several workers have evaluated the effect of applied fields on nerve function, particularly the transmission of the action potential. PETERSON and KENNELLY, and DRINKER used nerve-muscle preparations, exposing the nerve to the field and requiring the stimulus to pass the exposed portion. No obvious alterations in the ability of the fiber to transmit the impulse were noted. LIBERMAN (1959), determined the effect of a 10,000 oersted field upon the excitation threshold. The field was applied directly to the section of the nerve that was stimulated, and no changes were noted in the threshold, chronaxie or rheobase. In a previous paper (LIBERMAN, 1958), the same author had discussed the possible ways of detecting electron conduction in nervous elements, and suggested that the galvano-magnetic (Hall) effect, be used. The magnitude of the Hall effect is directly related to the mobility of the charge carriers. It is highest for electronic conduction in semiconductors, and lowest for ionic conduction in solutions. For this reason, and since the ionic flux in the action potential is transverse to the fiber axis, it is exceedingly unlikely that even very high strength fields applied transversely to the neural axis could influence the passage of the action potential. LIBERMAN calculated the carrier mobilities involved in magnetic phosphenes, assuming that this phenomenon was produced by the Hall effect. The calculated mobilities agreed well with those previously determined for electrons or units of small size. BECKER (1961*a*) reported finding Hall voltages across the extremities of intact amphibians when exposed to steady fields of 8,000 G. The values of these voltages also indicated carriers possessing high mobilities. These Hall voltages were neural-dependent, disappearing if the nerves to the extremity were severed, and varying in proportion to the depth of anesthesia. The author postulated that electronic conduction occurs in nervous elements independent of action potential activity, and that applied fields can produce alteration in it by means of the galvano-magnetic effect. This evidence is, of course, indirect and would require identification of the same phenomenon in isolated nerve fibers themselves. There have been reports (SEIPEL, 1960; GENGERELLI, 1961) in which detection of magnetic fields accompanying transmission of action potentials has been claimed. Pickup coils of various types were utilized as sensing elements, and while both authors attempted to guard against artifacts in their experimental techniques, their evidence is not altogether convincing. The present concept of action potentials, as mentioned above, would not indicate the generation of magnetic fields detectable by any presently available device, including Hall probes, let alone simple wire-wound coils.

6. NATURAL GEOMAGNETIC FIELD

The natural geomagnetic field has been postulated to be a factor in bird navigation, biological cycles, and variations in human behaviour.

YEAGLEY (1947), proposed a theory of bird navigation based on "organ or organs in the birds physiology which are sensitive to the effect of its motion through the vertical component of the earth's magnetic field and to the effort exerted to overcome the Coriolis force, due to the earth's rotation". To test his thesis, he attached small permanent magnets to both wings of homing pigeons (copper weights of same size were similarly used in a control series). In a series of 20 birds (10 controls and 10 experimental) released 65 miles from their roost, 8 with the copper weights returned home within 2 days, 1 with one wing magnet still attached returned home on the 3rd day, and 1 with two wing magnets returned on the 4th day. The remainder (2 control and 8 experimental) failed to return. The initial directions taken by the birds on release were much further off the true homing path in the experimental group than in the control group. YEAGLEY calculated that the movement of the wings with the attached magnets induced an alternating voltage in the vicinity of the bird's head of approximately 0·12 μV/cm. He concluded that this was the mechanism of action involved in disorienting the experimental group, and that the normal homing mechanism involved a similar process of current induction by movement of the bird through the magnetic field. SLEPIAN (1948), challenged this view and pointed out that the bird's movement through the horizontal component of the electrostatic field would induce much greater potentials which would vary with terrain features, weather, etc. He concluded that YEAGLEY must postulate a sensitivity to the magnetic field directly rather than through induction mechanisms. VARIAN (1948) and DAVIS (1948) also commented in similar fashion on YEAGLEY's paper. All commentators, however, stressed their objection to the mechanism postulated by YEAGLEY, rather than to his experimental results. YEAGLEY later reported (1951) on further experiments involving aircraft tracking of pigeon flight paths and flights to conjugate points. Again he presented some evidence that is tantalizing, but not conclusive. The flight paths followed in detail were non-random and many did follow the vector path predicted on the basis of YEAGLEY's theory. It is the reviewer's understanding that these experiments are continuing at present with newer techniques.

The phenomenon of biological cycles has been receiving increasing interest during the past decade. It is not the purpose of this review to present the subject in any detail, and to avoid emphasizing only one side of a controversy, the reader is referred to CLOUDSLEY-THOMPSON (1961), a current review of this subject. He discusses the two alternate views on the origin of the cycles:—endogenous (i.e., based on some natural oscillatory mechanism existing within the organism), and exogenous (i.e., impressed upon the organism by environmental factors). It is with this latter view that we are concerned. Since most of the cyclic patterns obtained under "constant" conditions of light, temperature, humidity and barometric pressure have periods coinciding with certain natural geophysical periodicities (circadian, i.e., about 24 hr, lunar tidal and 27–29 days), the proposal has been made that some geophysical parameter "drives" the cycles. While it is not feasible to review the geophysical literature, it should be noted that many environmental parameters vary with solar and lunar periodicities (i.e., air ionization, cosmic radiation, atmospheric electric charge and magnetic field intensities). All of these are subject to perturbations of various sorts, some man-made (air ionization in industrial areas), others naturally occurring (magnetic storms, etc.). If the natural magnetic field is of biological significance, then one must postulate that organisms possess an organ capable of acting as a direct magnetometer, since field strengths and variations are of such low values that induced currents are negligible. In addition, one should be able to determine variations from the normal in the appropriate biological parameter produced by the variations from the normal in the geomagnetic field.

In 1959 BROWN reviewed his data and thesis for the exogenous timing of biological cycles in a comprehensive paper. At that time his most impressive experiment involved the transportation of oysters from New Haven, Connecticut to Evanston, Illinois, in a manner excluding environmental cues. Over a period of 2 weeks, the cycles of shell opening, which were previously synchronized to the New Haven tidal rhythm, shifted phase to synchronize with the Evanston lunar tidal rhythm (BROWN, 1954). More recently, BROWN (1960*a*) reported that the application of 1G steady-state fields to a test organism population produced a significant change in the measurable daily cycle in orientation. He concludes that the orientation of the animals normally includes a true response to the earth's magnetic field, and proposes that "every cell of the body contains the perceptive capacity for magnetic field" (BROWN, 1960*b*). These represent only a few of BROWN's published papers, and while he seems to neglect somewhat the theoretical aspects pertaining to the mechanism of field action, his experimentation could well be considered conclusive. The response of the organism to the applied field was in each case a subtle one, evident only when its cyclic activity was analyzed in detail. There are two outstanding points of interest in his work. First, the response was to field strengths approximating the natural field, and mechanisms, such as current induction or differing magnetic susceptibilities, are inadequate to account for it. Second, the response, being an alteration in normal cyclic patterns, is not unrelated to cyclic behaviour patterns in higher animals including man. Therefore, discussion of natural field transients affecting the human population in similarly subtle fashion is not completely unrealistic.

Relationship between environmental geophysical parameters and the human population have been postulated for many years. The literature in this area is particularly confusing, and much of it represents work of a low technical calibre. BERG (1954) reviewed the literature fairly thoroughly and arrived at the conclusion that firm evidence for or against such a relationship is still lacking. He suggested more and better statistical studies and actual experimental work on the geophysical-biological relationship rather than publication of further "flights of fancy".

The paper by DÜLL and DÜLL (1935) represents the most ambitious study to date, with an analysis of approximately 40,000 cases from Copenhagen and Zurich over a period of 60 months. During this period, there were 67 magnetic storms, and graphically an impressive relationship appeared between the incidence of nervous and mental disease and suicides and the storm periods. The data, however, was not subjected to statistical analysis and the methods of case selection are not clearly defined. BECKER (1961*b*) reported on the initial results of a similar study using data processing equipment and statistical evaluation. A low, but significant, correlation was found between the K Index (of magnetic field) and the incidence of admissions to mental hospitals. This study is currently being continued with very large volumes of data and automatic data processing. BEISCHER discussed the possible human tolerance to high and low field strengths in relation to problems of space exploration. He stressed the need for systematic whole-body experimentation and pointed out that all previous human studies have been in the nature of incidental observations or limited to specialized application. Most pertinent to space vehicle applications is the question of the effect of fields lower than earth normal and lacking in the normal rhythmic fluctuations. As BEISCHER points out, "man on his earth may have become so accustomed to the geomagnetic field that only its absence can reveal any effects". He is currently involved in direct experimentation to evaluate this possibility.

7. CONCLUSION

In conclusion, the evidence for certain biological actions of magnetic fields is fairly impressive. Some inhibition of rapidly growing cell populations by high gradient fields is evident. The alterations of normal cyclic behaviour caused by low field strengths indicate the possibility of organisms being regulated in part by the natural field. Mechanisms of action have so far been subjected to speculation only. The future of this field of study would appear to be dependent upon well planned experimentation and accurate statistical studies.

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LES EFFETS BIOLOGIQUES DES CHAMPS MAGNÉTIQUES—RAPPEL D'ENSEMBLE

Résumé—Aperçu de la bibliographie traitant des effets biologiques des champs magnétiques appliqués. Les effets sur lesquels il est rapporté varient suivant la nature du champs en question et la durée de l'application.

La création de magnétophosphènes par l'application de champs magnétiques (d'une certaine fréquence) est un phénomène connu. La question principale semble, à l'heure actuelle, être le mode d'action responsable de ce phénomène.

L'expérience a démontré que des champs statiques non uniformes, moyens à très forts, influent sur des tissus à croissance rapide.

Des champs statiques dont la force atteint approximativement celle du champ magnétique terrestre, provoquent des modifications dans le déroulement de cycles biologiques.

DIE BIOLOGISCHEN AUSWIRKUNGEN VON MAGNETFELDERN—EIN ÜBERBLICK

Zusammenfassung—Ubersicht über die Literatur, welche die bilogischen Wirkungen angelegter Magnetfelder behandelt. Die Auswirkungen, über die berichtet wird, ändern sich je nach dem einwirkenden Feld bzw. der Wirkungsdauer des Feldes.

Die Erzeugung von Magnetophosphenen durch Einkung von Wechselfeldern (bestimmter Frequenzen) ist eine bekannte Erscheinung. Gegenwärtig scheint die Hauptfrage die Wirkungsweise zu sein, welche diese Erscheinung auslöst.

Mittlere bis sehr starke, uneinheitliche statische Felder haben erwiesenermaßen Wirkungen auf schnell wachsende Gewebe.

Statische Felder, deren Stärken ungefähr an die des Erdfeldes heranreichen sollen Änderungen im Ablauf biologischer Zyklen hervorrufen.

БИОЛОГИЧЕСКОЕ ВОЗДЕЙСТВИЕ МАГНИТНЫХ ПОЛЕЙ — ОБЗОР

Резюме — Даётся обзор литературы, по вопросу биологического воздействия приложенных магнитных полей. Воздействия, о которых реферируется, меняются соответственно влияющему полю или времени действия поля.

Генерация магнитофосфенов воздействием переменных полей (определённых частот) — уже известное явление. В настоящее время основным вопросом является повидимому действие, вызывающее это явление.

Доказано, что средние и очень сильные статические поля имеют влияние на быстро растущие ткани.

Реферируется, что статические поля, напряжённость которых достигает напряжённости геомагнитного поля, вызывают изменения в процессе биологических циклов.