ELF and VLF Electromagnetic Field Effects

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PREFACE

Recent emphasis upon the importance of the physical environment has made science and the public even more cognizant of the many components of the biosphere. While much attention has been given to ionizing electromagnetic stimuli which causes blatant and unalterable changes in biological systems, relatively little research has been concerned with those electromagnetic signals whose frequencies overlap with time-varying processes in living organisms. Extremely low frequency (ELF) electromagnetic fields can occur as waves between about 1 Hz to 100 Hz or as short pulses within this range of very low frequency (VLF) and higher frequency sources. The natural occurrence of ELF signals is associated with weather changes, solar disturbances and geophysical-ionospheric perturbations. Man-made sources have also been reported.

Certain physical properties of ELF signals make them excellent candidates for biologically important stimuli. Unlike many other weather components, ELF signals have the capacity to penetrate structures which house living organisms. ELF wave configurations allow long distance propagational capacities without appreciable attenuation of intensity, thus making them antecedent stimuli to approaching weather changes. Most importantly, ELF signals exhibit the frequencies and wave forms of bio-electrical events that occur within the brain and body. Thus resonance interactions between animal and nature become attractive possibilities.

Following a short introduction, this book includes information on the physical parameters of ELF-VLF electromagnetic fields as well as their penetrability and shielding properties. Correlational and experimental data are presented which strongly indicate that ELF fields have significant effects on human activities. Difficulties and methodological formats encountered with measuring detection of

ELF fields by non-human animals are presented in conjunction with the behavioural-biological effects of maintained exposure. In this manner the distinction between detectability versus the effect of ELF signals are recognized. Care is given to differentiate the biological changes possible at natural ELF field intensities from those applied during experimental settings. Results from animal experiments are also presented to demonstrate some of the significant physiological and biochemical changes associated with ELF magnetic field exposures. Speculation on the fundamental role of ELF magnetic fields in the phylogeny of life forms is presented in the chapter concerned with abiogenesis. The conclusion integrates the chapters and points out the applicability of experimentally collected data to naturally occurring phenomena and suggests general approaches for future research.

The editor expresses his gratitude to the researchers who have contributed their excellent articles to this text and to Plenum Press for publishing a text concerned with a controversial and unestablished research area. Thanks to Jean T. Janes, manuscript typist, Ruth Scott, proof reader, and Patricia P. Lyons, draftsman, for their fine technical assistance. The editor thanks Klaus-Peter Ossenkopp for translating from German the articles written by Dr. König and Dr. Altmann, and Irene P. Huk for translating Dr. Ludwig's manuscript. Special thanks to Klaus-Peter Ossenkopp and Gyslaine Lafrenière for their dedicated assistance and to Milo A. Persinger and Violet M. Knight for their wise gift of a basement laboratory many years ago.

Michael A. Persinger

23 August, 1974

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INTRODUCTION

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Living organisms are complex matrices of electric and magnetic fields. Some of these fields are time-varying; others are relatively constant. Life forms also display ordered liquid crystal structures and a variety of electronic solid state physical properties such as semiconduction. However, living organisms are not the only sources of electromagnetic fields. The physical environment is replete with electric and magnetic field sources, both time-varying and time-invariant, from meteorological, geophysical and perhaps solar origins. Strong evidence now exists that living organisms may respond systematically to these external fields. Experimentally, it has been shown that neural semiconductor control systems exist within the organism and may indeed mediate the effects from applied electrical currents and magnetic fields (Becker, 1965). This text is primarily concerned with a relatively narrow frequency band of electromagnetic phenomena which has been called the ELF or extremely low frequency region, and its effects (if any) upon biological systems.

Electromagnetic fields, waves and impulses which occupy the frequency band between 3 Hz and 3 kHz have been termed ELF (Campbell, 1967). Very low frequency or VLF (3 kHz to 30 kHz) and ultra low frequency or ULF (< 3 Hz) phenomena occupy adjacent wavebands. Such labels have been applied primarily to time-varying electromagnetic processes associated with geophysical and meteorological sources. Persinger, Ludwig and Ossenkopp (1973), from a more psychophysiological reference point, have included time-varying magnetic and electric fields and electromagnetic waves between 0.01 Hz and 100 Hz within the ELF band. The main point is that there exists in nature electromagnetic phenomena whose time-variation properties overlap with fundamental electromagnetic conditions generated by living organisms. Such "biogenic" ELF electric and magnetic phenomena are an integral part of life forms and their survival. Consequently, the theoretical interactions between ambient and biogenic ELF fields evoke interesting possibilities.

ELF ELECTROMAGNETIC PHENOMENA IN THE ENVIRONMENT

A recent review by Persinger, Ludwig and Ossenkopp (1973) has discussed the physical sources and characteristics of ELF field-waves. In summary, ELF sources primarily arise from meteorological processes or are associated with a unique geophysical mechanism called the Schumann resonance system (within the earth-ionosphere spherical wave guide). These ELF waves, with low attenuation and high penetrability characteristics, are modified by ionospheric conditions, geomagnetic field vectors and local variations in surface conductivity. Some geomagnetic disturbances show time-variations within the ELF range. Man-made sources of ELF fields are also present. As the amount of electromagnetic pollution has increased with cultural density, the generation of ELF disturbances from advanced technologies has also increased. In the near future, agencies may intentionally produce higher ELF signal densities in order to facilitate long distance communication.

ELF electromagnetic field waves from natural sources have been reported to occur as wave forms or as ELF pulses (10^{-1} to 10^{-4} second pulse widths) from higher frequency "carrier" waves, e.g., VLF waves. The intensity values for electric and magnetic components of these field-waves are frequency dependent and show relatively large ranges. Electric field components have been reported to vary from less than 1 mV/m to about 10 mV/m. Magnetic field components vary from 10^{-6} gauss to 10^{-8} gauss around 5 Hz to less than 10^{-10} gauss over 100 Hz. Local magnetic field fluctuations within the ELF range can presumably reach values of 10^{-2} gauss (see Konig, this text). ELF components from cultural noise can reach even higher intensity values.

ELF ELECTROMAGNETIC PHENOMENA IN LIFE FORMS

The two most potent ELF generators in higher life forms are the brain-spinal cord complex and the heart. ELF components of the brain, usually measured with an electroencephalograph, mainly range between 1 Hz and 50 Hz. Major power outputs from the brain peak around 10 Hz. Electric components of the ELF processes generated by the brain (10 to 100 μV) are equivalent to 1 to 10 mV/m while the magnetic components (of the alpha wave) have been measured around 10^{-9} gauss (Cohen, 1968). The magnetic field pattern generated outside the skull by alpha rhythm currents can be depicted as coronally ordered concentric circles that connect opposite portions of the hemispheres. ELF components of the heart demonstrate a frequency maximum around 1 Hz, although higher frequency harmonics have been reported (Presman, 1970). The electric component (ECG) can be measured within the mV/m to V/m range while the rotating magnetic field component peaks between 10^{-8} and 10^{-7} gauss (Cohen, 1967), and can extend several centimeters outside the torsal. Still lower frequencies have been called "slow potentials" or infra-slow potentials. These electromagnetic phenomena involve periods of several seconds to several minutes and originate in the brain (Aladjalova, 1964) and abdomen (Cohen, 1970).

At a more microscopic level, ELF processes are an integral part of the compositional elements of the brain: the neurons. Firing frequencies of neurons have been observed between 0.01 Hz and asymptotic values of 1 kHz. Full activation of the skeletal nervous system requires stimulation ranges between 75 Hz to 200 Hz (impulses/second). On the other hand, only one pulse every few seconds is sufficient to maintain normal sympathetic and parasympathetic effect. Full activation of the two systems occurs when nerve fibers discharge between 10 Hz and 15 Hz (Guyton, 1971). Both electric and magnetic components have been measured for neurons in the process of time-variation.

The functional significances of ELF processes in the body are immense in number and implication. Viable functioning of the heart is a more obvious correlative aspect. Changes in electroencephalographic frequencies between 3 Hz and 15 Hz are known to be associated with "attention", "levels of consciousness", hypnotic suggestibility and a wide variety of more diffuse behaviours, e.g., emotional experiences. Infra-slow potentials in the brain are related to learning, memory and stress reactions. In fact, high correlations of time-varying processes between cortical points situated in opposite (contralateral) hemispheres can be used as extremely reliable indices of "thought" behaviour (Livanov, Gavrilova and Aslanov, 1973).

It must not be forgotten that the ELF processes in the brain are small (10 to 100 μV) compared to the more intense d.c. potentials of the body upon which ELF variations are superimposed. Potential differences between the frontal and occipital lobes or between the cerebral cortices and ventricles, display absolute magnitudes in the order of 10 mV (Cowen, 1974; Becker, 1965; Bures, 1957). A topographic extension of d.c. potentials around the (cranial-spinal) neuroaxis with respect to the appendages has been mapped by Becker and is displayed by Presman (1970). Relationships between d.c. potentials of the body-brain and the time-varying properties of this three-dimensional structure are clearly evident, but the dynamics of interaction remain to be elucidated. Correlational or experimentally induced changes in brain-body d.c. potentials are known to influence learning (Rowland, 1968), memory consolidation (e.g., spreading depression), and "consciousness" (Photiades et. al., 1970; Freidman and Taub, 1969; Herin, 1968), during which time changes in polarity can occur. Most of these studies have dealt with small intensity voltages or currents applied directly across the transcephalic fields.

INTERACTIONS

ELF electromagnetic fields and waves may be important biological stimuli because of their penetrability and long distance propagation. As mentioned, their frequencies and intensities are within the ranges of processes generated by living organisms. Because of the low attenuation properties of ELF field-waves (such as those associated with weather changes), penetration of housing structures that contain human organisms is possible. The technical aspects of shielding ELF-EM phenomena has been discussed by Ludwig for this text.

In nature a variety of different wave forms can be manifested within the ELF band. Many of these forms are remarkably similar to those produced by biological systems, and have been discussed by Konig. Such similarities between

environmentally derived and biogenic ELF phenomena have prompted theoretical discussions of the role of these fields during abiogenesis. These ideas have been developed by Graf and Cole. The possibility that ambient ELF field-waves may still influence fundamentally important bio-rhythmic mechanisms, such as circadian variations, has been experimentally investigated and reported by Wever. It is not untenable that naturally or experimentally produced ELF electric or magnetic fields may influence those behaviours which are in turn associated with similar frequency bioelectrical processes. The chapters by DeLorge and Marr and Persinger, Lafrenière and Ossenkopp have dealt with these possibilities.

It should be apparent that biogenic and naturally produced ELF electric and magnetic fields also share similarities in intensity levels. These similarities may not be spurious, but imply a close interrelationship between the electricity and magnetism produced by biological forms and their environment. Recent data has indicated that life forms, in addition to their usual response repertoire, may be selective and sensitive to a narrow band of natural energies.

The extensive work of Frank A. Brown, Jr. indicates that snails and similar species can be sensitive to a narrow band of magnetic field intensities which approximate natural values. Field intensities significantly above natural values were less effective (although much higher intensities, e.g. > kgauss, can be bioeffective). Recent research with homing behaviour in birds has indicated a similar narrow band intensity sensitivity as well as a possible state-dependence for the effect to take place. Apparently, field values around 0.6 gauss can influence homing orientation of birds in flight, assuming other cues (e.g., the sun) do not interfere (Walcott and Green, 1974). Narrow band sensitivities have been reported for tissue. Becker (1972) has stated that 1 to 3 mμ amps have optimal effects, whereas greater intensities can be ineffective or destructive. Such current levels can be calculated to occur in biological systems during intense geomagnetic disturbances. Furthermore, calculations indicate the 100 mV/m VLF impulses (10^{-3} sec.) can induce significant bioeffective energies in organic crystal structures that are characterized by double membranes, e.g., cell walls and synapses.

The responses of living systems to applied electromagnetic forces may not only show selectivities in stimulus intensity levels, but also specificities for stimulus frequency. Some behaviours, such as electrosleep, are controlled by the application of current frequencies as high as 500 Hz. Other organismic responses, such as bone growth, demonstrate a narrower frequency sensitivity around 0.7 Hz (Cochran, 1972).

Now it appears that some fish may both generate and respond to ELF and VLF fields as a part of normal social communication. Bullock (1973) has reported that certain fish are sensitive to electrical fields in water in the order of 1 μV/m. Some species emit wave patterns while others display pulse patterns in ranges that vary between 50 Hz and 150 Hz or 250 Hz to 600 Hz. Some species can apparently respond to frequency differences of 3 Hz to 4 Hz and even to differences of 0.1 Hz. That ocean organisms can detect and be conditioned to weak electric and magnetic fields has been reported by other experimenters as well (Rommel and McCleave, 1973).

Care must be taken when the results of directly applied currents are compared with the results from applied electric or magnetic fields. No doubt time-varying electric and magnetic fields may induce currents, but the mechanisms of interaction may not be the same or for that matter even exist. The importance, if any, of studying ELF field effects must be answered by experimentation and systematic design. The chapters in this text are concerned with verifying the possible occurrence of ELF electromagnetic field effects within behavioural and biochemical systems.

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ELF AND VLF SIGNAL PROPERTIES: PHYSICAL CHARACTERISTICS

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1. INTRODUCTION

In connection with the study of the biological effects of ELF (extremely low frequency, frequency range approximately 1 Hz ....1 kHz) and VLF (very low frequency, frequency range approximately 1 kHz .... 100 kHz) electromagnetic fields, it is of interest to know more details concerning the existence and physical nature of these fields.

In this respect it is necessary to conceptually distinguish between fields having their origin in a natural process (for which weather processes almost exclusively play a role) and those of artificial origin, that is, processes produced by man. Such man-made sources include d.c. - motors, European railway trains with 16 2/3 Hz operating frequencies, 25 Hz signals from telephone bells, 50 Hz and 60 Hz alternating currents, harmonic waves from all these signals, overland conductors of all sorts and broadcasting stations from the smallest to largest output with signal frequencies between 10 kHz and 10 GHz. This article will survey the origin of naturally produced fields in the atmosphere.

2. SOURCES OF ELECTRIC AND MAGNETIC FIELDS

Most electromagnetic phenomena of a natural origin in the ELF- and VLF-region originate primarily from weather processes. It must be remembered, however, that certain geophysical mechanisms in the ionosphere also have a releasing impetus, controlled via processes of an extraterrestrial nature - naturally, almost entirely from the sun. Such processes lie, for the most part, in the ULF-region (ultra-low frequency; frequency range of < 1 Hz).

Recently the existence of so-called quasars was demonstrated by means of radioastronomical measurements. The waves from these sources also have signal components in the ELF- and VLF-region. It is, however, not yet possible to determine if such phenomena are of importance in comparison to the processes in our earthly atmosphere.

2.1 Electromagnetic Waves

Under this heading can be placed those processes which demonstrate a propagating behavior appropriate for an electromagnetic wave, as for example, a certain relationship between the electrical and magnetic field components (wave resistence of a free space), propagation speed of approximately the speed of light as well as a relatively small attenuation rate in course of the propagation.

2.2 Field Fluctuations

These processes are predominantly of a local character, i.e., their intensity rapidly decreases with an increasing distance from their point of origin. Especially for electric and magnetic fields in the ELF-region, one can observe such independent field fluctuations. It is true that in terms of Maxwell's theory, a changing electric or magnetic field produces, respectively, appearances of the opposite type of field (fundamental principle of wave propagation). An essential supposition with regard to this principle is that the field has a spatial expansion size lying in the order of the wavelength, even at its point of origin. This stipulation is not always feasible for signals in the ELF-region, since, for example, an electromagnetic wave with a signal frequency of 10 Hz in a free space has a wave length of approximately 30,000 km. Whereas the formation of electromagnetic waves in the VLF band as a result of corresponding lightning strokes is obviously not problematic, certain favourable stipulations are necessary for this to happen in the ELF-region. These conditions will be discussed in connection with the so-called Schumann-resonances.

3. ORIGIN OF THE SIGNALS

3.1 Electromagnetic Waves

From the literature (Alpert and Fligel, 1970) one can infer that ELF and VLF signals with wave characteristics have their origin almost exclusively in lightning strokes, even though relationships to disturbances in the earth's magnetic field as well as the ionosphere and more outward layers, are known. With lightning strokes one is dealing with, as is well known, sudden equalization processes of electrical potential differences in the atmosphere (or between atmosphere and earth) which can have current strengths of well over 10,000A. For lightning strokes of 2 km length, voltage differences of 30 to 200 x 10^6 V can arise. The resulting electrical charge is judged to be 10 to 20 C. The discharge process does not proceed in a regular manner. It contains a broad frequency spectrum, which is one of the main factors that causes signals of various frequencies to arise from lightning strokes which are usually classified as atmospherics. It should be clear that we are dealing not only with visible lightning strokes, which glow in the distant sky, but also with smaller discharge phenomena, such as those occurring in turbulent clouds and especially in cold or warm fronts.

The variety of lightning stroke manifestations (intensity, spectrum, direction, duration, etc.) indicates various "generator conditions" for the emitted atmospherics. Certain parameters, which are in general a function of the state of the earth-ionosphere cavity and consequently a function of frequency, time of day, time of year and geographic location, determine the propagation of atmospherics. In addition, one can add the statistical relationships with respect to the time-place distribution of world-wide thunder storm activity, such that for a stationary observer, the total processes occurring in the VLF-ELF region, can be viewed only in terms of their statistical aspects.

3.2 Field Fluctuation

Signals with strong local characteristics occur especially in the ELF-region. For example, they can be related to a thunderstorm occurring in the vicinity of the observation locality, since lightning discharges probably have a spectral component in the region of 1 Hz. These types of occurrences can be considered under the electrophysical aspects of a purely local field observation. Such locally limited processes occur much more frequently in relationship to strongly electrically charged clouds whose turbulence arises outwardly in the form of corresponding extremely low frequency electrical field fluctuations.

Furthermore, certain observations indicate that inversion layers also play a role in this matter (König, 1959, 1960). If they are appropriately charged with electricity (for which, among other things, theoretical prerequisites are given for air streams at the boundary layer of the inversion) then rhythmical changes over distance occur, for an observer on the earth's surface, as electrical field fluctuations whose frequency is at the lower end of the ELF region.

The reverse effect, i.e., shielding the components of the electrical fields instead of producing a signal, can be produced by low-lying electrically conductive air masses. In extremely stable weather conditions, such as those occurring predominantly during the autumn in central Europe, intense fog conditions can build up which may have such shielding effects. However, during relatively stable-situated inversion layers, a complete shielding of any signal in the ELF-region has been observed under cloudless skies in large cities. No doubt the smoke plumes and smog were not without involvement.

In this respect, there is a possibility that ionized rain can produce extremely low frequency electric field fluctuations. Not only the individually charged raindrop would have an impulse type of effect, but also the precipitation of rain masses with relatively strong ionization could summate and occur as electrical field fluctuations with respect to a stationary observation area.

4. SIGNAL CHARACTERISTICS

The typical temporal processes of atmospherics with a broad-band type of measurement pattern, are depicted in Fig. 1 (Alpert and Fligel, 1970). In general an atmospheric has two parts (Fig. 1, a and b). The part of the signal that is composed of waves with frequencies of 1 to 30 kHz and received during the emission of a lightning discharge is called the high-frequency part of the signal. It often has a quasi-periodic amplitude-damped oscillatory waveform with an increasing period on the order of 500 - 1000 μsec (Fig. 1a). The energy maximum of this part of the signal occurs in the frequency interval 5 - 10 kHz. Very often, after the high-frequency part of the signal, whose last period has a very small amplitude, a slow rise in amplitude begins, resulting in a long "tail", comprising the low-frequency part of the signal, which is composed of waves with $f < 1 - 2$ kHz. The energy maximum of this part of the signal is in the interval $f \sim 10 - 200$ Hz. The tail of the atmospheric usually consists of one or two half-periods and lasts as long as several tenths of a second (Fig. 1 b). It has been shown by Tepley (1959) that in 98% of the cases atmospherics have a low frequency part spanning two half-periods. According to Belyanskil and Mikhailova (1961), however, only in 35% of the cases do atmospherics have tails, most often in the early morning (48.1%) and most infrequently at night (28.4%).

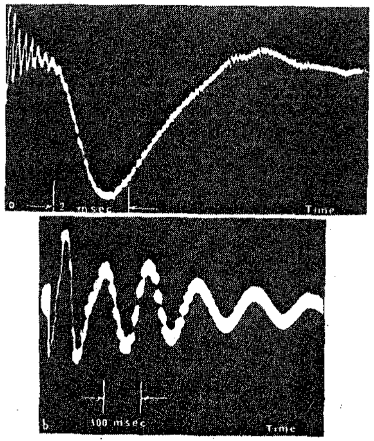

Figure 1. The high-frequency (a) and "tail" portions (b) of an atmospheric.

The cavity between the earth's surface and the ionosphere comprises wave guide in which signals, arising from lightning strokes and with a suitable frequency, can propagate as electromagnetic waves whose damping characteristics strongly depend on the condition of the ionosphere (Alpert and Fligel, 1970). For a stationary observation station, such a large number of atmospherics can occur as a result of momentary propagation factors and general world thunderstorm activity. Consequently, the sum of all the signal formations within a certain band width can be observed as a so-called "noise". This is especially the case for a certain narrow band of ELF atmospherics whose propagation can obviously occur over the total earth's surface and whose signal activity is thus to a certain degree a measure of world thunderstorm activity (Keefe et al, 1973; Polk, 1969). VLF signals on the other hand can also be observed to propagate over the entire earth's surface (Watt and Groghan, 1964). Thunderstorm activity at medium distances (500 - 2000 km) clearly produce increased field strength reception at the observation stations (particularly because of the greater ease of signal summation at this frequency). For this reason VLF atmospherics easily register as single discrete signals.

It was found that the wave attenuation in the earth-ionosphere waveguide was maximum at a frequency on the order of 2 kHz and minimum at about 10 kHz. Chapman and Matthews (1953) and Chapman and Macario (1956) recorded the amplitude spectrum of atmospherics over a wider frequency range at distances of 250 to 2000 km. A maximum was located at $f \sim 10$ kHz, and a new maximum was discovered below 0.5 kHz.

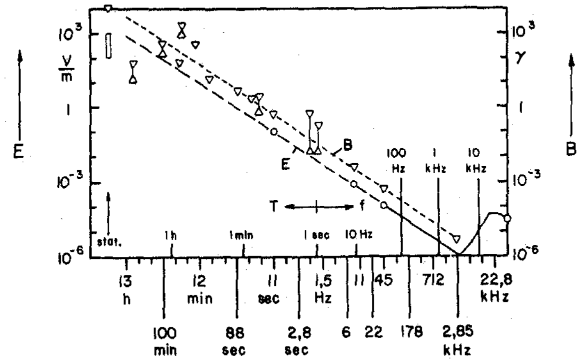

Figure 2. Amplitudes of the natural E- and H-Field measured with wide-band amplifiers in the frequency range 0 to 50 kHz.

Figure 2 depicts a composite of sufficient middle amplitude values of the electrical field component E in V/m (circles) and the magnetic field component B in γ* (triangles) of specific individual signals over a wide frequency band as measured by a broad band receiver (Oehrl and König, 1968). In the region of f = 2 kHz down to period length T of several hours, the field strengths obviously increase proportionately with respect to $(1/f)^{1,1}$ or $T^{1,1}$ and occur everywhere in the E/H ratio with values typical for electromagnetic waves in free space.

4.1 Magnetic and Electric Fields in the ELF Band

Ionospheric Processes. In general it is difficult to measure those extremely low frequency electric field variations in the lower atmosphere which are due to any closed current system in the ionosphere or due to any magnetospheric or planetary scale excitation which causes an Ionospheric current system. The reason is the same as for the practical absence of measurable electric fields in the vicinity of any current carrying circuit which is small in terms of wavelength and does not contain closely spaced elements (such as opposite plates in a capacitor or opposite wires of a transmission line) which are at substantially different potential (Polk, 1973).

ELF- and Micropulsation magnetic fields do lead to conveniently measurable electric fields in the ground which are the basis of the "Telluric currents" or "Telluric fields" methods (Garland, 1960; Lokken, 1964; Hopkins and Smith, 1966). The appearance of such currents is related to the properties of the upper part of the earth's crust which make it an extemely good conductor for signals of the ELF-band in the sense that the conduction current is much larger than the displacement current.

ELF-Atmospherics. As frequencies of a few Hertz are exceeded, most of the electric and magnetic fields measured in fair weather near the ground are neither of local origin nor due to extra-terrestrial sources, but result from

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* 1γ = 10^{-5} Gauss = 10^{-9} Tesla

excitation of the earth-ionosphere cavity by distant thunderstorms (König, 1959, 1960; Schumann, 1952; Schumann and König, 1954; Wait, 1960; Galejs, 1972; Chapman and Jones, 1964; Rycroft, 1965; Balser and Wagner, 1960). In the instance of "Schumann"-resonances, a cavity resonator has been formed because the circumference of the earth is equal to one wavelength at a frequency of 7.5 Hz.

When conduction losses in the ionosphere boundary are considered, the resonance frequencies become:
(for n = 1,2,3...)

$$f \simeq 8 \sqrt{\frac{n(n+1)}{2}} \text{ Hz.}$$

The power spectrum of the measured noise (Keefe et al, 1973; Balser and Wagner, 1960) has the appearance indicated by Fig. 3 and typical levels are:

$0.63\ \text{m}\gamma/(\text{Hz}^{\frac{1}{2}})$ for horizontal magnetic flux density and

$0.10\ \text{mV}/(\text{m Hz}^{\frac{1}{2}})$ for vertical electric field strength.

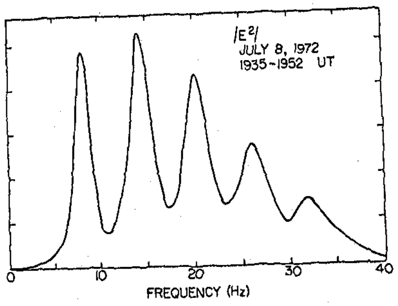

Figure 3. Spectrum of the vertical electric field ($/E^2/$) obtained near Kingston, R.I., USA.

At any particular observation point, at a given time, the vertical ELF electric field due to distant sources is related to the magnitude of the horizontal magnetic field roughly, but not exactly by the free space wave impedance such that:

$$(E/H) \simeq 377\Omega \qquad \text{(Polk, 1969).}$$

The "Schumann resonances" may be explained in terms of "standing waves" which exist in the earth-ionosphere cavity as a result of extremely low attenuation at ELF frequencies (for expl. 0.50 db/1000 km at 20 Hz) (Tran and Polk, 1972). In sea water, a medium damping rate of about 0.1 db/m can be calculated (Soderberg and Finkle, 1970). Frequently the "Schumann" resonances become obscured by other noise above the third harmonic (about 20 Hz) and they are almost never observable on experimental spectra above the fifth resonance (about 32 Hz) primarily because the cavity Q at the higher resonances becomes too small (or, equivalently, the width of the resonance peaks becomes too large).

As a consequence of the differential relationships between ionosphere and signals in the VLF and ELF region,

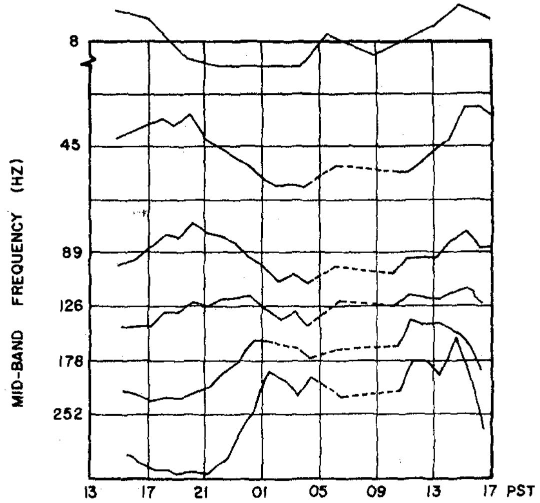

Figure 4. Comparison of diurnal variation of mean electromagnetic signal amplitude in various frequency bands.

changing daily states occur with a frequency dependence relative to the mean signal intensity received. Whereas for VLF atmospherics there is a clear dominance of signal intensity at night, a dominance during the day occurs for the ELF region. The cross-over occurs at approximately 120 Hz as is shown in Fig. 4 (König, 1959, 1960; Schumann and König, 1954; Holzer et al., 1957). More detailed observations of atmospherics in the Schumann resonance region have produced the following. With respect to resonance fluctuations or wave characteristics, the signals have a sine-wave type of temporal process for a *stationary* observer (I in Fig. 15) whose envelope is either fast rising (for signals consisting of only a few oscillations) or flat (for signals which usually extend over several oscillations).

Often a tendency for a decrease in the frequency at the end of a signal is shown for recorded wave lines. The frequency decrease can consist of up to 30% of the original value. The degree of frequency change is quite variable for individual signals. It has been noticed, however, that oscillations that reach very large amplitutdes and thus had a fast rising envelope as well as being of relatively short duration, also show marked changes in their frequency. For long duration signals with relatively small amplitude and flat envelope, a change in frequency is practically impossible to measure.

Fair weather strongly favoured these signals in an obvious manner. At the very least they could almost always be clearly received under these weather conditions. Thus it is probable that under bad weather conditions, signals of Type I, which are *not* recorded during bad weather conditions, may be masked by other manifestations with larger amplitudes. At night Type I signals occur much less than during the daytime. The ratio of daytime to nighttime intensity ranges from 3:1 to 10:1 (Fig. 5).

In performing measurements at frequencies below 100 Hz (Keefe et al., 1973; Lokken, 1964; Schumann and König, 1954; König et al., 1964; Clayton et al., 1973), it is of course extremely important to suppress by suitable filter techniques the noise due to local power systems (60 Hz in the U.S., 50 Hz in Europe) which is almost always much larger than the fields caused by natural sources. Power-line noise, including noise due to railway systems which may operate at lower frequencies (for example, 16.67 Hz in Germany [Schumann and König, 1954]) is, however, not the only man-made noise in this frequency range. In the U.S. most telephone ringing systems employ frequencies in the vicinity of 20 Hz and ELF fields measured near telephone lines may be dominated by this source. Modulation of higher frequency communication carriers (particularly VLF carriers, 10 kHz to 100 kHz) may also be detected by non-linearities in ELF-measurement systems when the carrier level is large enough to overload high sensitivity input circuitry. Thus a strong 30 Hz signal was measured (König et al., 1964) whenever ship-borne ELF detecting equipment was brought to within perhaps 100 km of a "Loran" navigation transmitter. The reasons for this were the modulation of a Loran signal. ELF electric and magnetic energies generated by man thus frequently mask the noise due to natural phenomena.

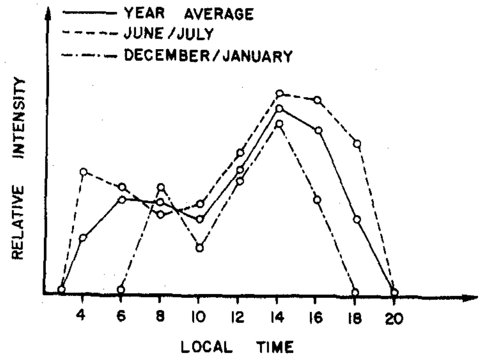

Figure 5. Diurnal variation of strong ELF atmospherics (Schumann resonance at 8 Hz).

4.2 VLF - Atmospherics

For a stationary observer, waves in the VLF region, arising from various electrical discharge phenomena in the atmosphere, change their temporal pattern of waveforms with increasing distance from their point of origin during the process of a propagating in the earth - ionosphere waveguide. An example of this is shown in Fig. 6 (Alpert and Fligel, 1970). One measure, with which dampening of the signal during propagation of VLF signals can be expected, is depicted in Fig. 7 (Rhoads and Garner, 1967). In the range of approximately 200 km and 2,000 km, the signal amplitude decreases by approximately 15 - 18 db/1000 km. As is shown in Fig. 8 for even greater distances the attenuation of signals of 15 kHz is approximately 4 db/1000 km (Watt and Groghan, 1964). The attenuation factor as a function of frequency is given in Fig. 9 (Watt and Maxwell, 1957).

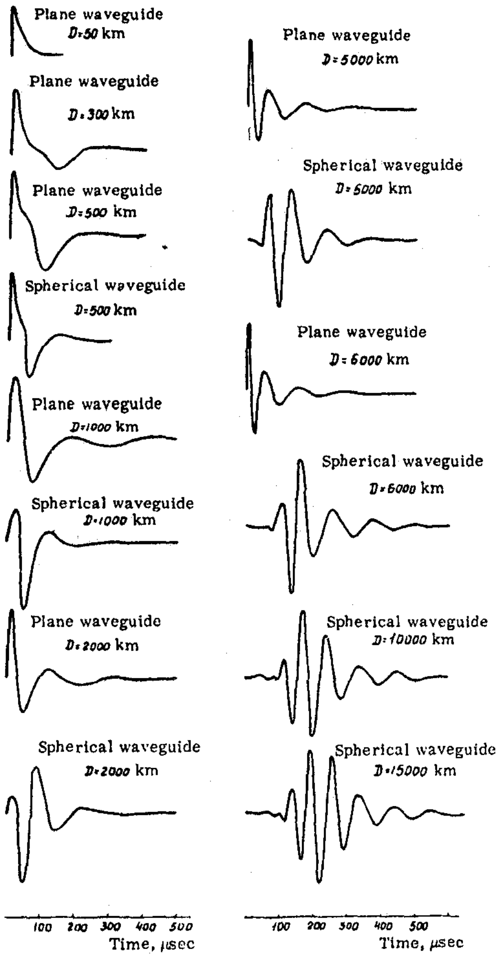

Figure 6. Signal forms E (t,D) calculated for atmospherics at distances of 50 - 15,000 km in plane and spherical waveguides.

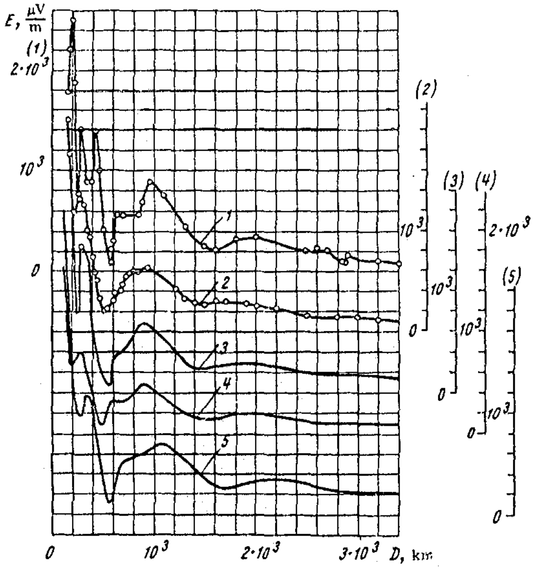

Figure 7. Comparison of the results of field intensity measurements at a frequency of 16.6 kHz and power W = 1 kW (curves 1 and 2) with theoretical calculations (curves 3 - 5).

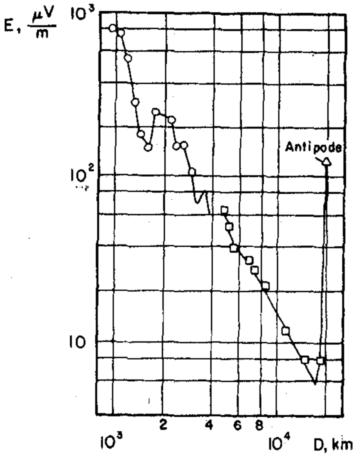

Figure 8. Results of field strength measurements at frequencies of 16.6 kHz (circles), 17.5 kHz (squares) and 14.7 kHz (triangles).

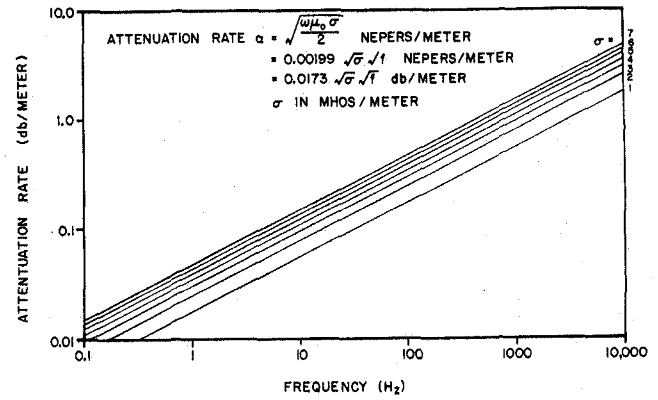

Figure 9. Attenuation factor for different situations as a function of frequency.

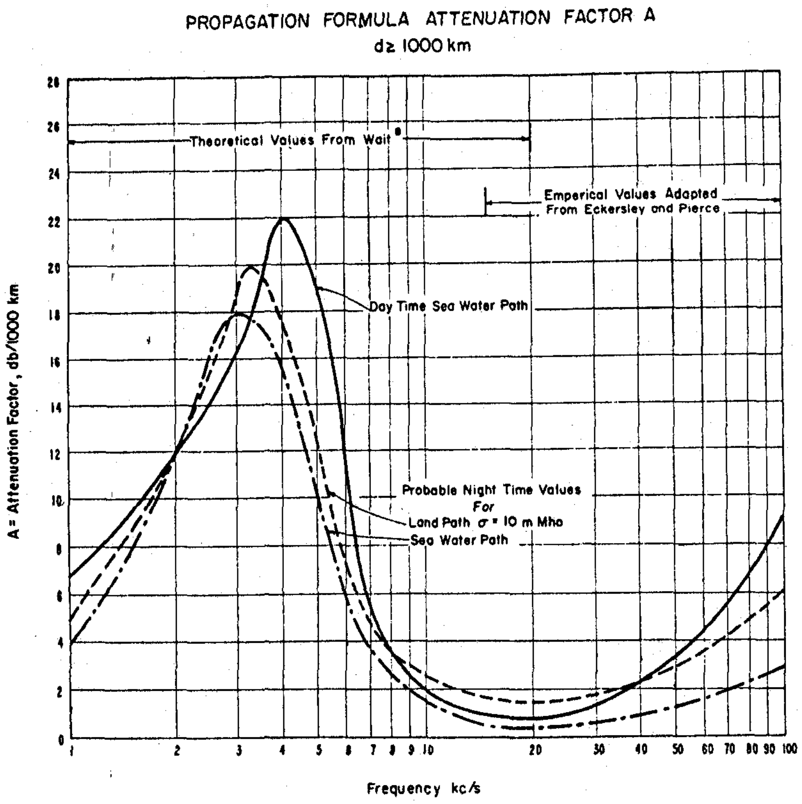

Figure 10. Attenuation rate in sea water for various values of sea water conductivity.

For comparison purposes, Fig. 10 shows that a mean attenuation rate of approximately 2 db/m takes place in sea water for 10 kHz (Soderberg and Finkle, 1970).

It is well known (Alpert and Fligel, 1970; Storey, 1953) that a considerable part of the energy of low frequency waves (and particularly of those emitted by lightning discharges) emerges from the surface waveguide, passing beyond the boundaries of the ionosphere. In the frequency band from 1 to 10 kHz and above, this leads to the formation of the so-called whistling atmospherics, which propagate along the lines of force of the earth's magnetic field between magnetically coupled points. This explains the high signal flux for "magnetic antipods" as can be seen in Fig. 8.

Another important effect associated with the magnetic field is the following. It has been shown in a number of experiments that the reciprocity principle is violated inside the waveguide over sufficiently long paths. If a wave propagates from east to west the field amplitude is smaller than when the wave propagates from west to east (Watt and Groghan, 1964; Taylor, 1960a; Hanselman et al., 1964; Taylor, 1960b; Martin, 1961; Crombie, 1958, 1963). Pertinent data are given in Table 1 and Fig. 11. The table shows the mean values of the field strength measured on the

TABLE 1

Field Strength Measured on Different Routes

Transmitter	Receiver	Field Strengths	
		Day	Night
Hawaii (W)	Canal Zone (E)	37	70
Canal Zone (E)	Hawaii (W)	3	20
New York (N)	Canal Zone (S)	83	140
Canal Zone (S)	New York (N)	81	135
New York (NE)	Hawaii (SW)	8	63
Hawaii (SW)	New York (NE)	15	61

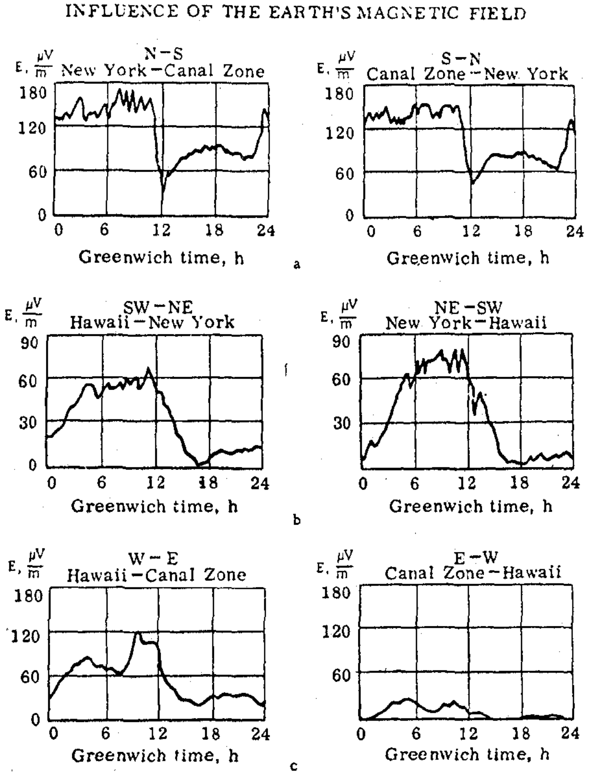

Figure 11. Diurnal variation of the field intensity, measured on different routes at a frequency of 10.2 kHz.

routes Hawaii-Canal Zone (8450 km along the geomagnetic equator from west to east (W-E), Canal Zone-New York (3820 km along the geomagnetic meridian from north to south and back, N-S and S-N), and Hawaii-New York (7830 km obliquely to the magnetic meridian) (Hanselman et al., 1964). On the N-S and S-N routes (Fig. 11a) the field strength in both directions has almost identical values. Reciprocity begins to fail, however, when the waves propagate in a SW-NE direction or vice versa (see Fig. 11b) and is completely upset on W-E and E-W routes (Fig. 11c). As the table indicates, on W-E and E-W routes, where reciprocity is clearly lacking, the daytime field strength differs by a factor of 12, while at night it differs by a factor of 3, 5.

Proximal field observation of lightning discharges reveal noticeable field strength values, as can be seen in Fig. 12 (Watt and Maxwell, 1957). Such atmospherics, whose intensity is much greater than the usual background signal intensity, can thus naturally be picked up as individual signals. Fig. 13 tells us which intensities of the electric field one can expect to be a function of frequency, with the parameters of distance and time of day (Galejs, 1970; Ishida, 1969). In reference to correlational studies dealing with the biological effects of natural VLF signals, it is customary to record the number of atmospherics occurring

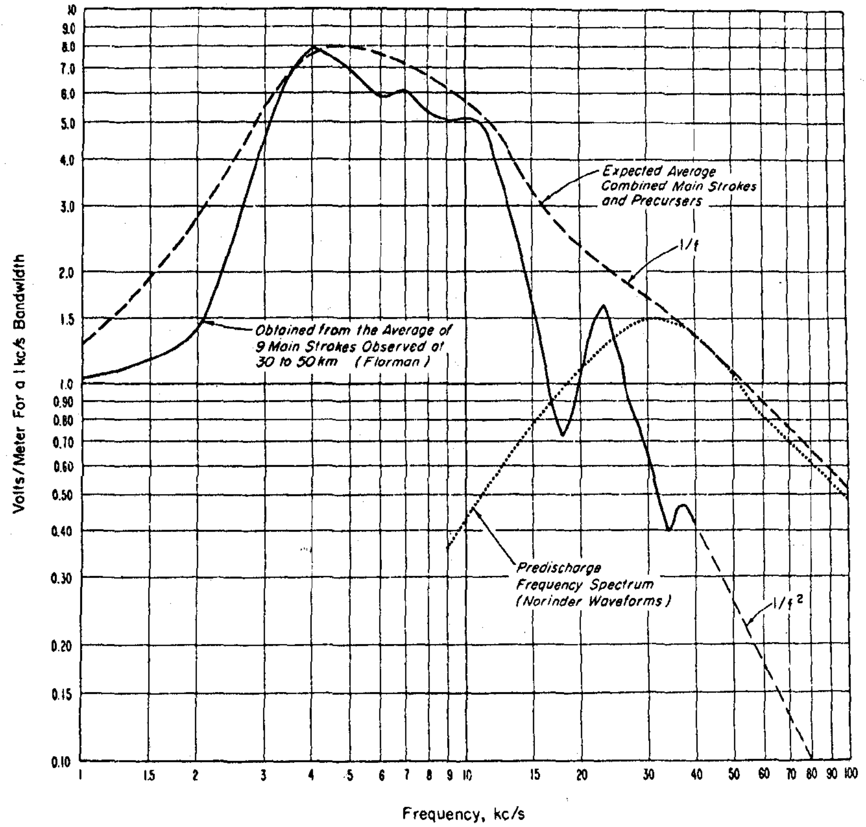

Figure 12. Frequency spectrum of the radiation component, equivalent field intensity at a distance of one mile.

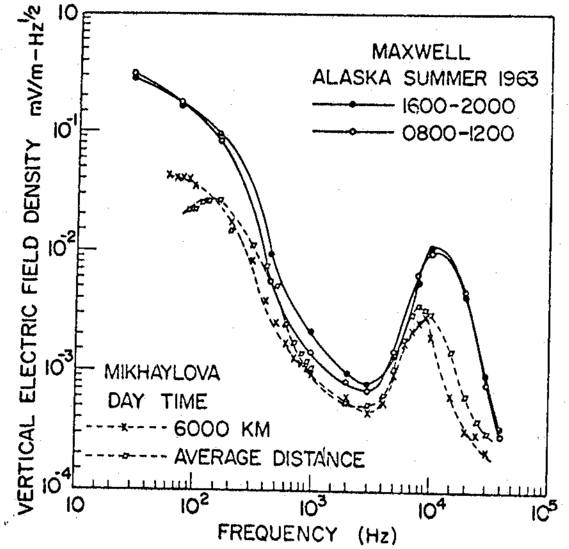

Figure 13. Frequency spectrum of atmospheric noise at the ELF and VLF range.

per unit time. At the same time, intensity values of atmospherics falling within various intensity ranges are tallied by means of the appropriate measuring devices (König, 1954, 1955; Schulze, 1970). Further subdivision is possible by means of limiting the recording frequency range for various bands.

4.3 Relations Between ELF and VLF Signals

Since both ELF and VLF electromagnetic fields seem to have demonstrable biological effects, it is appropriate to look for the physical bases for these effects. Biological effectiveness of electromagnetic fields in the VLF region is usually reported for signals with at least median intensities, e.g., atmospherics that can be individually recorded (propagation is favourable for a distance of less than 1000 km). The number of atmospherics (one wave train is considered an impulse) per unit time is recorded and the resulting impulse frequency is the parameter used. Appropriate correlations between biological factors and the occurrence of VLF atmospherics most often result when the

impulse frequency of the latter lies in the ELF region, i.e., between 1 Hz and approximately 50 Hz. If one further takes into consideration the non-linear properties, which biological systems seem to prefer in relation to electrical processes, it can be found that for each VLF impulse, a polarity impulse takes place in such systems as a result of processes similar to rectification, with a duration of the total original VLF impulse (see Fig. 14). The following results can thus be expected. Biological systems are not only influenced by higher frequency ELF energies but additionally by any form, even through impulse trains with a fundamental frequency in the ELF region on the basis of the nonlinearly produced direct current components. When investigating the physical basis of the origin of VLF - atmospherics (or the corresponding extremely low frequency produced VLF-fields) one should not forget to include components of the total signal information, lying in the ELF region, in relation to the frequency aspects of the VLF region.

4.4 Existence of Field Fluctuations

Fluctuations of electric or magnetic fields are presumably of a strictly local nature. Such events are observed frequently in the ELF region (II & III in Fig. 15) (König, 1959, 1960; Schumann and König, 1954). Recordings demonstrate that in contrast to the sine-wave type of oscillation of electromagnetic waves (I in Fig. 15), the temporal processes of such waves are usually of an irregular nature.

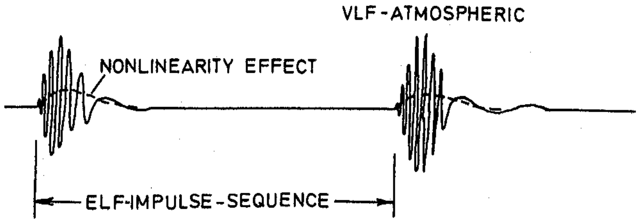

Figure 14. ELF-signal caused by VLF-signals in connection with non-linear effects.

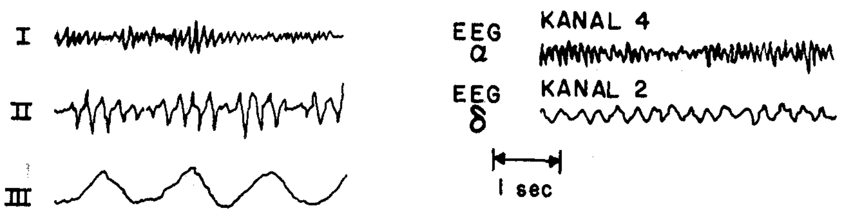

Figure 15. Different signal types of natural ELF electric field components compared with EEG ∞ and δ rhythm.

The duration of these types of signals is often greater than one hour. During this time the field strength values can deviate considerably and often reach values of over 10 V/m. The recorded signals had almost always a strong content of harmonics. Usually they varied statistically in their fundamental frequency. It was not possible to show a peak in the occurrence of these signals for any given favourable time period. They could be recorded at all times and the obvious day-night difference found for signals of the Schumann-resonance type, was not visible.

The existence of this type of signal obviously depends to a certain extent on the local weather conditions. Thus, almost no recording of this type of signal occurred during cloud-free fair weather conditions. On the other hand, these signals seemed to occur more frequently during low-lying cloud conditions as well as during initial rain conditions foll following longer dry periods. Nevertheless, no absolute relation existed between rain and signal activity, since signal recordings were noted during rain-free periods and not always during rain.

Observations over longer periods indicated the existence of certain relationships between such processes associated with Föhn weather conditions, which are well known in the Alp region. The frequency of these types of phenomena usually lie in the region between 3 Hz and 6 Hz (II in Fig. 15). Furthermore, one can observe a certain frequency of occurrence of electric field fluctuations of approximately 0.6 Hz, with closer approximations to sine-wave characteristics, as clearly demonstrated by comparative measurements

TABLE 2

Order and Magnitude of Attenuation Factors and the Intensities of Electromagnetic ELF and VLF Waves from a Natural Origin

	ELF-Region		VLF-Region	
	atmospherics Schumann Resonances (waves) approx. 8 Hz	local field-fluctuations approx. 0.6 Hz, 3 - 6 Hz	atmospherics (10 kHz)	local field-fluctuations
Propagation Attenuation (damping)	0.5 db/1000 km in air 0.1 db/m in sea water	- - - - - - - - -	12...18 db/1000 in air 2 db/m in sea water	- - - - - - - - -
E-field	(distant field) 1 mV/m	3...6 Hz: 1mV/m 10V/m 0.6 Hz: 10mV/m	1mV/m (distant field)	10 V/m
H-field	10^{-5} A/m in air approx. 10^{-6} Gauss	up to 0.1 A/m in air approx. 10^{-2} Gauss	10^{-5} A/m in air approx. 10^{-6} Gauss	lightning stroke of 10 KA for 10 km distance up to 0.1 A/m in air approx. 10^{-2} Gauss

over a few kilometers. No doubt one can also expect to find, as a result of certain atmospheric phenomena, signals in the VLF region which are confined to a relatively small area. However, on a physical basis, they are of no further importance, unless one considers their relevance to lightning

5. SUMMARY

A stationary observer can observe electromagnetic process of natural origin in both the ELF and VLF region. These processes have their origin in the propagation of electromagnetic waves as well as in local phenomena. Taken in summary, signals exist over the whole frequency band, whose intensities range from relatively small values up to those intensities possible from local fields during thunderstorms. A general summary of the results is shown in Table 2. The respective approximate values of field strengths given are for those signals clearly greater than the background noise and whose observed intensities do not appreciably increase when the recording frequency band of the measuring device is increased

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ELECTRIC AND MAGNETIC FIELD STRENGTHS IN THE OPEN AND IN SHIELDED ROOMS IN THE ULF- TO LF-ZONE

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INTRODUCTION

A. System of Measurement and Basic Equations

In this chapter the Centimeter-Second-Ampere-Volt system (cm-s-A-V), used conventionally in electrodynamics is employed. The Maxwell Equations are thus written:

$$\text{Curl } \vec{H} = \sigma E + \varepsilon \frac{\partial \vec{E}}{\partial t} \qquad (1)$$

$$\text{Curl } \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t} = -\frac{\partial \vec{B}}{\partial t} \qquad (2)$$

The arrows over E and H are to express the vector-nature of field strength.

In calculating the propagation of electromagnetic waves in free space, in the earth surface-ionosphere system, and through materials (insulators, semi-conductors, metals), these differential equations are written up in their respective co-ordinate systems (sphere co-ordinates for the earth system, cartesian co-ordinates for prismatic shielded rooms, etc.); and these equations are solved for, taking into account the edge-constraints. The edge-constraints at the border-surfaces between electric conductors and non-conductors (e.g. to a good approximation, air)are:

1. Continuity of the tangential component of H (or the magnetic potential);

2. Continuity of the normal component of B or the tangential component of E.

In addition to this, there are edge-constraints in infinity, i.e. for $r = 0$ (in the center of a shielded room) and for $r \to \infty$, where regularity, finite values for E and H, or else singularity at the locus of the source, must be under consideration.

In the case of shielded rooms having a more complex shape, these fairly versatile integrations can be done only to a good approximation or by using computers. They can be found in texts on theoretical physics and need not be repeated here. We offer only the results and the limits of validity (see Döring, 1956 and Kaden, 1959).

B. Abbreviations

A	Ampere (electric current)
a	grid constant in cm
B	$\mu \cdot H$ = magnetic induction in V s/cm^2
b	band-width in 1/s
c	velocity of light $= 299{,}792 \cdot 10^5$ cm/s
cm	centimeter = 0.3937 inches
d	thickness of a shielding material in cm
E	electric field strength in V/cm
e	elementary charge $= 1.6 \cdot 10^{-19}$ A·s
f	form factor of a shielded room
H	magnetic field strength in A/cm
$\hbar$	$h/2\pi$, where h = Planck's constant $6.623\ 10^{-34}$ VAs^2
J	electric current in A
i	Index for size in the center of a shielded room

$j = \sqrt{-1}$	(imaginary unit)
K	reciprocal grid co-ordinate
$k = 1.38\ 10^{-23}$	VAs / Temperature gradient = Boltzmann's constant
l	length in cm
n	ion density in cm^{-3}
o	index for size outside of a shielded room, or for a distant room
P	electric power in V/A
q	shielding factor
R	electric resistance in V/A
r	radius in cm (in general, the average radius of a shielded room)
s	second
T	absolute temperature in $^{\circ}$Kelvin
t	time in s
U	voltage in V
u	ion velocity in cm^2/V·s
V	volt
v	enlargement factor
x	abscissa of cartesian co-ordinates
y	ordinate of cartesian co-ordinates
z	the third dimension of cartesian co-ordinates
δ	penetration depth in cm

$\varepsilon = \varepsilon_r \cdot \varepsilon_0$

$\varepsilon_0 = \frac{1}{4\pi 9 \cdot 10^{11}} \frac{\text{A s}}{\text{Vcm}}$ = di-electric constant of a vacuum

ε_r = relative di-electric constant

ζ	pole angle in the polar co-ordinates
κ	extinction coefficient in s/cm
λ	wavelength in cm

$\mu = \mu_r \cdot \mu_0$

$\mu_0 = 4\pi \cdot 10^{-9}$ Vs/Acm magnetic permeability of a vacuum

μ_r = relative magnetic permeability

ν frequency in 1/s

$\pi = 3.141592....$

ρ polar co-ordinate

σ electric conductivity in A/Vcm

τ adaption time in s

ϕ asymptote angle in the polar co-ordinate system

$\omega = 2\pi\nu$ = circular frequency in 1/s

I. MAGNETIC AND ELECTRIC FIELD STRENGTHS IN NATURE (IN FREE SPACE)

1. Wave Types

Near the earth's surface, essentially five electromagnetic wave types are recorded; at low frequencies, chiefly four:

1) the earth's static magnetic field;
2) an electromagnetic cavity radiation of the earth-crust-resonator, earth surface-ionosphere in the ULF- and ELF-range; this radiation is stimulated not only through electric discharge in this cavity, but also through magnetic changes in the sun;
3) the pulsating magnetic field of the sun; magnetic dipole radiation from a distant source (by "distant" is meant that the distance of the source from the observer is large relative to the wavelength of the ray);

4) the so-called Atmospherics, which are emitted from electric dipole rays into the atmosphere in the form of lightning and small micro-storms; in this case, the distance of the source from the observer is low (i.e. less than a wave-length) for the low frequency portion due to the wide frequency spectrum; for the higher frequency portion, however, it is long. Between these lies a transition range;
5) electromagnetic waves emitted from variable elementary particle currents near the earth's surface (the Van Allen belt) -- electric dipole radiation of higher frequency.

Strictly speaking, for effects (3) and (5), one is dealing with multipolar radiation, in which, however, the dipolar portion is the greatest. Though all five effects occur simultaneously, they cannot always be clearly separated from one another. Thus, for example, effect (3) overlaps with the static field (1), resulting in a pulsating magnetic field.

On the basis of equations (1) and (2), each magnetic oscillation field brings about an electric curl, and vice versa. The concept of a curl should be explained more precisely: if one holds a small fly-wheel with an elongated axle (as a handle) in a turbulently flowing liquid, there exists a definite position and a definite direction of the wheel axle, at which the wheel rotates the fastest. Thus, the rotation velocity is a measure for the strength of the curl and the spatial position of the axle, a measure for its direction. Hence, we have a defined vector which lies perpendicular to the plane of the curl.

As a simple demonstration, let us calculate the field strength of the curl: An electric alternating field strength in the y-direction is generated through two condensor plates perpendicular to the y-axis, through which an alternating potential U is applied to the plates. If 1 equals the distance between the plates in cm, we have:

$$\vec{E} = E_y \exp(j\omega t) \quad \text{with } E_y = U_0/1$$

(We are using complex symbols for the description of the

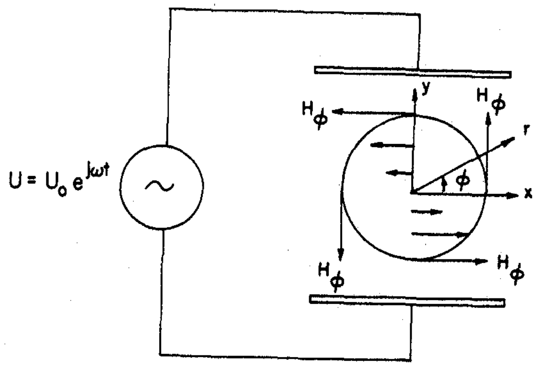


Figure 1. H-curl in an artificially induced field between two condensor plates.

size of the alternating voltage or alternating current). If the electrical conductivity $\sigma = 0$ (a vacuum, also holds to a good approximation for air), we obtain for the first Maxwell equation:

$$\text{curl } H = (\text{curl } H)_z = \left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y}\right) \tag{3}$$

or, in polar co-ordinates (cylinder co-ordinates):

$$(\text{curl } H)_z = \frac{1}{\rho} \cdot \frac{\partial (H\phi \cdot \rho)}{\partial \rho} \tag{4}$$

From this, the magnetic field strength $H\phi$ can be calculated ($H\phi$ occurs circularly, i.e. as the tangent to a circle with a radius ρ):

$$H\phi = \frac{1}{\rho} \int_0^\rho r(\text{curl } H)_z \cdot dr \tag{5}$$

with r = integration variable.

From the first Maxwell equation we obtain as a result:

$$H\phi = \frac{1}{\rho} \int_0^\rho r\varepsilon \frac{\partial E}{\partial t} \cdot dr = \tfrac{1}{2}\varepsilon \cdot \frac{\partial E}{\partial t} \cdot \rho = \tfrac{1}{2}\, j\varepsilon\omega\rho E_y \tag{6}$$

where the factor j merely indicates a phase shift of 90°.

For $\varepsilon_r = 1$ (vacuum, or approximately, for air), the value for $H\phi$ becomes:

$$|H\phi| = \tfrac{1}{2}\, \varepsilon_0 \omega . \rho . E_y \tag{7}$$

independent of ϕ.

Thus, $\rho \leq \frac{1}{2}$, the greatest magnetic curl field strength occurs closest to the plates; and to be sure, the magnetic curl field strength on the upper plate is in a direction exactly opposed to the one of that on the lower plate (Fig. 1). It is important to note that the H-curl is dependent on the circular frequency ω. In a static field E ($\omega = 0$), no curl is produced; and at low frequencies, only a quite weak one. If we have perpendicular to the E-vector E_y, an H-field (generated through two Helmholtz coils), then $H\phi$ would be added to H_x in one half of the field-induced room; in the other half, $H\phi$ would be subtracted from H_x. The field H_x is strengthened only in a limited area. We have analagous results for the E-curl generated from an H_x -alternating field. It becomes:

$$|E\phi| = \tfrac{1}{2}\mu_0 \omega\rho . H_x \tag{8}$$

In the frequency range which is of interest to us here, and for those field strength ratios E to H which occur in nature, both components $H\phi$ and $E\phi$ are negligibly small. This is important, for example, in the re-creation of Atmospherics by means of condensor plates and Helmholtz coils (Ludwig, 1968a).

At a frequency of 500 kHz, in a spatial expansion of $l = 50$ cm, and for the ratio $E/H = 120\pi$, which occurs in the long distance field of an electric dipole (see below), both adjunct component fields $E\phi$ and $H\phi$ constitute less than 1% of the primary field strengths E_y and H_y. However, were one to shield the E-field at more than four orders of magnitude, then $E\phi$ becomes the sole remaining electric field strength within the shielded room, insofar as H is not substantially shielded off (see below).

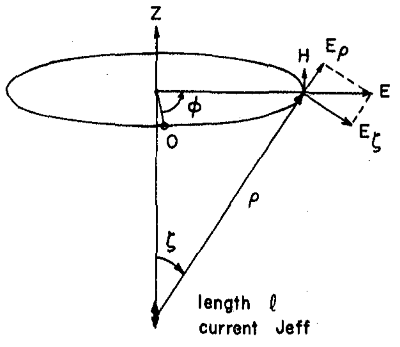
Following this discussion of curl-formation, we will return to the wave types previously mentioned. In the frequency range they distinguish themselves from the others by the ratio E/H. This will be treated in the following section.

2. The Ratio of Electric to Magnetic Field Strengths as Dependent on Distance to the Source and on Frequency or Wavelength.

Dipole radiation. We will go through the calculation of an electric dipole; this holds analogously for a magnetic dipole.

If we omit the complex time-factor exponent ($j\omega t$), the field of an electric dipole in free space consists of the following components (H. Hertz, 1892),

$$\text{(it is: } \rho^{1} = \sqrt{\rho^2 + \ell^2}\text{);} \qquad (9)$$



(H=H$_\phi$ BACKWARDS IN FIG. 2)

Figure 2. Spatial polar co-ordinates ρ, φ, ζ, for the computation of electric dipole radiation E, H, in the open. 0 = zero point of the φ -angle count.

$$E\rho = \frac{1}{j} \cdot \frac{J\cdot\ell}{(2\pi)^2} \sqrt{\frac{\mu_0}{\varepsilon_0}}\, \frac{\lambda\cos\zeta}{{\rho^{1}}^{3}} \left(1 + j\,\frac{2\pi\rho}{\lambda}\right) \exp\left(-j\,\frac{2\pi\rho^{1}}{\lambda}\right) \qquad (10)$$

$$E\zeta = \frac{1}{j} \cdot \frac{J\cdot\ell}{2(2\pi)^2} \sqrt{\frac{\mu_0}{\varepsilon_0}}\, \frac{\lambda\sin\zeta}{{\rho^{1}}^{3}} \left(1+j\,\frac{2\pi\rho}{\lambda} - \left[\frac{2\pi\rho}{\lambda}\right]^2\right)\exp\left(-j\frac{2\pi\rho^{1}}{\lambda}\right) \qquad (11)$$

$$H = H\rho = \frac{J\cdot\ell}{4\pi} \cdot \frac{\sin\zeta}{{\rho^{1}}^{2}} \left(1 + j\,\frac{2\pi\rho^{1}}{\lambda}\right) \exp\left(-j\,\frac{2\pi\rho^{1}}{\lambda}\right) \qquad (12)$$

All other components of E and H disappear ($E\phi = H\rho = H\zeta = 0$). For the low distance field, $\rho \ll \lambda/2\pi$ and the field components become, to a good approximation:

$$E\rho = \frac{1}{j} \cdot \frac{J\cdot\ell}{(2\pi)^2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \cdot \frac{\lambda\cos\zeta}{{\rho^{1}}^{3}} \qquad (13)$$

$$E\zeta = \frac{1}{j} \cdot \frac{J\cdot\ell}{2(2\pi)^2} \sqrt{\frac{\mu_0}{\varepsilon_0}} \cdot \frac{\lambda\sin\zeta}{{\rho^{1}}^{3}} \qquad (14)$$

$$H\phi = \frac{J\cdot\ell}{4\pi} \cdot \frac{\sin\zeta}{{\rho^{1}}^{2}} \qquad (15)$$

The amplitude ratio E/H (dimensions V/A, thus, that of electric resistance) is in the low distance field for $\zeta \leq 90^o$:

$$\left(\frac{E}{H}\right)_{low} \geq 120\pi \cdot \frac{\lambda}{2\pi\rho^{1}} \gg 120\pi \qquad (16)$$

Because of the factor j^{-1} in E (equations (13) and (14)), the phase shift Ψ between E and H is:

$$\Psi_{low}\ (E,H) = 90^{o} \qquad (17)$$

In the long distance field, $\rho \gg \lambda/2\pi$ and the field components become, in good approximation:

$$E\rho = 0 \qquad (18)$$

$$E\zeta = j \cdot \frac{J \cdot \ell}{2\lambda} \sqrt{\frac{\mu_0}{\varepsilon_0}} \cdot \frac{\sin \zeta}{\rho^1} \exp\left(-j\,\frac{2\pi\rho^1}{\lambda}\right) \qquad (19)$$

$$H\phi = j \cdot \frac{J \cdot \ell}{2\lambda} \cdot \frac{\sin \zeta}{\rho^1} \exp\left(-j\,\frac{2\pi\rho^1}{\lambda}\right) \qquad (20)$$

The amplitude ratio E/H for all ζ is, in this case:

$$(E/H)_{long} = 120\pi \qquad (21)$$

thus, substantially smaller than in (16); this means that the magnetic field is proportionally much greater in the long distance field than in the low distance field. The value 120π is also referred to as the characteristic impedance of a vacuum. The phase shift Ψ becomes:

$$\Psi \simeq 0^{o}. \qquad (22)$$

At $\lambda \simeq 2\pi\rho$, hence in the transition zone, when $\zeta = 90^{o}$, we obtain:

$$E \simeq \frac{J \cdot \ell}{2(2\pi)^2} \sqrt{\frac{\mu_0}{\epsilon_0}}\ \frac{\lambda}{\rho^{1\,3}}\ (0.54 - 0.84j) \qquad (23)$$

$$H \simeq \frac{J \cdot \ell}{4\pi} \cdot \frac{1}{\rho^{1\,2}}\ (1 + j)\ (0.54 - 0.84j) \qquad (24)$$

The amplitude ratio E/H becomes:

$$\left(\frac{E}{H}\right)_{\lambda = 2\pi\rho} \simeq 0.6 \cdot 120\pi \qquad (25)$$

and the phase shift:

$$\psi = \text{avetg } 0.22 - \text{avetg } 1.55 = 45^{o} \qquad (26)$$

In the range $\rho \geq \lambda/2\pi$, one can compute using the following values:

$$\frac{E}{120\pi \cdot H} = 0.6 \ldots 1 \quad \text{and} \quad \Psi = 0 \ldots 45^{o} \qquad (27)$$

For a magnetic dipole, all this is exactly reciprocal, relative to E and H; i.e., in the proximity of the source, E is a great deal smaller than H, etc.

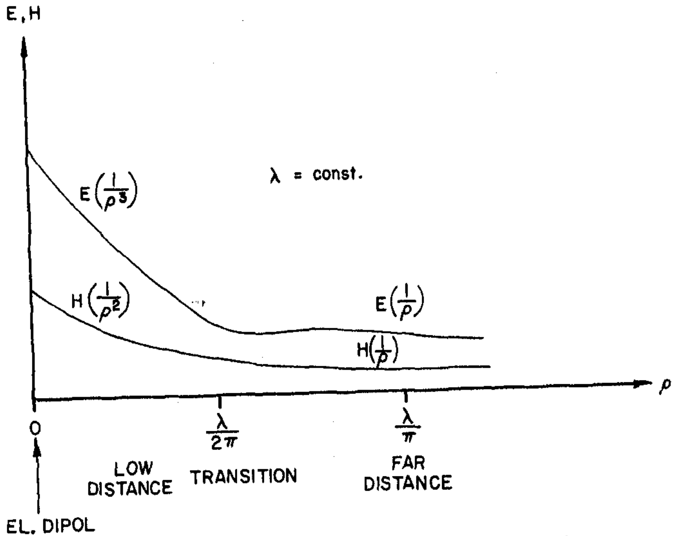


Figure 3. E- and H-field strengths as dependent on distance from the source (electric dipole at the co-ordinate source) for constant frequency or wavelength.

Discussion on the electric dipole. Fig. 3 depicts qualitatively the decline of the field strengths E and H. From their initial values (which are arbitrarily drawn on the ordinate as being of equal sizes), the field strengths decline as their distance from the source increases. The frequency or the wavelength is held constant. Up to the transition zone, hence in the low distance field, E falls more sharply--by $1/\rho^3$ --than H, which falls by $1/\rho^2$; while in the long distance field, both decline more slowly-- by a value of $1/\rho$. Thus, H and E approach each other mutually in their strengths in accord with the distance from the source, until, in the long distance field, a constant ratio of $120\pi = 377$ ohms is maintained.

In Fig. 4 the frequency, instead of the wavelength, is drawn on the abscissa; the distance from the source ρ is held constant. The current through the antenna would likewise be constant (effective current). When the frequency reaches a value of $2\pi c/\lambda$, then one changes over from the low distance field to the long distance field. At $\nu \to 0$ (electrostatic field), H does not disappear, as we saw in the case of the H-curl; rather, a static magnetic field remains--there we have a direct current J in the dipole,

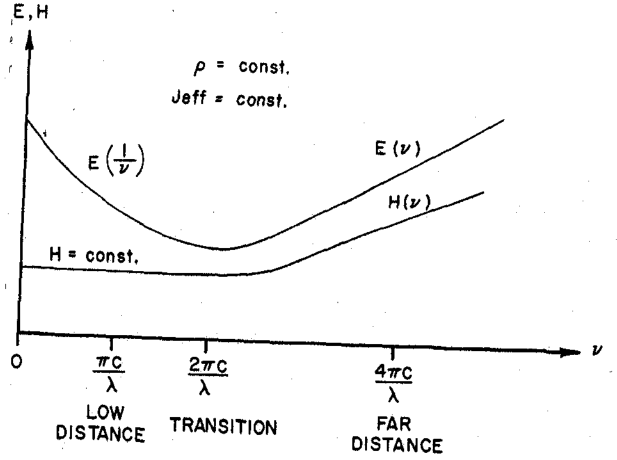


Figure 4. E- and H-field strengths at a fixed distance from the source as dependent on the frequency. Effective antenna current J_{eff} is held constant.

in opposition to the condensor field in Fig. 1 (in reality, a direct current in a dipole antenna would only be possible with point discharges in the room; i.e., in Fig. 4 for actual cases, the constraint J_{eff} = constant, must be omitted).

It is evident from the location- and freqeuncy dependencies of electric and magnetic field strengths, qualitatively depicted in Figs. 3 and 4, that the field strengths recorded at the observation locus depend quite strongly on the distance from the source locus and on the frequency of the source. In the long distance field, the ratio E/H is constant.

The formulas (10) through (12) are valid for a dipole floating freely in space. Now, however, the source is found in the clouds, between the wave conducting earth surface-ionosphere underside, through which the diffusion of the waves is modified. Wait solved this problem with the help of curvilinear co-ordinates through numerical integration using computers (Y.A. Wait, 1957). H. Brenner (1958), H. Volland (1964), and K. Davies (1966) have done further calculations which take into account rough earth surfaces, mountains, and conductive-capacity fissures (e.g. land-water). H.W. Ludwig (1968a) carried out measurements with a scaled-down model of the earth surface-ionosphere system. Essentially, there exists a mode of the stratum earth surface-ionosphere with a main frequency of 10 kHz. This is the frequency preferentially transmitted from there; 10 kHz carrier waves are recorded from distant storms. These carrier waves are modulated with cavity resonance to within the Hz range (see below). For near-by storms, the measurable carrier frequencies reach into the MHz range.

Cavity radiation. At cavity resonance we are practically always near the source; there, all the space oscillates. The calculation of the sphere-crust-cavity resonance between the earth's surface and the ionosphere (resonance which is stimulated by lightning) is proportionally complex and has been done by W.O. Schumann; whence the name Schumann waves or Schumann resonance. We give the results here:

$$E\rho = -j\frac{1}{\sqrt{\varepsilon_0\mu_0}}\;n(n+1)\;Pn(\zeta)\left(j\frac{2\pi\rho}{\lambda}\right)^{-3/2}\cdot\left[a_i\mathfrak{h}^{(1)}_{n+\frac{1}{2}}\left(j\frac{2\pi\rho}{\lambda}\right)+b_i\mathfrak{h}^{(2)}_{n+\frac{1}{2}}\left(j\frac{2\pi\rho}{\lambda}\right)\right] \tag{28}$$

$$E\zeta = j\frac{1}{\sqrt{\varepsilon_0\mu_0}\,{}^{1}\lambda}\cdot\frac{\partial Pn(\zeta)}{\partial\zeta}\left(j\frac{2\pi\rho}{\lambda}\right)^{-3/2}\cdot\left[a_iF^{(1)}\left(j\frac{2\pi\rho}{\lambda}\right)+b_iF^{(2)}\left(j\frac{2\pi\rho}{\lambda}\right)\right] \tag{29}$$

$$H\phi = \frac{j\,2\pi}{\mu_0\lambda\sqrt{j\frac{2\pi\rho^1}{\lambda}}}\cdot\frac{\partial Pn(\zeta)}{\partial\zeta}\cdot\left[a_i\mathfrak{h}^{(1)}_{n+\frac{1}{2}}\left(j\frac{2\pi\rho}{\lambda}\right)+b_i\mathfrak{h}^{(2)}_{n+\frac{1}{2}}\left(j\frac{2\pi\rho}{\lambda}\right)\right] \tag{30}$$

with $F(x) = n\,\mathfrak{h}_{n+\frac{1}{2}}(x) - x\,\mathfrak{h}_{n-\frac{1}{2}}(x)$ (31)

$\mathfrak{h}$ = Hankel function

Pn = zonal sphere function in order, e.g., $P_0(\zeta) = 1$; $P_1(\zeta) = \cos\zeta$; $P_2 = \frac{1}{4}(3\cdot\cos 2\zeta - 1)$, etc.)

a_i, b_i = constants, which follow from the edge-constraints.

n = order of the wave type.

The Hankel functions are solutions to the differential equation for cylinder functions, and in the cases under consideration (half-number indices), are expressed in series of trigonometric functions. The spherical functions are solutions to the differential equation for sphere functions and can also be given through trigonometric series. The ratio of Eρ to Hφ becomes:

$$\frac{E\rho}{H\phi} = j\cdot 120\pi\cdot\frac{n(n+1)}{2\pi}\cdot\frac{\lambda}{2\pi\rho}\cdot\frac{Pn(\zeta)}{\frac{\partial Pn(\zeta)}{\partial\zeta}} \tag{32}$$

this is comparable to (16). At n = 1, for example, it becomes:

$$\frac{P_n|\zeta|}{\frac{\partial P_n(\zeta)}{\partial\zeta}} = \text{vtg}\,\zeta\,.$$

The ratio of Eζ to Hφ at $\rho \ll \lambda/2\pi$ becomes:

$$\frac{E\zeta}{H\phi} = -j.120\pi\cdot\frac{n}{2\pi}\cdot\frac{\lambda}{2\pi\rho} \tag{33}$$

This ratio is also comparable to the low distance field of an electric dipole. A distinction from (16) is to be noted particularly in the order n; as the order increases, the ratio E/H becomes greater to the detriment of H. However, where n = 0, only the H-field is present.

With magnetic impulses, for example, those arising through solar flares, inverse ratios in regard to E and H, analogous to the magnetic dipole radiation, are at hand. There, the measured values cited below reveal relatively high magnetic field strengths in comparison to (32), (33); thus, we are not dealing only with electrical impulses.

Discussion. In Fig. 5 we see that TM waves arise;

this means that the H-lines of force move clockwise around the axis of the storm center (illustrated above in Fig. 5) through the center of the earth (cylinder-symmetry), and are independent of order. The E-lines of force run equally in accordance with order, or else they are divided into groups (ζ -dependent), perpendicular to the axis defined by the storm center-center of the earth.

The natural resonances are dependent on the ground conductivity, on the ion density, and on the temperature of the gas in the ionosphere as well as on the distance earth surface-ionosphere (edge-constraints, from which we get the constants a_i, b_i in equations (28) to (30)). Above all, it is the ion density and the distance earth-ionosphere which underlie the daily and seasonal variations; i.e., the night-side behaves differently than the day-side, etc. The equations (28) to (30) are thus only to be taken as (spherically-symmetric) approximations. The natural resonances which were originally calculated by Schumann on the basis of incomplete data on the ionosphere lie at 10.6, 18.3, and 25.9 Hz. More recent investigations have resulted in other values; 7.8, 14.1, 20.3, 26.4, and 32.5 Hz (J. Toomey and C. Polk, 1970). Measurements done by H.L. König brought out variable frequencies, dependent on season, time of day, and weather (H.L. König, 1962).

Measurements taken during the explosion of atomic bombs at a height of 400 km in 1958 and 1962, through which the intrinsic value of the earth surface-ionosphere system was stimulated from outside, gave as the main frequency 0.3 Hz. The diverse data indicate that we are dealing with a quite complex resonance phenomenon and that extensive and lengthy measurements at as many locations as possible are desirable.

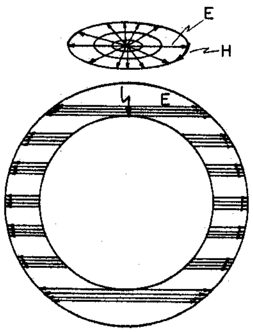


Figure 5. Schumann waves in the earth-ionosphere system for lightning events (above in Fig. 5). A higher order is shown.

3. The Absolute Value of Electric and Magnetic Field Strengths Near the Earth's Surface (in nature) as Dependent on Time and Place.

A.D. Watt, F.S. Mathews, and E.L. Maxwell (1963) have published studies on the electric conductivity of various earth surface materials. The Consultative Committee on International Radio (CCIR) has compiled a comprehensive table of the location and time divisions for variations of the Atmospherics (World Distribution and Characteristics of Atmospheric Radio Noise, CCIR-Report 322, Geneva, 1964). In the report, however, only those electric field strengths above 10 kHz have been gathered, and these are given in the form of a standardized size, Fa = "effective antenna noise-factor" in decibels (db) over kTb. The conversion formula in electric peak-field strength (E_{ss} = peak-to-peak amplitude) is as follows:

The source-impedance of a perpendicular, short, receiving antenna (length $1 \ll \lambda$) across a floor that is an infinitely good conductor is:

$$R = 40\pi^2 \left(\frac{\ell}{\lambda} \right)^2 \qquad (34)$$

For the power matching, the power P maximally available from the antenna becomes, with this:

$$P = \frac{U_{eff}^2}{4R} = 1.42 \cdot 10^{17} \; \frac{E_{eff}^2}{\nu^2} \qquad (35)$$

$$\text{with } U_{eff} = E_{eff} \cdot 1. \qquad (36)$$

The above Fa is defined as:

$$Fa = 10 \log (P/kTb) \qquad (37)$$

where $kT = 4 \cdot 10^{-21}$ VAs ($T = 310^{o}K$) is put in (self-noise energy of the receiver). So for equations (35) to (37) we obtain:

$$E_{ss}(V/cm) = 4.75 \cdot 10^{-19} \sqrt{b(Hz)} \cdot \nu(Hz) \cdot 10^{(\frac{Fa}{20})} \qquad (38)$$

The measured results are thus dependent on the band-width b of the receiver. The CCIR's measurements were taken world-wide with a receiver band-width of between 1 kHz and 10 kHz, and then standardized to Fa. For $\nu = 10$ kHz, these values lie approximately between Fa = 140 db and Fa = 175 db; at lower frequencies, the values are higher. At each decade of lower frequency, they are higher by about 20 db; thus, for $\nu = 1$ kHz, Fa = 160 db to Fa = 195 db; indeed, the increase in the ELF-zone ultimately becomes smaller--Fa runs to a maximum and drops off again after the frequency $\nu = 0$. In the ULF- and ELF-zone, only sporadic measurements exist. If the principal studies that have been done up to the present time were collected together, we would have the following figures for wide-band measurements (note: band-width = total zone, thus for ULF, b = 3 Hz; ELF, b = 3 kHz; VLF, b = 30 kHz; LF, b = 300 kHz);

$$E_{ss} = 10^{-5} \text{ to } 10^{-3} \text{ V/cm}; \quad H_{ss} = 10^{-7} \text{ to } 10^{-5} \text{ A/cm}$$

(value ranges are in accordance with location, time, and weather). These values can still be exceeded when there are powerful near-by storms or solar flares.

Dependence on Location. Electric and magnetic field strengths are significantly greater across well-conducting floors, those rich in ground-water, or across ore-pockets than over dry floors or rocks; ice is also a poor conductor. Between rock and damp meadows we get differences in field strengths of several orders of magnitude. As will be demonstrated later (Fig. 17), this also signifies a difference in the acting series frequency of the Atmospherics-impulse above a defined field strength limit. The ratio of series frequencies above 1 mV/cm, measured with a band-width of 100 kHz--for example, between an asphalt-covered city with a deep ground-water table (50 m; Freiburg im Breslau, Germany, Black Forest) and the North Sea coast (Sylt, Germany), in mid-year is 1:40 (Ludwig, 1968a).

Also field strengths at great heights are about one to two powers of ten greater than at sea-level. W. Rauh reports of a mountain sickness in Peru which occurs only in the vicinity of an ore-pocket; this mountain sickness is probably produced by the extremely high Atmospherics variation (W. Rauh, 1956).

Dependence on Time. Normally, the electric and magnetic field strengths, and hence the series frequencies above an amplitude limit, lie about one order of magnitude higher in the daytime and in summer than at night and in winter. In extreme cases, for example, where there exists extremely poor ground conductivity, the day-night rhythm can reverse itself, time-wise, as when in summer nightly near-by storms occur. In shielded rooms, these ratios are substantially modified (Ludwig, 1968a).

Static Fields. Through the radioactive rays on the ground, the previously mentioned ion-discharge in the air passes through a potential gradient of 1 to 2 V/cm in dry weather, whereby the earth is negative relative to the surrounding air. A.M. Roberts showed that this static field primarily could have no influence on organisms (A.M. Roberts, 1969). According to Roberts, an effect of artificially-induced static fields which is often demonstrated might merely be founded on the suction of the ions through the surface charges of the field which is artificially generated through condensor plates. It is known that ion-discharges in the air have an influence on organisms (J. Eichmeier, 1962).

On the other hand, the static magnetic field has a measurable influence on living creatures (G. Becker, 1964). For calculating purposes, the magnetic field strength in Gauss units is:

$$0.8 \text{ A/cm} = 1 \text{ Gauss}$$

The static portion of the earth's magnetic field comes to about:

$$H = 0.4 \text{ A/cm}.$$

II. THE ABSORPTION AND REFLECTION OF ELECTROMAGNETIC WAVES BY DIFFERENT MATERIALS

1. Absorption

The curves drawn in Fig. 6 show the absorption as a function of the frequency (units on both axes are logarithmic) over the total frequency range up to the γ -rays, for insulators, semi-conductors, and metals (the reflection effect relative to E at low frequencies--on the left in Fig. 6--is entered in dashed lines, see below, heading 2).

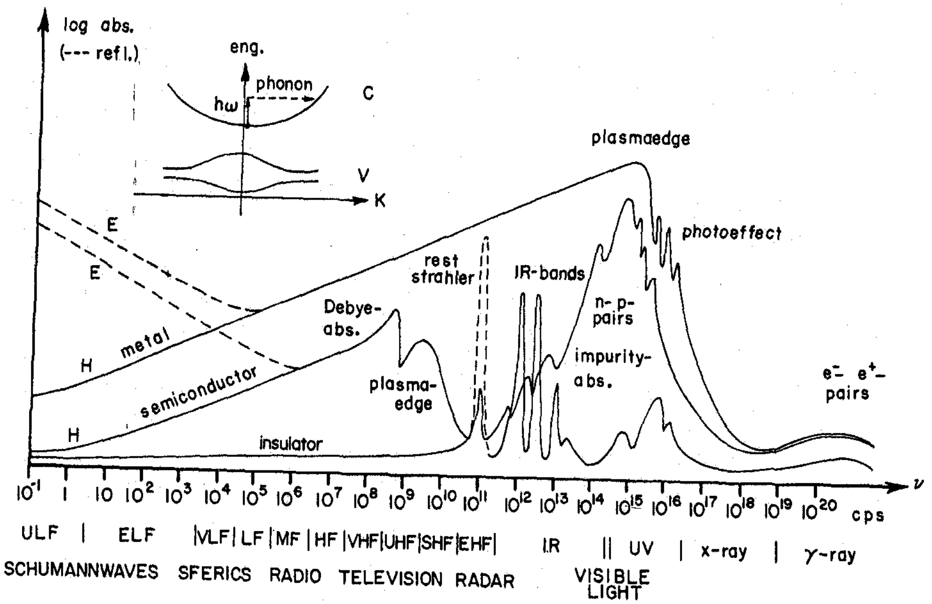


Figure 6. Absorption (and dashed, reflection) of insulators, semi-conductors and metals (qualitatively) as a function of the frequency. Above: Band-diagram for clarification of the plasma-absorption.

Beginning at low frequencies, we have the following phenomena: By scattering the photons of the electromagnetic waves with electrons of the material, and scattering the electrons with phonons, at low frequencies the electromagnetic energy is converted into sound energy. This leads to a heating of the material. At low frequencies, the electrons can follow the wave frequencies without a retardation-time. If there are very powerful waves in the acoustic zone, these phonons are audible (phonons are sound quants).

This absorption is designated as "free carrier absorption". It is proportional to the fourth root of the frequency up to the so-called plasma edge; at this plasma edge, the electrons no longer follow the wave oscillations. Above the plasma edge, the free carrier absorption disappears and the material becomes transparent to the wave.

For semi-conductors, the plasma edge lies in the UHF to the microwave zone; for metals, it is above the UV-zone. Although only the area under the plasma edge is of interest to us here, let us briefly go into the absorption effect at higher frequencies:

a) Insulators: Here there is no free carrier, i.e. these materials are transparent at low frequencies, provided that the di-electric constant is not so high (as it would be for barium titanate, $BaTiO_4$ where $\varepsilon_r = 10{,}000$) that the electric field lines might be absorbed into the material, on the basis of other phenomena (see below).

In the far infrared, some crystals have the so-called Rest-ray Reflection. These are not part of the absorption process; on the contrary, they prevent the penetration of the wave by almost complete reflection. In the infrared (IR) zone, vibrations of atoms or ions in the crystal bonds are stimulated by the waves into resonance, which leads to discrete, so-called bands. In the UV-zone, then, energetic photo-effects are possible through the promotion of valence electrons into higher energy states. In the X-ray region, all materials going this far finally become transparent. Only when the radiation energy becomes so great that electron-positron pairs can be generated, does absorption occur again; however, due to its relatively low probability, this absorption is insignificant.

b) Semi-conductors: Here we have Debyabsorption at low frequencies occurring before the plasma edge for liquid crystals (e.g. organic tissue), at the VLF- and LF-zones; or, at higher frequencies (in Fig. 6, solid semi-conductors in the UHF-zone). Above the rest-ray zone, which also occurs here, the impurity-absorption begins to have an effect, and at higher frequencies, electron-defectelectron pairs can be formed; it is these which frequently give the greatest absorption in semi-conductors.

c) Metals: For metals, the plasma edge is very high; the remainder runs as described above. The absorption which is important to us lies below the plasma edge and is illustrated in Fig. 6, above, in the so-called Band-diagram: If one draws the stimulation energy across the reciprocal grid-co-ordinate K (K in Fig. 6 goes from $-\pi/a$ to $+\pi/a$, where a = grid-constant), then the valence bands V lie on the lower energy levels and the conductor band C lies on the higher level. A photon $\hbar\omega$ gives up its energy to a conductor-electron and this causes a phonon-wave in the material. The energy is divided in the material in this manner. This energy will be lost from the electromagnetic wave, the end result being that the wave is weakened. The penetration depth δ of an electromagnetic wave in a material that is infinitely expanded over a half-room is given in electrodynamics as (Kaden, 1959):

$$\delta = \frac{1}{\omega\kappa} \tag{39}$$

$$\text{with } \kappa = \sqrt{\frac{\mu}{2}\left(\sqrt{\varepsilon^2 + \frac{\sigma^2}{\omega^2}} - \varepsilon\right)} \simeq \sqrt{\frac{\sigma\mu}{2\omega}} \tag{40}$$

By this, δ is the same depth in the material at which the magnetic field strength declines by $1/e = 1/2.718 \simeq 37\%$ (e equals here the base of natural logarithms, in deviation from list B at the beginning of this article).

For a shielded box in the form of a spherical shell or an enclosed cylinder (cross-section, see Fig. 7), the shielding factor, insofar as it is independent of the special form, is to a good approximation:

$$q = \frac{\text{magnetic field strength at the center}}{\text{magnetic field strength without shielding}}$$

$$= 2\sqrt{\frac{b}{a}}\ \exp\left[-\frac{(b-a)}{\delta}\right] \tag{41}$$

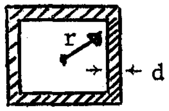
(R.W.P. King, 1958). This formula is valid only for:

$$b - a \geq 2\delta \tag{42}$$

(F.E. Terman, 1943). In the ELF-zone, δ becomes so great that (42) is no longer attainable.

For low frequencies up to the ELF-zone, the formula equals (H. Kaden, 1959):

$$q = \left(\frac{H_o}{H_i}\right)_{\mu_{r=1}} \simeq \sqrt{1 + \tfrac{1}{2}\cdot f\cdot r\cdot d\cdot \omega\mu_0\,\sigma} \tag{43}$$



where f lies between 0.5 and 1 according to the shape of the shielded box.

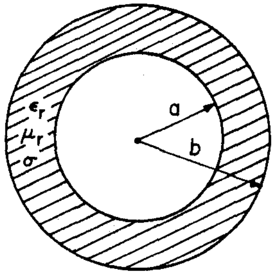
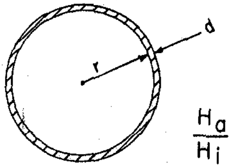


Figure 7. Cross-section of a shielded box having the material constants, ε_r, μ_r, σ.



$$\frac{H_a}{H_i} \approx A \; \frac{3\sqrt{1+(kr)^2}\,\left|\sin kr - kr \cos kr\right|}{(kr)^3}$$

$$\frac{E_a}{E_i} \approx A \, \frac{3\sqrt{1-(kr)^2+(kr)^4}\,\left|\left[(kr)^2-1\right]\sin kr + kr \cos kr\right|}{(kr)^5}$$

$$A = \left\{\frac{1}{9}\left[\left(\frac{r}{u+\delta}\right)^2 + \left(\frac{\mu+\delta}{r}\right)^2\right]\left(\cos h\,\frac{2d}{\delta} - \cos\frac{2d}{\delta}\right) + \frac{1}{3}\,\frac{r}{\mu\, d}\left(\sin h\,\frac{2d}{\delta} - \sin\frac{2d}{\delta}\right) + \right.$$
$$\left. + \frac{1}{3}\,\frac{\mu_r\,\delta}{r}\left(\sin h\,\frac{2d}{\delta} + \sin\frac{2d}{\delta}\right) + \frac{1}{2}\left(\cos h\,\frac{2d}{\delta} + \cos\frac{2d}{\delta}\right)\right\}^{\frac{1}{2}}$$

$k = \frac{\omega}{c}$, c = velocity of light ; $\delta = \frac{2}{\omega \mu_r \mu_0 \chi}$; χ = el conductivity

$$\underline{\omega = 2\pi\nu \longrightarrow 0} \; \left(\frac{H_a}{H_i}\right)_{Cu} \approx \sqrt{1 + \frac{r}{3}\, d\, \omega \mu_0 \chi} \; ; \; \left(\frac{H_a}{H_i}\right)_{Fe} \approx 1 + \frac{2}{3}\cdot\frac{d}{r}\,\mu_r$$

$$\frac{E_a}{E_i} \approx 1 + \frac{1}{3} Z d \chi \; ; \; Z_0 = 120\pi \;\Omega$$

Figure 8. General shielding formula by H. Kaden. (The abbreviations here are taken from the original work and deviate from the ones used in this article.

The formula worked out in Fig. 8 (H. Kaden, 1959) is valid up to the plasma edge. In Fig. 8 we use Kaden's symbols, in deviation from our List B.

The electric field strength must be considered separately, due to reflection loss, as will be seen in the following section.

2. Reflection

In this section, we assume that the power of the electromagnetic field is great in relation to the noise power of the material. In other cases where there is very weak field power, reflection becomes negligeable, so that weak fields, hence the electric field strength, will penetrate all materials. This is important in respect to the so-called Zinsser-effect (W. Peschka, 1973).

That which was said in Part 1. Absorption, holds unconditionally for magnetic field strength; whereas the electric field strength in metals is substantially smaller. The ratio E/H is much smaller in materials, especially in metals, than it is in a vacuum or in air, i.e. the wave-impedance of a metal is substantially smaller than 120π and it completely disappears in the case of superconductivity (Döring, 1956).

As we have seen, the conductor-electrons of a metal under the plasma edge vibrate synchronically with the field; there, they are carried along by the electric vector. With this arise countless electric dipole rays, which on their part emit elementary sphere-waves. The result of all these elementary waves gives off a secondary wave, diffusing both outwards and inwards from itself; the secondary wave superimposes itself on the still-occurring primary wave. (This is only valid for isotropic materials, which is not the case for organic tissue.)

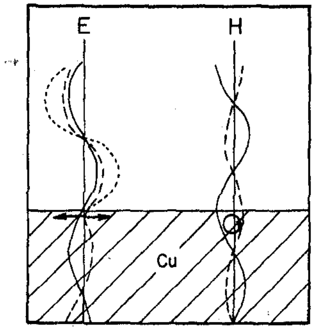


Figure 9. Perpendicular incidence of an electromagnetic wave on copper for the explanation of reflection and weakening.

Fig. 9 shows these events at the meeting point of a vibrating electric or magnetic vector tangent to the material's surface: left in Fig. 9, we have a wave coming from above onto the material, and already, secondary waves (dashed line) emerge at the surface. For the electric vector, Fig. 9 indicates that the waves are already in phase, a condition where, through superimposition, an E-node is built up at the metal's surface. Outside of the material a standing wave (dotted line) emerges and inside the material, we get an extinction between primary and secondary waves. Total extinction happens only at superconductivity. In that case, we have no absorption, but instead complete reflection of the wave.

In the case of incomplete extinction, where we are dealing with very large wavelengths (which for the ULF-zone are over 10^{10} cm!) in the total observed room, we also have an E-node having an almost imperceptible field strength. For this reason, shielding at the lower frequencies is always better.

On the right in Fig. 9, it is shown that the magnetic field strength is less weakened by reflection than is the electric field. A magnetic vector vibrating parallel to the surface of the metal generates eddy-currents in the material, whose secondary waves weaken the primary field on both sides of the surface (W. Döring, 1956). In the case of infinitely high electrical conductivity (superconductivity), the magnetic vector shifts through superimposition, so that, at the metal's surface, arises not only an E-node, but an H-node as well; and hence, offers the analogous picture--left in Fig. 9. (Were it otherwise, infinitely high eddy currents would flow). However, at room temperature, the eddy attenuation on the one hand is too strong to generate a large counter-field; on the other hand, it is too weak to make possible absorption of any extent. The reader will find a discussion of these quite complicated events at the border surfaces of finite conductors in texts on theoretical physics and electrotechnology (W. Döring, 1956; H. Kaden, 1959). We wish only to maintain that the reflection loss for magnetic field strength is negligeable, relative to the absorption loss at room temperature. In Fig. 6 on the left we have indicated that this does not hold for an electric field strength--there linear currents in metals are subjected to a very small attenuation (the electrons only "shake" with the field, whereas in the case of eddy currents, they must travel along longer paths).

At low frequencies, the plasma-collective-vibration occurs, which collects larger and larger groups as the frequency declines. The reflection loss up to this point rises in inverse proportion to the frequency. As opposed to static fields, shielding of electric fields is almost ideal. For these, coarse-meshed cages are sufficient, as described by Faraday.

The shielding formula for electric field strengths is:

$$q = \frac{E_o}{E_i} \approx 1 + f \cdot \frac{d}{r} \sqrt{\frac{\sigma^2 + \omega^2 \varepsilon_r^2 \varepsilon_0^2}{n^2 e^2 u^2 + \omega^2 \varepsilon_A^2 \varepsilon_0^2}} \qquad (44)$$

Here, ε_A is the di-electric constant of air and ε_r, that of the material. As taken from selected cases, $\varepsilon_r \lesssim 10$. At low frequencies then, we have ($\omega > 0$):

$$q = \frac{E_o}{E_i} \approx 1 + f \cdot \frac{d}{r} \cdot \frac{\sigma}{\omega \varepsilon_r \varepsilon_0} \qquad (45)$$

For the frequency $\omega = 0$ (static field), we obtain the following from (44):

$$q = \left(\frac{E_o}{E_i} \right)_{\omega = 0} = 1 + f \cdot \frac{d}{r} \cdot \frac{\sigma}{neu} \qquad (46)$$

Here, n e u is the conductivity of air, based on its ion content (charge e; charge carrier / cm^3=n; velocity u). To a good approximation, $n = 10^3\ cm^{-3}$ and $u = 2\ cm^2/Vs$.

3. Field-line Concentration in the Material

High di-electric constant. Fig. 10 shows on the left a cross-section through a shielded box made from a material having a high di-electric constant (for example, $BaTiO_4$

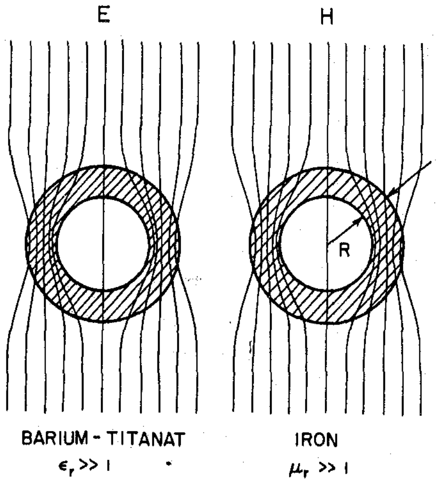


Figure 10. E- and H-field line paths in materials with high ε_r or μ_r.

has an $\varepsilon_r = 10{,}000$). In this instance, the electric field-lines travel through the material in such a way that they are directed out from the inside of the box. This is equivalent to a shielding. From equation (44), for $\sigma = 0$, a large ε_r, and $\varepsilon_A \simeq 1$, we derive:

$$q = \left(\frac{E_o}{E_i}\right)_{\text{insulator}} = 1 + f \cdot \frac{d}{r} \cdot \varepsilon_r \tag{47}$$

<u>High Magnetic Permeability</u>. In Fig. 10 on the right, we have the analog for the weakening of a magnetic field through a material with high μ_r (Mu-metal, Permalloy: $\mu_r = 80{,}000$, see Table 1). From the analogous equation (47), the shielding factor is:

$$q = \left(\frac{H_o}{H_i}\right)_{\mu_r >> 1} \simeq 1 + f \cdot \frac{d}{r} \cdot \mu_r \tag{48}$$

Were m shielding walls, separated by air or insulator plates, used, we would then have a greater shielding factor of approximately:

$$q = \left(\frac{H_o}{H_i}\right)_{\mu_r >> 1} \simeq \left(1 + f \cdot \frac{d}{r} \cdot \mu_r\right)^m \tag{49}$$

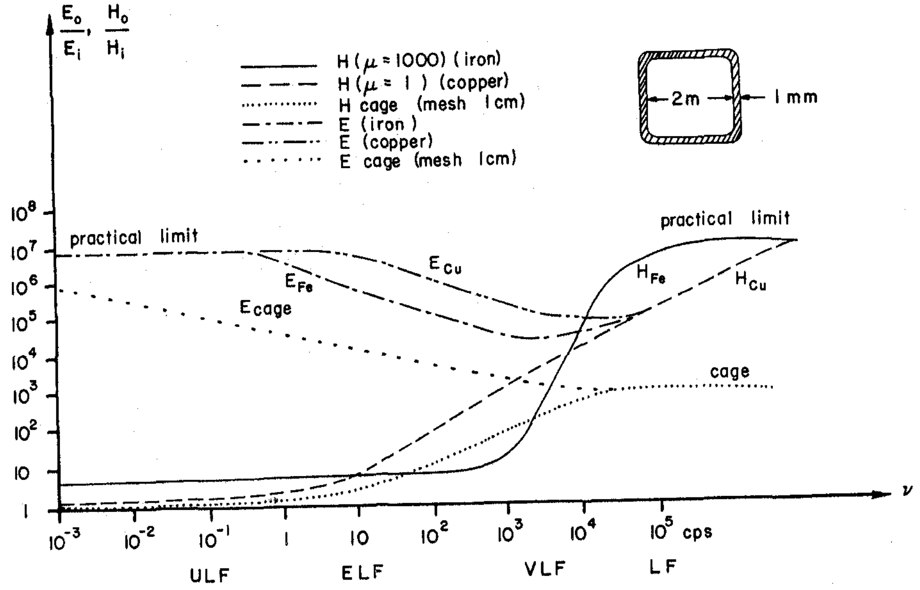


Figure 11. Practical shield factors for electric (Eo/Ei) and magnetic (Ho/Hi) components at low frequencies for a special box or cage made of copper or steel (r = 100 cm; d = 0.1 cm; mesh distance 1 cm). The practical limit in respect to the theory (eqn 39 to 49) is due to idealization in the theory (homogenity, smooth surfaces, perfect joints a.s.o.).

TABLE 1

Material constants σ and μ_r for various metals

Metal	σ el. conductivity (A/Vcm)	μ_r rel. magnetic permeability
silver	$6.0 \cdot 10^5$	1
copper	$5.7 \cdot 10^5$	1
aluminium	$3.5 \cdot 10^5$	1
magnesium	$2.1 \cdot 10^5$	1
brass	$1.5 \cdot 10^5$	1
iron	$1.0 \cdot 10^5$	1,000
steel (SAE lo45)	$5.7 \cdot 10^4$	1,000
stainless steel	$1.1 \cdot 10^4$	1,000
monel (nickel alloy	$2.3 \cdot 10^4$	1
Mu-metal	$1.7 \cdot 10^4$	80,000
Hypernick	$3.4 \cdot 10^4$	80,000
Permalloy	$1.7 \cdot 10^4$	80,000
ferromagnetic metals at superconductivity	∞	∞

In the case of superconductivity with ferro-magnetic materials, the so-called Meissner-Ochsenfeld-Effect comes into effect, and μ_r becomes infinitely great. Here, the magnetic shielding is ideal.

Fig. 11 shows the shielding factors of a standard box with respect to E and H for frequencies up to 10^5 Hz. These curves have been collected from various sources and they have been standardized to the box shown in Fig. 11, with the help of the preceding formulas (Kaden, 1959; Terman, 1943). H. Kaden was able to demonstrate, on the basis of numerous measurements at the Siemens Firm, Germany, that the preceding formulas (43) to (49) are in quite successful agreement with actual practice.

Table 1 lists the material constants σ and μ_r for several important metals (Cockrell, 1958). The last entry, superconductivity, has only been partially investigated. Actually, this effect is used for the stringent shielding requirements in electron-optics, which is prone to interference.

4. The Construction of Faraday Boxes

The shielding of real boxes gives less yield than the preceding formulas would indicate (this is taken into account in Fig. 11). This is not due to the fact that the formulas are incorrect, but rather to the negligence known to exist in the building of the boxes. The formulas hold for evenly rounded containers or rooms having smooth walls and made out of homogeneous, isotropic material without seams and joints. Often, this cannot be achieved in practice. Cages made of wire-netting are only appropriate for the shielding of electric field strength. In order to shield the magnetic field strength, one should preferably choose complete material (or see below, a honey-comb construction). Other reasons for poor shielding results are:

a) Sharp corners and edges cause high field strength due to distortion in their vicinity. With Δr = distance from the corner, the enlargement factor v becomes:

$$v \simeq 1/3 \left(\frac{r}{\Delta r} \right)^{4/3} \qquad (50)$$

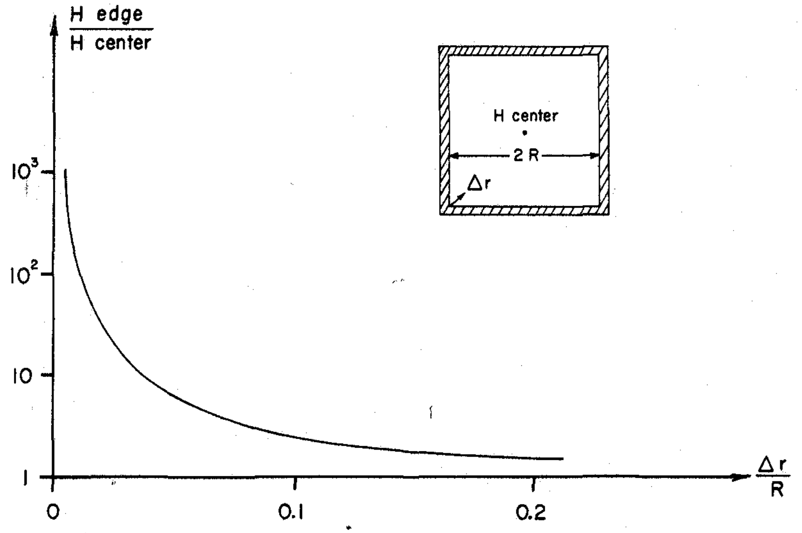


Figure 12. "Corner Effect" in an angular shielded chamber.

Fig. 12 depicts equation (50) graphically. Thus, corners and edges should be avoided.

b) Each hole used to supply air and light to the inside of the box increases the transparency. Fig. 13 shows this effect. In it, $E\rho$ is the field strength at a distance ρ from the hole, measured from inside. If a pipe having length 1 is introduced through the hole, the field strength in the center of the box decreases considerably. It follows from the formula given in Fig. 13, that it is sufficient when $1 = 2 \cdot r$. As indicated in Fig. 13, one can make an entire wall of the box out of such "honey-comb pipes". This construction is recommended in place of a wire-netting in all cases where live creatures are contained in the box.

Left in Fig. 13 we have a representation of the above numerical values for one hole with and without a pipe.

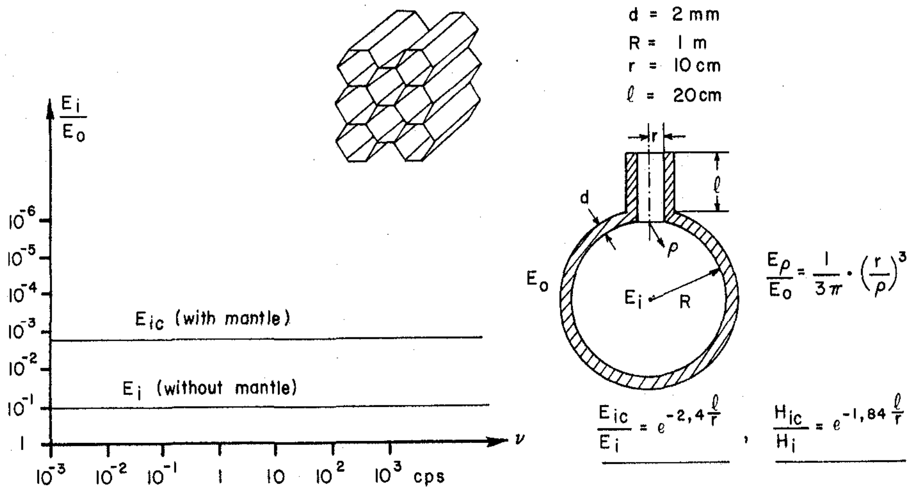


Figure 13.

Right: The impingement of a field through a hole in a shielded chamber and the relieving of this through the use of "mantle attenuation".

Left: Example of electric field strengths at the center of the box with and without mantle for the data written above right.

Above middle: Honey-comb construction used for mantle attenuation.

c) Each telephone or power-supply cable which is introduced into the box from outside behaves as an antenna for electromagnetic waves and conducts them into the box.

Fig. 14 clarifies this phenomenon: if the cable outside the box has an earth capacity C_1 and an average distance from the earth d_1, and inside the box, the corresponding values, C_2 and d_2, then the formula given in Fig. 14 holds because $U_1 = U_2$ and for the maximally filled case $C_1 >> C_2$. The formula follows from the schematic diagram shown. In many cases, $d_1 > d_2$, or even, $d_1 >> d_2$, so that E_2 inside the box can become even greater than outside (E_1); at least, in the vicinity of the cable. Then we get not shielding but strengthening! It is sensible then to use battery-operated instruments inside the box, or else a versatile filter should be connected to a netted cable, and the filter itself must be well shielded.

In order to convey the measured data out of the box, it would naturally be fruitless to use a wireless transmitter.

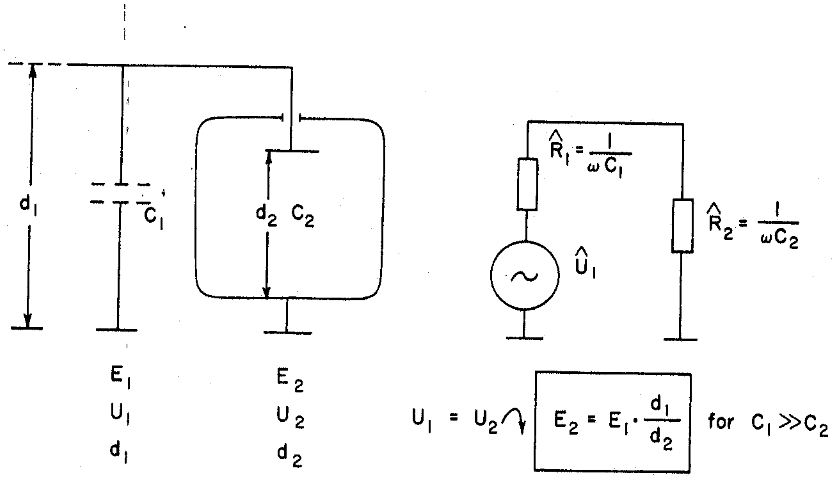


Figure 14. "Antenna Effect" through cables which conduct electromagnetic waves into a shielded chamber from outside. Right: schematic diagram. The circumflex accent over U and R indicate alternating size.

Photo-optic systems would be possible, through honey-comb pipes. As has already been mentioned in II. 3.b, shielding can be improved by using multilayered walls.

Fig. 15 shows an actual model of a box (H. Kaden, 1959). The box consists of two copper layers of equal thickness (thickness a), which are separated by sheet iron having a thickness x which is varied from experiment to experiment. The total thickness is held constant at 6 mm, hence $2a + x = 6$; the copper layer thickness a is varied from experiment to experiment as well.

It follows from Fig. 15 on the left, that the best shielding of magnetic field strength for 1 kHz to 10 kHz is delivered when all three layers are of equal thickness, $a = x = 2$ mm. In the ULF-zone (precisely under 300 Hz) however, the copper no longer contributes to the shielding of the magnetic field strength, so that 6 mm of iron is better. Though the shielding using iron as regards the

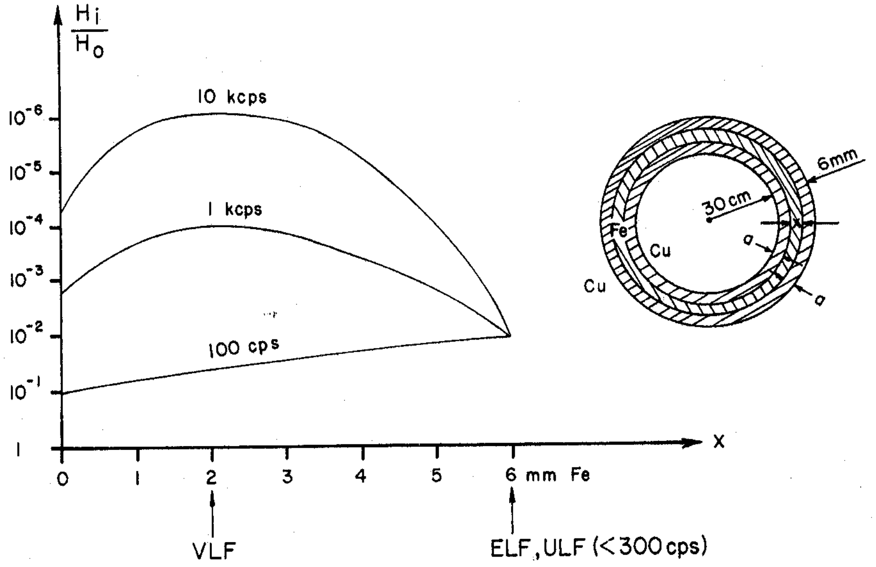


Figure 15. Three-layer shielding as a function of thickness ratios between the three layers.

electric field strength would be sufficient, according to equation (45), the same result also holds for the electric field strength. The shielding would be even better if instead of all iron, laminated sheet iron with insulated spaces in between were used. Through the uncoupling effect, one would achieve approximately the attenuation given in equation (49).

Since materials having a high μ_r are expensive, one might use the cheaper sheet iron which has a $\mu_r \simeq 1000$. As can be seen from formulas (43) to (49) and Fig. 11, the shielding of electric field strength is no problem. Already with relatively poorly conducting metals, like iron, a shielding factor of 10^5 and greater is attained. So, one can direct all his attention to the shielding of H at low frequencies, which, according to Fig. 11, is a genuine problem. If we take iron having a $\mu_r = 1000$ and a box like the one sketched above in Fig. 11, but having 5 layers of Fe, each being 2 mm in width, and 4 in-between layers, again each 2 mm, made of whatever insulating material or even varnished aluminum, then according to equation (49) we obtain the following shielding factor (substituting f = 1):

$$q \approx \left(1 + \frac{0.2}{200} \cdot 1000\right)^5 = 32 \qquad (51)$$

Where d = 3 mm per layer (total thickness then would equal 27 mm) we have:

$$q \approx \left(1 + \frac{0.3}{200} \cdot 1000\right)^5 = 97.5 \qquad (52)$$

Such values have been obtained in practice (R. Wever, 1971).

III. RESULTS

1. Buildings

Fig. 16 shows the instrument room used for the measurements tabulated in Table 2. We have here several paired, certified, battery-operated atmospherics-receivers and a battery-operated oscilloscope. The key to Fig. 16 is as follows:

1, 2 - synchronized, certified, four-channel transistor receiver with ferrite antenna; output: register.

3, 4 - as above, but output: analog print-out (right front in picture).

5,6,7 - as above, but output: pace motor with scale.

8 - battery oscilloscope with wide band intensifier and antenna (above right in picture).

9, 10 - nine-channel receiver with ferrite antenna; output: magnetic band.

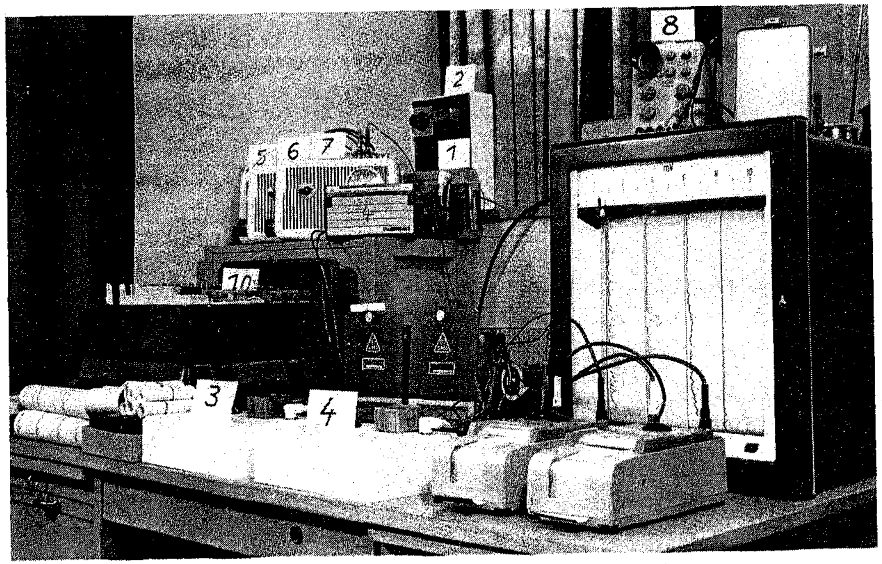


Figure 16. Instrument room (No. 9 under No. 10) - see text.

TABLE 2

Transparencies of different objects at 10 kHz with respect to the E and H components

Object	Ei/Eo in %	Hi/Ho in %
Faraday cage (r = 50 cm, d = 0.1 cm, iron mesh distance 3 cm)	0.5%	65%
Faraday cage (r = 50 cm, d = 0.1 cm, iron mesh distance 0.3 cm)	0.1%	10%
Volkswagen	1.0%	50%
iron sheet garage	0.1%	7%
steel bungalow	0.1%	8%
bunker (steel concrete d = 60 cm)	0.1%	0.1%
sleeping bag with copper layer, buttoned up	0.1%	90%

Table 2 presents the most important results at 10 kHz, where the transparencies (i.e. the reciprocal shielding factors) are given in %. The measurements were carried out using artificial transmitters with rod and frame antennas, as well as with natural atmospherics. Because of the high shielding of electric field strength, only boundary values are given. As can be seen, only the bunker, which has a 60 cm thickness of steel-reinforced concrete (which preferably should be of steel-netting), achieves shielding to any noteworthy extent.

2. Organisms

First of all, we must refer to the assumption made at the beginning of II, 2. One item of interest is the penetration of electromagnetic waves into organisms. We see from formulas (43) and (45) that at low frequencies, the magnetic field strength penetrates unhindered (the electric conductivity of well-circulating organic tissue is $\sigma \simeq 10^{-2}$ A/Vcm). The electric field strength, however, is already very well shielded by the epidermis. At higher atmospherics frequencies (100 kHz), $d = 0.1$ cm, $r = 20$ cm, $\varepsilon_r = 80$, $\sigma = 10^{-2}$ A/Vcm, and $f = 0.5$, we get from equation (45):

$$q = \frac{E_o}{E_i} = 1 + 0.5\,\frac{0.1}{20}\cdot\frac{10^{-2}\;4\pi\;9\cdot 10^{11}}{2\pi\cdot 10^{5}\cdot 80} = 6.6\;^{*} \qquad (53)$$

This shielding is not complete; 15% of the outer field still penetrates. Now, in a 1 mm-strong outer layer (below the poorly conducting and slightly shielding skin) in humans, there are certain nerve-endings which act as receptors (Ludwig, 1968b). (In animals, the coat and the fat layer shield less strongly; first, the intensively vascularized tissue attains the conductivity of a physiological saline solution.) In fish, the electric receptors in the skin are documented (Szabo, et al. 1973).

Measurements by Burr and Markson, taken deep in the tails of salamanders, in plants (trees), etc., using electrodes of Type Two, demonstrated that the inner electric field vibrates synchronically and with comparable strength with the outer (Markson, 1972). In trees, each fiber from the root to the leaf crown acts as a high antenna; thus, shielding has no effect. In animal experiments, however, the inner field is to be understood only as a response to the reception of the peripheral nerves. Obviously, the outer electromagnetic waves are also absorbed by the

---

* All these formulas are valid on the assumption of isotropic materials. Organic tissue is non-isotropic. The shielding factors then will be smaller than calculated by the formulas (see II. 2.).

organism. It is interesting to note that rarely do times occur where there is counter-phase movement between the inner and outer field (after a previous field strength decline below the trigger threshold of the electronic voltmeter used, having as output the print-out. This case should be further investigated.

IV DISCUSSION

While the magnetic field through organic tissue or ordinary buildings is hardly weakened below the LF-zone, in the over-VLF-zone, it is already substantially weakened by steel-reinforced structures or steel-aluminum houses (Fig. 11). The electric field is still more severely dampened, and indeed, above all in the ULF-and VLF-zones. For a sleeping bag having a copper layer, E is already efficiently kept away from a person inside (Ludwig, 1973).

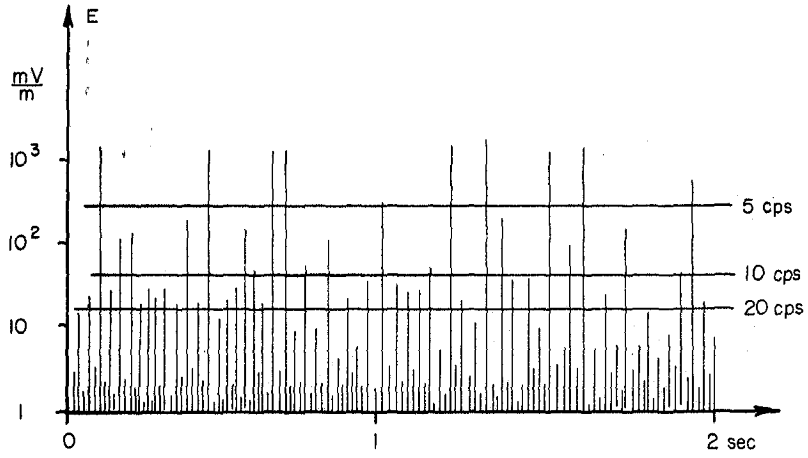


Figure 17. Actual series frequency of the Atmospherics as dependent on the trigger - level in the organism (three thresholds are indicated horizontally).

On considering what influences shielding has on the action of the atmospherics on organisms, it is essential that the atmospherics-impulse have a statistical distribution, according to Fig. 17.

If one takes a trigger-level in the organism, then, in accordance with the position of the level, only a lesser mean series frequency (e.g. 5 Hz) would be effective; at lower thresholds, however, a higher one (e.g. 10 or 20 Hz, see Fig. 17). Thus, shielding decreases not only the amplitude, but also the quantity of the impulse peak lying above the threshold, and with it, the mean series frequency. During a natural rise in the atmospherics level--e.g. in the vicinity of a storm--there will certainly be an adaption-time, during which the organism adjusts to the new level. This is illustrated in Fig. 18 on the right.

The adapted trigger level is designated by C and the rest level by B. In the time τ, C adjusts to the new field strength E. During this time, a higher series frequency is

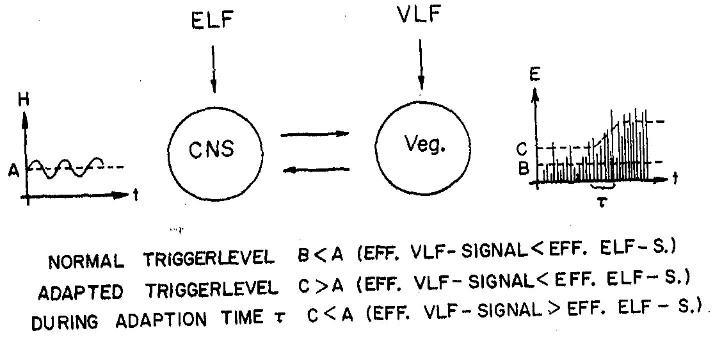


Figure 18. Diagram of the action of ULF- and ELF-waves on the central nervous system (CNS) and the VLF-waves on the vegetative nervous system (Veg.). A, B, C are trigger levels of the nervous systems; τ is the adaption time for field strength changes (s. text).

intercepted, subsequent to the still-reigning but not yet adapted former trigger-level B. At this time, it has changed little empirically in the ULF program, for these frequencies are the natural resonances of the earth-ionosphere system, which are influenced only very slowly by weather (H.L. König, 1962).

If one accepts that the ULF field acts on the central nervous system (CNS) chiefly through its magnetic component (H.W. Ludwig, 1971), while the VLF field acts, by means of its electric component, on the peripheral nerves which are divided over the entire organism (vegetative nervous system), then the following events can come to pass when there is an atmospherics increase. Before the increase in the atmospheric field strength, the organic action of the effective ELF field prevails, in opposition to that of the effective VLF-signal, relative to the series frequency produced. During the adaption time τ, then, the effective VLF-signal will potentially prevail (through higher, acting series frequencies) and finally, the original state is again reached. Through internal driving-mechanisms, however, the no-longer significant difference in the trigger level can signify a shift in the vegetative adjustment position. For the time τ, there is probably a short- and long-term value.

Shielding interferes differently in ELF and VLF field strengths, to the detriment of the VLF-field. The influence of ULF with regards to ELF-field becomes relatively greater. As for the question of how much longer a containment in a shielded room generates a long-term adaption, it has yet to be investigated.

V. FORMULAS

In conclusion, the most important requirements for a Faraday Box and the formulas necessary in calculating these requirements are given in Table 3 and Fig. 19.

TABLE 3

The most important requirements of a Faraday Box
for ULF, ELF and VLF

1. Multilayer-walls with airgaps (equal thickness)
2. No sharp edges
3. Tubes in all openings or honeycomb-construction
4. No telephone- or power supply-cables in the shielded room (battery operation or choking coils in cables)

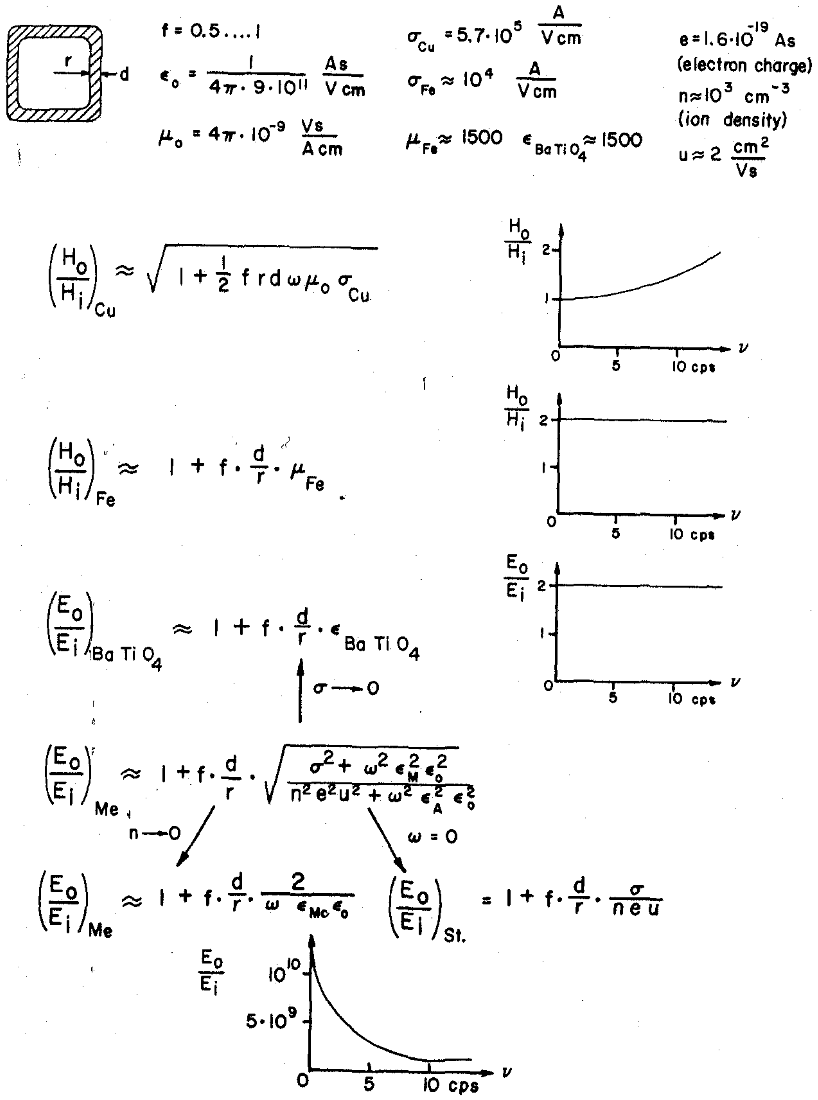


Figure 19. Collection of formulas with graphically-represented examples.

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BEHAVIOURAL CHANGES IN HUMAN SUBJECTS ASSOCIATED WITH ELF ELECTRIC FIELDS

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1. INTRODUCTION

Detailed experiments dealing with the biological effects of electromagnetic fields in the ELF and VLF regions had their beginnings after the last war. The starting point consisted of basic research of an electrophysical nature, which dealt with the manifestation and origins of the fields which arise from natural sources. At that time Reiter (1951) first reported bioclimatic research dealing with the biological effects of VLF fields in the frequency range of 4 kHz to 50 kHz, in which he also mentioned noticeable correlations between certain weather conditions and the activity of atmospherics. Among other peculiarities, Reiter mentioned certain days during which especially low signal activity occurred. A series of different experiments was completed which dealt with the biological meaning of these types of fields. These experiments were based on observations of similar occurrences in the ELF region (see Part 1: Physical Characteristics, ELF and VLF Properties) in which natural ELF signals of a certain type occurred noticeably more often during certain weather conditions.

The fundamental question can be stated generally as: Are the atmospheric signals observed in the studied frequency range of 1 to 25 Hz of special significance for the world about us and especially for human beings? The experiments performed to answer this question could not give a comprehensive explanation of all these processes due to their small scale. They merely presented at that time an exploratory effort.

An answer for the question posed was sought, first by attempting to discover various correlations between reception of certain signals and occurrences of certain events. Then, using a different approach, atmospheric signals were reproduced artificially, in order to be able to study their effects. There was an attempt to reproduce the effects observed in the correlational studies with experiments designed to measure the influences of the described signals on zoological processes, e.g., the molting process of the virus transmitting aphid Mycus persicae S. (Haine and König, 1960, 1961; Haine et al., 1964).

Further biological tests dealing with the growth of lactic acid bacteria and yeast cultures in electric fields as well as similar studies with wheat seedlings, were carried out (König and Krempl-Lamprecht, 1959). However, in this chapter the question of an effect of the observed signals on human beings and especially on their reaction time, will be primarily considered.

2. STUDIES DEALING WITH THE DEPENDENCE OF REACTION TIME ON NATURAL ELECTRIC ELF FIELDS

On the occasion of the German 1953 Traffic Exhibition in Munich, the reaction times of visitors were measured on the exhibition grounds on a continuous basis. The results of this study are presented in detail by Reiter (1953). The reaction time measurements of the visitors to the exhibition consisted of the time span taken by each subject to release a key upon the presentation of a light stimulus. A Morse key was used, since no mechanical artifacts relating to the production of an electrical signal were contributing to the measured time intervals. In the depressed state, the Morse key completes an electric circuit which is broken by the smallest mechanical movement of the lever and is not a function of the speed with which the lever is released. By varying the time intervals between trials, an anticipation effect due to repeated measurements was avoided. The experiments were conducted in a cubicle and were relatively unaffected by the other events at the exhibition. Single measurement values of reaction times vary to some extent; thus it seemed desirable to make several repeated measurements of trials for certain subjects. Immediate feedback of information on the reaction time length to the subject allowed modification of performance. The number of tests and the cumulative reaction times were stored in time intervals between 15 and 60 minutes and later recorded. The test apparatus was available to the public on a continuous basis, but unfortunately, it was only periodically monitored for 15 to 60 minutes. This naturally resulted in an uncertainty factor in the calculation of the measurements for the time periods during which the apparatus was not monitored.

Dr. Reiter was kind enough to make this comprehensive data available so that a comparison of the reaction time and concomitant signal measurements in the region between 1 Hz and 25 Hz (components of the electrical fields described in Chapter 2) could be made (König, 1960).

2.1 Comparison of Reaction Times with Naturally Occuring Type II Signals

Since it seemed from observations during the test period that Type II signals (see Fig. 1) were most likely to have an effect, analysis in this direction was done first. During the duration of the exhibition, measurable signals of Type II occurred on 10 occasions. Using the n-method (sample hour n), reaction times were averaged for 30-minute time periods before and after n (n ± t, for t = 0, 30, 60 and 90 minutes). The point in time n was taken as the moment spontaneous appearances of Type II signals occurred. The reaction time curve during the sample period (Fig. 2) was obtained by averaging the reaction times for the 10 occurrences of the Type II signals. The points on the resulting curve consisted of 2000 to 3000 different reaction time measurements. The curve "Type II signal intensities" presents the averaged relative intensities over time for the 10 sample cases. A mean time of occurrence for the 10 occurrences of the Type II signals, was calculated to be 14.30 hr (L.T.), since the samples were close to this point in time. The graph presents a curve of "normal mean reaction times" for this time period on the basis of Reiter's data, as well as the variance intervals for the entire period of the exhibition. The individual points on the curve represent approximately 4500 individual reaction time measurements. Fig. 2 demonstrates that up to point n, the reaction

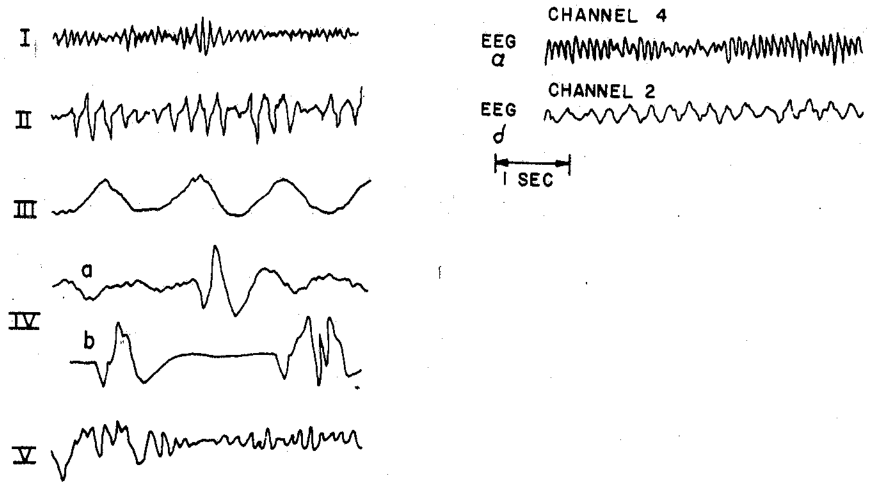

Figure 1. Various types of signals (electric fields) of natural origin in the ELF region.

I) Electromagnetic waves, Schumann-Resonance;

II) Local field fluctuations of about 3 Hz;

III) Local field fluctuations of about 0.7 Hz;

IV) Field fluctuation as a result of thunderstorm activity:

- a) Thunderstorm not yet visible on the horizon;
- b) Thunderstorm on the horizon;

V) Sunrise appearance of signals. Compare Type I with EEG ∝ rhythms and Type II with δ rhythms.

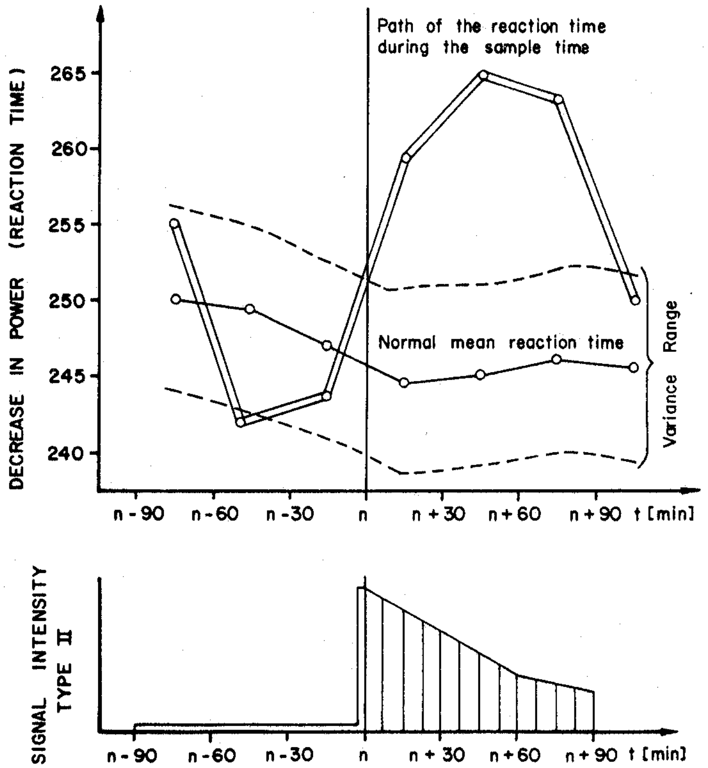

Figure 2. Relationship of reaction times of test subject to Type II signals.

Place: Reaction time measurements during the German Traffic Exhibition, 1953, in Munich;

Time: August - September, 1953;

Number of cases: 10;

Mean time of the n time: 14:30;

Number of data points per point on the curve:

- a) reaction time of the sample hour approximately 2,500;
- b) normal mean reaction time approximately 40,000.

times fall within the normal variance interval. Upon the occurrence of Type II signals the reaction times of the subjects become substantially longer and lie conspicuously outside the normal variance interval. A maximum in reaction time increases occurred between 30 to 60 minutes after the sample time, whereas the intensity of the signals remained elevated for 90 minutes after their appearance.

2.2 Comparison of Reaction Times with Naturally Occurring Type I Signals

Type I signals were recorded during 18 days in September 1953. For these selected 18 days the calculation of the mean relative intensity of the signals and the corresponding calculations of the mean reaction times was possible. In order to better indicate the correspondence between the two curves in Fig. 3, the reaction time axis is inverted. The reaction time values used were for one-half to one hour periods. The number of reaction time measurements per data point on the curve was approximately 4500. As can be seen in Fig. 3, the effects of Type I signals are opposite to those of Type II signals, since with increasing intensity of Type I signals, the reaction times were shortened, thus resulting in an increase in performance.

In conclusion, it should be noted that a control is not viewed with respect to the statistical significance of the results, since - especially in the first case - the number of sample cases seemed to be too small and above all because of the uncertainty of the reaction time measurements. However, the results seem to be of significance, insofar as they indicate a correlation in each case. In summary, it could be stated that presumably Type II (3 - 6 Hz) signals decrease the performance of subjects, whereas Type I (10 Hz) signals increase performance.

3. EFFECTS OF ARTIFICIALLY PRODUCED ELF ELECTRIC FIELDS

Motivated by the results of the experiments discussed, signals of Type I and II were artificially generated. The desired electric fields were produced by means of a specially constructed generator connected to two wire mesh sheets between which the desired electric fields were produced. The electric fields of the 10 Hz frequency were sinusoidal

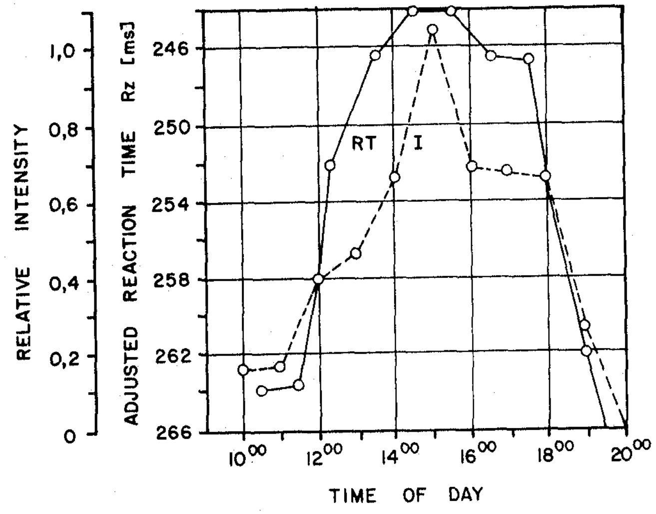

Figure 3. Relationship of reaction times of test subject to the appearance of Type I signals.

Place: Reaction time measurements during the German Traffic Exhibition in 1953 in Munich. Recording of the Type I signals at "Techurshla Hochschule Munchen";

Time: September 1953;

Number of reaction time measurements per point on the curve: approximately 4500.

while the fields with a basic frequency of 3 Hz had a large harmonic content. The wire mesh sheets located in the experimental chamber were located in the ceiling and the floor of the chamber and had a mesh size of 0.01 m with a separation distance of approximately 2.50 m. This arrangement stipulated that single test subjects be placed in the artificial electric field so that after the noted measurements the procedure resembled the natural conditions.

The test procedure was as follows: the apparatus used in the traffic exhibition was used to measure the reaction times of test subjects. The subjects were required to release the switch when a specific stimulus consisting of two light stimuli within a triangle of 3 light bulbs was presented. The discriminable stimulus configurations were presented in various combinations of two lit bulbs. Thus a discrimination had to be made. False reactions were recorded, but, as was the case for the measurements at the traffic exhibition, did not produce any results. Additional acoustic stimuli (buzzer and bell sounds) were arbitrarily superimposed over the entire test sequence and were to be ignored by the test subject. A test session consisted of 15 trials during which only 10 of the correct light stimulus configurations occurred. The mean of these 10 measurements was taken as the reaction time value for this one session. Several selected programs of discriminable light stimulus configurations and acoustic signals were available to preclude a learning effect.

The test subjects' mean reaction times were measured for 8 hour periods of 20-minute interval sessions. This enabled a calculation of individual daily rhythms in reaction times. Furthermore, subjects could be exposed to the artificial electric field for a 10-minute period within the eight hour test series, at other times of the day. This naturally occurred without the knowledge of the subject. However, this was only a simple single blind design, since the experimenter had to switch on the field.

The typical results of deviations from the daily mean (320 msec) of a subject responding well to the imposed fields is presented in Fig. 4. The 3 Hz electric field (plate voltage of 2V for 20 and 10 minutes and 7V for 2.5 minutes), which had a strong harmonic content obviously produced a more or less spontaneous effect in the direction of performance decrement (10% and over) in the test subject.

The total number of experiments was small; however, upon analysis, the interesting effect of the imposed electric field on reaction time was indicated. Fig. 5 depicts the effects of electric fields of Type II (3 Hz, heavily top-waved). Using the $\bar{n}$ - method, 8 instances of imposition of the artificial field are summarized. The field was on for approximately 12 minutes with field strength of approximately 1 V/m (2.50 m plate separations, 2.5V applied to the plates). Following the imposition of the field, an increase in reaction time -i.e., a decrease in performance- is readily seen. The effects of an artificial electric field of Type I signals (10 Hz to 25 Hz, sine-waved) are shown in Fig. 6.

In this case, 4 instances of imposition of a field with an average of 2 V/m and 8-minutes duration are shown. As can be seen, a decrease in reaction time - i.e., an increase in performance - occurred.

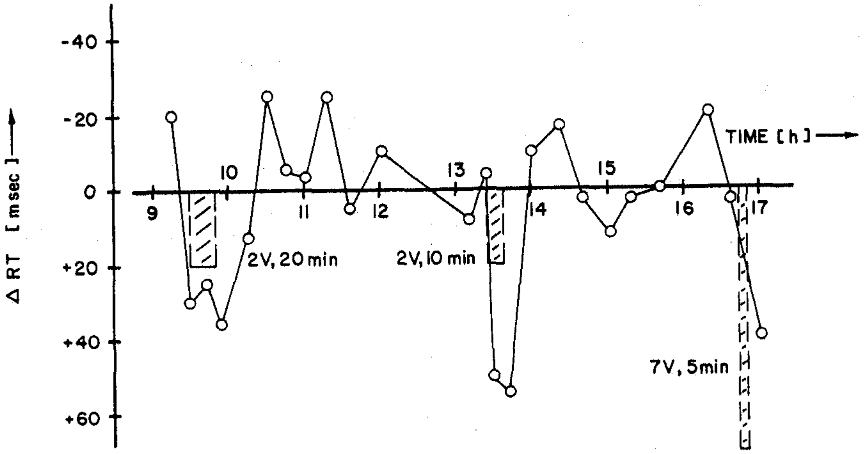

Figure 4. Typical effect of a vertical electric field (plate separation 2.5 m) with a frequency of 3 Hz (strong harmonic content) on the reaction time of a single test subject in a single-blind design (field used was modelled after natural Type II signals).

The figures indicating field strength are plate voltages; those indicating time are the duration of field imposition. The deviation of reaction time from the daily mean were calculated using ten sequential measurements to obtain the value for each point on the curve.

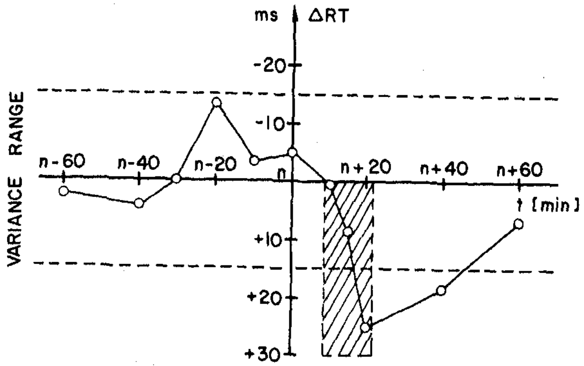

Figure 5. Effect of an artificial field of Type II signals (3 Hz, harmonic content) on the reaction time of test subjects. The result was a decrease in performance.

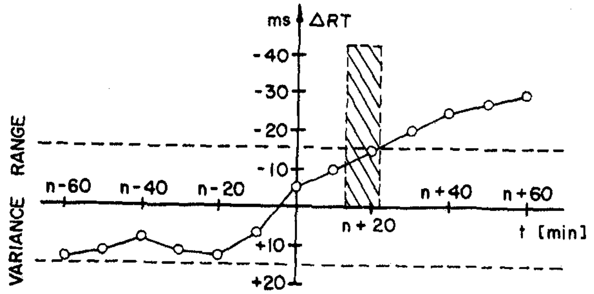

Figure 6. Effect of an artificial field of Type I signals (10 Hz, sine-wave) on the reaction time of test subjects. The result was an increase in performance.

In these two experiments, the small number of cases did not allow for statistically significant results; however, the results concurred with those obtained at the German Traffic Exhibition. It thus seems to be the case that, in all probability, people can be influenced by natural electric fields of the described types, since artificially produced fields of a similar type produce comparable results.

4. CLINICAL TEST

In order to supplement the relatively subjective experimental methods with results from more objective methods, measurements of the galvanic skin response (GSR) in the artificial electric fields, were conducted. Whereas subjects were in a sitting position for measurements of reaction time, they were in a reclining position during the measurements of the GSR. Fig. 7 illustrates the changes in the

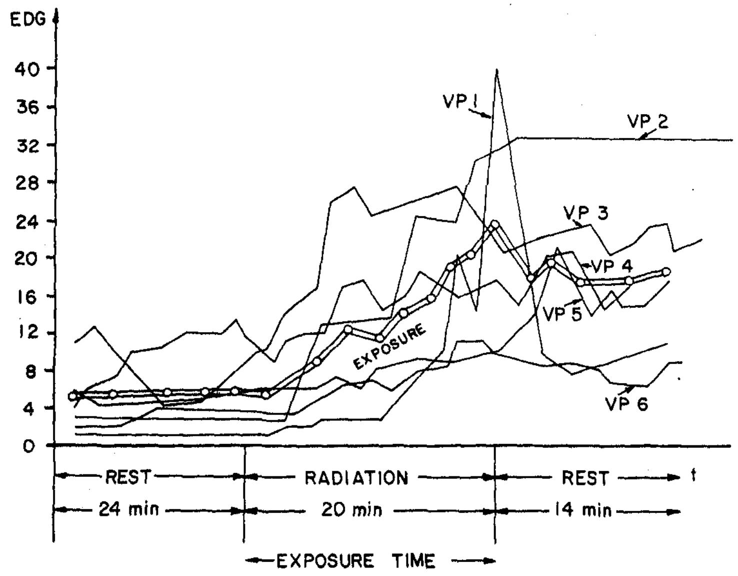

Figure 7. Effect of an artificially produced field of Type II signals on the Galvanic Skin Response of test subjects. Field strengths 1 V3m: 12 test subjects, positive reaction in 1 test subject; Field strength 5 V/m; positive reaction 5 out of 10 subjects.

GSR for subjects reacting positively. Thus, it was possible to influence 5 out of 10 subjects with electric fields in the order of more than 5 V/m (frequency 3 Hz harmonic content) as indicated by the decreasing skin resistance after initial exposure to the artificial fields. These partially successful experiments may have been limited by the distorting electrical factors present in the experimental chamber in the clinic.

5. SUBJECTIVE REPORTS OF THE SUBJECTS

In addition to the data presented, interesting subjective reports from the subjects were obtained when the artificial electric field was imposed, especially the Type II signals (in reference to section 3). Thus, repeated complaints about headaches occurred after several minutes of brief exposure to the field. The complaints sometimes increased in number with subsequent exposures, or feelings of fatigue were reported. A general fatigue was apparent upon cessation of headaches. The various complaints including a "tightness in the chest" or "sweating of the palms of the hand" eventually disappeared, becoming random after several hours.

6. REACTION TIME MEASUREMENTS BY HAMER

Additional information concerning reaction time measurements of persons in artificial ELF electric fields come from Hamer (1965, 1969). He reported that the objective of a first phase in the experimental program was to establish, with a high degree of confidence, that electric fields (frequency range 1 - 20 Hz) do influence the observed shifts in measured reaction time. For this reason a 2 V_{rms} potential was placed across two field plates (horizontal distance 50 cm). Circle and triangle marks in Fig. 8 show the results of two different experiments. Comparisons of the mean reaction time of persons in "no field" with those in a 3 Hz and a 8 Hz field and in a 3 Hz and a 12 Hz field are given. The results shown in Fig. 9 confirm the fact that the reaction time is inversely proportional to the frequency of the electric field applied. The objective of the second phase in the experimental program was to determine minimum voltage threshold for the above described effects and what modifications in the field frequency may be required. Three

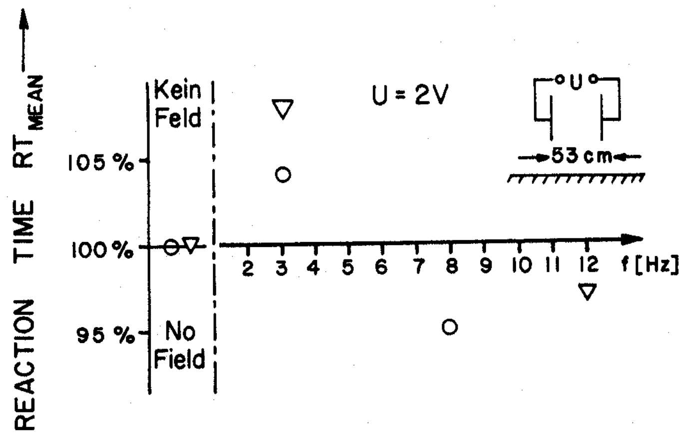

Figure 8

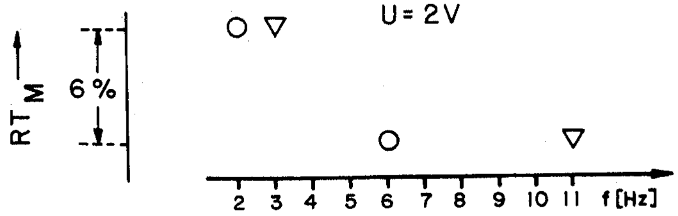

Figure 9

Figures 8 and 9. Effect of man-made signals on humans as a function of ELF signal frequency for constant field strength (two sets of experiments, 0,∇).

voltage levels were used: .2, .02 and .002 V_{rms}, at constant plate spacing. The results are shown in Figure 10 for two sets of experiments. Lines describe the frequency range in which the frequency of the electric field could be changed without any measurable influence on the reaction time of the test persons. It seems apparent that the lower the field intensity, the smaller this range. At a plate voltage of .002 V, a change of 1 Hz (from 7.5 to 8.5 Hz, or from 8.5 to 9.5 Hz) was already sufficient to result in a statistically significant change in reaction time.

Hamer finally writes that under proper experimental conditions, human reaction time may be influenced by ELF electric fields in a predictable way. Also, the minimum voltage threshold or field strength can be quite low and in the range of the natural fields in the atmosphere.

7. GENERAL INFORMATION RELATING TO THE SIGNIFICANCE OF ELF FIELD PROCESSES

The described reaction time measurements are only one type of possibility that draws attention to the significance of biological effects from processes in the ELF region, in this case electric fields. In this respect, also note the possibility that VLF-atmospherics or general VLF-fields, which occur as impulse cascades in the ELF region, can act

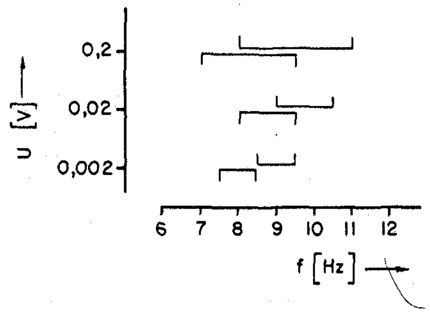

Figure 10. Frequency band in which no frequency-depending influence of man-made ELF signals on humans was measurable as a function of field strength (two sets of experiments ┌┐ └┘).

on non-linear biological systems in a manner similar to that of ELF signals. The relevant experiments with respect to VLF-atmospherics were conducted by Reiter (1951, 1953, 1960), König (1954, 1955, 1958), as well as several other authors, to which the present volume draws attention.

The described experiments and studies represent, as already mentioned, the first major attempt to demonstrate the biological effects of electromagnetic fields, especially in the ELF-region. Similar experiments were carried out in the meantime in a variety of areas by several authors and are described in more detail in other chapters of this book.

The numerous biological experiments involving electrostatic fields should not be left unmentioned, even though the results are often contradictory. Upon closer inspection, it is often the case that when these types of electrostatic fields are produced by means of electrodes, one of which is fastened to the ceiling of the laboratory room, mechanical vibrations in the ELF-region (in the electrode mass itself or together with the ceiling mass) can occur. Mechanical vibration amplitudes of 1 mm can result for an electrode separation of 2.5 m. Since voltages on the order of 1000 V are applied to these "plate condensors" to produce the static fields, a fluctuating field component in the ELF-region is superimposed on the electrostatic field, with an amplitude of the order of 0.1 V/m in a homogeneous field (test subjects in the experimental space between the two electrodes can appreciably increase this value). These are intensities well within natural field values; thus, the problems associated with such experiments become obvious.

Similar problems occur due to electromagnetic fields in the ELF- and VLF-regions which are produced during air-ionization as a result of corona discharge. No unequivocal experimental controls for ELF-VLF contributions are present in this case either. Finally, the interesting experiments by Rohracher (1952) should be mentioned. These dealt with the mechanical micro-vibrations of the human body (such muscle vibrations and the like are now generally well known) and later with earth vibrations which also occur with a frequency of approximately 10 Hz. These earth vibrations are similar in their pattern to the Schumann resonance signals.

In this respect, findings from electroencephalographic studies are pertinent. The α -rhythm of the brain resembles Type I signals in frequency and wave form to a remarkable degree, whereas certain disturbances in the electric processes of the brain resemble Type II signals (see Fig. 1). The above observations, together with the assumptions of Bioclimatology, i.e., that so-called "biotropic factors" inherent in weather process act on the vegetative (autonomic) nervous system of the human organism, could be considered to support the notion that "atmospherics" have an effect on people and can be considered one of the biotropic factors.

An effect of atmospherics on people is also suggested by the observation of the correspondence between the daily rhythm in the signals with the daily rhythm of the human organism. In this connection Type V signals (see Fig. 1) are of special interest. These signals are recorded especially frequently at sunrise. Perhaps these signals together with Type I signals which increase in intensity at the same time, play a role in the switching of the autonomic (vegetative) nervous system to ergotropy; i.e., sympathetic activation.

In conclusion, it is perhaps not too tangential to speculatively discuss the obviously far reaching significance of electromagnetic fields in VLF- and especially in the ELF-region, to areas concerned with evolution theory (see Chapter by Cole and Graf). Certain higher organisms were in a position to adapt appropriately to environmental factors in the course of their evolution. Adoption to electromagnetic stimuli in the frequency spectrum which penetrated the outer atmospheric layers and reached the earth surface, is one such example. In the course of the evolution of life, a narrow band electromagnetic sensor developed--the eye.

Atmospherics most likely existed in time periods for which no evidence of life or biological systems exists. Therefore, why couldn't the originally existing electromagnetic stimuli in the ELF- and VLF-regions have had an effect on the development of certain organismic electrical control and regulatory processes, during the course of evolution? The EEG events in the human brain (see Fig. 1) as well as the EKG processes controlling the heart are in this respect relevant examples. Also the relatively higher-frequency muscle control impulses can, in an evolutionary sense, be connected with VLF atmospherics. The electromagnetic environmental stimuli of natural origin and the comparable biological processes demonstrate so remarkable a similarity with respect to the temporal pattern and the intensity relationships, that one is easily led to speculate about this area ad absurdum. Presman (1970) arrived at similar reflections, but he limited himself to more general considerations; hence, he did not go deeper into the events which are obviously important in their significance and which occur in the biological frequency zone (ELF).

8. SUMMARY

As a result of a comparison between measurements of naturally occurring electromagnetic signals in the ELF region and concomitant measurements of a large number of reaction times in test subjects, it was demonstrated that a certain relationship exists between prevailing electric fields and the reaction time of test subjects. Further experiments in the laboratory with artificially produced electric fields (which simulated the natural fields), supported the initial observation with regard to the frequency specificity of the applied field. Signal frequencies of 3 Hz slow down reaction times and signal frequencies over 10 Hz decrease reaction times (i.e., produce an increase in performance in the test subjects). Independent of this, subjective complaints were received from the test subjects which resembled the so-called weather sensitivity complaints.

Similar experiments from other laboratories point out the dependence of the reaction time effect upon field frequency and in addition indicate at which minimum intensities the effects are still statistically significant. The experiments originally conducted at field strengths in the order of 1 V/m, were still effective at field strengths of 1 mV/m, a magnitude which can easily occur in natural fields. In future studies of a similar nature, it would be of significance to study the relationship between intensity of the fields and reaction times or similar parameters of the test subjects, since previous studies lead one to expect an intensity region with an optimal effect.

Analysis of results from recent psychophysiological tests (Schulz, 1970), as well as studies dealing with air-ionization (Rheinstein, 1960; Friedrich, 1966), indicate the possibility of pre-selecting subjects in experimental groups into subgroups which display opposite reactions to the same experimental situation. Related problems should be obviated in future studies where larger numbers of test subjects are involved. Certain reactions may cancel each other out if only mean values are taken, when in fact, careful and rational subdivision of the groups would lead to statistically significant results. The results in this chapter are concerned with ELF effects. Discussion of electric and magnetic field effects from static to UHF fields has been discussed elsewhere (König, 1974).

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ELF-EFFECTS ON HUMAN CIRCADIAN RHYTHMS

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INTRODUCTION

Electromagnetic fields of extremely low frequency have been shown at a high statistical level to influence human circadian rhythms. This means that circadian rhythms can be used as very sensitive indicators to test the influence of ELF electromagnetic fields on human beings in general. Before discussing the special ELF-effects, the indicator itself has to be introduced. Therefore, some basic features of human circadian rhythms will be mentioned.

HUMAN CIRCADIAN RHYTHMS

Just as in other organisms, all measurable human biological variables vary diurnally in their values (Conroy and Mills, 1970). This periodicity (with a period of 24 hours) concerns physiological as well as psychological variables and influences sensitivities towards external stimuli including drugs and noxious influences. As an example, Fig. 1 shows records of different variables measured in a young man for about one week when he was living with a strong 24-hr routine. Beside the change between wakefulness and sleep, Fig. 1 shows the rhythmic courses of two physiological and of two psychological variables, measured either continuously (rectal temperature), or at regular intervals (other variables). During night, the subject had been awakened for the tests. It has been shown in other

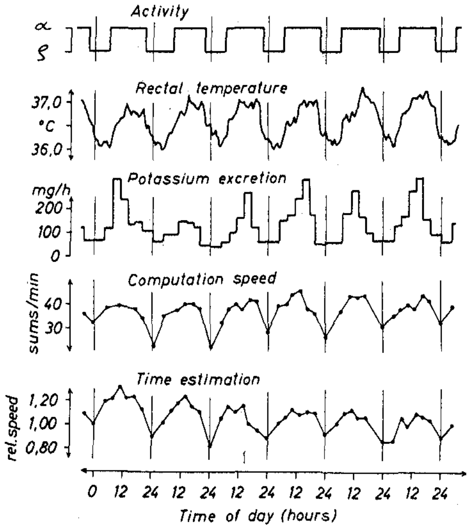

Figure 1. Temporal course of some physiological and psychological variables, measured in a young man over a week under strictly regular conditions. Demonstrated are (from top to bottom) the change between wakefulness (activity-time α) and sleep (rest-time ρ), rectal temperature (measured continuously), excretion of potassium with the urine, speed of computation (automatic Pauli-Test), and the speed of time estimation (production of 10 sec), all as a function of local time. The last mentioned three variables were measured at regular intervals. (Wever, in print[a])

experiments that those awakenings from sleep do not alter the rhythm; even sleep deprivation does not fundamentally alter the rhythm (Wever, in print[a]). The figure demonstrates that all variables oscillate periodically in a regular manner.

The first question in the examination of biological 24-hr rhythms is that of their origin. Because in the natural environment, all organisms are under the influence of the change between day and night, this question can be answered only in constant laboratory conditions (Aschoff, 1963). Accordingly, biological rhythms had been tested

under conditions artificially held constant, without any environmental time cues. It was the result of the corresponding experiments that the rhythms persist but with a period deviating slightly from 24 hr. This slight deviation of the period from the duration of one day when measured under constant conditions, has led to the name "circadian" rhythms (from lat.: circa = about; dies = day) (Halberg, 1959). Only that deviation of the biological period from all possible environmental periods is the unequivocal proof that the biological rhythm is of endogenous origin and cannot be induced by any environmental rhythm (Aschoff, 1963).

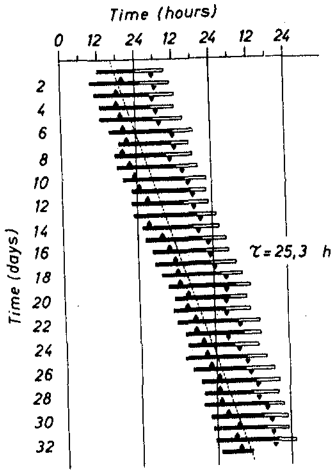

Figure 2. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues. The activity rhythm is demonstrated by bars (black: activity; white: rest); the rhythm of rectal temperature is demonstrated by triangles indicating the temporal positions of the extrema (▲: maxima; ▼: minima). Successive periods are drawn beneath each other, temporally correct with respect to local time (abscissa). The ordinate shows (from top to bottom) the sequence of the subjective days. (Wever, 1971b)

Not only in all animals examined but also in man, the endogenous origin of circadian rhythms has been proven (Aschoff, 1962). Figure 2 shows, as an example, the course of a relevant experiment. The records originate from a young man who lived for nearly five weeks in a constant environment without any external time cues. The data used in Fig. 2 show obviously the deviation of the "free-running" period from the normal period of exactly 24 hr. For clarity, only the rhythms of activity and of rectal temperature are presented out of a variety of measured variables. During the total experiment, the phase of the biological rhythm shifts for nearly two days against local time, and with this, for much more than 360° against possible environmental periodicities. In fact, a phase shift of more than 360° against "Zeitgebers" is the only unambiguous proof that the rhythm is really "free-running", i.e. that it is not induced by any environmental periodic stimulus, known or unknown. Therefore, the persisting rhythm can be described by a self-sustained oscillator. In Fig. 2a, a computed period analysis (Fourier analysis) of each time series is given. It shows one single "spectral line" in each time series, with the center of gravity at 25.3 hr, significantly deviating from 24.0 hr. Period analyses from all other measured variables show the same picture, namely one sharp spectral line at 25.3 hr.

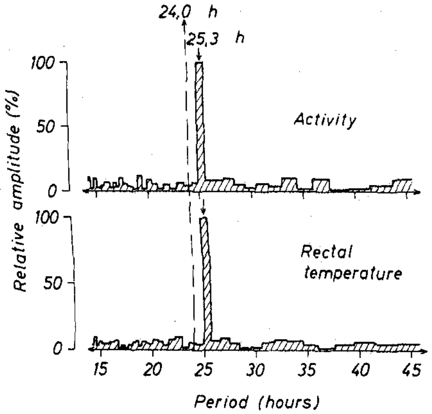

Figure 2a. Period analyses (Fourier analyses) of the two time series (rhythm of activity and rectal temperature) shown in Fig. 2. (Wever, 1973)

In the experiment underlying Fig. 2, the rhythms of all different variables measured run synchronously to each other, as can be seen in the courses of the rhythms for activity and rectal temperature. This internal synchronization is, indeed, the case in most but not in all experiments. In about 20% of the experiments, "internal desynchronization" occurs, with different period values in the rhythms of different variables in the steady state (Aschoff, 1967b; Wever, 1967a). Fig. 3 shows an example of this state. The results originate from a subject living in a constant environment like the other subject whose results are given in Fig. 2. During the first two weeks, the results are very similar to those shown in Fig. 2, but after that time, the two rhythms ran separately of each other in their temporal courses, without any known change in the experimental conditions. An interpretation of this picture may postulate the existence of not only one but of two internal oscillators, one of which controlling the activity rhythm, and the other one controlling the rectal temperature rhythm. During the first section of the experiment, the two oscillators were coupled to each other but not during the second section. In other experiments, the state of internal desynchroniza-

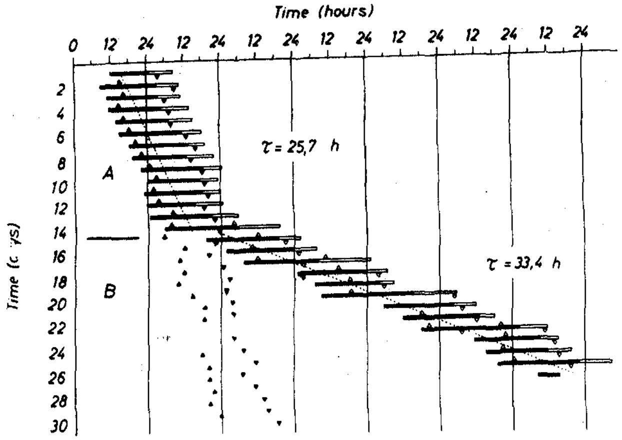

Figure 3. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues. Designations as in Fig. 2; white triangles: temporally correct repetitions of corresponding black triangles. After two weeks, "internal desynchronization" occurred spontaneously. (Wever, 1973)

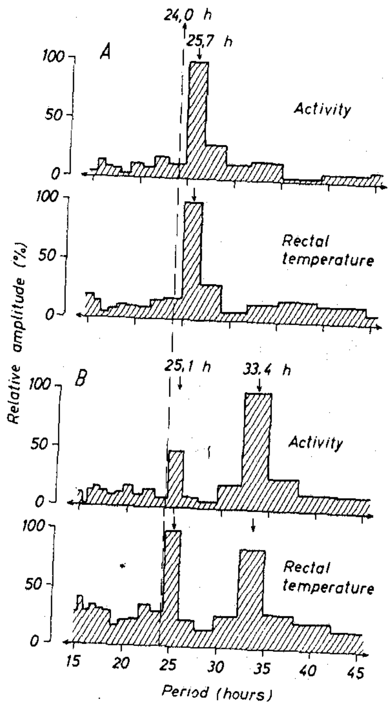

Figure 3a. Period analyses (Fourier analyses) of the time series (rhythms of activity and rectal temperature) shown in Fig. 3, computed separately for the sections A and B. (Wever, 1973)

tion occurred right from the beginning of the experiment, and in a small number of the experiments, the activity rhythm was not slower than the temperature rhythm as in Fig. 3, but faster (Wever, 1969b).

The computed period analyses presented in Fig. 3a show that slight modifications of the simple two-oscillator model are necessary (Wever, 1973). The analysis of the first section (A) show again one single spectral line in each time series; because the time series (14 days) is shorter than that in Fig. 2 (33 days), the spectral lines are broader than those in Fig. 2a. The analysis of the second section (B), however, shows another picture: the period analysis of each time series shows two peaks. The interpretation is that there are, indeed, two oscillators each controlling both rhythms simultaneously but in different proportions; the activity rhythm is controlled more strongly by the slower oscillator than by the faster oscillator, whereas the rectal temperature rhythm is controlled more by the faster oscillator than by the slower one. This model can be generalized: each of the many rhythms within one subject is controlled by several internal oscillators, and by a special quantitative combination (Wever, 1972).

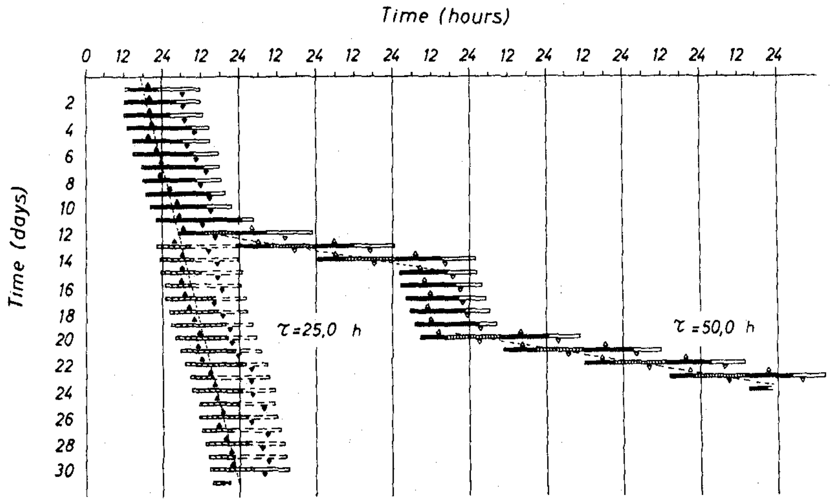

Figure 4. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues. Designations as in Figs. 2 and 3; shaded areas within the black bars: sleep which is subjectively indicated as a nap; dotted bars: temporally correct repetitions of corresponding solid bars, with naps weighted for rest-time. At the 12th, and again at the 20th subjective day, "apparent desynchronization" occurred spontaneously.

Finally, an additional case of interaction between different rhythms has to be discussed. An example of this casé is given in Fig. 4. In its first part, Fig. 4 shows once more an internally synchronized rhythm, with a period of 25.0 hr. After 12 days, internal desynchronization seems to occur which is at the first look, similar to that in Fig. 3. A closer inspection shows, however, that the period of the activity rhythm is exactly twice as long as that of the temperature rhythm and of the two synchronized rhythms in the first section; consequently, there is a fixed phase relationship between the two rhythms in contrast to the continuously varying phase relationship in Fig. 3. To differentiate this state from that of real internal desynchronization (Fig. 3), it has been called "apparent internal desynchronization", in this special case with a "circa-bidian" activity rhythm (Wever, 1967b). The term "apparent" may indicate that the two oscillators are not uncoupled as in case of real internal desynchronization, but mutually synchronized in a 1:2 ratio, in contrast to the normal 1:1 ratio. In the course of the experiment, the relationship between the rhythms of activity and rectal temperature changes sometimes spontaneously between the 1:1 and the 1:2 synchronization. In total, the state of apparent internal desynchronization has occurred spontaneously in about 5% of all experiments.

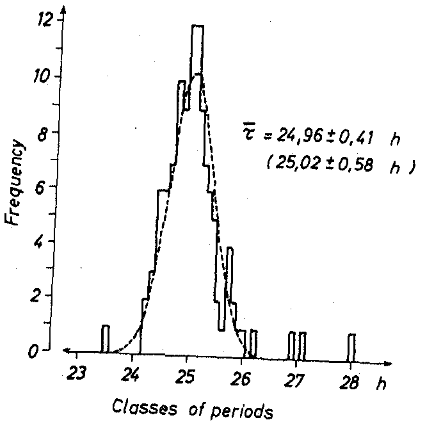

Figure 5. Histogram of the mean periods of all subjects living under constant conditions with strict isolation from environmental time cues (periods of the rectal temperature rhythm). The numbers indicate the mean (with standard deviation) of all periods except the four values dropping out of the distribution; the dotted line indicates the inherent normal distribution. Numbers in paranthesis: mean (with standard deviation) of all periods including the dropping out values. (Wever, 1971a)

Summarizing all experiments discussed so far, the rhythm of rectal temperature always demonstrated a period close to 25 hr, despite the fact that the activity rhythm had a period partly deviating from that value (Wever, 1971a). Fig. 5 shows a histogram of the rectal temperature periods of all subjects examined so far; it is remarkably narrow in its distribution. These periods are independent of sex (about 30% of the subjects were females), and age of the subjects (the subjects were 17 to 69 years old) (Wever, 1969b). Furthermore, the average period does not only deviate significantly from the period of the earth's rotation (24.0 hr), but also significantly from the apparent revolution of the moon (24.8 hr) (Wever, 1969b).

The results gained from experiments under constant conditions with autonomously free-running rhythms, prove the endogenous origin of circadian rhythms. In the normal environment, all organisms including man have a period of exactly 24.0 hr. This means that the endogenously generated rhythms are exogenously synchronized, or entrained. In general, circadian rhythms, although of endogenous origin, are influenced by external stimuli. Therefore, in the next step, the question has to be answered what environmental stimuli are able to influence human circadian rhythms and how they do it.

In most animals examined so far, light has been demonstrated to be the most efficient environmental stimulus. This can be shown also by the influence of light intensity on the autonomous rhythms: in most animals, the period of the free-running rhythm (and many other parameters of the rhythm) depends regularly on the intensity of the constant illumination (Aschoff, 1964). Therefore, human circadian rhythms have likewise been examined under varying light intensities. In the corresponding experiments subjects were exposed, in different sections of the same experiment lasting 10 to 14 days duration, to different light intensities. The overall result of these experiments was that light had on the average no influence on human circadian rhythms (Wever, 1969a). In many of these experiments, indeed, the period changed slightly when the intensity of illumination changes, but not according to a rule. This result is even valid when the range of light intensities was reduced to total darkness (Wever, in print[b]). Moreover, the tendency towards internal desynchronization was independent of the intensity of illumination (Wever, 1969a). Thus, not only the inter-individual distribution of free-running periods in man is remarkably small but also the intra-individual variability.

The other and more natural way to influence circadian rhythms is by periodically changing environmental stimuli which act as "Zeitgebers" and synchronize the rhythm. In most animals, out of the great variety of external periodicities combined with the change between day and night, a light-dark cycle has been shown to be the most efficient Zeitgeber (Aschoff, 1964). In contrast to this, human circadian rhythm cannot even be entrained by a pure light-dark cycle (without other time informations) to a period of 24.0 hr when exposed to a 12:12 (or a 15:9 hr) light-dark Zeitgeber. All human subjects showed a clear free-running rhythm with a period of about 25 hr. However, the subjects did have the option to switch on small auxilary lamps when the "evening twilight" started. Thus, they were not restricted to rest during dark-time (Wever, 1970c).

The results of these experiments, and those of the experiments under constant conditions with varying light intensities seem to support the ineffectiveness of light on human circadian rhythms. This conclusion, however, is not totally correct because in another kind of experiment, light has been shown to have a strong and statistically significant influence on human circadian rhythms. When light intensity is not constant during activity-time and rest-time, and the subjects can switch off the illumination when going to bed and switch it on when getting up, the period is significantly lengthened (Wever, 1969a). Thus, light has been proven to affect human circadian rhythms when applied in a special manner; it is, however, ineffective when applied in a manner in which it is effective in most animal experiments (Wever, 1968b). As a special hypothesis, two reversed effects of light interfere with each other (Wever, in print[b]), thus exposure to continuous light results in a compensatory effect.

So far, the question is still unanswered as to which external stimuli do normally entrain human circadian rhythms to 24 hr. In other experiments of a different type, social contacts have been proven to be the most effective Zeitgeber (Wever, 1973). For instance, when the ineffective light-dark Zeitgeber is coupled with signals at regular intervals - calling the subjects for urine samples and for

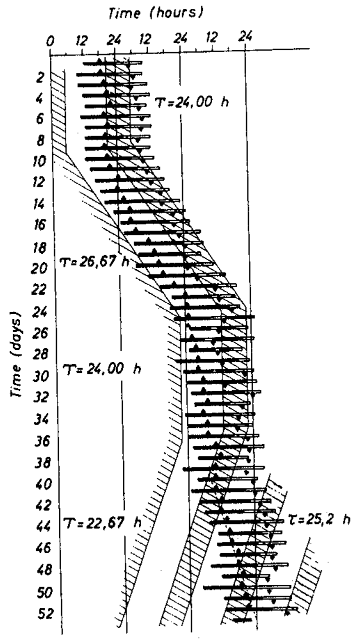

Figure 6. Circadian rhythm of a subject living under strict isolation from environmental time cues but under the influence of an artificial Zeitgeber, with three changes of the Zeitgeber period. Designations as in Fig. 2; shaded areas: dark-time. Entrained rhythm in the first three sections but free-running rhythm in the last section. (Aschoff, 1969).

some psychomotor tests, the resulting combined Zeitgeber is able to entrain the human rhythm not only to a period of 24.0 hr but within a range of entrainment between periods of about 23 to 27 hr (Aschoff, 1969). The signals for social contacts were perceived by the subjects as stimuli released automatically by a signal clock (Wever, 1970a). As an example, Fig. 6 shows results from a subject who lived under the influence of such an artificial Zeitgeber, with three changes of the Zeitgeber period. As can be seen, the subject was entrained to periods of 24.0 hr and 26.7 hr but not to the period of 22.7 hr; this last period was outside the range of entrainment. Inside this range, the temporal relationship between the biological rhythms and the Zeitgeber as well as the internal phase relationship between the rhythms of different variables depends on the period (Wever, 1970b).

The sensitivity of human circadian rhythms to external environmental stimuli can be used to detect stimuli which are normally not perceptible. Thus, human circadian rhythms can serve as an indicator to test biological effects of subtle stimuli. In order to understand the kind of application of these stimuli, a detailed description of the measuring facilities has to be given.

METHODS

In order to do research on human circadian rhythms, a special underground isolation station has been built (Wever, 1967b; 1969b). Fig. 7 shows an outline of this building. The building contains two experimental units, each consisting of a living room (20 m^2) with a bed, a small kitchen (3 m^2), and a bathroom (3 m^2). The only communication between an experimental unit and the control room is through a lock (2 m^2) whose two doors are automatically closed against each other. Finally, the station contains a small chamber for special animal experiments. The experimental rooms are furnished like normal living rooms, so that the subjects had not the feeling of being in an experiment. Fig. 8 shows one of the rooms.

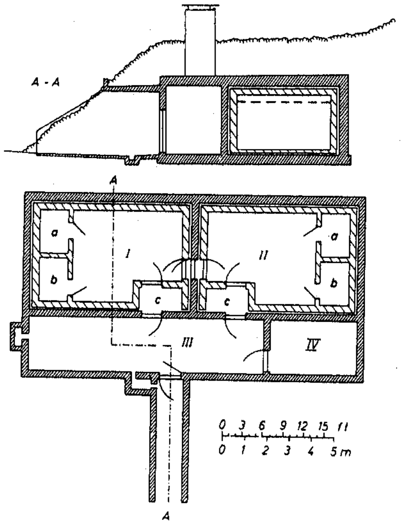

Figure 7. Floor plan and cross section of the isolation station. Narrowly shaded areas: reinforced concrete; widely shaded areas: brick walls. I and II: experimental units (a: kitchen; b: bath room; c: lock); III: control room; IV: experimental chamber. (Wever, 1969b)

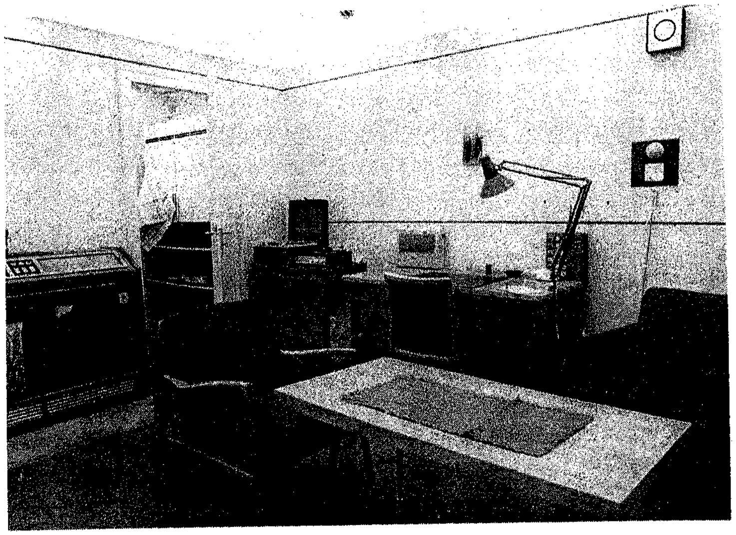

Figure 8. View in one of the experimental units.

The main point when constructing the station was to exclude all environmental noises. For this purpose, the units are completely double walled, with floor, walls, and ceiling, and without any stiff connection with the concrete of the outer building. After finishing the station, the sound absorption between the outside and each experimental room has been measured to be at least 90 db; the sound absorption between the two experimental units has been measured to be 90 db. To eliminate the last possible contact by noise, a small masking noise of the air condition plant of a constant 50 db has been introduced into the two rooms independently. Thus, outside noises must exceed 140 db (more than the pain threshold) before being perceptible inside.

One of the two experimental rooms is, in addition, shielded against electric and magnetic fields. Two independent shieldings have been performed. Firstly, the reinforced concrete around this room contains more structural steel than usual, and all the steel elements around this room were mutually welded together. Secondly, five thin layers of mild steel are mounted between the two walls surrounding the room. Because of the complicated construction within the building, it was impossible to test the efficiency of the two shielding independently. After finishing the total equipment, the vertical intensity of the natural magnetic field of the earth has been measured (by means of a "Foerster-Sonde"). Outside the station the field-strength was 405mOe, inside the non-shielded room on the average, 365mOe (decrease of 10%), and inside the shielded room on the average, 4mOe (decrease of 99%); the latter value could, indeed, only be measured after a demagnetization of the shielding (see below). This result means that the natural magnetic field of the earth penetrates into the non-shielded room nearly undiminished whereas it is diminished within the shielded room by 40 db. High frequency electromagnetic fields are diminished within the shielded room by more than 40 db. Therefore, low frequency electromagnetic fields which could be expected to have any biological efficiency, are diminished by the shielding mentioned by at least 40 db.

In addition to the shielding, one experimental unit is equipped with facilities for introducing all kinds of artificial AC or DC electric or magnetic fields. For this purpose, the unit (including kitchen and bathroom) is surrounded in all three directions by coils (100 spires each), and built-in pairs of electrodes. The coils as well as the electrodes are imbedded in the plaster of the inner walls, and thus, they are invisible after finishing the building. Fig. 9 shows the room when it was under construction. Many miles of wire are attached on the cork insulation covering the inner walls, floor and ceiling (See Fig. 10). After checking the total equipment, it was covered with a thick layer of asbestos plaster. In Fig. 9, the floor was just finished. The connections to the coils and the electrodes are outside the experimental room in the control room. Corresponding generators (AC or DC current generators for the coils and AC or DC voltage generators for the electrodes) can be plugged into these connections without any knowledge by the subjects. All artificial fields generated by means of these facilities were so weak in field strength that it was impossible for the subjects to perceive the fields consciously.

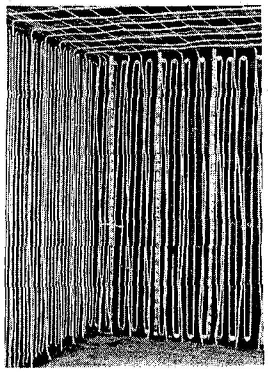

Figure 9. Experimental unit II when under construction.

The total construction of a wall (of the shielded room) can be seen in the scheme of Fig. 10. The reinforced concrete is part of the outer building, the brick work is part of the inner room which floats in the outer building on a layer of glass wool. Between the two separated walls, five round-about closed layers of iron are arranged, which form, in addition to the likewise round-about welded structural steel contained in the reinforced concrete, the electro-magnetic shielding. Within the asbestos plaster at the inner walls, the wires constituting the coils and electrodes are imbedded.

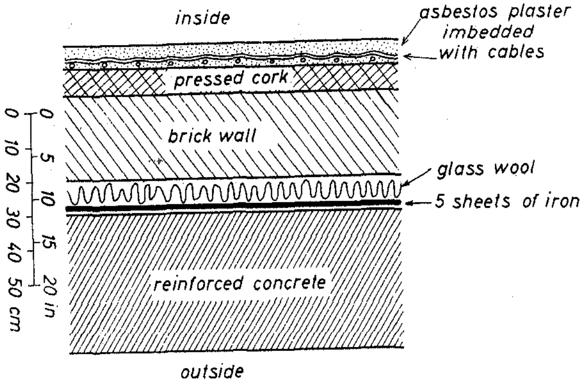

Figure 10. Cross section through a wall of experimental unit II.

The coils have a multiple action. Besides for the generation of magnetic fields, they are necessary for the demagnetization of the iron shielding; in this case, they are connected with the normal 50-cps line voltage, and the current can be slowly diminished from 30 amp to zero. And finally, the coils can be used as an antenna for telemeter systems inside the experimental unit; the telemeter information cannot penetrate the shielding, and therefore, an antenna system inside the shielding was inevitable if telemeters were to be used.

The total equipment for controlling the physical experimental conditions, and for recording the biological variables, is in the control room. Total activity of the subjects (by means of contacts, invisible under the floor, and in the bed), and some subjective statements like urine mictions, defecation, meals, and subjective onset and end of a "day" are all measured by event recorders. On other recorders, rectal temperature and room temperature are recorded continuously. The subjects are asked to give all urine samples into bottles to store in an icebox within the lock, for analyses of some substances like electrolytes, different catecholamines or steroids, etc. Beside these physiological measurements, some psychological or performance measurements are done, like computation speed, reaction time, time estimation, etc. For all these psychomotor tests, fully automatic machines have been developed which operate without an experimenter, and which do not allow the subjects any knowledge of the results (Wever, 1972). Fig. 11 shows a part of the recording equipment outside the experimental units. It cannot be seen in Fig. 11 that most of the measurements run parallel to the visible recordings on-line into a computer system for automatic analyses.

Up to now, more than 200 subjects have been examined within this isolation station. Most of these subjects lived alone, about 40 in groups of two, and 8 in groups of four each. Significant differences in the results depending on whether the subjects were isolated singly, or lived in groups, have not been observed. The duration of the isolated experiments was, on the average, one month. Nearly all of the subjects felt very well during the experiments; only six subjects finished the experiment before the fixed time, and only two of them because they "could no longer endure the solitude" (the other four for personal reasons). On the other hand, about 70% of the subjects asked spontaneously,

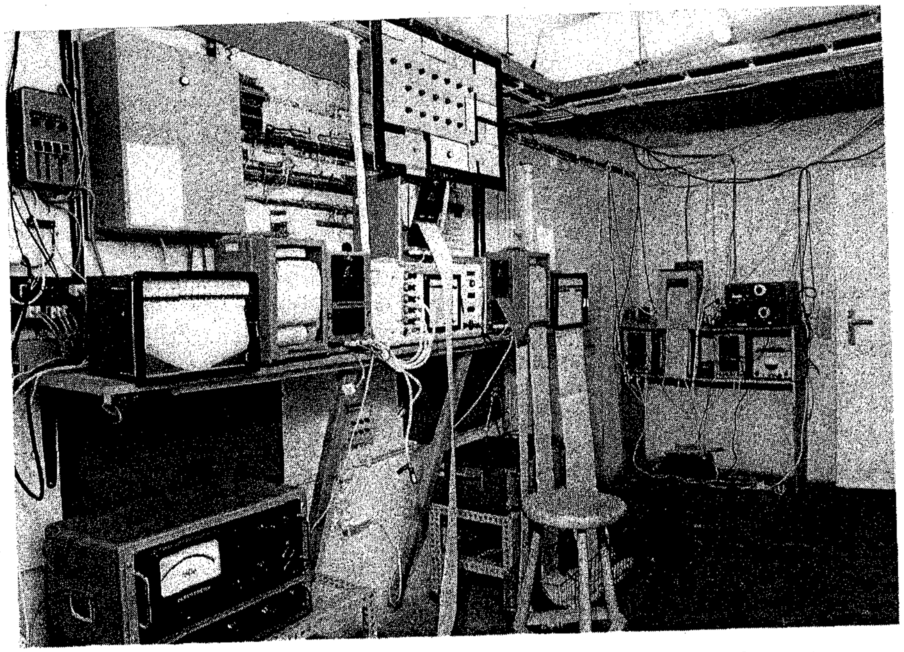

Figure 11. View of a part of the recording equipment in the control room.

after finishing an isolation experiment, for another experiment. It was certainly important for the well being of the subjects that they explicitly knew that they were not locked up and that they were able to finish the experiment at any time.

The subjects lived either in constant conditions, in order to measure the free-running rhythm, or under the influence of artificial Zeitgebers, to study the conditions of entrainment. In most experiments, the physical conditions of the experiment were altered once or several times to study the dependency of human circadian rhythms on external stimuli. Such an external stimulus is, for instance, the intensity of illumination which can be perceived consciously; an external stimulus, however, which can be so subtle that it cannot be perceived consciously, is a weak electromagnetic field.

RESULTS

Effects of Natural Fields

The first reference to biological effects of electromagnetic fields on human circadian rhythms has been given by comparison of the results obtained in the two experimental rooms (Wever, 1967b). This comparison is significant only during the first six years of experimentation, because after that time, one of the rooms was equipped with a much larger air conditioning machine, for special temperature experiments. Therefore, only during the first six years, the visible equipment of the two rooms was the same; after that time, the two rooms differed from each other in space. Up to that time, the only known difference between the two rooms was the electromagnetic shielding of room II.

TABLE 1

Results of the free-running experiments, presented separately for the two experimental units; room II is shielded from electric and magnetic fields

Parameter	Room I (34 subjects)	Room II (50 subjects)	Statistical significance
Mean value of τ	24.87 h	25.26 h	$p < 0.01$
Standard deviation of τ	± 0.44 h	± 0.85 h	$p < 0.01$
Internal desynchronization	0 subjects	15 subjects	$p < 0.001$
Apparent desynchronization	5 subjects	0 subjects	$p < 0.01$

Table 1 shows the summarized results of the first six years, presented separately for the two rooms. In a few experiments, subjects were partly exposed to artificial fields; these sections of the experiments have been excluded. Table 1 shows that:

(1) the free-running periods were significantly longer in the shielded room,

(2) the inter-individual differences in the free-running periods were significantly greater in the shielded room,

(3) real internal desynchronization occurred spontaneously only in the shielded room, and

(4) apparent internal desynchronization occurred spontaneously only in the non-shielded room.

Because the electromagnetic shielding of room II is the most striking difference between the two rooms, the hypothesis is suggested that natural electromagnetic fields which penetrate into room I but not (or much weaker) into room II, are responsible for these differences (Wever, 1967b; 1968a). This hypothesis means that the total of the natural electromagnetic fields shortens the free-running period, diminishes the inter-individual differences, and strengthens the coupling between different rhythms within one subject (Wever, 1971a). To be sure, in the following years, a few cases of real internal desynchronization have occurred also in the non-shielded room, but this has been much less than in the shielded room. Thus, the general picture with regard to the differences between the two rooms was also the same when all hitherto existing results are considered.

With respect to the occurrence of internal desynchronization, a remark has to be inserted concerning the steady state. It has been recommended to use the term "desynchronization" only if it has been proven that the periods of the different rhythms deviate from each other in the steady state, and this means, only if the different rhythms shift their phases against each other for more than 360°

(Aschoff, 1973). On the other hand, it was a remarkable result that the internal phase-angle differences between the rhythms of different variables within one subject are significantly different in the normal 24-hr day and in the free-running rhythm (Aschoff et al, 1967a). Therefore, during the first few days of each free-running experiment, the internal phase-angle differences shift gradually, due to the inevitable transition from the 24-hr day to the (normally longer) free-running period (Wever, 1969a). As a consequence, in all the experiments, different rhythms show different periods during the first few days, whether measured in the non-shielded room or in the shielded room. This is normally only a transient behaviour and not internal desynchronization. Only after the fading away of these transients, is a steady state reached; and only in that steady state can it be decided whether internal desynchronization is present or not. If an isolation experiment is too short, it cannot be concluded whether the steady state is reached or not, and whether internal desynchronization is present or not (Mills et al, in print).

The idea of biological effects from natural electromagnetic fields sounded very strange because it was, at that time, far from all normal experience. Therefore, corresponding results need a much higher level of statistical significance before a discussion about the meaning of such results should be opened. Whereas normally a significance of $p < 0.05$ is sufficient in biology, strange results like effects of electromagnetic fields should be significant at $p < 0.001$. The different effects of the natural electromagnetic fields on human circadian rhythms as included in Table 1, are not all significant at that level. However, the different results are not independent of each other. They are correlated to each other in a direction which is derived from predictions of a special model of circadian rhythms which has been confirmed by many other experimental results independently (Wever, 1965; 1966). Therefore, the different effects released by the electromagnetic fields as included in Table 1, can be combined. The efficiency of these fields is then significant at a level much higher than $p < 0.001$.

Nevertheless, a hypothesis about influences of electromagnetic fields on human beings cannot be accepted without independent confirmations, despite the high statistical significance of the underlying results. With only one type of experiment, it can never be excluded that another hypothesis may also be able to describe the results. In the present discussion, for instance, the mirror-picture structure of the two experimental units has been disregarded, and it cannot be excluded with absolute certainty that this difference in the structures is responsible for the differences in the results obtained in the two rooms. This hypothesis, however, is very unlikely: as mentioned above, one of the rooms had been equipped, four years ago, with a much larger air conditioning machine which altered the obvious impression of this room remarkably. Nevertheless, the results obtained in this room during the last four years, do not deviate from those results which had been obtained in the former years, and as included in Table 1. Moreover, the difference in the results obtained in the two rooms during the last four years, equals that difference which had been obtained in the former years, in each tested respect. This means that the conclusion drawn from the results included in Table 1, holds true as well if the results of all hitherto experiments would be included, instead of only results from experiments performed during the first six years when the two rooms gave equal obvious impressions. Finally, it cannot even be excluded that any other differences between the two rooms have been overlooked. Such uncertainties can be overcome, in general, only by other experiments which confirm the hypothesis independently. Fortunately, in this case independent experiments can be performed with artificial electric fields.

Effects of 10-cps Fields

Beside obvious environmental stimuli like light or temperature, unperceptible physical stimuli have been studied with regard to their effects on human circadian rhythms. After natural electromagnetic fields had been shown to be possibly effective, influences of artificial fields were studied. All fields applied were so weak that they could only be measured with sensitive physical equipment; they were not perceptible consciously (Wever, 1969b). At the beginning, a vertical electric alternating field was used, a square wave with a frequency of 10 cps and a field strength (peak to peak) of 2.5 V/m (Wever, 1967b; 1968a).

As a first step, this field was operated continuously. This means that subjects were exposed to the artificial

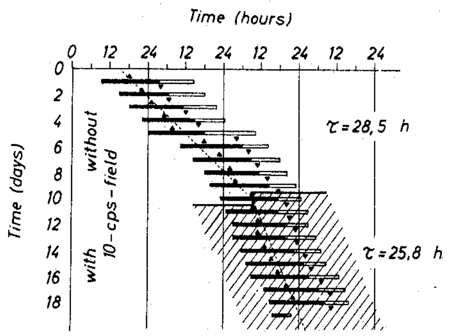

Figure 12. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section protected from natural and artificial electromagnetic fields, during the second section under the influence of a continuously operating electric 10-cps field. Designations as in Fig. 2; shaded area: field in operation. (Wever, 1968c)

field continuously in operation during one to two weeks. Alternatively, the subjects were protected from any field (artificial as well as natural) during another section of the same experiment, again for one to two weeks. In some experiments, the state of the field was changed not only once but several times. Thus, each subject served as his own control (Wever, 1970a). Results from the first experiment of this type are shown in Fig. 12; the subject had lived during the first section of the experiment without, and during the second section of the experiment with, the field continuously in operation. As can be seen, the period of the free-running rhythm is shorter in the second section, i.e. under the influence of the field. This impression is objectively confirmed by period analyses computed separately for the two sections of the experiment (Fig. 12a). The "spectral lines" resulting from the two sections, although broad because of the shortness of each time series, do not overlap. To be sure, the subject in this experiment (and in all other corresponding experiments) was not familiar with the special purpose of this experiment. He neither felt the switching on of the field at the 10th day, nor the change in his period released by this switching on; he did not even know anything about the existence of the facilities for generating the field.

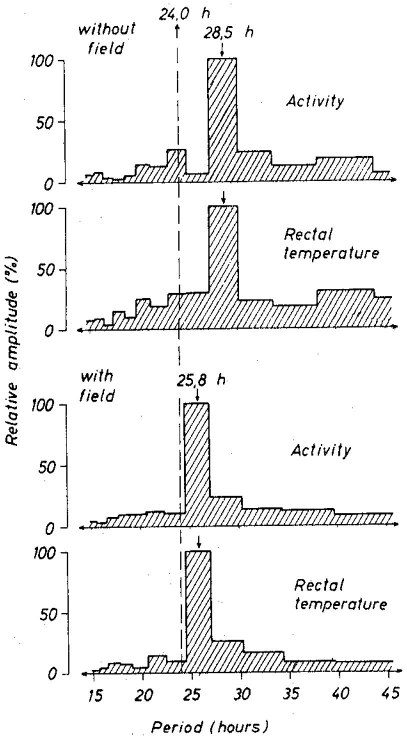

Figure 12a. Period analyses (Fourier analyses) of the time series (rhythm of activity and rectal temperature) shown in Fig. 12, computed separately for the sections without and with the artificial 10-cps field in operation. (Wever, 1973).

In the next experiment, the temporal sequence of the sections with and without the field in operation has been altered. Fig. 13 shows results from an experiment in which the field was in operation during the first section but not during the second section. Additionally, in a third section the field has been switched on and off periodically, with a period of 23.5 hr (11 3/4 hr on and 11 3/4 hr off). Again, the free-running period was shorter in the section with the

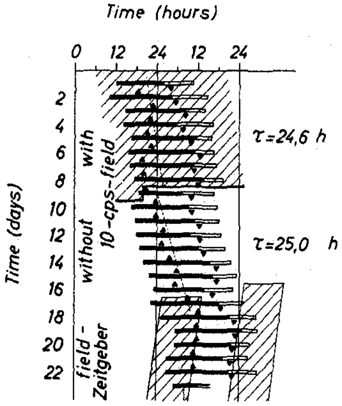

Figure 13. Circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section free-running under the influence of a continuously operating electric 10-cps field, during the second section free-running while protected from natural and artificial electromagnetic fields, during the third section possibly entrained by a periodically operating electric 10-cps field (11.75 hr on, 11.75 hr off) Designations as in Figs. 2 and 12. (Wever, 1970a)

field in operation than in that without it. In the third section, the period was even shorter than 24.0 hr, suggesting entrainment by the "field Zeitgeber", but this part of the experiment was too short to decide what had really happened. Therefore, this suggestion has to be tested in further experiments.

Fig. 14 shows results from a third experiment of this series, in which the field was in operation during the second section, whereas it was not in operation during the first nor during the third section. When the field was switched on, the period shortened immediately, as in the other experiments. When the field was switched off again, the period

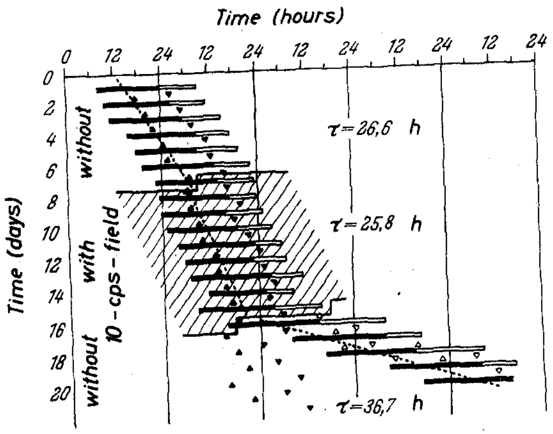

Figure 14. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first and third sections protected from natural and artificial electromagnetic fields, during the second section under the influence of a continuously operating electric 10-cps field. Designations as in Figs. 2, 3, and 12. (Wever, 1968a)

of the activity rhythm not only lengthened remarkably but, in addition, internal desynchronization occurred. This result suggests that the internal desynchronization occurred, in this case, not spontaneously as in the other examples (cf. Fig. 3) but as a consequence of the switching off of the field. In further experiments this suggestion has to be tested.

In a total of 10 experiments, the free-running period of internally synchronized circadian rhythms has been measured, with the field in operation as well as without it. Fig. 15 shows the summary of all period measurements in these experiments. It shows that the period was, without any exception, and independent of the temporal sequence of the section within an experiment, shorter with the field

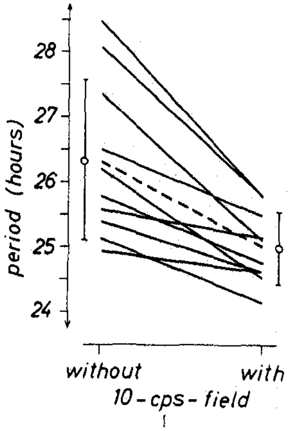

Figure 15. Summary of 10 experiments concerning the influence of an electric 10-cps field on the free-running period. The lines combine periods obtained in different sections (without and with the field continuously in operation) of the same experiments. Dotted line: connection of the corresponding means. At left and right, means with standard deviations of the sections without and with the field in operation are indicated. (Wever, 1970a)

than without it. It shows furthermore that the inter-individual distribution of the periods was smaller with the field than without it. Both these statements are statistically significant with $p < 0.001$ (Wever, 1970a). The last mentioned statement indicates that the shortening effect of the field depends on the original period; the effect is greater the longer the period is without the field in operation, as can be seen in Fig. 16. The coefficient of correlation is different from zero at a high statistical level ($p < 0.001$) (Wever, 1969b).

In the sections with and without the field in operation, other parameters than the periods of circadian

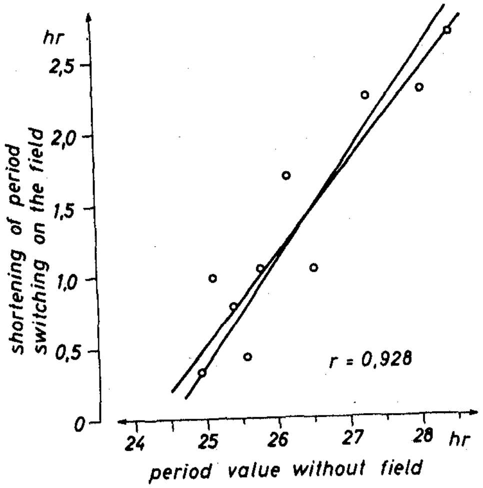

Figure 16. Correlation between the shortening effect of an electric 10-cps field and the original period obtained during the sections without the field. Lines: computed regression lines. r: computed coefficient of correlation. (Wever, 1969b)

rhythms are also significantly different from each other. For instance, from the rhythms of activity the ratio between activity-time and rest-time of the subjects ($\alpha : \rho$-ratio) can be determined; it is significantly greater in the sections with the field in operation than in those without the field (Wever, 1968c). Thus, a negative correlation between the period and the $\alpha : \rho$-ratio is present. This correlation is the same as in animal experiments, and as predicted from a special mathematical model of circadian rhythms (Wever, 1965; 1966). Moreover, from successive onsets and ends of activity, the "precision" of the activity rhythm (ratio between average period and its standard deviation) can be determined; it likewise is greater in the sections with the field in operation (and with the shorter period) than in those without it (and with the longer periods) (Wever, 1971b). Thus, the precision with which a period is held constant, depends on the period intra-individually in the same direction as inter-individually.

And finally, the distributions of onset and termination of activity around the respective mean depends differently on the period; the standard deviation of the ends of activity are always greater than that of the onsets (Wever, 1969b). The ratio between the standard deviations of the ends of activity and that of the onsets of activity is significantly greater in the sections with the field in operation than in those without the field (Wever, 1971b). The correlation between the two last mentioned parameters of the activity rhythm and the period is also the same as in corresponding animal experiments, and in the model predictions (Wever, 1971b).

Also, from the rhythms of rectal temperature some parameters can be determined. These are the mean value of temperature, the amplitude of the temperature rhythm, and a factor describing the form of the temperature rhythms (ratio between the descending part and the ascending part of the temperature course within a period) (Wever, 1968c). These three parameters are significantly greater in the sections with the field in operation than in those without any field, and therefore, they are all negatively correlated with the period. Like the correlations of the activity rhythm parameters to the period, the parameters of the rectal temperature rhythm are correlated with the period in the same direction as in corresponding animal experiments, and in the model predictions (Wever, 1971b).

The dependency of many parameters of circadian rhythms on the state of an artificial electric 10-cps field has two very different implications. On the one hand, it shows that this field has a profound influence on human physiology, not only on the circadian period. On the other hand, it allows studies on regularities of circadian rhythms, in general, because it determines interdependencies which seem to be characteristic (Aschoff et al, 1971).

The summarized results of experiments with artificial electric 10-cps field include so far only experiments in which the circadian rhythms were internally synchronized. The experiments with natural fields had given evidence that these fields influence, in addition, the tendency towards internal desynchronization. The experiment shown in Fig. 14 suggested an equal influence of the artificial field. To verify this result, all experiments have to be considered, in summary. As has been mentioned, internal desynchronization has occurred in numerous experiments in the shielded room when the artificial field was not in operation. However, no case of internal desynchronization has occurred in this room as long as the artificial 10-cps field was in operation. Taking all experiments in this room together, this difference is significant with $p < 0.001$ (Wever, 1969b). Thus, it has been proven at a high statistical level that the artificial electric 10-cps field diminishes the tendency towards internal desynchronization, as does the natural field.

More obvious than the summarized inspection of all experiments, is the separate inspection of single experiments in which the state of the field has been altered. In Fig. 14, internal desynchronization occurred immediately after the field was switched off. Fig. 17 shows the results of another experiment in which internal desynchronization occurred from the beginning of the experiment. In this special case where the activity rhythm was much quicker than the temperature rhythm, at the 17th objective day of the experiment (or at the 21st subjective day), the artificial

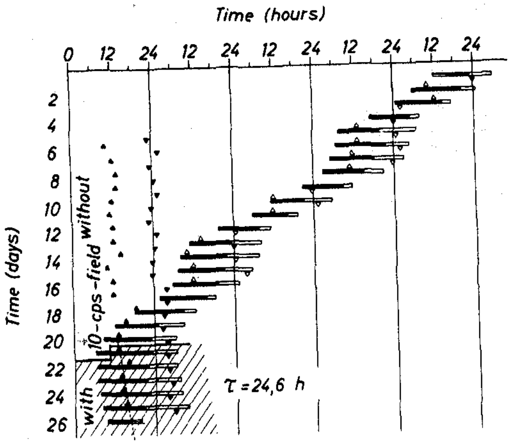

Figure 17. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section protected from natural and artificial electromagnetic fields, during the second section under the influence of a continuously operating electric 10-cps field. Designations as in Figs. 2, 3, and 12. (Wever, 1970a)

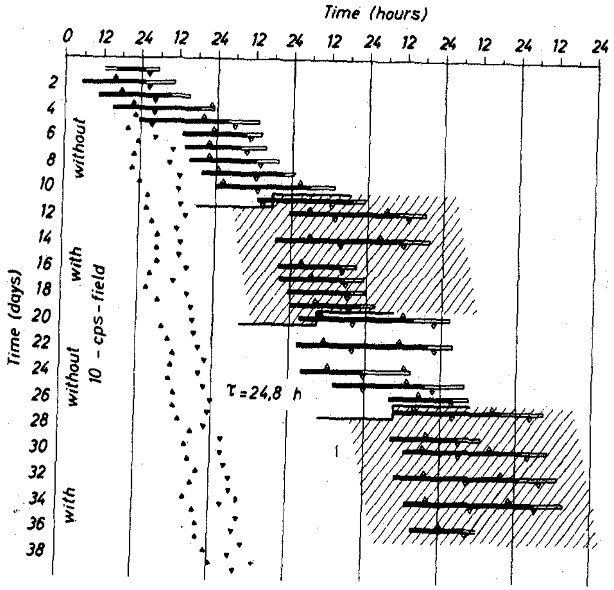

Figure 18. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first and third section protected from natural and artificial electromagnetic fields, during the second and fourth sections under the influence of a continuously operating electric 10-cps field. Designations as in Figs. 2, 3 and 12. (Wever, 1970a)

field has been switched on. On that day, the internal desynchronization stopped. Fig. 18 shows results from another experiment in which the state of the field has been altered several times. From the beginning of the experiment (without field), internal desynchronization occurred. During the course of the experiment, each onset of the field is accompanied immediately by a strengthening of the internal coupling between different rhythms, resulting either in full internal 1:1 synchronization, or in a 1:2 synchronization (with a circa-bidian activity rhythm). Each switching off of the field is accompanied by an immediate loosing of the internal coupling, resulting in internal desynchronization. In several further experiments, similar results have been obtained.

Especially the last experiment mentioned (Fig. 18) supports the hypothesis that it is the coupling between different rhythms which is influenced by the field. A strengthening of this coupling can lead to the normal 1:1 synchronization, but it can likewise lead to an internal 1:2 synchronization. What type of internal synchronization will occur in a given experiment in which a subject shows internal desynchronization before the field is switched on, depends on the period of the activity rhythm. When the rhythm is closer to a "circadian" value (about 25 hr), 1:1 synchronization will occur; when it is, however, closer to a "circa-bi-dian" value (about 50 hr), 2:1 synchronization will occur.

Summarizing the results obtained with the artificial 10-cps field as discussed so far, it can be stated that this field has the same effect on human circadian rhythms as the natural electromagnetic fields. In each examined respect:

(1) it shortens the period;

(2) it diminishes the inter-individual differences; and

(3) it strengthens the coupling between different rhythms within one subject.

With this, the hpothesis has been confirmed at a high statistical level that weak electromagnetic fields are able to influence human circadian rhythms. Moreover, the results suggest that the natural 10-cps field which is present in the earth's atmosphere (König, 1959), is at least one important component within the total of the natural fields responsible for the observed effects associated with the natural fields. It cannot be excluded, however, that other components (other frequencies) are likewise able to influence human circadian rhythms. Before discussing experiments with other artificial fields, additional experiments with the 10-cps field will be considered, in which a field is periodically in operation.

In the experiment shown in Fig. 13, the results of the last section suggested the possibility that a periodically operating field can act as a Zeitgeber. To test the question whether this Zeitgeber effect is real, or whether it was only accidental, a series of corresponding experiments was designed. Fig. 19 shows results from the first experiment of this series. During the first section of this

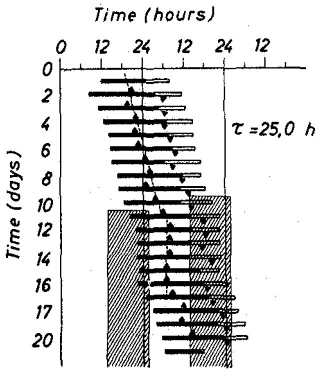

Figure 19. Circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section free-running while protected from natural and artificial electromagnetic fields, during the second section temporarily entrained by a periodically operating electric 10-cps field (12 hr on, 12-hr off). Designations as in Figs. 2 and 12. (Wever, 1968c)

experiment, the subject was protected from any field, and consequently showed a normal free-running period. During the second section, he was exposed to a periodically operating field (12 hr on, 12 hr off). As can be seen, the rhythm became synchronized but only for about one week; after this time, the rhythm looked again free-running, with the same period as at the beginning of the experiment when no field was present. The interpretation of this result is that the periodically operating field acted, indeed, as a Zeitgeber but as a Zeitgeber which is too weak for complete synchronization in the long run. This interpretation is unsatisfactory for several reasons:

(1) a synchronization to 24.0 hr can be induced also by unknown natural Zeitgebers; in this special case, this is unlikely because the phase relationship of the human rhythm to local time is just reversed, compared with the natural phase relationship;

(2) data indicate that the natural field, when given continuously, shortens the period; it cannot be excluded that an only temporarily operating field also shortens the period in this special case to a value which is, by chance, very close to 24.0 hr.

This is again unlikely because during the last days when the field was temporarily in operation, the period was clearly longer than 24 hr. In addition, a partial shift of the Zeitgeber was included in the experiment.

Fig. 20 shows results from another experiment. During the first section, the subject was again protected from the

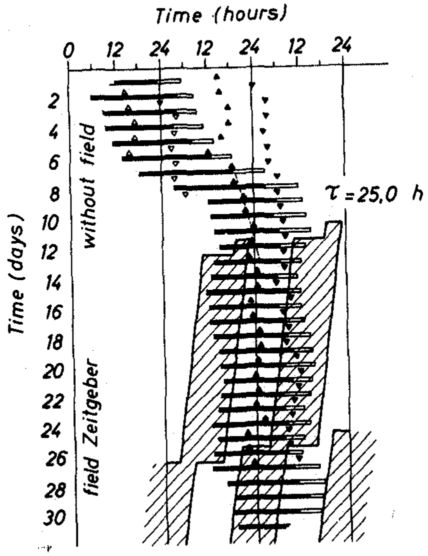

Figure 20. Circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section free-running while protected from natural and artificial electromagnetic fields, during the second section entrained by a periodically operating electric 10-cps field (11.75 hr on, 11.75 hr off); at the 26th subjective day, the "field-Zeitgeber" has been shifted in phase. Designations as Figs. 2, 3, and 12. (Wever, 1969b).

field. The period of the rectal temperature rhythm was 25.0 hr and the activity rhythm showed a beginning of internal desynchronization. After about two weeks, a field Zeitgeber was introduced, with a period of 23.5 hr. Immediately, the onsets of activity followed this Zeitgeber, but the end of activity and the temperature rhythm did not. Only a week later, both rhythms followed the Zeitgeber completely. To answer the question whether the biological rhythms had, just by chance, the same period as the Zeitgeber, the Zeitgeber was phase-shifted. In case of only occasional coincidence of the periods, this phase shift may not influence the biological rhythm. But in fact, at the day of the phase shift, the biological rhythms changed their periods. Unfortunately, the experiment was not long enough to get the new steady state, i.e. entrainment to the shifted Zeitgeber. Nevertheless, the result obtained indicates unambiguously that the circadian rhythm of this subject was really entrained to the field Zeitgeber, in spite of the fact that the subject could neither realize any external influence, nor any change in his period.

Summarizing the results of all experiments with a field Zeitgeber, with periods between 23.5 hr and 26.0 hr, the following significant generalization can be stated:

(1) all subjects were synchronized to the field Zeitgeber, at least for a few days;

(2) the external phase relationship between the biological rhythms and the Zeitgeber during the days of entrainment changed regularly with the period in the same way as under the influence of other Zeitgebers: the quicker the Zeitgeber, the more the biological rhythms lagged behind; and

(3) the internal phase relationship between different rhythms changed regularly with the period, in the same way as under the influence of other Zeitgebers: the quicker the Zeitgeber, the more the temperature rhythm lagged behind the activity rhythm (Wever, 1969b).

The experiments with an artificial field as a Zeitgeber cannot be compared with experiments using the natural fields, because it is impossible to manipulate the electromagnetic shielding arbitrarily. On the other hand, it is known that the natural 10-cps field alters its field strength diurnally (König, 1959). Thus, the question arises whether this periodical change in the intensity of the 10-cps field can act as a natural field Zeitgeber and complement other natural 24-hr Zeitgebers. The experiments with the artificial field Zeitgeber indicate that an effect of the natural field Zeitgeber can be excluded indirectly. From the experiments discussed, the range of entrainment of the artificial field Zeitgeber can be determined to about ± 1 hr; the change in intensity with the natural field Zeitgeber is, at least, 1000 times weaker than that of the artificial field Zeitgeber, and thus, its range of entrainment cannot exceed a few minutes. Such a range of entrainment is too small to be proven in any biological experiment. On the other hand, the natural field Zeitgeber penetrates nearly unimpaired into the non-shielded room; but in no case has synchronization to 24.0 hr been observed in this room when artificial Zeitgebers were absent. Also this result proves that a possible Zeitgeber effect of the change in the intensity of the natural 10-cps field (or of any other natural field) can be absolutely neglected. It can, however, not be excluded from these results that other organisms are more sensitive to the natural field Zeitgeber than man. But there is, up to the present, not one reference concerned with effects of Zeitgebers as subtle as the natural field Zeitgeber. In all experiments where biological rhythms held a period of exactly 24.0 hr under apparently constant conditions, less subtle Zeitgebers could be detected.

Since the influence of light on human circadian rhythms was tested, the only unambiguous influence was observed when light was given in a self-control mode. To answer the question whether this effect is a specific effect of light when given in such a mode, or whether it is a general effect of self-control, some experiments were performed in which the artificial 10-cps field was given in a self-controlled mode. Fig. 21 shows the result of an experiment in which a subject was, in the medium section, exposed to the field, but only during his activity-time, whereas he was protected from all fields during his rest-time. The switching on and off of the field was coupled automatically to the activity of the subject, without his knowledge, and without any perception. The result was that the period was longer during the self-control condition than during the first and third section without a field at all. This lengthening occurred in spite of the well-proven fact that a continuously operating field shortens the period. Because the other corresponding experiments showed similar results, the

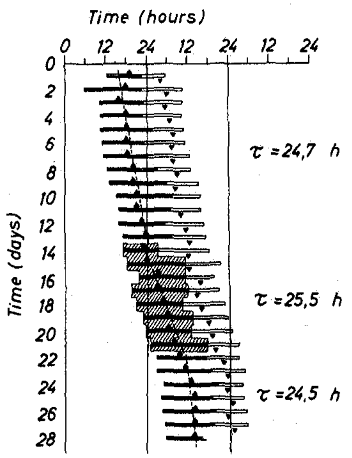

Figure 21. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first and third section protected from natural and artificial electromagnetic fields, during the second section under the influence of an electric 10-cps field which was in operation only during the activity-time of the subject. Designations as in Figs. 2 and 12. (Wever, 1968c)

difference in the direction of period changes, released on the one hand by a continuously operating field and on the other by a self-controlled change in the field, is statistically significant. Thus, the influence of a self-control condition, which has been proven with light as the stimulus in animals (Aschoff, 1968) as well as in man (Wever, 1969a), and which has been predicted by a special mathematical model of circadian rhythms (Wever, 1967a) is not restricted to light as the stimulus but is a general phenomenon.

Effects of Static Fields

Some preliminary experiments have been performed with artificial DC fields, electric as well as magnetic ones (Wever, 1969b). The field strengths in these experiments were 300 V/m, and 1.5 Oe respectively; thus, both fields were about three times stronger than the corresponding natural fields. The results of an experiment with the DC field is shown in Fig. 22. During the first 12 days, the subject was protected from any natural and artificial field, during the next 12 days, he was exposed continuously to an artificial electric DC field, and during the last week of the experiment, he was again protected from any field. The figure shows that the period of the rhythms was the same in all three sections of the experiment; also each parameter measured with the rhythms remained unchanged. Therefore, it must be concluded that the electric DC field does not influence the circadian rhythm of that subject. The result of another experiment of this type is shown in

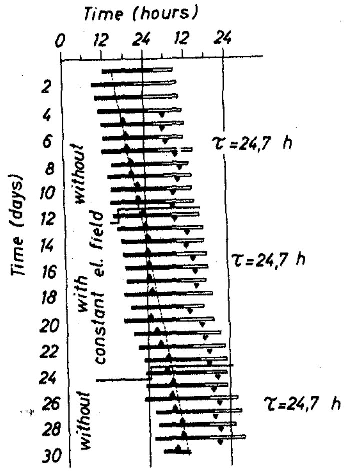

Figure 22. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first and third section protected from natural and artificial electromagnetic fields, during the second section under the influence of a continuously operating artificial electric DC-field. Designations as in Fig. 2. (Wever, 1971a)

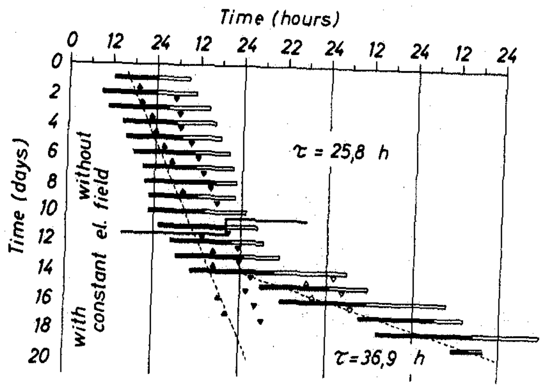

Figure 23. Free-running circadian rhythm of a subject living under strict isolation from environmental time cues, during the first section protected from natural and artificial electromagnetic fields, during the second section under the influence of a continuously operating artificial electric DC-field. Designations as in Figs. 2 and 3. (Wever, 1971a)

Fig. 23. Here, the artificial electric DC field has been switched on after 11 days. The figure shows that a few days later, internal desynchronization occurred. Certainly, it cannot be stated that the DC field has released internal desynchronization in this case. However, it can be stated with certainty that the DC field is, in this case, not able to prevent internal desynchronization. The natural fields as well as the artificial 10-cps field could accomplish this. The other experiments with an artificial electric DC-field had similar results (Wever, 1971a).

When experiments were performed to test possible effects of magnetic DC fields, it was necessary to demagnetize the iron shielding before each experiment. In these experiments, no effect could be detected. In experiments in which the rhythms remained internally synchronized, no change in the period could be observed with the switching on or off of the magnetic DC field. In another experiment, internal desynchronization occurred spontaneously, in spite of the fact that the magnetic DC-field was switched on a few days earlier. Similar effects were noted with the electric DC-field presented in Fig. 23. Therefore, it can be stated even from those few experiments that DC-fields, electric as well as magnetic ones, are neither able to influence the internally synchronized circadian rhythm, nor to prevent internal desynchronization. On the other hand, both these effects have been demonstrated clearly with the natural electromagnetic fields as well as with artificial electric 10-cps fields.

The statement that DC-fields are ineffective to human circadian rhythms must be restricted to weak and homogeneous fields. If a field is, indeed, temporally constant but spatially inhomogeneous, each movement of a surface relative to the field results in a temporally changing field strength at this surface; consequently, a mechanically vibrating surface induces, in an inhomogeneous DC-field, an AC-field. It has been proven that the total surface of man as well as that of all other homeothermic organisms vibrates mechanically, with a frequency of about 10 cps (Rohracher, 1969; Wever, 1965). Thus, even in a static field which is inhomogeneous, humans are exposed to 10-cps fields which have been proven to be effective. Therefore, DC-fields which are ineffective when homogeneous, may be effective on human circadian rhythms when inhomogeneous.

CONCLUSIONS

The experiments discussed in this paper have produced significant proof that electromagnetic fields in the ELF-range influence human circadian rhythms, and therefore, human beings. Human circadian rhythms have been shown to be a very sensitive indicator for such subtle stimuli. This indicator has the great advantage that it allows objective statements. In the experiments described, the subjects had, first of all, no knowledge about the introduction (or exclusion) of fields within the experimental room. They could not perceive consciously in any way the fields used. Secondly, not only the stimulus but also the reaction to the stimulus, i.e. the change in the period and in many other parameters of the circadian rhythm released by the stimulus were imperceptible. Thus, preconditions were met to obtain objective results, independent of the motivation of the subjects.

In contrast to this advantage, the indicator used has the great disadvantage that its application needs a great amount of time; each single measurement lasts about one month. Therefore, an unusually long time would be required to evaluate, with this indicator, the dependency of the observed effects on the frequency, the intensity, or any other parameter of electromagnetic fields. That is the reason why, up to the present, results are obtained only with a 10-cps field, and in a preliminary way, with static fields. It cannot even be stated with certainty that the effects observed are due to the 10-cps frequency, because only square waves have been used; it cannot be excluded that the effects are due to the higher harmonics included in the square wave. Even harmonics in the 10 kcps range are included, with a field strength of some mV/m, i.e. with a field strength similar to that of the natural radiation in this frequency range. To differentiate this, the same experiments have to be performed as described above, but with sine waves of 10 cps instead of square waves. Even those experiments would need a few years before a complete answer could be given.

The experiments discussed in this paper have not been performed primarily in order to detect influences of electromagnetic fields on human beings. Instead, they have been performed in order to study the properties of human circadian rhythms. Because light has been found to be an insufficient stimulus, in contrast to what has been found in most animal rhythms, other successful stimuli had to be isolated. More or less by chance, it has been found in the form of the weak electric 10-cps field. Using this stimulus as a tool, all the different types of experiments mentioned have been performed to evaluate the regularities of human circadian rhythms. The only relevance of the stimulus was, in this research, whether it was successful or not.

Nevertheless, the stimulus itself needs greater attention. Therefore, besides the search for another indicator which detects the efficiency of electromagnetic fields faster, experiments with human circadian rhythms under the influence of these fields will be continued but with a

shifted emphasis in the question. Until now, the main aspect of the experiments was the general behaviour of the reaction to any stimulus. In the future, the stimulus aspect will be accentuated more specifically.

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OPERANT METHODS ASSESSING THE EFFECTS OF ELF ELECTROMAGNETIC FIELDS

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The recent surge of research on ELF electromagnetic radiation has devoted much concern to behavioral effects on animals. Frequently, the rationale for this research has been to reveal effects of ELF fields on physiological substrates manifested by the measured behavior. While this goal is laudable, such an approach often ignores the rich but orderly fabric of the primary dependent variable - behavior. The physiological bases of all but the simplest behaviors are, at best, obscure and likely to remain so in the absence of careful specification of the environmental variables of which behavior is a function. Thus analyses of the effects of ELF electromagnetic radiation (as well as other agents) on behavior should be pursued in its own right without the necessity to physiologize. Appropriately identified behavioral effects of ELF fields might prove of enormous significance. For example, Marr, Rivers, & Burns (1973) noted: "Considering the ubiquity of ELF electromagnetic fields of low intensity it is of considerable biological interest to determine whether they are detectable by organisms. If a species of organism could detect the presence of such fields, it might imply that natural fields play a role in controlling significant behaviors of the species. The imposition of 'unnatural' fields, e.g., those generated by power lines and communications equipment might interfere with those behaviors. An additional possibility is that ELF fields might be of no particular significance to species-specific behavior but the presence and detection of such fields could lead to active avoidance or approach. These behaviors could alter local population distributions with possible deleterious effects (pp. 2-3)." Enlightenment on these possibilities as well as many others clearly requires the application of a technology of behavior.

Various research approaches have been utilized to study animal behavior in the presence of nonionizing radiation. One of the most popular approaches involves the measurement of general motor activity. Motor activity that consists of traversing portions of open-field mazes (Persinger, Persinger, Ossenkopp, & Glavin, 1972), moving about in a tilt-cage (Altmann, 1969) and other ambulatory behaviors (Ludwig & Mecke, 1968; Moos, Clark, & Krown, 1965) have been assessed in animals exposed to ELF fields. The results of these studies indicate that general motor activity is a poorly differentiated behavior whose characteristics depend crucially upon the measuring techniques employed. The various behaviors included in an animal's activity obviously result from many variables; hence, changes in a conglomerate motor activity defy identification of probable routes of the responsible variables. Behavior is the most complex biological feature of an organism in that it is the manifestation of the action and interaction of many variables operating throughout the life-span of the animal. Behavior is a dynamic process in that the influence of variables upon it depends on its present as well as its past states and in that the present state determines the future state. The complexity of behavior, however, does not imply that it is intractable to analysis or that the controlling variables cannot be shown to operate according to relatively simple principles. Enormous complexity can result from the interaction of only a few processes or elements as demonstrated in the field of chemistry. However, because of this complexity, the use of "general" behaviors, e.g., motor activity, as prototypes for studying the effects of agents, provides little understanding since the variables controlling these behaviors are little understood.

This chapter will present a brief account of certain behavioral principles which may be of value to the development and assessment of procedures for studying the behavioral effect of physical agents and will illustrate the application of some of these procedures. Our approach is based upon that of Kelleher & Morse (1968) who provided a similar account for pharmacological investigators. Both ionizing and nonionizing radiation may be considered from the methodological point as "drugs" in that they may have biological effects on an organism dependent on dosage, exposed organ system and its state of activity, species, etc. Indeed, the approaches derived from behavioral pharmacology appear to be directly applicable to the study of ELF electromagnetic radiation on behavior. As a science, behavioral pharmacology has advanced rapidly through systematic studies of the effects of drugs on relatively simple behaviors whose controlling variables are reasonably well understood.

ELICITED BEHAVIOR

Certain behaviors show highly specific relationships with changes in the environment. For example, light in the eye elicits pupillary constriction; a tap on the patellar tendon, extension of the leg; food in the mouth, salivation. These behaviors, called respondents, follow the presentations of specific classes of stimuli; and the magnitude and latency of a respondent is dependent on the magnitude, duration and frequency of the preceding stimulus. We speak of such behaviors as being elicited by the stimulus. The elicitation of respondents by appropriate stimuli may depend little upon a special environmental history but rather upon a genetic endowment as manifested by particular biochemical and structural characteristics as in the examples above. In this case the responses are termed unconditioned and the associated eliciting event, unconditioned stimulus. Unconditioned responses may be relatively simple, or they may be quite complex. Examples of the latter include certain species-specific behaviors as represented by taxes, orienting responses, and certain courtship, mating and migratory behaviors (Fraenkel & Gunn, 1961; Marler & Hamilton, 1966). Considerable research efforts have been devoted to the notion that electromagnetic fields may serve as unconditioned eliciting stimuli for simple as well as complex respondents (Barnothy, 1964, 1969; Presman, 1970). Although each respondent has an associated class of unconditioned stimuli, the occurrence of the respondent may not always require the presentation of an unconditioned stimulus. Through a special environmental history, a new, previously "neutral" stimulus, may acquire eliciting properties. When it does, it is designated as a conditioned stimulus and the response it elicits as the conditioned response. The establishment of an environmental event as a conditioned stimulus requires that (1) it be detectable by the organism and, (2) that it be correlated with the occurrence of an unconditioned stimulus. This process of extending the control of respondents to new stimuli is called respondent, classical, or Pavlovian conditioning and has provided a useful technique to establish whether an organism can detect ELF electromagnetic fields (Kholodov, 1967; Presman, 1970; Reille, 1968) as well as other classes of stimuli.

EMITTED BEHAVIOR

Despite the fact that respondents can come under the control of new stimuli through conditioning, such behaviors represent a very restricted repertoire, especially in higher organisms. Most of the behavior of higher organisms cannot be effectively analyzed as respondent. From birth organisms display a variety of relatively undifferentiated behaviors whose relationship to present or past stimuli is obscure. Because no specific eliciting stimuli can be identified, such behaviors are said to be emitted. Out of this behavioral anlage certain specific categories of responses become differentiated by virtue of the consequences with which they are correlated. We designate that class of behaviors, controlled by its consequences, as operant.

The experimental arrangement of certain consequences for the purpose of controlling operant behavior is called operant conditioning. Notice that the emphasis here is on the interaction of consequent events with ongoing operant behavior that leads to subsequent modification in the probability of that behavior. This is opposed to the emphasis on antecedent events in the case of respondents and respondent conditioning. The difference in emphasis comes about, in part, through the fact that respondents are initially identified with eliciting (i.e., antecedent) stimuli. However, because such, "ready-made" stimuli are unknown in the case of emitted behaviors this does not imply that identifiable present or prior stimuli may play little or no role in the control of operant behavior. Some aspects of the stimulus control of operant behavior will be treated below.

Those consequences which, following some emitted behavior, increase the subsequent probability of that behavior are designated reinforcers or reinforcing stimuli. Stimuli have no a priori status as reinforcers, but certain events coupled with a more or less special history may manifest reinforcing properties. For example, food or water might serve as reinforcers, but their ability to do so will depend minimally upon an appropriate history of deprivation. Operant conditioning, then, involves the delivery of a reinforcer to develop, modify, and/or maintain some behavior. Whatever behavior occurs just prior to the presentation of a reinforcer will be strengthened. In this way very complex behaviors may be "shaped" by judiciously presenting or witholding the reinforcing stimulus dependent upon the presence or absence of appropriate components of the final desired performance. In most operant conditioning studies, the reference behavior chosen for analysis is usually simple, and therefore easily acquired, e.g., pressing a lever, or pecking a transilluminated key. Once such behaviors have been acquired, the emphasis is upon how the rate and pattern of responding are controlled by various independent variables, e.g., type and schedule of reinforcement, stimulus conditions, drugs, etc. While rate and pattern of responding are the principal dependent variables, other response characteristics may be the focus of interest, e.g., latencies (frequently expressed as a distribution of inter-response times), correct responses vs. errors, or topography.

Investigations of operant behavior typically use few subjects, each as his own control, and the methods employed ensure that the subject behaves consistently from session to session to provide a stable baseline performance. (See Sidman (1960) for a detailed discussion of methodology in the experimental analysis of behavior.) Perturbations in this baseline due to manipulated variables become immediately apparent. Since intersubject differences are not obscured by traditional between group averages, statistical analyses become less important. Behavioral variability is also reduced because simple operants, such as lever presses, are well defined, easily executed, and can occur over prolonged experimental sessions. Other advantages of operant conditioning are: (1) The operant does not remove the animal from its immediate environment (as does locomotor activity), hence, behavior tends to be more stable and, (2) if the reinforcement is infrequently delivered, satiation does not affect the data.

Operant behavior does not have to be reinforced on each occurrence to be maintained; indeed, such would be biologically maladaptive. Operant behavior reveals its most salient features through intermittent reinforcement, namely, alterations in the rate and pattern of responding. A procedure for delivery of reinforcing stimuli in time and in relation to responding is termed a schedule of reinforcement. Schedules have been shown to be fundamental determinants of behavior (Morse & Kelleher, 1970) in that their effects as independent variables frequently overshadow the more traditional variables such as motivation. A reinforcer may be scheduled on the basis of time or number of operant responses or some combination of the two. If the reinforcer is delivered after the execution of a specifiable number of responses, a ratio schedule is defined. The number of responses required for each reinforcer occurrence may be fixed (fixed-ratio or FR schedule) or variable (variable ratio or VR schedule). The requirement of a single response (FR 1) is called continuous reinforcement or simply a CRF schedule. If no responses are reinforced, the schedule is extinction (ext). A response may be reinforced only after a specified time interval has elapsed since the previous reinforcer presentation. This is termed an interval schedule. As in the case of the ratio schedule values, the time interval may be fixed (FI) or variable (VI). Under another frequently studied and utilized schedule, a response is reinforced only if it has followed the previous response by a minimal time interval, i.e., the interresponse time (IRT) must be greater than some specified value. Such a dependency is termed a differential-reinforcement-for-low-rate-of-responding (DRL) or more precisely, an IRT schedule. There are many other schedules and combinations thereof, and the reader is referred to Ferster & Skinner (1957), Honig (1966), and Schoenfeld (1970) for in-depth analyses of schedules.

Although operant behavior is maintained by reinforcers which follow the behavior rather than being elicited by prior stimuli, such behavior can be brought under stimulus control. When stimuli that have been associated with a particular schedule of reinforcement are presented, those stimuli can control the occurrence of the pattern of responding engendered by that schedule. The essence of stimulus control is that changes in the rate and pattern of operant behavior accompany changes in stimulus value. A stimulus that has acquired control over an operant is called a discriminative stimulus. Utilization of discriminative stimuli and schedules of reinforcement has provided operant investigators with an extremely powerful tool to restrict behavioral variance to the specific variables under consideration.

In operant investigations both intersubject and intrasubject variability are reduced by the use of well-controlled and well-defined environments. Traditionally, an enclosed light- and sound-isolated chamber is used with rats, pigeons, monkeys or other animal subjects. The chamber contains work panels with response manipulanda, stimulus devices such as lights and speakers, and reinforcement devices. Figure 1 illustrates a rhesus monkey responding on a representative work panel in a typical operant chamber. The chambers are connected to recording and controlling mechanisms distally located, and behavior is automatically and continuously recorded, thereby producing more objectivity and minimizing extraneous variables. In ELF studies these chambers, when appropriately designed, can be easily inserted into Helmholtz coils or between electric plates.

Stimulus Control 1: Detection of ELF Radiation

Conditioned suppression. An organism may be said to detect a stimulus if that stimulus can acquire eliciting or discriminative properties. Thus, any procedure which may establish these properties can be utilized to determine whether an organism can detect the presence of a stimulus. We have mentioned previously that respondent conditioning techniques have been utilized to assess detection of ELF

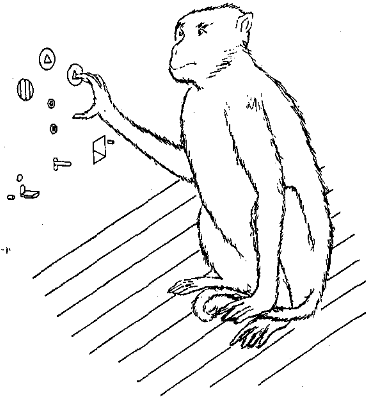

Figure 1. A rhesus pressing one of the match-to-sample keys. G and R refer to green and red panel lights. The response lever is in the lower center of the panel with a water trough on the left and a food aperture on the right. Food and water apertures have push buttons next to them.

electromagnetic fields in various organisms (Kholodov, 1967; Reille, 1968). A very powerful psychological technique which combines methodological features of both operant and respondent conditioning is known as conditioned suppression (Estes & Skinner, 1941). A stable pattern of responding is established under an intermittent schedule of reinforcement. The VI schedule - reinforcement at irregular periods of time - is used most frequently because it generates a relatively constant rate of responding which can be maintained throughout lengthy experimental sessions. When stable performance is established, a stimulus of short duration, e.g., 1 minute, is presented at varying intervals and terminated by a brief occurrence of noxious electric shock. Pairing of the stimulus with shock represents a respondent conditioning paradigm although neither the conditioned nor unconditioned response is specified. After a number of stimulus-shock pairings, the operant responding is suppressed during the stimulus presentation, while remaining relatively unaltered in the absence of the stimulus. Thus, by association with electric shock the presentation of the stimulus can modulate ongoing operant behavior. The extent to which such modulation occurs will depend on the detectability of the stimulus. For this reason the conditioned suppression technique has been of enormous value in animal psychophysics. For example, it has been used with rats to determine detection thresholds for X-radiation (Morris, 1966) and microwave radiation (King, Jutesen, & Clark, 1971).

Marr et al. (1973) used the conditioned suppression technique to determine whether rats could detect the presence of ELF electric and magnetic fields at 45 and 75 Hz. Four rats, maintained at 80% of their ad libitum weights, served as subjects. A lever-pressing performance was developed and maintained under a VI 1-min schedule of food presentation. When a stable performance was attained, a flashing chamber light was superimposed on the VI 1-min baseline. This stimulus had a duration of 1 minute and was scheduled to occur at irregular intervals averaging 10 minutes apart. After a number of adaptation sessions, conditions were changed so that the 1-minute flashing light terminated in the presentation of an electric shock delivered to the feet through a grid floor. After a few pairings of the flashing light with shock, responding during the light decreased to a low level in comparison with that in the absence of the light. This procedure confirmed that conditioned suppression would occur when a salient stimulus was paired with shock. Experimental sessions were also run where intermittent shocks occurred with no preceding stimulus. Attempts were then made to use an ELF signal as a preshock stimulus in the manner of the flashing light. The ELF fields consisted of either a uniform magnetic field perpendicular to the chamber, or that field in combination with an orthogonal electric field parallel with the work panel. Both signaled and unsignaled shock sessions were interspersed between field conditions. If an ELF signal as a preshock stimulus were detectable by the organism, its presentation after a few trials should have resulted in conditioned suppression, particularly when compared with the unsignaled shock condition. The basic measure of performance was a rate ratio, i.e., the ratio of the lever-pressing rate during the 1-minute preshock stimulus to that during the immediately preceding 1-minute period of responding. Thus, a value of zero would mean complete suppression during the preshock stimulus while a value of unity would mean no change in rate of responding as a function of stimulus condition. Figure 2 shows the rate ratios (±99% confidence limits) for Rat 4 under the various control and field conditions. The other three subjects showed virtually identical performances. When the flashing light (F) served as a preshock stimulus, the rate ratio was

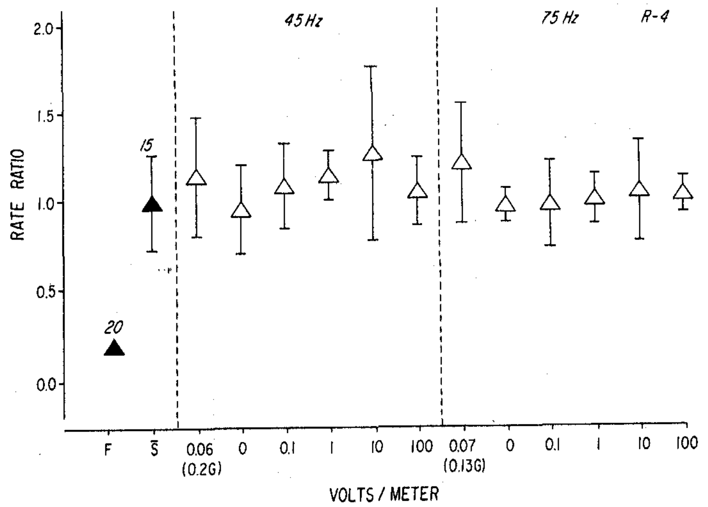

Figure 2. The mean (±99% confidence interval) rate ratio per session under each experimental condition for Subject R-4. The number of control sessions (F and $\bar{S}$) is also noted. Unless otherwise noted, the magnetic field was 2 G.

approximately 0.2; when shocks were unsignaled ($\overline{S}$), the rate ratio was near unity. Under all the field conditions, the rate ratio did not reliably depart from unity which indicated that the fields did not act as stimuli to control responding, i.e., they were undetected.

Conditioned acceleration. A similar experiment was conducted using four pigeons as subjects. It is technically difficult to deliver electric shock to pigeons without interfering with the ELF field uniformity; therefore, a modification of the conditioned suppression procedure was used which did not involve shock but did allow for a threshold determination. Pecking on a transilluminated plastic key was maintained under a VI 2-min schedule of food presentation in the presence of a white keylight. After a stable, constant rate of responding was attained, the conditions were altered so that a change in the key color from white to red was programmed to occur at irregular intervals averaging about 10 minutes apart. The response key remained red for 1 minute and was terminated by a 10-minute period of extinction signalled by a green keylight. During the 10-minute extinction period keypecks were not reinforced, and each keypeck reset the 10-minute clock, thus further delaying the onset of the white keylight and the availability of reinforcement. The green keylight therefore controlled a very low response rate. Of principal interest, however, was the rate during the 1 minute pre-extinction red keylight. Responding during the red keylight increased over the baseline rate which occurred in the presence of the white keylight, a phenomenon known as conditioned acceleration (Leitenberg, 1966). The rationale of this procedure was an attempt to use an ELF field as a pre-extinction stimulus. If the ELF field were detectable, conditioned acceleration should develop in its presence. The performance of each subject under the ELF field conditions was compared with that under a condition in which no stimulus change occurred before the onset of the extinction period as well as that during the red keylight pre-extinction signal. The field conditions were as in the previous detection experiment.

Figure 3 shows the performance of Bird 276 under the various conditions. Again, the dependent variable was a rate ratio, i.e., the ratio of the rate during the 1 minute-pre-extinction signal to the rate during the preceding 1-minute period. If no rate change took place during the 1 minute pre-extinction period, then the value would be unity; if the rate increased during the pre-extinction period, the ratio would be greater than unity. When the red keylight (RL) served as a pre-extinction signal, the rate increased more than 50% during this stimulus. When no stimulus ($\overline{S}$) signaled the extinction period, the rate ratio was unity. The rate ratio did not reliably depart from unity at any value of the ELF field which indicated again that the field was not detectable at the parameter values studied. These results were clearly replicated in the other three subjects.

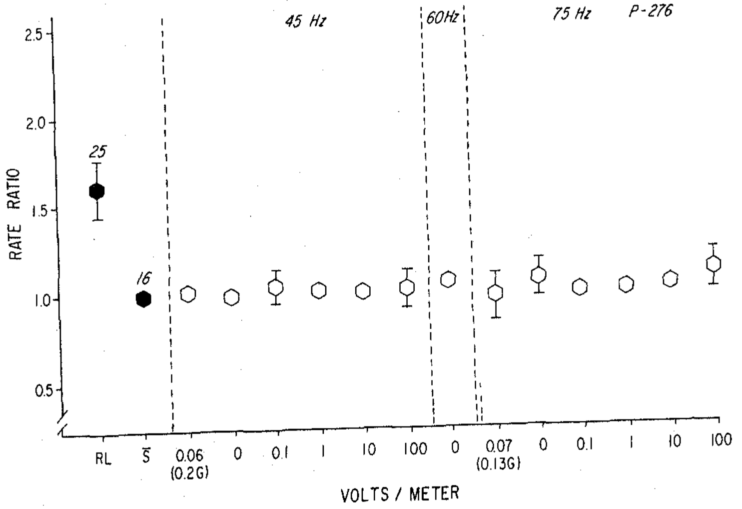

Figure 3. The mean (±99% confidence interval) rate ratio under each experimental condition for Subject P-276. The number of control sessions (RL and $\overline{S}$) is also noted. The magnetic field was 2 G unless otherwise noted.

Conditioned suppression and conditioned acceleration represent but two of a large number of techniques to obtain psychophysical data using conditioning techniques. The reader is referred to Stebbins (1970) for an excellent presentation of the application of these procedures.

Stimulus Control II: The Effects of ELF Radiation on Performance

Different patterns as well as classes of responses can be controlled by different stimuli. When discriminative stimuli are associated with various consecutive schedules of reinforcement, the overall schedule is called a multiple schedule of reinforcement. Typically, the various schedules are sequenced in either a regular or irregular manner and are independent of one another. Multiple schedules are useful in that they allow an investigator to study two or more different behaviors in the same animal during the same experimental session (Sidman, 1960). A multiple schedule was used by de Lorge (1972, 1973a, 1973b) to study behavior on an FI schedule, reaction time behavior and match-to-sample behavior in the presence of 10, 45, 60, and 75 Hz-10 G magnetic fields. In addition, electric fields at the same frequency and various low intensities were present. Each of these individual tasks will be discussed independently in sections where the behavior can be analyzed in the context of similar work by others.

Stimulus control is not limited to differentiating schedules. Within a specific schedule different discriminative stimuli can be used to control different operants so that complex repertoires of behavior can be constructed. Hence, the adroit use of discriminative stimuli permits the investigator to study behavior in animals similar to that observed in humans. Examples of this behavior are the topics in the following sections.

Reaction time. Numerous studies have reported differences in human reaction time as a consequence of ELF field exposure (Friedman, Becker, & Bachman, 1967; Konig, 1962). The results are contradictory with increases, decreases, or no effects having been observed dependent on slight changes in the field frequency. When reaction time was studied in two other primate species, no effects were indicated (de Lorge, 1972, 1973a, 1973b; Grissett, 1971; Grissett & de Lorge, 1971). For example, as one component of a multiple schedule, de Lorge trained two male and two female rhesus monkeys to lift a lever in the presence of a red light and release it when a tone occurred. Immediately, the tone and red light went off and food or water was made available. If the lever were held up more than a limited time, the red light and tone went off and a 10 second-intertrial interval (ITI) intervened between the lever release and the next onset of the red light. The period between the lever lift during the red light and the tone onset was a variable foreperiod (0.5 to 10 seconds). Lever releases during the foreperiod (anticipatory responses) and lever lifts during the ITI restarted the 10-second interval before the next red light. The reaction time schedule was in effect for a 15-minute period once each hour. Animals were exposed to the

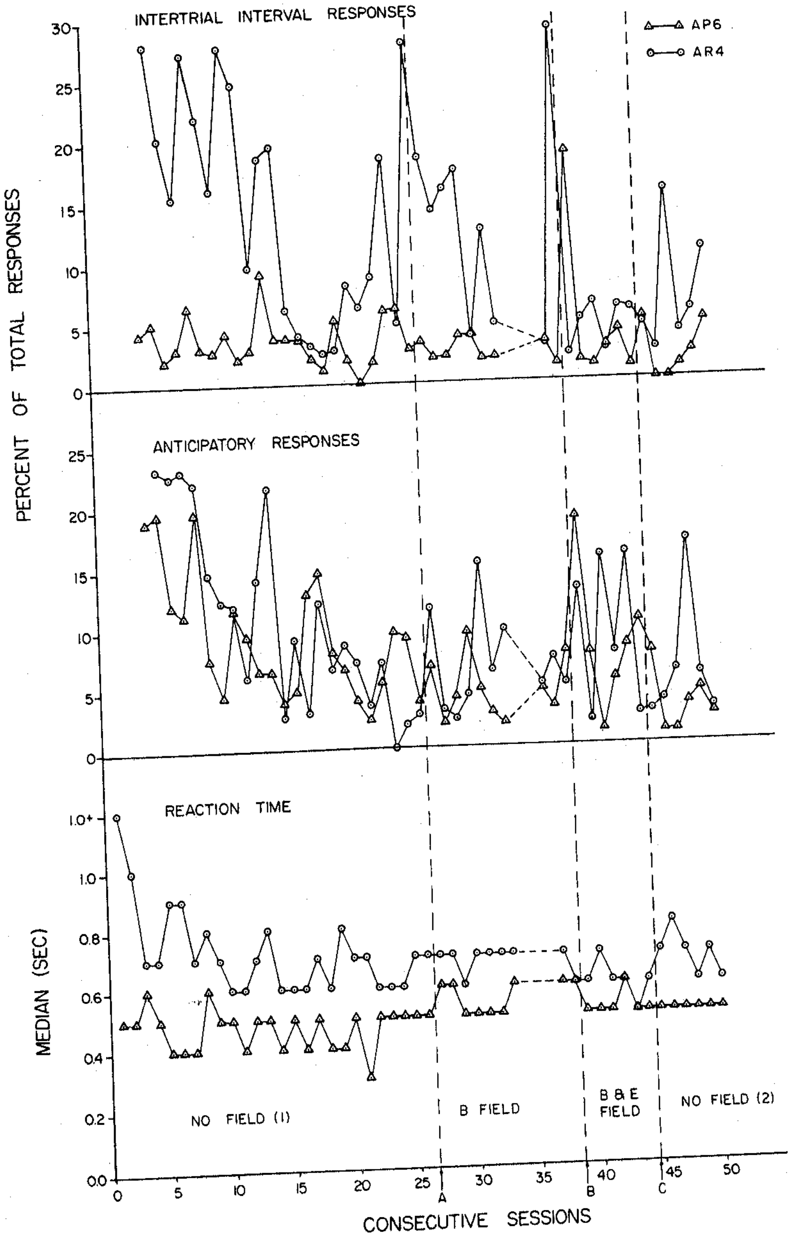

Figure 4. Reaction time performance for two male rhesus as a function of the 75-Hz fields. The short-dashed lines occur where data were invalidated due to equipment malfunction.

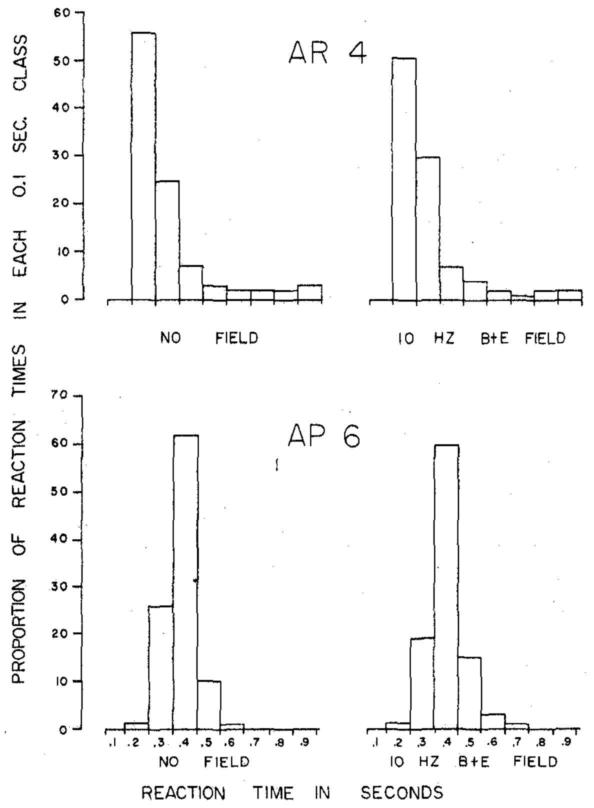

Figure 5. Reaction time histograms of two male rhesus as a function of the 10-Hz fields. The NO FIELD data were obtained from 6 sessions before and 6 sessions following the presence of the fields. Field data were obtained from 12 sessions when the fields were present.

fields in daily sessions of either 3 hours (de Lorge, 1972) or 22 hours (de Lorge, 1973a, 1973b). In the longer sessions measurements were obtained during an 8-hour period. Figure 4 illustrates reaction time performance in two male rhesus in the presence of 75-Hz magnetic and electric fields during 3-hour sessions (de Lorge, 1972). All of de Lorge's experiments used 10 ± 0.5 G magnetic fields with associated electric fields of approximately 7.4 V/m. The B & E fields were in phase. Fields were measured with a Bell 620 gaussmeter and an electric field probe. ITI responses and anticipatory responses were highly variable and, although large

changes occurred in AP6's data when the B & E fields were both introduced, these changes were not statistically significant. AR4 did not show similarly large changes related to the B & E fields. Figure 5 contains histograms of the distribution of reaction times as a function of the 10-Hz fields when behavior was measured in 8-hour periods. The histograms of these two animals reveal no essential differences due to the fields. No influences on reaction time of any of the various fields (10, 45, 60, and 75 Hz) were observed.

Matching-to-sample. In a reaction time experiment different stimuli are presented successively and behavior is easily brought under stimulus control. In many experiments, however, the investigator desires to assess behavior in the simultaneous presence of more than one controlling stimulus. A matching-to-sample task can be used in such experiments. Matching-to-sample requires an organism to respond to a stimulus on one display that is the same as a stimulus on another display. In the present experiment the monkey sat in front of three plastic circular keys as in Figure 1. The animal pressed the top key when it was transilluminated with one of 10 different colors or symbols. A response on this key was followed by removal of the stimulus and 1.0 second later the same stimulus appeared on either the left or right lower key. A different stimulus appeared on the other lower key. When the key with the matching stimulus was pressed, all stimuli were removed and reinforcement be-

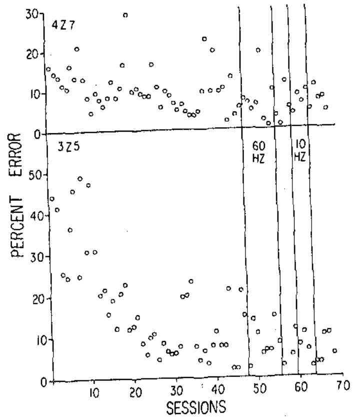

Figure 6. Percentage of error on match-to-sample for two female rhesus as a function of 60- and 10-Hz fields.

came available. Ten seconds later the top key was lighted with another stimulus. If the key with the nonmatching stimulus were pressed, all stimuli were removed for 15 seconds followed by the reappearance of the same stimulus on the top key. The various stimuli and left and right presentations were randomly determined. The task was available for 15 minutes once each hour. When delays are imposed between the presentation of the standard stimulus and presentation of the comparison stimuli, matching-to-sample becomes not only a measure of stimulus control but also may be a measure of memory. In addition, recording the latency of the animal's matching response provides an index of his alertness or attention. Figure 6 demonstrates the percentage of error of matching-to-sample responses made by two female rhesus monkeys in the presence of 60- and 10-Hz magnetic fields. No ELF effects on matching behavior were evident with these frequencies or the other frequencies examined by de Lorge (1972, 1973a, 1973b).

Temporal discrimination. The duration of a stimulus is a discriminable property just as intensity, frequency, size or configuration (Catania, 1970). Therefore, differential probability of a response as a function of stimulus duration is an expression of behavior under stimulus control. A number of studies have been concerned with the effects of various agents, mostly pharmacological, on temporal discrimination or "timing behavior". An experiment by Gavalas, Walter, Hamer, & Adey (1970), measuring IRT performance was executed with the rationale of studying the effect of ELF electromagnetic radiation on temporal discrimination. Their approach is subject to some criticism, however, because the controlling relations and the inherent dynamic quality of the performance generated under such dependencies as the interresponse-time and fixed-interval schedules are too complex to be subsumed under any simple notion of timing behavior (Dews, 1970; Kramer & Rilling, 1970; Morse, 1966). The experiment of Gavalas et al. (1970) is further discussed below.

Ideally, the establishment of stimulus control along the dimension of duration would not involve procedures where the performance itself determined the durations presented, as in the IRT schedule, or where the principal measured behavior occurred during the presentation of the temporal stimulus, as in the FI schedule. Perhaps the most precise and unambiguous procedure would involve differentially reinforcing a response dependent on the duration of a previously presented stimulus (Catania, 1970; Stubbs, 1968), the durations being selected by the experimenter, and the measured performance occurring in the absence of the stimulus. Marr et al. (1973) utilized such a technique to determine whether ELF electromagnetic fields exerted any effects on temporal discrimination in the pigeon. The basic method followed that of Stubbs (1968). A schematic of the procedure is shown in Figure 7. In a three-key chamber a trial began with the center key transilluminated by a blue light; the two adjacent side keys remained dark and inoperative. A single peck (FR 1) on the blue key changed the key to white for discrete durations of 1, 2, 3 ... 10 seconds in an irregular order. Responses on white had no programmed consequences. Following the selected duration, the white key extinguished and the two side keys were transilluminated, one green, the other red in a random left-right alternation from trial to trial. If the white key had been on for 1-5 seconds, a peck on the green key was correct. An incorrect response produced a 10 second time-out period (TO) during which all lights were extinguished. On the average, every fifth correct response (VR 5) was followed by food presentation. Correct responses not followed by food delivery produced a brief stimulus paired with food presentation (S^P). Following the presentation of food, the S^P or a TO, a new trial began with the onset of the blue keylight. A daily experimental session comprised 540 of such trials. Four pigeons served as subjects. A number of behavioral variables were measured with this procedure. Figure 8 shows for subject P-69 the point-of-subjective-equality (PSE) under con-

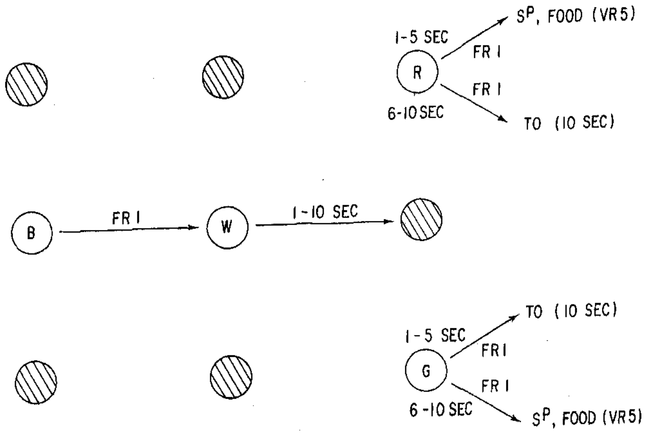

Figure 7. The sequence of stimulus and response contingencies in the temporal discrimination procedure.

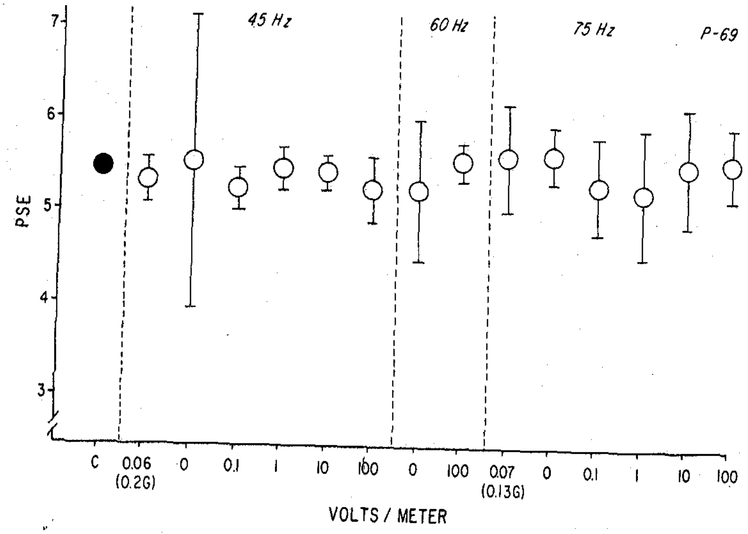

Figure 8. The mean (±99% confidence interval) point of subjective equality (PSE) per session under each experimental condition for Subject P-69. The magnetic field was 2 G unless otherwise noted.

trol (C) and various ELF field conditions like those in the previously discussed detection experiment. The PSE is a "neutral" point above which the probability of a 6-10 second choice is greater than 0.50, or below which the probability of a 1-5 second choice is greater than 0.50. No reliable effects at any of the field parameters were observed in this or any of the other subjects. In addition, no reliable effects occurred in percentage of correct responses, or other measures of discriminability thus providing no indications of ELF field effects on temporal discrimination in the organisms at the parameter values and exposure times studied.

Schedule Performance

Although operant responses have been previously used in animal studies of nonionizing radiation effects, sophistication in operant methodology has been the exception rather than the rule. For example, there has been a tendency to use only the CRF schedule (FR 1) (e.g., Spittka, Taege, & Tembrock, 1969). Since rates and patterns of responding are the primary ingredients of an operant analysis of behavior, the CRF schedule essentially represents, like the tip of the cone in the study of conic sections, a degenerate condition. Studies in behavioral pharmacology have clearly shown that the effects of drugs on performance can depend crucially upon the ongoing rate of responding (Kelleher & Morse, 1968). Such results were derived from careful analyses of drug-induced changes in performance under various schedules of intermittent reinforcement controlling different distributions of rate in time, i.e., different patterns of responding. The rate-dependency findings would have been very difficult if not impossible to obtain under conditions where each response was reinforced. It is possible that other agents such as ionizing and nonionizing radiation might differentially affect responding dependent on its pattern in time. Thus it is essential that the possible effects of such agents on schedule-controlled behavior are explicitly explored. It should also be emphasized that in *any* behavioral experiment the schedule conditions should receive very careful consideration and analysis before any putative effects are attributed to other, possibly less significant, variables.

Fixed interval. FI schedules have been used extensively in behavioral pharmacological studies because they engender gradually accelerated rates of responding during the interval thus allowing for an analysis of how a drug might interact with rate. Low rates in the initial part of the interval may be differently affected by a given drug than high rates nearer the end of the interval (Kelleher & Morse, 1968). The differential sensitivity to chemical agents of responding reinforced under FI schedules prompted de Lorge to use this schedule in an investigation of nonionizing radiation (1972, 1973a, 1973b). In these studies monkeys were trained to lift momentarily a lever in the presence of a green light on the work panel. The response was reinforced under an FI 20-sec schedule with food or water availability. An FI 30-sec schedule was also used as part of one study (1973a). The FI schedule was available for a 15-minute period once each hour. The general procedure was to produce stable rates of responding, turn on the ELF fields, and after several sessions, turn the fields off again. The number of sessions in the presence of the ELF fields varied from 6 to 13. Figure 9 presents daily averages of FI data obtained when two male rhesus were exposed to 45-Hz magnetic and electric fields. These data are typical of FI behavior we observed under other ELF parameters. The measures were *reinforcement time*, the time between reinforcement being made available and a reinforced response; *pause time*, the time between a reinforced response and the next lever response; and *response rate*, the number of lever responses per minute.

Except for AR4's reinforcement time, the measures in Figure 9 were relatively stable and no relationship to the presence or absence of the ELF fields was evident. Figure 10 illustrates more clearly the failure of the 45-Hz fields to affect FI responding. The mean rate of responding per minute in each 2.0-second segment of the FI 20-sec interval is plotted on a logarithmic scale as a function of the

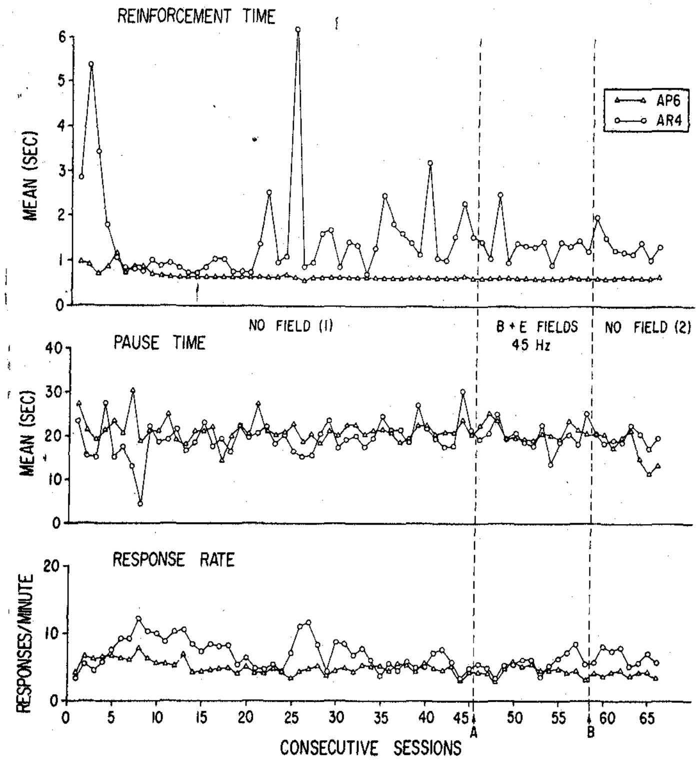

Figure 9. FI performance of two male rhesus before, during, and after the 45-Hz fields were introduced. Whereas AR4 had very unstable reinforcement times, AP6 showed virtually no variation in this measure.

fields' presence or absence. The only differences appeared at extremely low response rates (less than one per minute) and tended to be related to the chronological course of the experiment and not to the ELF fields. That is, as the number of sessions increased, the response rate in the initial segments of the FI intervals decreased. The high- and low-rate segments in the FI were not differentially sensitive to the ELF fields under any of the frequencies (10, 45, 60, and 75 Hz). The lack of concurrence among de Lorge's studies and those of Spittka et al. (1969), who found a decrement in the bar-pressing rates of rats when they were exposed to electric fields,and La Forge (1973), who also found response rate decrements in exposed rats, might be due not only to the different reinforcement schedules but also to the enormous differences in the intensity of the fields applied. Spittka et al. used 500 to 700 V/cm electric fields alternating at 50 Hz, and La Forge used 800-G magnetic fields alternating at 0.2 and 2 Hz.

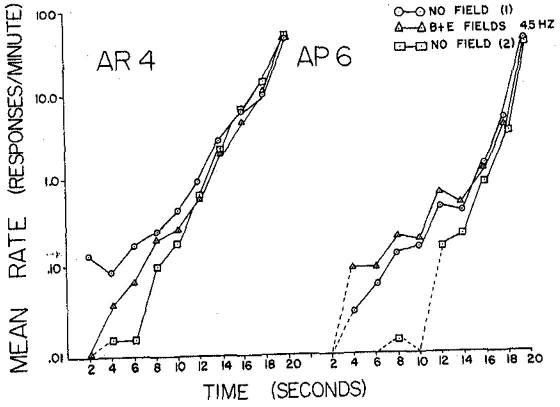

Figure 10. The mean response rate per 2.0-second segment as a function of the 45-Hz fields. Responses were sorted according to the successive 2.0-second segment following the start of an FI 20-sec component wherein the response occurred. The ordinate is a log scale.

Preference. It is of considerable interest to determine the extent to which an organism will approach, avoid or be indifferent to a stimulus condition. The basic question concerns the potential reinforcing or punishing property of a stimulus. Procedures for studying preference have included noting position in "open fields" and choice points in mazes. Such procedures generally include discrete trials and depend on the use of large numbers of subjects. A number of conditioning techniques have developed to study choice behavior under more precisely controlled conditions which allow for continuous long-term assessment in individual organisms (Catania, 1966; Herrnstein, 1971). Marr et al. (1973) utilized a *concurrent-chained schedule* (Autor, 1969) to determine whether pigeons would prefer the presence or absence of an ELF field. A concurrent-chained schedule provides different consequences for executing alternative and incompatible responses. The basic scheme is shown in Figure 11. During the initial link of the schedule, identical and concurrently available white keys were present and associated with equal but independent variable-interval schedules (VI 120 sec). When a variable interval had timed out on the right key, a response on that key changed the key color from white to green and extinguished the left keylight. The first response after 30 seconds (FI 30 sec) on the right key resulted in food presentation following which the two white keys reappeared. If the variable interval had timed out on the left key and a response occurred on that key, a change from white to green resulted along with the extinguishing of the right keylight. An FI 30-sec schedule was also programmed on the left green key so that the consequences of responding, under control conditions, on the left or right keys were the same. While it might be expected that equal response rates would occur on the two white keys, in fact, the three subjects showed decided position preferences. The preferences were quite stable, however, and choices for field conditions were determined by accompanying either the left or right green key stimulus with the field, whichever was preferred under the control conditions. Preference was measured by the ratio of right-to-left key responding during the presence of the white keys. Figure 12 shows the means (±99% confidence interval) of the right-to-left ratio per session for each of the three subjects. Pigeon P-51 showed a slight preference for the right key while P-52 and P-300 showed a large preference for the left and right keys respectively. When 2 G-100 V/m fields (orthogonal to each other as in the detection experiments above) at either 45 or 75 Hz accompanied the FI 30-sec link on the preferred key, no reliable change in preference occurred, which indicated that subjects were indifferent to the presence of the fields. Since Marr et al. (1973) had shown that pigeons were unable to detect ELF fields at these parameters, the results of the preference experiment were not unexpected.

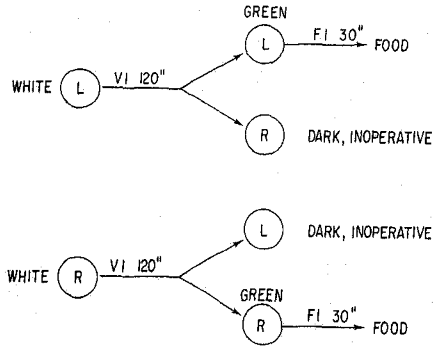

Figure 11. The sequence of stimulus and response contingencies in the preference procedure.

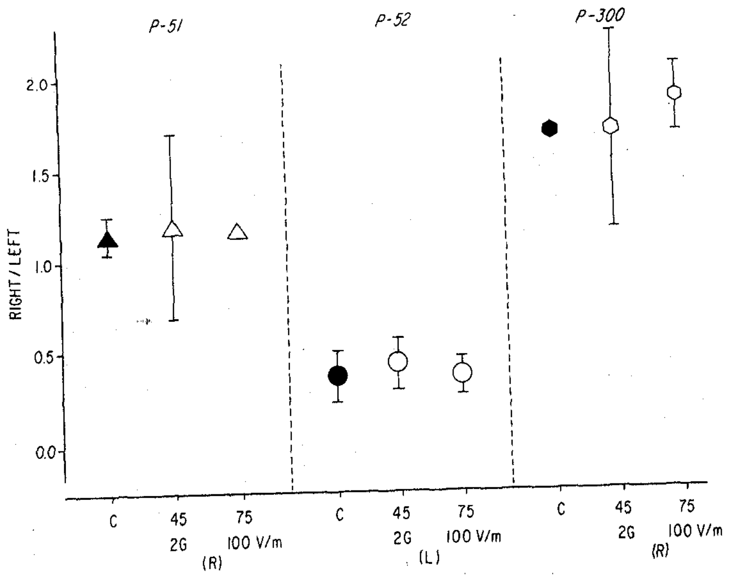

Figure 12. The preference performance under no field (C) and field conditions.

Interresponse-time schedule. The authors are familiar with only one other study in which reinforcement schedules were used to explore ELF field effects on behavior. Gavalas et al. (1970) trained *Macaca nemestrina* to respond on an IRT 5.0-sec schedule with a limited hold of 2.5 seconds. Interresponse times less than 5.0 or greater than 7.5 seconds reset the 5.0-second timer and no reinforcement occurred. When a 7 Hz-2.8 V/m electric field was introduced, shorter interresponse times were slightly increased thereby increasing response rates. A 10-Hz field did not have any effect on interresponse times.

SUMMARY AND CONCLUSIONS

Operant methodology and its advantages as a technique for the experimental analysis of the effects of agents on behavior were discussed. Methodological and conceptual contributions of behavioral pharmacology were also emphasized. Several experiments were presented as examples of operant techniques used to investigate ELF low intensity-electromagnetic radiation effects on animal behavior. Without exception, in all these experiments, no reliable effects of nonionizing radiation were found. Table 1 summarizes these experiments. The failure to observe ELF effects in these studies should not be considered as an indictment of the techniques. Operant techniques have been shown to be extremely sensitive in analyzing the effects of many physical agents including ionizing radiation (Smith, 1970). More than likely, the absence of effects in the present studies indicated that such effects are ephemeral or nonexistent, and only carefully controlled experiments with repeated measurements to preclude investigator intervention will provide adequate evidence. Much previous work by other experimenters on the behavioral effects of ELF fields seems more oriented towards providing confirmation of hypotheses derived from physiological evidence and less towards gathering behavioral data (Persinger et al., 1973). Principles involved in behavioral pharmacological research are also applicable. For example, Dews (1962) stated, "The results of studies conducted entirely in the behavioral frame of reference should be described in behavioral, and not neurophysiological, terms. Conversely, the validity of conclusions about behavior drawn from primarily neurophysiological studies are limited by the validity of the behavioral technique used - which in most instances in the past has been

TABLE 1

SUMMARY OF BEHAVIORS, SUBJECTS AND ELF PARAMETERS

Experiment	Subject	Behavior	Hz	B** (G)	E** (V/m)	Field Exposure
Grissett & de Lorge 1971	Squirrel Monkey	Reaction Time	45,7	3	---	10 hours
de Lorge 1972	Rhesus	Reaction Time	75	10	7.4	54 hours
	"	Fixed Interval	"	"	"	"
	"	Match-to-Sample	"	"	"	"
de Lorge 1973a	"	Reaction Time	45,10	"	"	33 days
	"	Fixed Interval	"	"	"	"
	"	Match-to-Sample	"	"	"	"
de Lorge 1973b	"	Reaction Time	60,10	"	"	12 days
	"	Fixed Interval	"	"	"	"
	"	Match-to-Sample	"	"	"	"
Marr, et al. 1973	Pigeon	Temporal Discrimination	45,60,75	2	100	166 hours
	"	Conditioned Acceleration	"	"	"	*
	"	Preference	45,75	"	"	*
	Rat	Conditioned Suppression	"	"	"	*

* Field exposure was brief, intermittent, and dependent on the animal's behavior.

**Field intensities refer to maximum values.

poor (p. 440)." Dews continued with a statement concerning drug dosage level which, when paraphrased to apply to ELF research, implies that valid conclusions about the specificity or qualitative effects of ELF fields cannot be made on the basis of behavioral data obtained at a single intensity or frequency. The reader is referred to Dews' article for other suggestions about research credibility that should apply to behavioral research with nonionizing radiation.

Pharmacology in general, and behavioral pharmacology in particular, could not have made much progress had researchers not carefully specified the agents studied. Single drugs studied at several dosage levels under relatively simple conditions have provided necessary experimental and conceptual foundations. That lesson should also be followed by investigators who are studying the effects of physical agents such as nonionizing radiation on any biological process. The initial use of complex and difficult-to-specify field conditions along with unreported, inappropriate or nonexistent measurement techniques will be of doubtful value in the advancement of this area of research.

The intention of this chapter was to present operant techniques in such a manner as to provide the reader without specialized knowledge in this area some basic tools to understand this approach to measuring behavior. It is hoped that the ideas expressed will permit the reader from other disciplines to better evaluate the use and significance of operant methodology and perhaps to further contribute to behavioral work in the ELF nonionizing radiation area.

FOOTNOTES

[1] Opinions expressed are those of the authors and do not necessarily reflect the views or endorsement of the U.S. Navy.

[2] Experiments conducted at Georgia Institute of Technology were sponsored by the Office of Naval Research, Contract No. N00014-67-0159-0009.

[3] The detection experiments were conducted by S.N. Robinson of the School of Psychology, Georgia Institute of Technology.

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BEHAVIOURAL, PHYSIOLOGICAL, AND HISTOLOGICAL CHANGES IN RATS EXPOSED DURING VARIOUS DEVELOPMENTAL STAGES TO ELF MAGNETIC FIELDS

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INTRODUCTION

Extremely low frequency (ELF) electromagnetic fields are produced in the physical environment and by living organisms. In nature, ELF processes are correlated with a number of fundamental geophysical and meteorological mechanisms. ELF processes in biological systems are known to be associated with memory storage, activation of the organism and certain stages of development. This chapter will be primarily concerned with the "long term" effects of ELF magnetic fields upon the rat as a consequence of prenatal, neonatal or adult exposures. The conceptual problems involved with magnetic field research have been discussed elsewhere (Persinger, 1974).

Rationale

All of the experiments reported in this chapter employed a 0.5 Hz. rotating magnetic field (RMF) with intensity levels ranging from ∿ 0.5 to 30 gauss. This particular

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frequency was selected since it overlaps with certain brain frequencies known to be associated with memory storage and autonomic functioning. Infraslow potential oscillations (.01 to 1 Hz) and their components contribute to the "slow control system" (Aladjalova, 1964) in the brain, and are involved with learning. Neurons in the autonomic nervous system (which is highly coupled with emotional behaviour) can maintain their influence by impulse chains within the ELF range. In general, less than one impulse per second is sufficient to maintain normal sympathetic and parasympathetic effects (Guyton, 1971). A magnetic field was used because of its greater penetrability relative to analogous electric fields. The exposure area for the experimental series was between two permanent horseshoe magnets which were rotated in opposite directions about their major axes. Such an exposure field configuration was considered to simulate some natural geophysical phenomena and to have a greater likelihood of biological effect. For a number of theoretical reasons beyond the scope of this chapter, a rotating permanent magnetic dipole field was assumed to be more bio-effective than magnetic fields of the same frequency generated by electric currents from (Helmholtz) coils.

The time factor is an important component of the magnetic field operation. If an applied time-varying magnetic field displays frequencies that overlap with those of the exposed biological system, then coupling between the external time-varying field and the biogenic time-varying field is at least theoretically possible. Conditions for resonance, driving and information exchange, could occur.

Rotating Magnetic Field Apparatus and Intensities

The rotating magnetic fields were produced by two horseshoe magnets rotating in opposite directions about their major axes at 29 to 30 RPMs. (Figure 1). The magnets were turned by either an electric motor or variable speed transmissions, depending upon the apparatus and experimental design. Experiments conducted from 1966 to 1971 at Madison, Wisconsin (1966-1967), Knoxville, Tennessee (1967-1969) and Winnipeg, Manitoba (1969-1971) involved field intensities ranging from 3 to 30 gauss ("high intensity" area) or 1 to 3 gauss ("low intensity" area). Control regions, selected within the experimental room in order to minimize other environmental differences, were 2

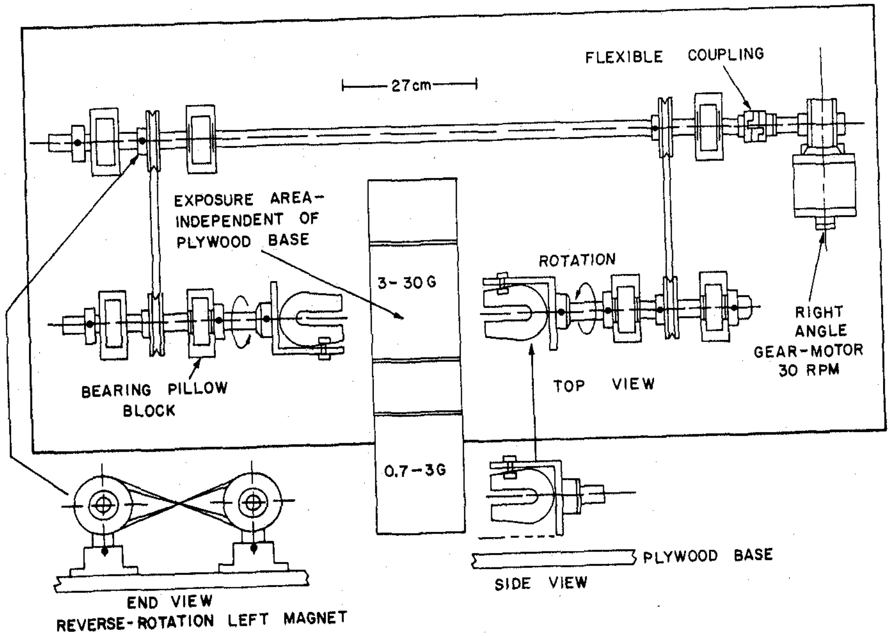

Figure 1. One of the rotating magnetic field apparatus and associated exposure areas (modified from Persinger and Pear, 1972).

to 3 m from the nearest magnet. Although Rawson-Lush Gaussmeters detected no significant deviation from background (earth) magnetic field levels in the control areas, magnetometric recordings indicated that 0.5 Hz fluctuations with amplitudes of 0.01 gauss were present.

Since 1972, when the laboratory was moved to Sudbury, Ontario, Canada, slight modifications have been made in the exposure area. Measurements with an RFL Industries Co. Model #750 Gaussmeter showed that the "high intensity" exposure area ranged from 8 to 20 gauss (mode = 10 gauss) while the "low intensity" exposure area ranged from 0.8 to 1.5 gauss (mode = 1.1 gauss). Field intensities in the "control" area ranged from 0.8 (local geomagnetic field levels) to 1.0 gauss, because of a local anomaly. However, the time-varying component (0.5 Hz) in the control area exhibited amplitudes of only 0.05 to 0.1 gauss. In a number of the studies, a "sham-field" condition was created by exposing subjects to the same spatial area in which the "high" and "low" intensity RMF subjects had been housed, after the magnets had been removed. With the motor operating, but with magnets removed, the sham-field condition was associated with ambient intensity levels of 0.5 to 0.8 gauss. A magnetometer indicated that no significant time-variations (to the nearest 100 gamma, i.e. 0.001 G), were present in the sham-field area. In some experiments sham-field control conditions were employed; subjects were placed in what had been the RMF control area.

At any given point in the RMF, the vector $\overline{B}$ field changed continuously in a sine-wave like pattern from a maximum intensity north polarity, to "zero", to a maximum intensity south polarity, to "zero", etc. Whereas under static field conditions a given area might be 3.0 gauss, when the RMF was initiated intensities in this area would slowly vary between 3.0 gauss N to 3.0 gauss S. The horizontal component of the RMF changed 360° every 2 seconds (A hand compass placed between the rotating magnets rotated 0° to 360° in 2 seconds).

Since the magnetic field was time-varying, an electric field $\overline{E}$ was produced. According to Faraday's law, with $\overline{B}$ = 10 gauss,

$$\left| \frac{dB}{dt} \right| = \frac{10 \text{ gauss}}{2 \text{ sec}} = 0.5 \times 10^{-3} \text{ MKS units/sec.}$$

Thus with 10 cm as the surface for an exposed animal,

$$| \text{curl } \overline{E} | = \text{space gradient of } \overline{E}$$

and E develops a peak value of

$$(10^{-3} \times 10^{-1}) = 10^{-4} \text{ V/m, or } 10^{-5} \text{ V/m}$$

within less intense field exposure areas.

Because vibration from the motor affected the plywood base, cages in the exposure areas were supported independent of the plywood base. Most of the studies involved exposure cages composed of plastic or floor tile with $\frac{1}{4}$ inch wire mesh covers. Cage dimensions, lighting, noise levels and other non-magnetic ambients have been described in earlier papers (e.g., Persinger and Pear, 1972).

Research Strategy and General Format

Our research strategy has been divided into four phases:

1) isolation of simple but reliable behavioural measures that differentiate RMF exposure effects,
2) measurement of RMF effects as a function of field intensity, frequency and exposure duration,
3) isolation of the organ, cellular, physiological and biochemical correlates of the behavioural changes,
4) detection and control of mechanisms.

Primarily, we are not interested in a particular discipline or in a particular level of discourse. Instead, we are interested in a problem: time-varying, biofrequency (ELF) magnetic fields and their interactions, if any, with life forms which produce similar time-varying fields.

Two animal models have been employed in our research: the developing rat and the adult rat. Many of the studies have been involved with testing rats that had been exposed during their prenatal or neonatal development to a RMF. Such a model was used since the developing rat is known to be sensitive to a number of weak environmental stimuli (Ludwig, Persinger, Ossenkopp, 1973). Initially, the behavioural and physiological measures for an experiment were selected as a consequence of results from the previous experiments. Once data indicated emotional behaviour-endocrine effects, experiments were more oriented towards these variables. Most of the studies involved chronic RMF exposure intervals between 4 to 30 days.

PRE- AND NEO-NATAL RMF EXPOSURE EFFECTS

Behavioural Results

Open field behaviour. In several studies between 1967-1969 (Persinger, 1969a) it was demonstrated that rats which had been exposed during their prenatal development (but removed within 12-hr after birth) to a 0.5 Hz RMF, traversed significantly fewer squares and defecated more frequently than controls when tested in an open field. Open field tests were always conducted for either three or five consecutive days between post-natal days 22 and 27. Later, Ossenkopp (1972), with another but similar RMF and open field apparatus, replicated these results. Table 1 contains the ratios of squares traversed by the RMF-exposed rats relative to the squares traversed by the control-exposed rats. The numbers in parentheses express the number of subjects in each condition. On the average, the 156 RMF-exposed rats from these studies traversed about half as many squares as the 121 control-exposed rats. Experimental and control rats in the 1969 experiment were tested "blind" by technicians who did not know the exposure condition of the subjects. Note that in both the Persinger and Ossenkopp studies, male RMF-exposed rats displayed greater decrements in ambulatory behaviour than the RMF-exposed females, relative to their appropriate controls.

TABLE 1

Ratios of Mean Squares Traversed in the Open Field for RMF (M) to Control (C) Rats

Experiment	Field Intensity	Male (M/C)	Female (M/C)
1967-68 (P)	3 - 30 G	0.45 (64/47)	0.81 (53/36)
1969 (P)	3 - 30 G	0.47 (9/14)	0.58 (10/ 6)
1972 (O)	3 - 12 G	0.66 (12/ 8)	0.85 (8/10)

Sham-field experiments indicated that the observed changes in ambulatory and defecation behaviours were not due likely to an artifact of the apparatus. Sham-field experiments were conducted by removing the magnets from the apparatus during the "exposure" period. In this manner, extra precautions against possible contributory effects from motor noise or vibrations were checked. Oscilloscope patterns indicated no appreciable difference in output vibration/sound from the motor with magnets on or off. The mean squares traversed by three sham-field litters (n = 24) was 33.1 ± 16.1 (± values indicate standard deviations), while the 15 "normal" control litters (n = 89) averaged 28.1 ± 18.0 squares. These differences were not statistically significant. As a comparison, the 24 RMF-exposed litters (n = 136) that were tested in the open field during this experimental series averaged 16.5 ± 14.3 squares.

From the above experiments, it was difficult to determine whether the changes in ambulation were a consequence of the prenatal exposure or due to post exposure-related mothering effects. Indeed, other experiments have suggested hormonal effects (e.g., Persinger et. al, 1972) which could have modified the mother's behaviour following removal from the RMF. Fostering studies were completed in order to answer this question. Results from an unpublished Master's thesis (Persinger, 1969b) strongly suggested that the behaviour of the RMF-exposed rats was not a consequence of post-natal mothering effects. Three litters (n = 20) that had been exposed during their entire prenatal development to the RMF, but removed at birth and given to control mothers (whose litters were eliminated), averaged 13.2 ± 14.0 squares, while four comparison RMF-exposed litters (n = 30), tested at the same time, averaged 13.9 ± 15.0 squares.

Shuttle-box avoidance conditioning. Rats that had been exposed during their prenatal development, but removed at birth from the RMF, demonstrated facillitated avoidance response acquisition. As reported in an unpublished Master's thesis by Persinger (1969b), 45 RMF-exposed males and 36 control males were tested in a Miller-Mower shuttle box. The conditioned stimulus (CS) was a 70 db noise of 4.4 seconds duration. The unconditioned stimulus (UCS) was a 0.9 mA electric shock delivered to the grid bars immediately after the cessation of the CS. Subjects were tested to a criterion of five consecutive shock avoidance responses, avoidance being defined as a barrier crossing made in less than 4.4 seconds after the CS onset. If a rat had not reached criterion by trial 100, it was removed from the experimental situation. At that particular shock intensity, only 33% of the control rats learned the task while 73% of the RMF-exposed rats reached criterion. These differences were statistically significant ($X^2 = 12.96$; $p < .001$). No sham-field rats were tested. A replication experiment one year later with a different test apparatus did not successfully differentiate the RMF-exposed and control animals.

Sidman avoidance. While at the University of Tennessee the first author (M.P.) was strongly influenced by the operant behaviourists H.M.B. Hurwitz and W.S. Verplanck. It became very clear that the precision and sensitivity of operant procedures would be an important tool for differentiating RMF effects. The Sidman avoidance or free operant avoidance paradigm was selected since it was known to differentiate autonomic (emotional) behaviours in rats. Data collected on open field and shuttle-box avoidance behaviour had indeed suggested an autonomic component to the RMF effect.

In the free operant avoidance procedure, which involves no extereoceptive stimulus, each avoidance response postpones an electrical shock for a predetermined interval of time (R-S interval). Failure to respond results in the delivery of a series of shocks separated in time by a fixed interval (S-S interval). Studies have found that rate of avoidance responding is related in an orderly manner to both R-S and S-S intervals, as well as shock intensity. Results from three different experiments indicated that male, 80 day old, prenatally RMF-exposed rats displayed significantly fewer lever presses than their controls (Persinger and Foster, 1970). Analysis of response intervals showed that the greatest difference between RMF-exposed and control subject responding occurred immediately after a shock delivery. Control rats displayed the typical post-shock response bursting while the RMF-exposed rats did not. Since later experiments by Pear, Moody and Persinger (1972) suggested that, at least in part, post-shock bursting is due to shock-elicited attacks on the lever, it is possible that the decrement in Sidman avoidance responding displayed by the RMF-exposed rats was due to less lever attacking (aggressive behaviour) relative to controls.

Data patterns also indicated that the differences in responding between RMF-exposed and control rats became greatest after the fourth or fifth consecutive daily session. RMF-exposed rats continued to respond at rates typical of earlier acquisition periods whereas the controls increased their responding. However, the response differences were not due primarily to decrements in task acquisition since both RMF-exposed and control rats received similar numbers of shock. No sham-field rats were tested in this experimental series.

Conditioned Suppression. Until 1971, there were at least two explanations for the prenatal RMF effects:

1) the RMF-exposed rats were displaying motor difficulties,
2) the RMF-exposed rats were more "emotional", i.e., autonomically reactive.

Consequently, Persinger and Pear (1972) decided to test these animals in a conditioned suppression paradigm. In this procedure, a conditioned stimulus (CS) followed by an unavoidable shock (UCS) is superimposed upon a baseline of responding (variable interval schedule) maintained by positive reinforcement. During the CS a suppression of responding occurs. Persinger and Pear hypothesized that if indeed the RMF-exposed rats were more "emotional", greater suppression of responding during the shock-associated CS periods would be expected. Such periods are reported by human subjects as being typified by private experiences of "anxiety" or "foreboding".

The results of the experiments are presented in Figure 2. It can be seen that not only do the RMF-exposed rats show greater response suppression during shock associated CS periods, but also a transient suppression when a novel stimulus (later the CS) was presented (CS alone in Figure 2). Unpublished data from this experimental series indicated that greatest differentiation between RMF-exposed and control groups took place when low level (0.5 mA, 0.5 sec) shock parameters were used. More intense shock parameters were associated with the development of similar conditioned suppression ratios by both the RMF-exposed and control groups, as a function of CS-UCS presentations. It is important to emphasize that the RMF exposure seemed to predominantly affect "emotional" behaviours, that is, the animals were more autonomically reactive to novel or aversive

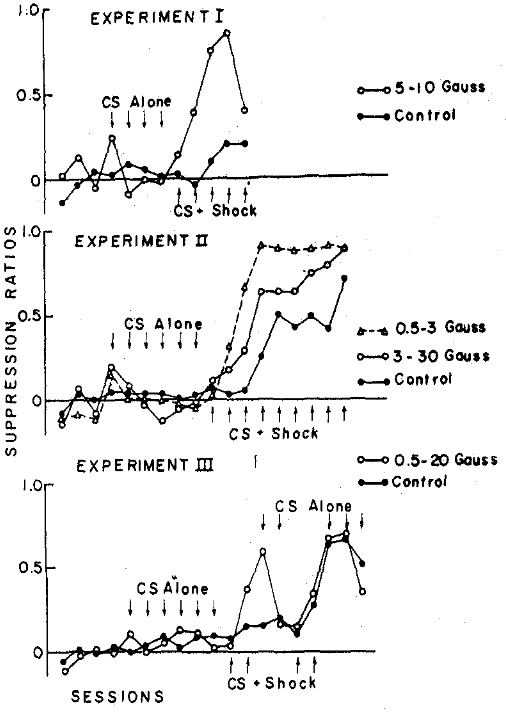

Figure 2. Mean suppression ratios for rats that had been exposed from prenatal day 1 to birth to the RMF or control conditions. The results of three different experiments involving 30 subjects are shown (Persinger and Pear, 1972).

stimuli. In a conditioned suppression paradigm, the response affected is one maintained by a variable interval reinforcement schedule that the animal had learned before the CS-UCS conditioning. During non CS periods, RMF-exposed rats did not differ significantly from control rats in either acquisition or maintenance of the VI schedule.

The Halasz procedure: delayed conditioned approach. In 1968 and 1970 M.F. Halasz published two important papers which illustrated applications of systems theory to behavioural patterns. Halasz emphasized that transient changes in response characteristics following reinforcement schedule changes, could be sensitive detectors of experimental manipulations. Step-, ramp- or impulse-like changes in acquired (steady-state) reinforcement schedules were associated with a number of predictable short-term perturbations in response patterns. Such schedules have been used to illustrate ionizing radiation damage (Halasz, Hughes, Humpherys and Persinger, 1970).

For his doctoral dissertation, Persinger (1971a) decided to test RMF-exposed rats, controls and sham-field rats on the Halasz paradigm. A total of 82 female rats, 60 to 90 days of age, from groups that had been exposed:

1) during their entire prenatal development to the RMF,
2) during prenatal days 13 to 16 to the RMF,
3) during neo-natal days 1-4 to the RMF,
4) to control conditions, or
5) to sham-field conditions,

were selected as subjects. In addition some of the RMF-exposed subjects had been exposed to "low" field strengths (∿ 0.5 - 3 gauss) while others had been exposed to "high" field strengths (3 to 30 gauss).

The testing procedure involved shaping the subjects to acquire a lever press response for water reinforcement, under 23-hr of water deprivation. Once this task was acquired the rats were conditioned to only press the lever for water reinforcement during the presence of a tone S^D but not during the absence of the tone (S^{Δ}). As a result, the onset of the tone was paired with the availability of water. When the animals had displayed this discrimination, a 10 second delay was instituted in a step like fashion half-way through one session and maintained for the remaining sessions. During the 10 second delay, water was no longer available following a lever press. A general summary of results can be seen in Figure 3 taken from Persinger and Ossenkopp (1973). The ratios of total responses during the step-change session relative to mean baseline total responses for various exposure groups are appropriately indicated. It can be seen that the RMF effect on delay interval responding is a function of ontogenetic development at the time of RMF exposure. Rats that had been exposed during their early prenatal development to the RMF did not differ from their controls. Rats that had been exposed during their entire prenatal development or only after birth (N 1-4) to the RMF,

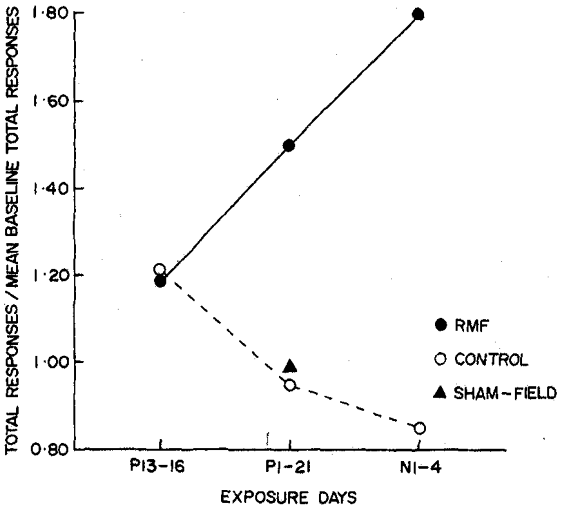

Figure 3. Summary of response changes for 82 adult female rats that had been exposed to either RMF, control or sham-field conditions during prenatal days 13-16 (P 13-16), prenatal days 1-21 and removed at birth (P 1-21) or neonatal days 1-4 (N 1-4). (Persinger and Ossenkopp, 1973).

emitted significantly more lever presses during the delay period than control or sham field rats.

One interpretation of these results was that the increased responding in the neonatal RMF-exposed rats was due to some generalized "frustration" component. If this were the case, then one would expect increased responding during initial exposures to the tone-water availability situation or in procedures where S^{Δ} responding postponed trial presentations. Both pre- and neo-natal RMF-exposed subjects were not signficantly different from their controls on these measures. It is interesting to point out that only the low intensity (0.5 - 3 gauss) prenatally RMF-exposed subjects and the high intensity neonatally RMF-exposed subjects showed significantly less non-tone (S^{Δ}) responding than their alternate RMF intensity groups.

Non-differentiating behavioural tests. Between 1967 and 1974 a number of behaviours were measured which did not differentiate prenatal RMF-exposed rats from controls. Rats exposed during their prenatal development to the RMF did not differ from their controls with regards to:

1) latency for obtaining food from a food-box,
2) Y-maze acquisition errors (food deprivation, 23-hr),
3) alley running speed after initial learning trials,
4) hanging reflexes, i.e., duration of parallel bar holding,
5) running wheel activity (1-hour per day for three days), and
6) lever presses on the first day of exposure to an operant chamber.

It should be emphasized that on the average RMF-exposed rats displayed less running activity and fewer bar presses, but the statistical significance was eliminated because of the high individual variation.

Developmental measurements: teeth eruption and eye opening. Ossenkopp (1972) noted that rat litters which had been exposed during their prenatal development to the RMF showed significant delays in eye opening and teeth eruption relative to controls. When sham-field replications were completed, there were no statistically significant differences (unpublished data, 1974) between sham-field and sham-field control litters. However, the absolute values (age at teeth eruption) of these measures showed considerable overlapping.

Physiological, Morphological and Biochemical Effects

The behavioural data indicated correlative changes in tissue morphology. As a result, starting in 1971, a series of experiments were conducted to determine these changes.

Preliminary data: sex ratios, body weights and water consumption. For 21 litters that had been exposed during their prenatal development to the RMF (3 to 30 gauss), the mean viable offspring at 12 hrs-postpartum was 10.6 ± 8.5.

Sixteen control litters averaged 10.6 ± 2.7 pups for this measure. The male/female ratios for RMF-exposed litters and their controls were 1.3 and 1.5, respectively, indicating a slight predominance of male survival. These data were reported in the unpublished Master's thesis by the first author (M.P.).

Mean body weights at weaning for rats exposed during their entire prenatal development to the RMF were 51.8 ± 4.49, while controls averaged 45.3 ± 5.09. These values represented the weights of 8 and 6 litters, respectively, and are marginally significant ($p < .05$). Mean body weight at weaning for rats exposed to the RMF from two days before birth to eight days after birth (-2 to + 8) was ($n = 20$, 3 litters) 59.0 ± 6.09, while control ($n = 18$, 3 litters) and sham-field ($n = 19$, 3 litters) rats averaged 59.8 ± 5.0 g, respectively. At one year of age, 10, -2 to + 8 day RMF-exposed male rats from four litters had mean weights of 594 g while 10 control rats from four control litters averaged 583 g. These differences were not significant.

Endocrine tissue weight changes. Ossenkopp, Koltek and Persinger (1972) reported that rats exposed between prenatal days 1 - 22 (birth) to the RMF showed significantly larger testicle and thyroid weights. The effects were shown to be a function of exposure duration and field intensity. An example of this functional relationship is shown for testicle weights in Table 2. Similar dose-exposure duration relationships were found for thyroid tissue. However, later unpublished histological studies by Persinger (1974) indicated that thymus nodule material may have been included in the total tissue weight. Since histological analysis was not conducted in the Ossenkopp, Koltek and Persinger (1972) study, only replication experiments can firmly establish the reliability of a thyroid effect.

Over many experiments adrenal weights, spleen weights and thymus weights were taken from rats exposed during:

1) prenatal days 1 - 22,
2) neonatal days 1 - 4, or
3) prenatal day 19 to neonatal day 8,

to the RMF. No significant differences from controls or sham-field rats were ever measured. An interesting and persistent trend, however, is for prenatal day 1 - 22 rats to show lighter thymus weights than controls. Unpublished histological experiments by Persinger (1974) also indicate that these animals show heavier thymus nodules distal to the main thymus body. Such involvement of thymus function would alter disease susceptibilities and may explain the higher mortality rate of RMF-exposed rats in some rat colonies (see Ossenkopp, et. al, 1972).

TABLE 2

Percentage Increase of Testicle Weights for RMF-Exposed Rats Compared to Controls and Sham-RMF to Controls as a Function of Exposure Duration and Field Intensity

Number of Subjects		Testicle	Exposure Duration	Intensity
RMF	Control	Increase	(in days)	(in gauss)
4	3	19%	1 - 22 *	3 - 15
8	4	9%	19 - 22	3 - 15
8	4	8%	1 - 22	0.5 - 3
4	4	-2%	1 - 22	sham

* birth

Other Physiological Measures. Mainprize (1973), in an unpublished thesis, reported that rats which had been exposed from two days before birth to eight days after birth to the RMF did not differ in their heart rates from controls. The ECG records had been taken while the 10 RMF-exposed one year old males and their 10 controls were under light Nembutal anesthesia. In addition, no significant differences in skull transcephalic potentials between 0.1 to 1.0 Hz were detected between groups. The later experiment had been conducted to determine possible power spectra changes in frequency output due to the 0.5 Hz RMF.

Morphological changes: endocrine tissue. In a long series of pilot and test histological experiments during 1973 in the laboratory of M.P., examinations of thyroid, testicle and pituitary tissue were initiated for rats of different ages that had been exposed from two days before to eight days after birth in the RMF. With routine staining and at intermediate magnification levels (∿ 100 X), no significant differences have been found in testicle tissue. Results from histological studies involving pituitary and thyroid tissue have not been completed at this time.

Morphological changes: brain. The marked increase in delay-interval responding in the Halasz procedure as a function of rats, suggested the involvement of a tissue which had a similar developmental sequence. Since rats that had received gamma (ionizing) radiation during the same neonatal period displayed similar behaviour in the Halasz procedure (Persinger, 1971a) and in addition showed the most massive destruction in the cerebellum, this tissue was selected for analysis. It was realized, of course, that other body tissue, including thyroid, were also developing during this period.

Measurements (Persinger, 1971a, unpublished dissertation) of width and lengths of cerebral and cerebellar hemispheres for 16 "high" and "low" intensity prenatal RMF-exposed rats, 16 "high" and "low" intensity neonatal RMF-exposed rats, and 16 controls, demonstrated no significant differences.

Histological analysis with cell body stains (cresyl violet and thionin) indicated no qualitative changes in Purkinje cell ordering or cortical layering between prenatal RMF-exposed, neonatal RMF-exposed or control rats. The kind of devastating damage produced by gamma radiation exposure during brain development, was never encountered. Perturbations in cerebral cortical layers in the parietal lobes were occasionally encountered, but were not systematic. Cell stains for 10 μ sections checked for every 100 μ of the brains of two prenatal RMF-exposed rats, two neonatal RMF-exposed rats and two control rats (all Ss, 100 days of age) did not indicate any gross disturbances.

Since the thyroid was implicated in the RMF effect, marked changes in cell bodies or numbers (with the exception of glial cells) would not be expected. Instead, changes in the degree of dendritic arborization would be anticipated, since these processes have been shown to be a direct consequence of thyroid hormone availability during neonatal-juvenile periods (Eayrs, 1968). However, results from a series of pilot experiments to test this hypothesis have not been consistent. Figure 4 compares representative brains from 30 day old rats that had been exposed to either the sham or RMF conditions between prenatal day 19 to neonatal day 8. A total of 3 RMF and 3 control litters were sampled. As can be seen, there is more Purkinje tree dendrite arborization in the RMF-exposed rat, relative to the sham-field animal. However, this relationship is not consistent across age. Subjects killed immediately after removal from the field (8 days of age) show less P-cell

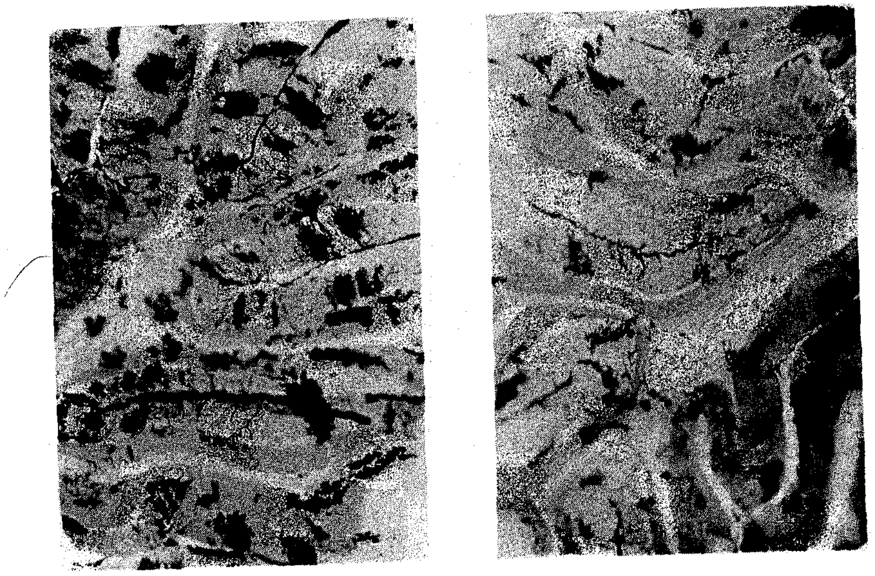

Figure 4. Modified Fox-Golgi zinc chromate stain for 20 μ medial saggital sections from cerebellums of 30-d rats that had been exposed to a 3 to 30 gauss, 0.5 Hz RMF (A) or to sham-field conditions (B). Exposures to experimental conditions occurred between two days before birth to eight days after birth (∿40 X).

dendrite growth, whereas the rats killed at 90 to 100 days old (subjects tested on Halasz procedure) showed no obvious differences from controls. That such results reflect a real oscillatory growth pattern following field removal, remains to be verified with more discrete age-interval sampling.

Many of the behaviours associated with RMF-exposure are similar to those reported for structural damage in other parts of the brain. Changes in aggressive behaviour, defecation, ambulation, serum lipid levels, and gonadal and thyroid weights have been reported following damage to the ventromedial hypothalamus (VMH). E. Nemett (unpublished data, 1973) counted the number of cells in 25 grid areas for 10 μ VMH sections from the brains of prenatal RMF-exposed, neonatal RMF-exposed and control groups. The results are presented in Table 3. The RMF-Neo groups had been exposed to the RMF during neonatal days 1-4 while the RMF-Pre groups had been exposed to the RMF during prenatal days 13-16. The RMF-Con group had been exposed to the control area while the Con-Extra group were subjects from another experiment and had been exposed to mild stress changes (handling and car transport) on neonatal day 4. As can be seen in Table 3, the differences between groups are marginal. In context of more recent data by Brownstein, et. al, (1974), these experiments will have to be re-evaluated. Brownstein and his colleagues found the greatest concentration of thyrotropin-releasing hormone in the *medial* portion of the VMH. Consequently cell averages over the entire VMH area would have masked any weak effect mediated by the RMF exposure, if it had existed.

TABLE 3

Means and Standard Deviations of Cell per Measurement Square in the Ventromedial Hypothalamus for Female Rats Exposed Prenatally or Neonatally to Different Conditions

	RMF-Neo	RMF-Pre	RMF-Con	Con-Extra
N	3	3	3	2
X	19.9	21.7	16.9	19.7
SD	3.2	2.6	0.5	1.4

Blood and biochemical measures. A number of biochemical measures have been taken on various RMF-exposed rats; most of the results have not been significant. Ossenkopp, Koltek and Persinger (1972) report that prenatally RMF-exposed rats did not differ from their controls in blood sugar or circulating bood eosinophil levels. Unpublished studies by Persinger and Lafrenière (1973-1974) also indicate that rats exposed from two days before to eight days after birth show no significant deviations in ascorbic acid in the adrenals, serum calcium or serum iron, when killed at 30 or 60 days old. Serum glutamate oxaloacetic transaminase (SGOT) levels were not consistent and involved a third, unidentified variable. In some studies with RMF litters between 30 to 60 days of age, the SGOT was significantly reduced relative to controls. In other studies these differences were not apparent.

Special Studies: Lunar Distance Correlations

Research during the 1960s indicate that ambient, naturally produced ELF waves and fields could confound the effects of experimentally produced fields (Persinger, Ludwig and Ossenkopp, 1973). One interesting and still unexplained correlation was reported by Persinger (1971b). Due to variability in the open field behaviour of prenatally RMF-exposed rats that could not be accounted for by normal environmental fluctuations, routine correlations were made with a number of geophysical and meteorological variables. Persinger noted that the juvenile open field behaviour of rats that had been prenatally exposed to the RMF but removed at birth significantly correlated with the *lunar distance* at birth. Other lunar and local weather variables did not contribute to the variability. When the open field data collected over a one year period for 19 RMF-exposed litters (n = 133) (from usual and blind testing conditions) were analyzed, a significant correlation of 0.88 was found between lunar distance at birth and open field ambulation for the RMF-exposed litters only. The twelve control and sham-field litters (n = 84) did not show a significant correlation (0.10). These studies were conducted at Knoxville, Tennessee between December 1967 to December, 1968; later replication studies in Winnipeg, Manitoba were not successful.

These data indicated interactions from environmental variables that were also correlated with lunar distance at that time. Interestingly, Ossenkopp and Ossenkopp (1973) and Lieber and Sherin (1972) have reported apogee perigee correlations with human behaviour, while Gauquelin and Gauquelin (1967) have noted that certain astrogeophysical correlations with human behaviour are potentiated during geomagnetic storm conditions at birth. Lunar distance correlations with human behaviour are interesting since, unlike lunar phase correlations, they are less likely to be confounded by placebo and expectancy effects.

JUVENILE AND ADULT RMF EXPOSURES

Behavioural Studies

Open field. In general, juvenile and adult male rats exposed for more than 21 days to the RMF displayed more ambulatory behaviour in the open field. Some experiments showed increased mean defecation for the RMF-exposed groups, but this effect was not consistent across experiments. Furthermore, female rats exposed as adults to the RMF did not demonstrate these effects. Graphic results of experiments between 1966 to 1971 have been published by Persinger, Persinger, Ossenkopp and Glavin (1972). The results of a more recent unpublished study by K-P. Ossenkopp and M. Ossenkopp (1973) are shown in Figure 5. It can be seen that the relative increase in ambulation noted in RMF-exposed males is primarily due to the decrease in ambulation displayed by the control males. These results are consistent with previous data (Persinger, Persinger, Ossenkopp and Glavin, 1972) and with normal habituation of ambulatory behaviour in the open fields used.

TABLE 4

Ratios of Mean Squares Traversed in Open Fields for RMF-Exposed Males to Control Males According to Age and Duration of Exposure

Experiment	Age	Exposure Duration	Number Ss (RMF/C)	Ratios (RMF/C)
1966	30	21 - 30	8/8	1.3
1967	160	21 - 30	7/8	1.8
1968	250	30 - 35	8/8	1.0
1969	100	30 - 35	6/6	1.7
1973	27	7 - 21	4/4	1.7

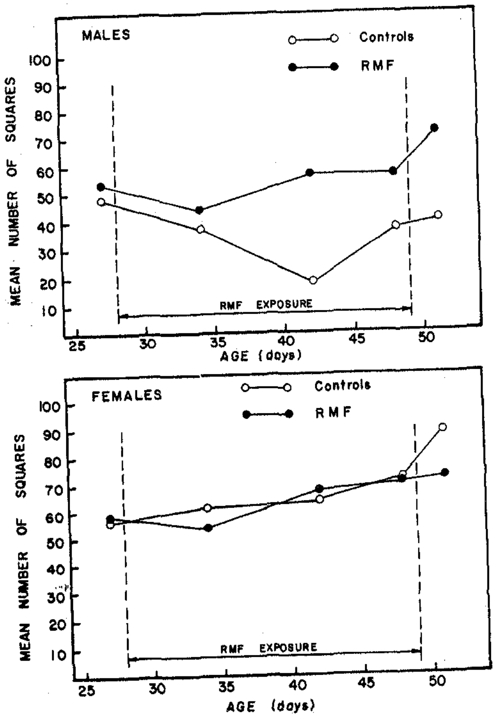

Figure 5. Mean number of squares traversed during 3 minute test periods in an open field for juvenile rats exposed to the RMF or control conditions. There were four male rats and five female rats per condition. Note that pre-exposure and post-exposure ambulation data were collected on these subjects (Ossenkopp and Ossenkopp, unpublished data).

The relative increase in ambulation displayed by RMF-exposed males has been consistent across experiments, as noted in Table 4. Results described in Table 4 were collected from experiments that used different RMF apparatus (still 0.5 Hz; 3 - 30 gauss) and open field apparatus. "Age" in Table 4 refers to age of subjects at the time of exposure. Except for the 1968 experiment, differences between male RMF-exposed and control rats were statistically significant ($p < .05$). No sham-field studies have been completed for this experimental series.

Two hypotheses can be evoked to explain the ambulation differences between RMF-exposed and control males:

1) the RMF-exposed rats are "more emotional" or
2) the RMF-exposed rats are "forgetting" previous open field tests.

The hypothesis that control males habituated to the open field stimuli, while the RMF-exposed rats did not because of some "memory" factor, was tested with simple learning paradigms.

Learning: Maze acquisition. A summary of the maze testing results is presented in Table 5. Only Experiments I and II resulted in statistically significant differences

between RMF and control subjects. It is apparent that the results were not consistent.

TABLE 5

Mean Number of Errors Before Y-maze Acquisition for RMF-Exposed and Control Males as a Function of Exposure Days and Age

Experiment	Age	Exposure Duration	Number Ss (RMF/C)	Mean Errors (RMF/Con)
I (1966)	21	234 - 291	8/7	12.0/6.6
II (1967a)	160	37 - 50	7/7	12.5/9.1
III (1967b)	120	26 - 50	9/8	10.2/9.9
IV (1967c)	100	30 - 50	8/8	11.6/9.5

Learning: DRL behaviour. Maze testing is subject to a great many extraneous and experimenter influences. As a result, interest in the possible effects of RMF exposure upon complex learning behaviour was rejuvinated in 1973 when more sophisticated operant techniques were available to the experimenters. In addition, research had indicated that memory consolidation undergoes a labile stage which may be mediated by slow potential or d.c. potential storage circuits (see Gaito, 1971; DeMott, 1970). Since the 0.5 Hz RMF was within these frequency ranges, investigation of the possible influences of RMF exposure on learning consolidation phases was considered a worthwhile endeavour. The DRL (differential reinforcement of low rate of responding) schedule was selected since:

1) it is a difficult task for the rat to maintain, and
2) it is sensitive to subtle environmental variables, e.g., carbon monoxide, etc.

Operationally, following a lever press for food reinforcement, the subject must postpone ("inhibit") responding for an experimentally selected duration. If the responding is not postponed, then reinforcement availability is delayed by the selected duration.

D. Swanson (unpublished thesis data, 1974) trained 80 day old male rats to respond to a DRL-6 second schedule for two days. In this situation, a subject had to inhibit responding for at least six seconds following the previous reinforced response or food availability was delayed another six seconds. Then, for three days, subjects were exposed to either RMF, control or sham-field conditions without DRL testing. Retesting began after the three exposure days. The results of Swanson's study can be seen in Figure 6. RMF exposure during "consolidation" periods for the DRL-6 second task was associated with a significantly greater deficit in DRL responding, as indicated by the increase in response/reinforcement ratios. However, the *age* of the animal was found to be a critical factor for the effect. In Swanson's experiments, the rats were only removed from the RMF during testing. Increased defecation rates were also noted for the RMF-exposed rats during testing following removal from field conditions.

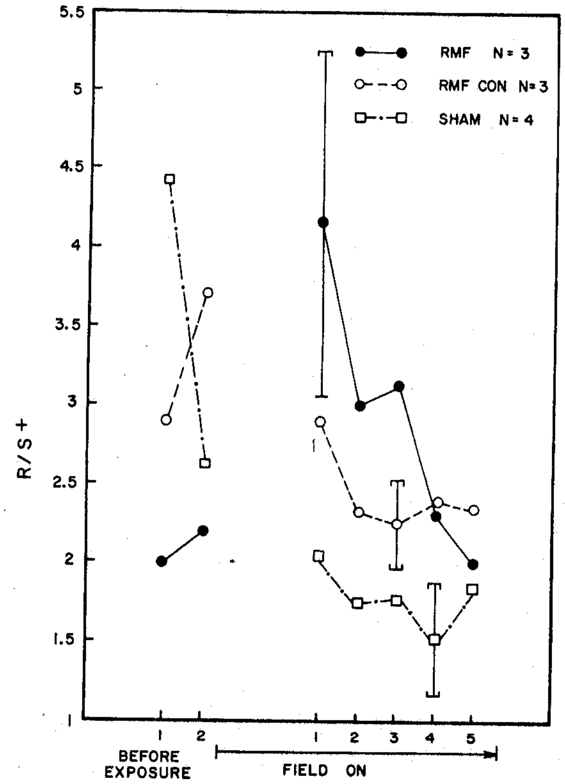

Figure 6. Efficiency ratios (total response/total reinforcements) displayed during a DRL- 6 second schedule by rats exposed to 0.5 Hz RMF high intensity (3 - 30 gauss), low intensity (0.8 - 1.0 gauss) and sham-field conditions following three days of no testing after training. All animals were kept in the experimental conditions except during testing in the operant chamber. Sample standard deviation brackets are given (D. Swanson, unpublished data).

A single organism design was used to test the effects of repeated RMF exposure/no exposure conditions upon well-learned DRL schedules. Whereas RMF application during learning may influence behaviour, once the task has been acquired and consolidated, different brain mechanisms would be involved for maintaining DRL behaviour. Four rats were trained over two months to obtain a smooth baseline of response/reinforcement ratios in a DRL- 12 second situation.

When the subjects were not being tested in the chamber (30 minutes per day), they were stored in the experimental area. During a period of 60 days, the RMF was initiated and removed three successive times. (When the condition was altered, the subject was exposed to the new condition for at least 22 hours before the next test session.) During the no field condition the magnets were removed but the motors were left running. Two of the subjects were exposed to the RMF (0.8 to 3 gauss), while the other two subjects were exposed to control conditions. Only one of the RMF rats showed any consistent changes in responding as can be seen in Figure 7.

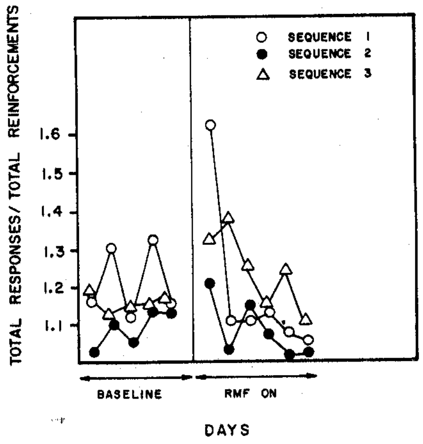

Figure 7. Efficiency ratios (R/S^+) for an adult rat daily tested on a DRL-12 second schedule (30 min. daily sessions) during various baseline (sham-field) and RMF (0.8 to 3.0 gauss) exposures. During testing in the operant chamber, the subject was removed from the exposure area. Two control/sham-field control condition rats and another sham-field/RMF condition rat did not display comparable results (Persinger, unpublished data, 1973).

Three different field presentations were associated with increased response/reinforcement ratios with consequent returns to baseline.

Aggressive behaviour. One impressive feature of long-term food deprivation schedules during RMF exposures was the increased intragroup aggression. Such aggression was not found in control rats. In one experiment, which lasted more than a year (June 1966-67), eight male rats housed together while exposed to the RMF began to display intragroup aggressive responses after 140 days of exposure. The aggression had become so noticeable that by exposure day 300, direct measurements were recorded. When food was placed for 12 minutes (one session) into the RMF-exposed group, significantly more attacks were exhibited than by the eight controls. An attack was defined by the presence of blood and loss of hair following a sustained, highly vocal interaction between two rats. The number of attacks displayed by each group is shown in Table 6. Two replication experiments with shorter durations of exposure (30 days) were not successful. Sham-field experiments were not conducted.

TABLE 6

Number of Within-Group Attacks for Eight Group Housed RMF-Exposed Male Rats and Eight Group Housed Control Rats

Session	RMF Group	Control Group
1	7	0
2	4	0
3	4	0
4	4	0
5	4	0

Physiological, Morphological and Biochemical Results

Weight changes. A variety of published (e.g., Persinger, Glavin and Ossenkopp, 1972) and unpublished experiments have reported significant weight changes in rats exposed to 0.5 Hz RMFs. However, the direction of the change is determined by at least three factors which include:

1) sex of the animal,
2) age of the animal, and
3) duration of exposure.

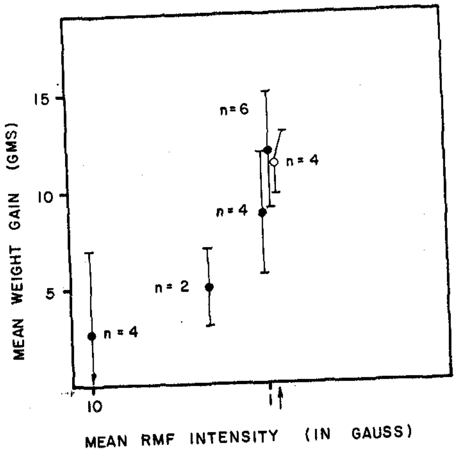

Figure 8. Mean weight gains for female rats exposed for 10 days to various RMF intensities, control areas and sham-field conditions. Only the difference between the 10 gauss group and sham-field group is statistically significant. Note that increased standard deviations are a function of field intensity (Persinger and Lafrenière, unpublished data, 1974).

Older male animals (> 160 days) lost 5% to 17% of their initial weights after 20 days of field exposure. Some younger male rats (100 to 150 days old) showed significant weight gains until after 10 days of RMF exposure. Despite the variability, weight changes for a particular age-exposure time-sex condition have been shown to be dose dependent. In Figure 8, the mean weight gain from pre-experimental weights for female rats exposed to various field intensities or the sham-field condition after 10 exposure days are shown. The more intense field values are associated with the least weight gains (and even weight loss).

Water and food consumption. Increases in water consumption by rats exposed to various 0.5 Hz RMF apparatus have been reported. However, this effect is also age/exposure duration dependent. A number of experiments which used male rats that were 27, 80, 90 or 100 days at the beginning of RMF exposure did not show significant water consumption increases. Other experiments, which used male rats that were 120 days or older showed significant 13 - 30% increases in water consumption by RMF rats housed in groups of eight or as pairs, relative to controls.

The general pattern from these experiments also indicates a time-dependence for the maximum effect to develop. Data published by Persinger, Glavin and Ossenkopp (1972) demonstrate peak water consumption by adult RMF-exposed rats after four days and around 10 to 12 days of RMF exposure. Following these peaks a gradual decrease in RMF/control group differences are noted. In two experiments, one of which lasted more than a year, RMF-exposed rats drank 13% more water than controls. No sham-field experiments were conducted in any of these studies.

Systematic studies of food consumption have not been completed. Both published and unpublished results do indicate decrements in food consumption after 20- to 30 days of field exposure. Such decreases in food consumption are reflected in concomitant weight losses.

Longevity-Disease. Animals which were exposed to the RMF at an earlier age (before 60 days in our studies) have survived quite adequately in the RMF for more than a year. Adult rats exposed to the RMF have been known to develop respiratory infections relative to control subjects, especially in experiments where subjects were housed in group conditions.

Tissue weight changes. An experiment by Persinger, Glavin and Ossenkopp (1972) showed that significant changes in thyroid weight can occur between RMF-exposed and control adult male rats. Again, the relationships between this tissue weight change and RMF exposure are not clear and involve age-sex characteristics of the subjects at the time of exposure. Considering the hypothesis by Ludwig and Mecke (1968), the antecedent autonomic conditioning or experience of the organism may also be a critical variable.

The initial studies by Persinger, Glavin and Ossenkopp (1972) were unsatisfactory since sham-field controls were not tested. Recently 180 day old female rats were exposed to either RMF, control or sham-field conditions (a total of 4 rats per group) over three separate experimental episodes for 10 days. No statistically significant differences were found among the three groups for adrenal weights, spleen weights, pituitary weights, thymus weights or thymus nodule weights. With regard to thyroid weights, the RMF-exposed control and sham-field rats averaged 73.0 ± 5 ug/g, 57.5 ± 4 ug/g and 56.8 ± 3 ug/g, respectively. These differences were statistically significant ($F = 5.50$; $p < .05$) and reflected a significant 23% reduction of follicle numbers for the RMF-exposed rats relative to controls and sham-field subjects. Reduction in follicle numbers was confirmed histologically and measured by a technician using a Baush and Lomb Tri-Simplex projector (with an accuracy of 5 μ^2 in tissue surface area). Sample thyroids are presented in Figure 9.

Biochemical changes. Short-term exposures to 0.5 Hz RMFs did not significantly alter a number of different blood measures. In a series of unpublished experiments, Persinger, Mainprize and Lafrenière exposed 80 retired breeder male rats (about one year old) for four hours to either RMF or sham-field conditions. Following death by decapitation, measures were taken on:

1) serum iron,
2) serum calcium,
3) oxyhemoglobin,
4) serum glutamate oxaloacetic transaminase,
5) serum creatinine,
6) ascorbic acid levels in the adrenals, and
7) eosinophil levels.

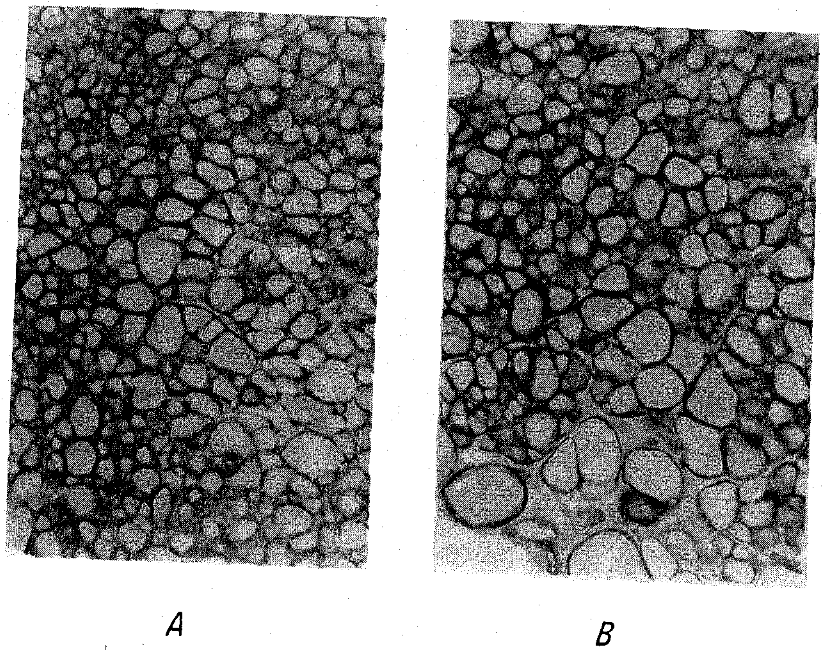

Figure 9. Sample thyroids from adult female rats which had been exposed for 10 days to either (A) sham-field or (B) RMF conditions (H & E, 8 μ, $\sim$40 X).

With the exception of a marginal but statistically significant ($p < .05$) increase (5-6%) in oxyhemoglobin in the RMF exposed rats, there were no significant differences between RMF-exposed and sham-exposed rats after four hours. Serum iron, serum calcium and oxyhemoglobin were not significantly altered, relative to sham-field rats following 8 hours of exposure.

Persinger, Glavin and Ossenkopp (1972) reported that exposure durations of between 10 to 21 days are associated with relative eosinopenia in the RMF-exposed males. After 10 days of exposure, RMF-exposed rats averaged 30% less circulating blood eosinophils than controls while after 21 days a different RMF-exposed group showed 60% less circulating blood eosinophil levels, relative to controls. These differences were not statistically significant.

However, RMF-associated eosinopenia could account for the increased respiratory infections noted with some RMF studies, by modifying the animals disease susceptibility. Blood sugar levels did not seem to vary as a function of RMF exposure. More recent data (M.P. and G.L.) from RMF, control and sham-field experiments employing 6 month old females, demonstrated no statistically significant differences between groups after 10 days of exposure for serum calcium levels or SGOT levels. However, highly statistically significant *increases* in total serum lipid levels for RMF-exposed female rats have been measured on three successive experiments. These results will be reported later once dose and exposure-time curves have been established. Significant increases of adrenal ascorbic acid content in the adrenals have been found in some RMF-exposed groups, but the results have not been consistent across experiments.

Special Studies: "Heart Driving"

The most intense ELF electromagnetic generator in the body, with the exception of the brain, is the heart. This electrically pulsating system, emerged in a complex and sensitively balanced ion milieu, also demonstrates a rotating magnetic dipole component. Since the measurement of this response system is simple (the ECG), a series of experiments were initiated to attempt to influence the heart by RMF-exposure.

Preliminary experiments. During 1972, a number of parameters were manipulated in an attempt to detect possible cardiac changes from RMF-exposure (M.P.). One sample experiment is presented in Figure 10. Following light Nembutal anesthesia, retired breeder rats were exposed to the RMF while ECG records were taken continuously. It was assumed that strong vagal control systems would compensate for any weak RMF effect that might be produced. Consequently, attempts were made to attenuate vagal control with atropine sulfate injections. Theoretically, the RMF would then be able to "drive" the heart system. As noted in Figure 10, no evidence of such a relationship was found. When the RMF was removed no significant alterations in heart rate were observed.

Possible heart driving. Persinger (1973) found that possible driving did take place if the frequency of the

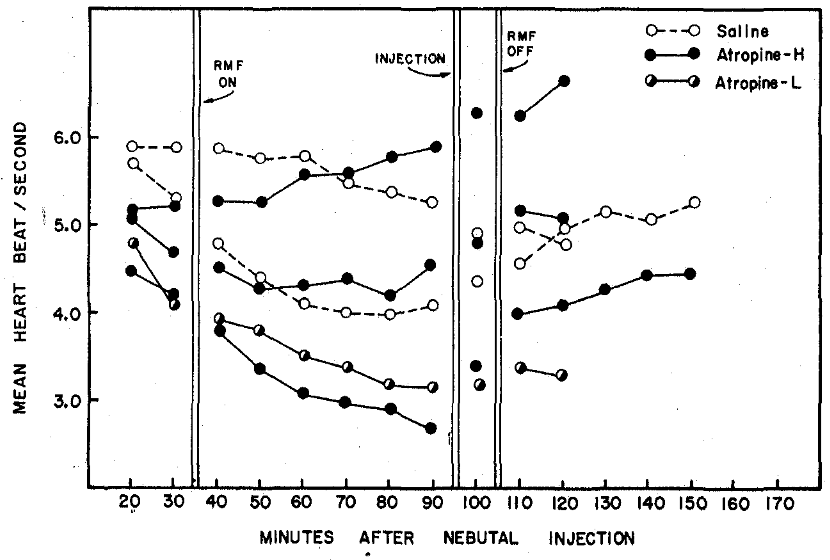

Figure 10. Mean heart rate (QRS/sec) for rats given saline or atropine (0.16 mg/kg or 0.08 mg/kg), during RMF field exposure and after field removal.

heart system was reduced to the RMF frequency range. He had assumed that:

1) if any RMF effect were to be evident, cardiofrequency must approach the RMF frequency;
2) the decreasing heart frequency must slowly approach the RMF frequency range; and
3) the heart must be in a failure sequence before a weak zeitgeber could be effective.

Male rats were given repeated doses of Nembutal over a four hour period. It was found that rats exposed to the 0.5 Hz RMF displayed cardiofrequencies within the RMF frequency range significantly longer than rats exposed to control (0.8 gauss) or sham-field conditions. Sample results are presented in Figure 11.

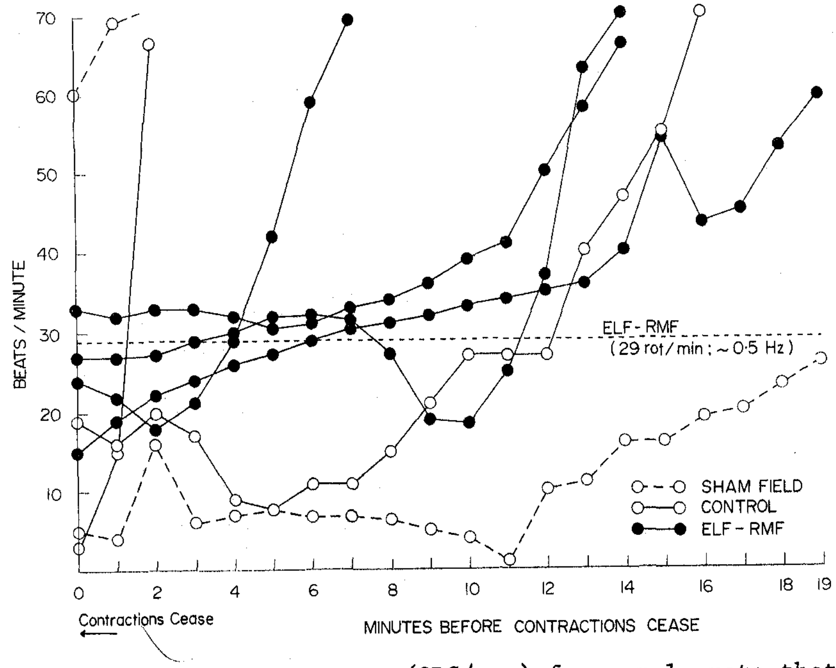

Figure 11. Mean heart rate (QRS/sec) for sample rats that gradually received overdoses of barbituate over a 4 hour period while exposed to RMF, control or sham-field conditions (Persinger, 1973).

PERINATAL EXPOSURE AND ADULT RE-EXPOSURE EXPERIMENTS

When the young organism is born, a number of electromagnetic and chemical processes are initiated or changed and may then be influenced by the birth environment. Our previous experiments suggested that exposure to a RMF during the perinatal period (around birth) was associated with long term effects. Does this suggest that the newborn organism is "electromagnetically plastic" and can be permanently influenced by its ambient electromagnetic environment? Secondly, if the perinatal RMF-exposed rat is returned to the field conditions as an adult, will the RMF effects be attenuated? In other words, would the RMF-exposed rat only display "normal" patterns when it is returned to the condition in which it was born?

In two separate experiments, Lafrenière and Persinger (unpublished manuscript, 1974) exposed rats to the RMF from two days before birth to eight days after birth. Other litters were exposed to control conditions. When the male rats were one year old, half of the RMF-exposed rats were returned to the RMF for 10 days while the other half were exposed to control conditions. Similarly, half of the male rats that had been exposed to control conditions perinatally, were re-exposed to the control condition while the other half was placed in the RMF. The amount of body weight change during exposure to the experimental conditions is presented in Table 7. It can be seen that the perinatal control rats (PC-AM) lost weight when exposed to the RMF as adults, an effect which had been noticed before with old rats. However, when the perinatal RMF-exposed rats were re-exposed to the RMF as adults (PM-AM), the mean weight gain was similar to the ("normal") perinatal controls that had been re-exposed to the control conditions as adults (PC-AC).

TABLE 7

Percent of Total Weight Change Relative to Pre-Experiment Weights After Ten Exposure Days for Groups that Had Been Exposed Perinatally to the Control Area and Re-Exposed as Adults to the Control Area (PC-AC) or the RMF area (PC-AM) or Exposed to the RMF Perinatally and Re-Exposed as Adults to the RMF (PM-AM) or to Control Conditions (PM-AM)

	PC-AM	PM-AM	PC-AC	PM-AC
N	4	4	4	4
X	-0.63	1.60	1.54	2.24
SD	0.80	1.00	0.61	0.80

These data suggested to us that perhaps re-exposure to the RMF attenuated the earlier effects. Consequently we re-analyzed some unpublished data that had been collected a few years before during which time prenatal-neonatal RMF-exposed rats were used for adult exposures. The results are presented in Table 8. Perinatal control rats exposed to the RMF as adults and tested in the open field demonstrated greater ambulation (noted in other studies) while perinatal RMF-exposed rats placed in adult control situations, traversed less squares (again an effect replicated many times). But note, when the perinatal RMF-exposed rats were re-exposed to the RMF as adults, their open field behaviour became similar to the perinatal control-adult control group.

Similar trends have been noted in testicle weights, and total lipid levels in the serum. Comparable data have been shown with thyroid follicle numbers per unit area, following 10 days of exposure to experimental conditions. Mean follicle numbers per mm^2 of 6 μ sections of thyroid tissue for five adult RMF-exposed and four control female rats were 18.0 ± 0.9 and 24.1 ± 0.9, respectively. Three perinatal RMF-exposed female rats that were re-exposed to the RMF showed a mean follicle count of $26.7 + 1.4/mm^2$.

TABLE 8

Mean Squares Traversed During 60 Seconds in an Open Field

	PC-AM	PM-AM	PC-AC	PM-AC
N	4	5	4	5
X	23.3	16.8	17.3	9.8
SD	3.2	6.7	2.2	7.1
(F = 4.47; p < .05)				

DISCUSSION

The main results from studies involving 0.5 Hz, 0.5 to 30 gauss rotating magnetic fields are that field-associated changes take place in emotional behaviours and some aspect of thyroid function. Whether these changes reflect direct thyroidal influence or merely induced changes because of the thyroid's inclusion in a circuit which is affected, has not been demonstrated. Moreover, the observed effects are not immediate (in normal animals) and may require several days of chronic exposure to develop.

In many ways it is unfortunate that the RMF effects seem to be primarily within diffuse systems such as the autonomic and thyroidal response networks. However, considering there is no known specific sensor for such a magnetic stimulus anyway, a non-specific response may indeed be involved. This feature makes the isolation of the mechanisms very difficult and will require a greater number of more precise experiments with detailed manipulations. However, a few general statements can be made about the results to date.

Behavioural Effects

The emotional-thyroid component of the RMF exposure effects was most evident in rats that had been exposed prenatally to the experimental conditions. After a series of different tests, it became apparent that stimulus operations which most specifically tested for emotional components were the most differentiating measures. Evidence from the adult exposures have been less apparent, in part because of the different measurements and experimental orientations employed. No experiments were completed with conditioned suppression or similar tests in the adult exposure series. However, the increased ambulation, aggressive behaviours, defecation and poorer performance in inhibition-learning situations may reflect strong emotional components. For example, the poorer DRL behaviour of adult rats exposed to the RMF may merely reflect increases in operant chamber activity that would compete with inhibitory response chains.

Physiological Results

The various behavioural changes noted during or following

RMF exposures have been correlated with thyroid activity changes. Whether the RMF directly influenced the thyroid or whether it acted upon some indirect mechanism - through the hypophysis, ventromedial hypothalamus or a more peripheral circuit - is yet to be answered. From a thyroid perspective, the results reported in this chapter would be expected. Unfortunately, taking a reference point (e.g., the thyroid) in any complex system which is based upon a large number of complicated feedback loops and interactions, often gives undue and exaggerated importance to the reference point. These limitations are recognized.

Changes in water and food consumption displayed by adult rats exposed to the RMF often occur with mild thyroid activation. Hyperexcitability and increased defecation have also been thyroid-linked. Tudhope (1969) has reported a number of interesting relationships between thyroid and blood which are relevant to the present studies. Changes in oxyhemoglobin, fluctuations in eosinophil counts, hyperplasia of thymus nodes and edemic contributions to gonadal weights, have been associated with thyroid dysfunction. The direction of the changes depends upon a variety of unspecified variables.

More specifically, a hypothyroid-like condition (for rats) may have been responsible for decrements of activity and increases in emotional behaviours displayed by the perinatal RMF-exposed rats. Such an initial hypothyroid condition during critical stages of neurodevelopment could have produced permanent effects. For example, migration of granule cells from their proliferative matrix (external granular layer) can be retarded by a hypothyroid condition. Interference with granule cell migrations during the critical post-natal period, produces permanent modifications in the number of granule cell glomeruli which receive the afferent information relayed to the Purkinje cells. Consequently the animals' capacity to adjust to changes in cerebellar input would be less, and greater responding during suddenly changed reinforcement schedules (e.g., the Halasz procedure) could result.

The relationship between thyroid-related changes and behaviour for RMF-exposed rats is not unique. In fact, the Maudsley Reactive Strain (Feuer and Broadhurst, 1962) which was specifically bred for high defecation over generations, demonstrated less activity in the open field, greater conditioning in aversive paradigms, heavier thyroid weights and biochemical decrements typical of hypothyroid conditions.

Comparisons to Other Studies

Comparisons with other experiments which utilized different field parameters must be made with considerable reservation. If our basic assumptions are correct, even small deviations in field frequency, intensity and configuration, (Persinger, 1974) may alter the response pattern of the organism. Such differences can be exemplified by the reports of Lazar and Barca (1969). Whereas a small intensity, pulsating magnetic field decreased sodium and increased potassium in the variety of tissues measured, a homogenous field of similar intensity had an opposite effect on these two cations.

Behavioural studies. Few experimenters have tested behavioural changes following or during exposure to field parameters used in our studies. Short-term and signal detection studies (see deLorge and Marr's chapter) have not been successful. Ambulation changes in rodents have been reported by Ludwig and Mecke (1968) when ELF electromagnetic fields from coils were used. Unpublished studies by LaForge (Persinger, Ludwig, Ossenkopp, 1973) have indicated that rats exposed to 0.2 Hz magnetic fields between bar press acquisition sessions displayed fewer responses.

Physiological studies. Rabbits exposed to rectangular electromagnetic fields with one second pulses after three seconds of excitation for 10 consecutive days (3 minutes per day) have shown increased leukocyte counts (Jitariu, Schneller-Pavelescu and Chera, 1971). The effects were exposure time dependent as indicated by the 12.2% and 21.9% increase after 5 and 10 exposure days, respectively. Magnetic fields at 50 Hz (200 Oe), 50 to 100 Hz (80 to 100 gauss) or .03 Hz (500 to 700 gauss) 15 minutes daily have been reported to stimulate immunogenic functions (Stavar, Stoenescu and Theodorescu, 1970; Boginich, 1971) or reduce tumor sizes (Ukolova and Kvakina, 1970) in rats.

Whereas ATP increases and ADP decreases after five days but returns to baseline after 10 days in red blood cells of rabbits following 1 to 3 second pulsatile excitations (Porumb, 1971), glucose-6-phosphate increases activity after 5 or 10 days of exposure and may remain at increased activity levels for 20 days after treatment (Porumb, 1971). Correspondingly, liver glycogen increased after 10 days of treatment while muscle glycogen decreased (Hefco, Hefco, and Badilita, 1969). Neaga, Lazar and Bazgan (1971) found that a 300 Oe pulsatile field increased ascorbic acid in the adrenals. Evtushenko, Kolodub and Frenkel (1970), using 1.5 hr/day exposure periods over 3 months with a 300 Oe pulsatile field (every 10 seconds), noted marked changes in carbohydrate-energy and nucleic acid metabolism. Collectively these apparently unrelated findings are compatible with changes in the hexose monophosphate (pentose) shunt pathways, and will be discussed.

Other morphological studies concerned with prenatal effects from exposure to field parameters similar to the ones used in our studies have not been reported for rats. Neaga and Ababii (1970) found that chicks exposed from 1 to 10 days of development to a 300 Oe pulsatile field showed decrements in SGOT activity which were significant up to 45 days of age. Similar but less consistent results were found in the perinatally exposed rats. Later Neaga and Lazar (1972) reported that embryo and young chicks exposed to the same field displayed increased thyroid follicle numbers and reductions in follicular diameters. Relationships between thyroid and SGOT activity are known for other subject populations as well.

Complicating Features

Transient oscillating adjustments. It has become quite clear in recent years that many systems do not maintain steady-state or unidirectional response patterns to changes in input conditions. Instead, depending upon the space-time shape of the stimulus change, the consequent response pattern of the system varies as it adjusts to the new demand. Step-like changes which are simulated when the animal is suddenly exposed and maintained for a long length of time to a new (magnetic field) condition, are associated with typical over- and under-adjustments (oscillations) to the new demand (magnetic field). The time that the measurement is taken after the step has been instituted will influence the apparent direction of the effect, e.g., the magnetic field group being greater, less than or equal to the control group. Furthermore, as each (rat) system responds differentially according to its own adjustments to the new demand, a greater variability (or standard deviation) of the measures will be reflected in the magnetic field exposed group. Several of the results reported in this chapter indicate that some type of oscillatory adjustment occurred following the sudden and maintained exposure to or removal from the RMF. Possible examples of such phenomena were noted with body weight changes and alterations in Purkinje cell growth.

Those studies which did not employ step-like field exposures, but were more of an impulse-like pattern (e.g., magnetic field pulses delivered 3 minutes per day), would not necessarily upset the homeostasis of the system, but only result in mild stimulation, (e.g., increased eosinophils). Maintained field applications, after initial stimulation, might produce opposite effects (e.g., increased tumor growth; Ukolova and Kvakina, 1970).

Sex, age and autonomic stability. Other potent factors which influence thyroid-related systems must be considered before the field is added. If adult field exposures stimulate thyroid activity, then an active thyroid (e.g., a young animal), already operating near asymptotic levels, would be less likely to respond to such a relatively mild stimulus. If a response did occur, it would be masked by the background activity. Sex differences would involve similar principles.

Autonomic stability before field exposure would determine the subject's response pattern as well. If the system is already unstable (the rat is adjusting to some other demand), then response to the RMF would be minimal. These factors are important and should be considered seriously in magnetic field research.

Mechanisms

A more detailed account of possible ELF electromagnetic field mechanisms at various levels of organismic investigation have been discussed elsewhere (Persinger, Ludwig and Ossenkopp, 1973; Persinger, 1974). However, a few points can be made which are relevant to this chapter and to present research plans.

Thyroid and the pentose shunt. In addition to the known intricate relationship between thyroid function and hexose-monophosphate (pentose) shunt pathways, this chemical system is important because it is:

1) a principal route for producing NADPH,
2) essential for the synthesis of nucleic acids, NAD and other electron carriers, and
3) a controlling key of lipid synthesis (Edwards and Hassall, 1971).

More particularly, NADPH must be available for the operation of certain microsomal electron transport systems whose principal role is to bring about oxidative changes in lipophilic molecules. One such microsomal system exists in the adrenal cortex and aids in the metabolism of steroids known to possess hormonal functions. From an immunological standpoint, these microsomal enzyme complexes can attack exogenous lipophilic substances which could be harmful if accumulation within the cell was allowed. It is known that hyperthyroid conditions often stimulate these pentose shunt processes while hypothyroid conditions may suppress the activity (Tudhope, 1969).

ELF magnetic field exposures have been reported to affect glucose-6-phosphate activity. Concomitant changes in carbohydrate and nucleic acid metabolism have also been mentioned. Whereas glycogen decreases in the muscle after 10 days of ELF magnetic field exposure, increased activity occurs in the liver. Such changes would be commensurate with the observation that a significant amount (20%) of carbohydrate oxidation in the liver occurs via the pentose-phosphate shunt pathway.

The reported changes in oxygen consumption during magnetic field exposure would be another corresponding feature of pentose shunt modifications. NADPH, an important component to the oxygen carrier system of the adult erythrocyte, is provided primarily by the oxidative reactions of the hexose monophosphate shunt pathway. Hyperthyroidism is known to increase the pathway's activity in the erythrocyte and increase carbonic anhydrase activity. This latter observation is interesting in context of the reports of hyperplastic reactions in glial cells during magnetic field exposure. Such reactions may only reflect the exceptionally high levels of carbonic anhydrase in these cells (Friede, 1966) and their correlative functions. However, it should not be forgotten that glial cells also demonstrate an exceptional pentose shunt activity.

Stimulation of the pentose shunt enzymes is known to increase lipid synthesis; increased serum lipid levels have been reported following ELF magnetic field exposures. (It is relevant that heart cells in vitro lose their pulsative, time-varying properties when lipids are removed from serum, s.f.e. Masoro, 1968, p. 261). One could also argue that the known effects of this pathway upon sex-related steroids contributes to the observed testicular changes. Hyperthyroidism and increased pentose shunt activities have been known to influence leukocytes--an effect which may be due to the ability for related microsomal systems to destroy foreign lipophilic substances. Consequently, facilitation of immunological responses during initial exposures or greater susceptibility to disease after maintained exposure could result.

On the other hand, hypothyroidism during development can markedly retard the activity of the pentose shunt enzymes in both the cerebellum and cerebrum (Schwark, Singhal and Ling, 1972). Corresponding alterations in nucleic acids and lipid metabolism also occur. However, like dendritic patterns, compensation for these hypothyroid-induced decrements can occur if thyroid hormone is returned (or stimulated) within a critical period.

Direct mechanisms of mediation. Since the magnetic field is essentially an electromagnetic stimulus, one would assume that the mechanism of interaction occurs at this level. Changes at other measurement and discourse levels merely reflect connections to this central process. Our initial hypothesis was that the ELF magnetic fields would influence electrical (neuronal) systems with similar signal patterns and frequency characteristics. The vagus nerve has been a prime candidate. In fact some theorists, as reviewed by Persinger, Ludwig and Ossenkopp (1973) suggest that ELF mediation occurs via vagotonic systems while VLF effects utilize sympathotonic systems.

On a behavioural level, vagal integrity is required for "fear" conditioning to take place (Slaughter and Hahn, 1974). Thyrotoxicosis in rabbits is accompanied by a decrease in spontaneous activity of the vagus nerve as well as disturbances in conduction (Gol'ber, Kandror and Shakhnarovich, 1970). Vagal contributions to heart and associated life support systems is well documented. Important patterns for vagal influence on the thyroid and enzyme systems has been reported by Leak (1970). Apparently, in vitro parasympathetic stimulation of thyroid slices increased glucose catabolism, through the hexose-monophosphate shunt.

Alternative mechanisms of RMF-vagal mediation are more closely connected with the vagal system itself. Pentose shunt enzymes show *exceptional* activity in the dorsal nucleus of the vagus (in the brainstem) as well as the paraventricular and supraoptic nucleus in the hypothalamus (Friede, 1966, p. 74). Stimulation of the latter two nuclei are known to produce thyroid changes and modifications in water consumption and emotional behaviour.

The crucial problem associated with ELF magnetic field effects is the extremely low magnitudes of forces produced within the organism. Induced current associated with the ELF field could be the mechanism, but the magnitudes would be very small. However, recent work by Becker (e.g., 1972) has led to a new concept for many areas of medicine and environmental psychophysiology. Becker reports that tissue seems to be sensitive to a small current intensity range between 1 and 3 mμ amps (10^{-9} amps). Currents above or below these values may be ineffective or destructive.

The current induced by the 0.5 Hz rotating magnetic field can be calculated according to:

$$I = \frac{B_o \, \omega\sigma \, H \, R^2}{4} \cos \omega t,$$

where $B_o = 10$ gauss $= 10 \times 10^{-4}$ Webers/m^2, $\omega = 2\pi \times \frac{1}{2}$ sec^{-1}, $\sigma = 1/\rho$, H = thickness of sample (10^{-1}m) and R = radius of the sample (10^{-1}m).

Assuming ρ (resistivity) to be 10 ohm-meters, then $I \simeq 8 \times 10^{-8}$ amps. At a field intensity of $\simeq 1$ gauss, $I \simeq 8 \times 10^{-9}$ amps. If Becker is correct, then those fields which induce the optimal currents would be most effective. Higher intensity fields would be effective merely because a small portion of the time-varying component overlaps with those optimal levels. Now it remains to identify which molecular species would be most affected by the induced currents and to locate the distribution of these molecules in the various behavioural-correlated structures of the organism.

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OXYGEN AND BIOCHEMICAL CHANGES FOLLOWING ELF EXPOSURE

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Schumann's (1954) measurements and calculations of atmospheric electric waves in the region of extremely long waves of 0 - 25 Hz, permitted speculation that these regularly appearing impulse cascades associated with certain weather conditions, could have an effect on the performance of organisms. The earth's electrostatic and magnetostatic fields can have as a boundary condition to the wave oscillations, a frequency of "zero". The effects of ELF on organisms was found in experiments involving physiological reactions of experimental animals such as in tissue, when the measurements deviated significantly from normal values. Many times it was observed that in a series of measurements lasting for several weeks and involving the same subjects, that erratic patterns appeared which could not be explained by known factors. The experimental methods used in the first findings of a physiological effect of ELF were not appropriate for an exact determination of these erratic phenomena. Lotmar and Hafelin (1956) compared the results of their study concerning the migration of sulfate ions across rabbit skin with the results of charts indicating the passage of meteorological fronts. They found that on days with stable weather conditions and on those with influxes of cold air, a minimum permeability and on the other hand during occlusion conditions, a high permeability to the ions. These results were found to be statistically significant. Reiter (1960) in an earlier study had found correlations between weather based complaints, birth and mortality frequencies, traffic accident frequencies, as well as changes in reaction times, and the appearance of meteorologically determined electromagnetic impulses in the atmosphere. In the same manner he found changes in tissue pH in guinea pigs.

Damaschke and Becker (1964) likewise found a statistically significant correlation between oxygen consumption of termites and atmospherics (Fig. 1). Increases in respiration usually occurred when atmospherics displayed a minimal value and vice versa. Even under laboratory conditions with artificial fluctuating electric fields, similar results were obtained. Specific effects of individual impulse types could not be established. In a similar manner Lotmar and Ranscht-Froemsdorff (1968) found a correlation between tissue respiration (rabbit tissue) and atmospherics. The respiration rates of 1,100 samples of rabbit tissue were measured over a period of 147 experimental days in a Warburg apparatus and were compared to the measured weather conditions. The in vitro respiration was clearly elevated during stable weather conditions and lowered during labile weather conditions. The authors point out that under these experimental conditions atmospheric impulse waves could be the only effective biotrophic factor since the other meteorotrophic factors were held constant. In further studies, Lotmar, Ranscht-Froemsdorff and Weise (1968) exposed

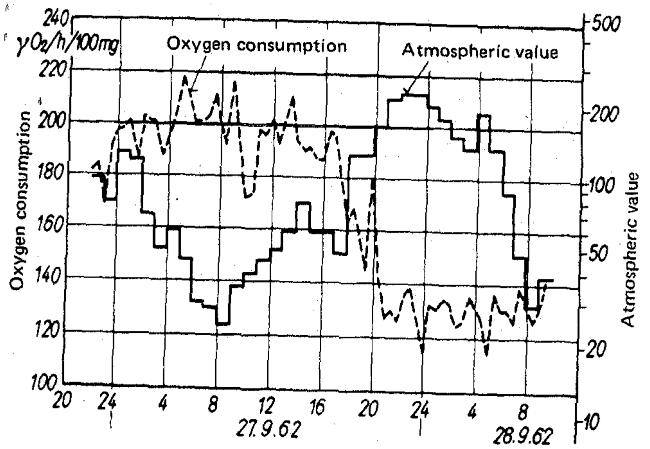

Figure 1. O_2-utilization of Zootermopsis nevadensis Hagen (workers) at 26°C and simultaneous atmospheric-values (K. Damaschke, U.G. Becker, 1964).

preparations of white mouse liver tissue to simulated electro-low bad weather conditions and electro-high good weather conditions. Concomitantly, a Faraday cage shielded out natural atmospheric impulse waves and the earth's magnetic field was compensated for by means of Helmholtz coils. A 42% decrease in the mean oxygen consumption of the liver tissue during artificial electro-low conditions, was demonstrated. An effect of impulse waves simulating good weather conditions could not be demonstrated. The exposure programs used were extensive imitations of the natural conditions. The bad weather-broad band impulse program consisted of a carrier frequency of 10 - 100 kHz and an impulse frequency of 30 - 100 Hz with a field intensity of over 100 mV/m. Good weather conditions were simulated by means of narrow-band impulses (carrier frequency -10 kHz, 3 - 10 impulses sec^{-1}, field intensity of 10 mV/m). These results constituted further evidence that natural electromagnetic fields could influence cell respiration. It was still necessary to clarify if the demonstrated damping effect occurred because of a direct effect on the respiration-enzyme system or if the effect occurred via other processes.

Subsequent to demonstrations by Altmann (1959, 1962, 1968, 1969) of a potentiating effect of static electric fields and low frequency impulse waves on the water economy and oxygen consumption of honeybees (control animals were kept under shielded conditions), comparative experiments dealing with oxygen consumption and protein metabolism in typical representatives of the most important classes of animals, were planned. Experiments investigating metabolism in various classes of animals found an increase in oxygen consumption in animals under static electric field conditions in contrast to totally shielded (Faraday cage) conditions. Measurements were done on insects, fish, frogs, birds and mammals (Altmann, 1969), (Fig. 2). Field intensities were 210 V/0.5m. These long duration metabolism measurements were compared to results of animals kept under the same conditions in a Faraday cage. The static field clearly elevated metabolism. The experimental results in the figure are the mean values of individual subjects (A-E). The same number of tests were done on the same animals after a reversal in conditions took place. Now animals previously in the Faraday cage were exposed to experimental conditions and experimental subjects were put in the Faraday cage (A-E). Similar results were obtained in both series of tests. Measurements of metabolism rates in mammals are made more

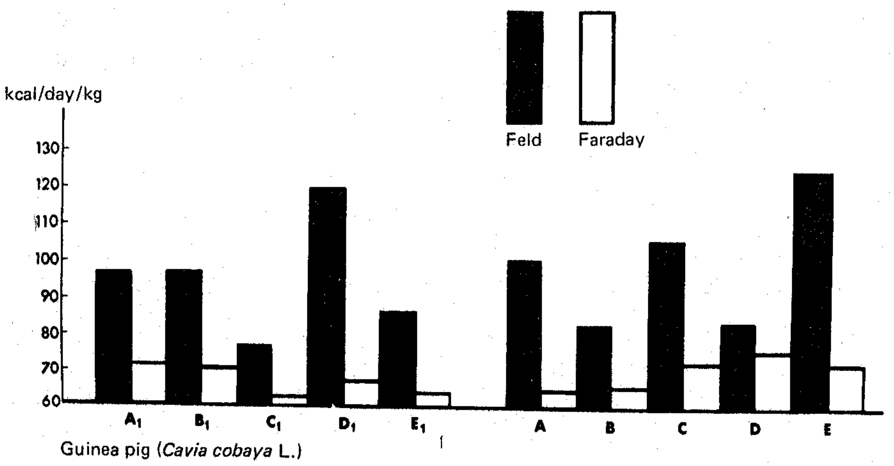

Figure 2. The metabolism of guinea pigs in static electric fields (210 V/0.5M) and in a Faraday cage per day and kilogram (G. Altmann, 1969).

difficult due to the necessity of carefully removing any marking odors from the apparatus before changing animals. Marking odors and "fear" odors from previously used animals could affect the activity levels and metabolism of subsequent subjects. In order to eliminate the marked differences in metabolism during active and passive phases in the animal, measurements were made at 12°C as well. At this relatively low temperature, white mice sleep in a curled up, heat conserving condition. Even under these carefully maintained precautionary conditions an elevation in metabolism during static electric field conditions was observed. Up to 30% increase in oxygen consumption was noted in all tests under static electric field conditions in comparison to pre and post phases during which animals were under Faraday cage conditions. An increased value in free amino acid concentration was demonstrated in muscle and liver preparations from mice and guinea pigs when these were exposed to the same static electric field (Altmann, 1968) (Fig. 3).

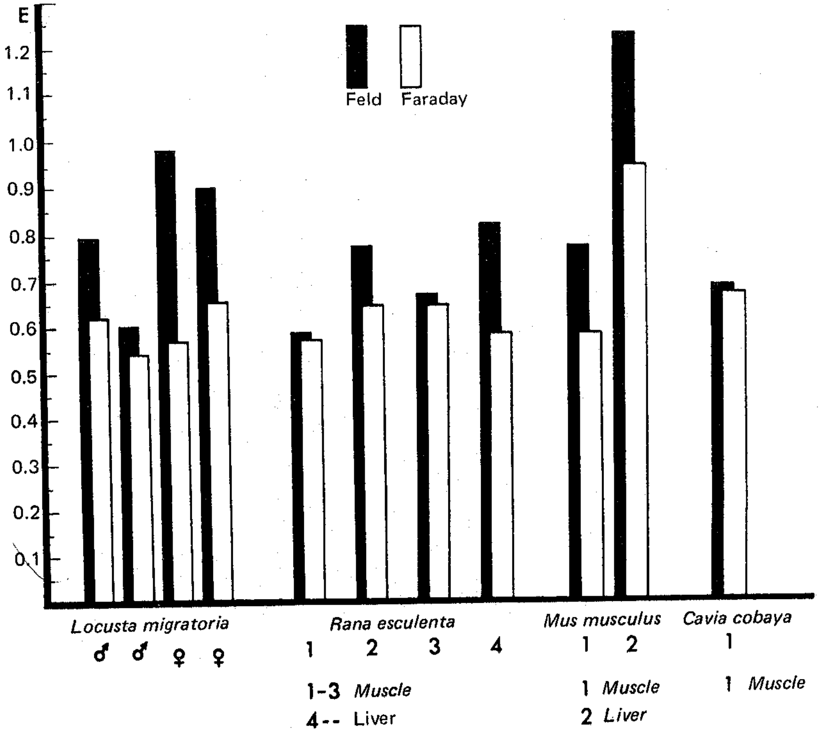

Figure 3. Colorimetric measurements of the breakdown of amino acid ninhydrin color complexes in relation to being located in Locusta migratoria (migratory locusts) Rana esculenta (water frog) and Mus musculus (white mice) (G. Altmann, 1969).

The effects of the static fields can be increased if they are periodically interrupted. Fluctuating fields with a slow impulse sequence frequency show a marked effect on the metabolism of organisms.

The oxygen consumption of fish showed definite elevations when the animals were kept in a galvanic field. Likewise, the oxygen consumption of frogs was elevated under the same conditions. Apparently the orientation of the animal with respect to the lines of force in the field is

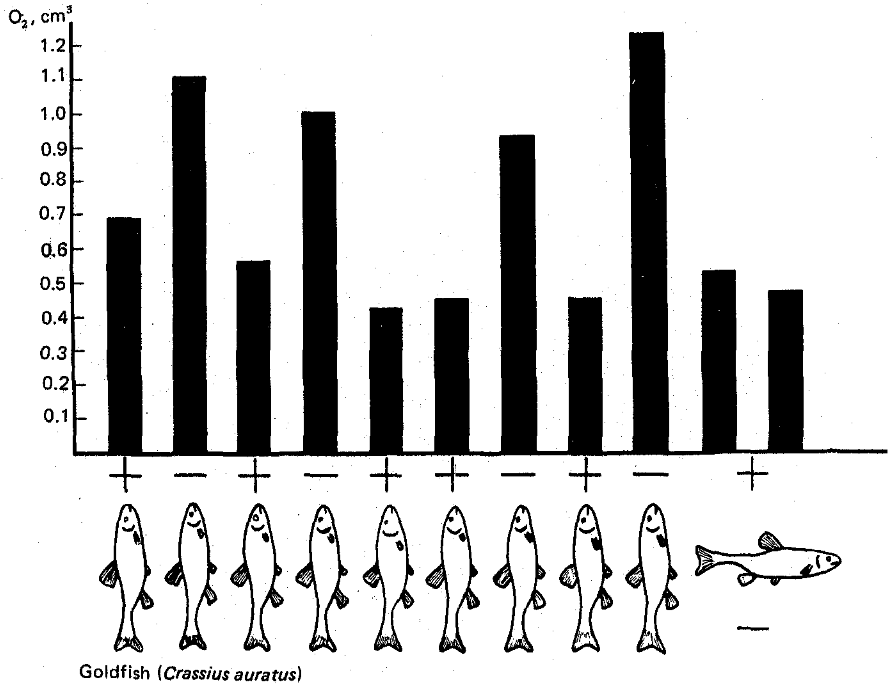

Figure 4. The oxygen consumption of a goldfish in relation to the current direction (2 volt) per 15 minutes (G. Altmann, 1969).

of special importance (Altmann, 1969). If the animal is oriented in a fixed manner with respect to the electrodes, an increase in oxygen consumption occurs when the head points toward the cathode, a decrease when it points to the anode (Fig. 4). Since the animals constantly change their orientation with respect to the lines of force, unless they are restrained, an increase in oxygen consumption occurs in freely moving animals (fluctuating field effect).

Similar results for metabolic rate measurements were obtained in animals oriented in various ways to the lines of force of natural static fields (frogs and laboratory mice were used) (Fig. 5). The differential effects of current direction, even on humans, can be observed in atmospheric electric fields with the correct direction. If the positive pole is located in the ceiling, a general beneficial stimulation is observed. In an opposite direction, however, the effect of the current is depression and irritability. When an organism moves in a static field, no constant field strength gradients are given. Even minimal movements such as respiratory movements, produce changes in the field as a result of which changes in metabolic physiology could be explained. It is not yet possible to determine to what extent not only amplitude size of impulses in an alternating field, but also the frequency of individual body movements, play a role.

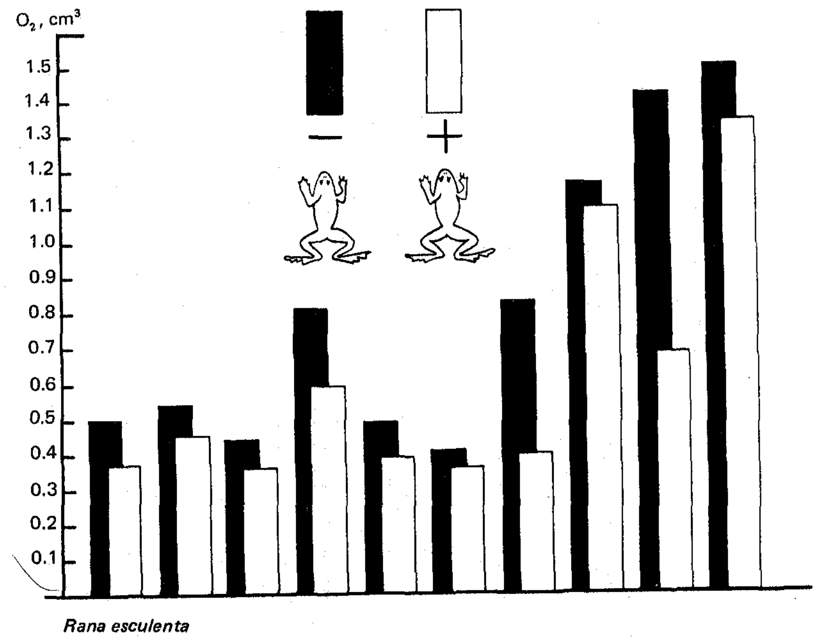

Figure 5. The oxygen consumption of a frog in a static field (210 V/10 cm) in relation to the current direction (length of test period: 15 minutes) (G. Altmann, 1969).

Activity periods play a very important role in the behaviour of an animal. They are influenced by such endogenous factors as nervous and hormone system activity as well as metabolism. Exogenous factors such as light intensity and temperature can also produce changes in activity. Effects of atmospheric electrical processes have also been demonstrated. Numerous experiments have shown that performance levels in humans is correlated with atmospheric conditions. Observations on accident frequency in relation to various weather conditions most clearly demonstrate the mentioned correlations. We have investigated by means of objective methods the relationship between motoric behaviour in various animals and the electrical environment (Altmann, 1962, 1968, 1969). Mice kept in electric fields showed clear elevations in total activity relative to controls in a Faraday cage (Fig. 6). Similar experiments were also done with budgerigars (Melopsittacus undulatus) and Zebra finches (Taeniophygia guttata). In this case the number of movements from one perch to another was measured. These experiments showed that low frequency alternating fields of 1.75 Hz and 5 Hz suppressed activity, whereas 10 Hz fields clearly showed an increase in activity, even greater than the mean

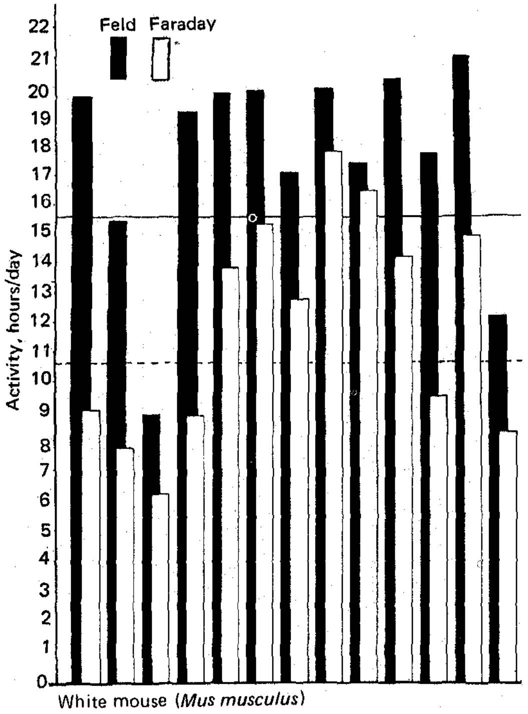

Figure 6. Activity levels in white mice per day in relation to location in an electric field or in a Faraday cage (mean values given by the horizontal lines) G. Altmann, 1969).

level in the static field. An improvement in physiological functioning and an increase in performance under these types of electric fields, can be clearly seen. The reaction time in humans is also shortened by 10 Hz fields. Alternating fields of 1.75 and 6 Hz, on the other hand, lengthen reaction time. At these frequencies the behaviour of honey bees, for example, is also altered. The number of foraging flights decreases and the so called "vorspiel" which serves in orientation of young bees doesn't appear. The sucking performance also decreases rapidly upon appearance of alternating fields of these frequencies. Instead of the normal recruitment dance, warning dances appear. The bees are irritable and readily sting (Huesing, 1965; Schua, 1952).

Recent studies dealing with static charge build up on the body surface of mice, rats, guinea pigs and insects, demonstrated the appearance of locally specific surface potentials and directed potential differences on the skin potentials of the small mammals as well as on the chitinous surface of the outer skeleton of the insects. The size of the charge build up depends among other things on the ambient electric field. Most likely a role is also played by endogenous factors. They are subjects for further investigations (Altmann, Lang and Waruke, unpublished observations). The size of the surface potentials can be crucial for the penetration of alternating fields. Effects of electrical factors on living cells is only possible by means of electrical charge carriers and dipoles. The watery solution in the cells and interstitial spaces is rich in ions and dipoles. These variables determine the cell potentials. The ion distribution and hydration processes play an important role. In order to further investigate changes in water and mineral concentration as a result of atmospheric electricity, our research group conducted extensive investigations on the intra-extracellular systems in over 2000 mice, guinea pigs and rats. The experimental animals were housed in three identical cages. Whereas the first cage was exposed to natural atmospheric electricity factors, the other two cages were shielded by means of Faraday cages. In one of the shielded cages an artificial 10 Hz impulse field was affecting the subjects (Lang, 1970, 1972). All other environmental factors such as temperature, humidity and light factors were kept constant. After a 14 day exposure period, an increase in water concentration in the blood of animals kept in the Faraday cage relative to control animals, was found (Table 1). The percentage volume ratio of blood cells to blood plasma

TABLE 1

CHANGES IN THE BLOOD OF MICE UNDER EXPERIMENTAL CONDITIONS (S. LANG, 1972)

Condition		Haematocrit	Sodium conc. m equiv/1	Potassium conc. m equiv/1	Water content % of net wt.
Normal	Plasma		95.3±3.4	11.5±0.8	89.88±0.72
	Whole blood	43.95±0.62	59.9±1.8	46.4±2.2	77.04±0.53
	Erythrocytes		6.2±0.9	92.3±1.8	67.71±0.40
In Faraday cage	Plasma		95.3±1.7	11.4±0.9	90.62±0.90
	Whole blood	32.21±1.21	67.7±2.7	34.6±1.5	80.76±0.98
	Erythrocytes		9.6±1.0	83.5±1.9	58.86±1.11
In Square Wave Impulse Field	Plasma		89.9±3.6	11.9±1.2	90.22±0.84
	Whole blood	36.29±1.35	58.9±2.0	40.6±3.3	77.52±0.82
	Erythrocytes		4.4±0.8	90.9±2.1	55.17±1.51

(haematocrit) fell from 43.95 in normal animals to 32.21 in Faraday housed animals. The sodium concentration in whole blood of the animals rose from 59.9 m equiv/1 to 67.7 m equiv/1. Simultaneously a 30% increase in water retention can be observed. In addition to the already familiar volume changes, which on their part produce a change in the ion concentration gradients, a noticeable increase in sodium concentration and a decrease in potassium concentration in the blood cells, was found (Table 1). This effect of the Faraday cage demonstrates that the purely physical external electric processes of the atmosphere impinging on the animals, can affect the ion milieu in the organism. As our experiments demonstrate, the nonphysiological changes in mice in the Faraday cage can be compensated for by means of the artificial square waved 10 Hz field (Bottom of the Table). As further experiments demonstrated, the main effect of the Faraday shielding was to increase the water content of the blood, whereas other tissue was less affected by this manipulation. The demonstrated volume changes between extra and intracellular phases in the blood of mice kept under Faraday conditions, was replicated in experiments using rats. In this case an increase in protein concentration was found by means of density determinations. As a result an increase in colloid osmotic pressure resulting in water inflow and a fall in the haematocrit values was observed under Faraday conditions. The electrophoretic measurements of protein breakdown showed a shift of all protein fractions in animals under Faraday conditions relative to normal subjects. Under the influence of the 10 Hz field, the values of the individual fractions noticeably approached the values of the controls. The value of individual protein fractions is kept very constant by the organism under normal physiological conditions and only change then when regulatory capacities are exceeded (Altmann and Soltan, unpublished observations)

The increased sodium concentration in the erythrocytes and the increased potassium concentrations in the blood plasma, point to a change in regulatory performance of the erythrocyte membrane (Lang, 1971). At the same time studies on the effects of air electricity on membrane potentials were carried out (Altmann, Andres and Lehmair, 1972). By measuring the potentials in the ventral skin of Rana esculenta a detailed study of the size of the inside/outside potential difference under the influence of a 10 Hz square wave field in relation to normal and field free (Faraday) conditions, was possible.

In the measurement of the inside/outside potential differences a strong decrease in the potentials of about 23 mV was found in "Faraday subjects" relative to "normal subjects". The decrease in membrane potential in the shielded animals could be largely compensated for by exposure to the 10 Hz square wave impulse field. Since the inside/outside potential difference depends on a specific ion distribution, the electric field must have an influence on the membrane system, specifically the ion permeability. Reversible structural changes in the membrane, brought about by external factors, can lead to functional changes. A weak ELF field is capable of shifting calcium ions in the cell membrane and thereby alter its permeability (Ludwig, 1971).

The mechanism underlying an effect of electric fields on the metabolism of organisms, can, in the light of the present results, only be discussed in terms of models.

Ludwig (1971) calculated a possible absorption mechanism for ELF waves in animals. He demonstrated that electromagnetic waves in the intensity range found under natural conditions, could change the ion milieu of synapse membranes. This influence results in an increased membrane permeability. Our measurements also demonstrated an influence of atmospheric electrical factors on the cell membrane. It is furthermore known that local shifts in the ion milieu of the cell can be caused by various stimuli (heat, pressure, chemical and electrical stimuli). In certain cases further physiological processes in cellular metabolism are controlled via higher centers in the central nervous system. VLF waves, on the other hand, primarily affect the peripheral nerves and free nerve endings in the skin. In choice behaviour studies, mice and other animals displayed special sensitivity for air electrical factors (Altmann, 1968; Lang, 1970). In terms of the behaviour of the animals it can be assumed that they are in a position to immediately perceive these factors in at least a qualitative manner. A transmission of this information to higher nervous centers is plausible via the receptors and proprioreceptors. In addition, the static charge on the skin surface control the penetration of atmospheric electric fields and the reactions of these.

According to the studies and speculations of many authors, the interstitial space plays an important role in

the regulation and control of various processes. Limited changes in the interstitial space can be rapidly compensated for by influxes of ions across the capillary network. Electric fields exert a directing influence on the various charged particles in the intracellular and cell systems. Consequently, non electrolytic structures such as macromolecular proteins, must be oriented in a very special manner in order for a plurality of greater or smaller polar bonds to occur between atom and molecular groups, for their respective functions. These systems can be affected by external factors. Regulation occurs via the adrenocorticotropic system (aldosterone, catecholamines) and the tissue hormone serotonin (Sulmann, 1964 and Andres, unpublished observations). The system reacts to high field strengths with a decrease in water concentration in the extracellular space; under shielding conditions, however, water is retained. In the same manner a shift in sodium-potassium relationship takes place. To this extent, in the manner that a normalization process of the conditions discontinues after being located in the shielded room, there is also an increase in cell respiration and the oxygen consumption rises.

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PRECAMBRIAN ELF AND ABIOGENESIS

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In 1938, Oparin, in his book, "The Origin of Life", proposed environmental conditions under which life or its chemical precursors could have been synthesized on the primitive Earth. Though unchanged in essential features, Oparin's conditions have been subsequently refined. A central feature of this primitive environment was an atmosphere that was reducing with respect to carbon. The predicted atmosphere (Rasool, 1972) of the Precambrian earth, based upon thermodynamic calculations, is given in Table 1.

TABLE 1

Predicted Atmosphere of the Precambrian Earth

Gas	Precambrian Earth % by weight
CH_4	0.26
Ar^{36}	0.15
H_2	63.50
He	34.90
Ne	0.34
NH_3	0.11
H_2O	0.60

For chemical reactions to proceed, activation energy must be supplied. Estimations of the contributions from the conventional forms of energy for syntheses in the Precambrian environment are shown in Table 2 (Miller and Urey, 1959). Less than two decades after Oparin's book, Stanley Miller (1953), a student of Urey's, synthesized several of the amino acids which are found in proteins and other organic compounds by passing an electric arc through a gas mixture of similar composition, thereby setting off a chain of similar experiments in laboratories worldwide. To date a near-complete roster of naturally occurring organic micromolecules has been synthesized under "primitive Earth conditions" and there are no theoretical shortcomings to prevent its completion.

Macromolecular synthesis has been partially successful, but there are theoretical as well as experimental deficiencies. Polypeptides have been synthesized by heating dry mixtures of amino acids (Fox et al, 1958) and by allowing HCN, a prominent product in arcing experiments, to polymerize (Kliss et al, 1962). Polypeptides, polysaccharides, and polynucleotides have been polymerized in the presence of polyphosphate and metaphosphate esters (Schramm et al, 1958, 1961) under mild conditions; however, these reactions are acid catalyzed and thus are of questionable compatability with the apparently basic ammoniacal solutions postulated for the primitive Earth (Miller and Urey, 1959). It is possible that the synthesis of polynucleotides and polysaccharides had to await catalytic or structural assistance from pre-existing proteins.

TABLE 2

Precambrian Energy Sources

Source	Energy (Cal $cm^{-2}yr^{-1}$)
Total radiation from sun	260,000
Ultraviolet light	
$\lambda < 2500$ Å	570
$\lambda < 2000$ Å	85
$\lambda < 1500$ Å	3.5
Lightning	4
Volcanos	.13
Radioactivity	.8

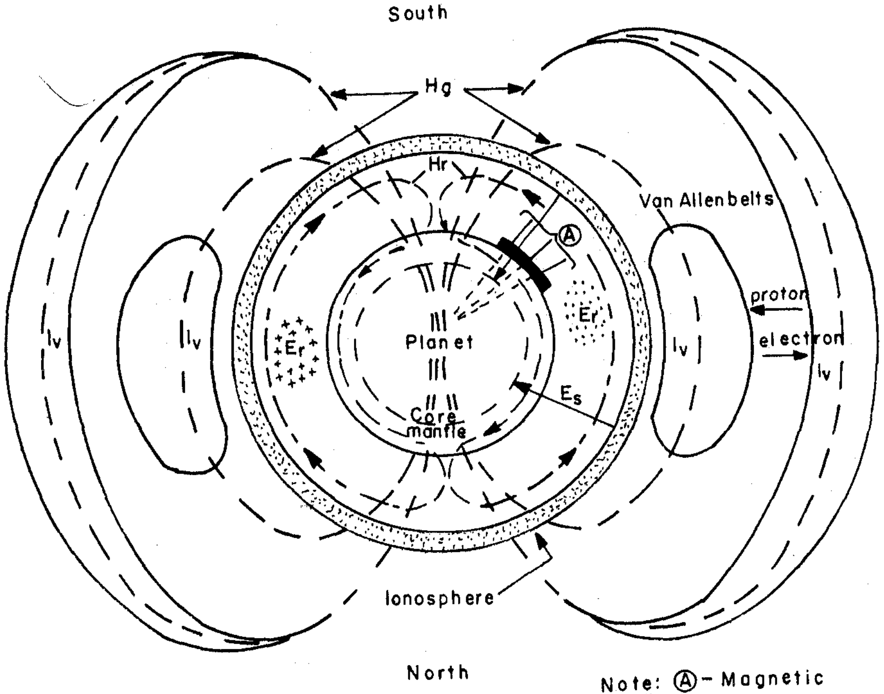
No one has achieved a chemical synthesis of a biopolymer containing only one of the two possible optical isomers without the use of asymmetric reagents. The presence on the primitive Earth of asymmetric polymer precursors has resisted an unequivocal explanation, yet their presence in polymers of biologic origin dates to hydrolysates of the earliest fossils, some at least three billion years old (Kvenvolden et al, 1969). This deficiency is not trivial, and it may represent, as Pasteur suggests, "The great characteristic which establishes perhaps the only well-marked line of demarcation that can at present be drawn between the chemistry of dead matter and the chemistry of living matter" (Japp, 1898). Clearly these results strongly suggest the presence of an asymmetric resolving force in the Earth's primitive environment.

The search for such an environmental asymmetric force has been relentless. Though more complex environmental resolving agents are now being considered, there is little in Bonner's recent (1972) review of the subject that would invalidate Wald's statement in his earlier (1957) review: "...all the organic sources of optical activity share the same disabilities; very restricted conditions, a very limited field of operation, poor yields, and the overwhelming tendency to result in only local and temporary asymmetry in what is otherwise a racemic continuum. For the origin of optical activity in living organisms, I think one must look elsewhere".

At the level of primitive pre-cellular organization, there are two principal theoretical models. Under experimental conditions both have been demonstrated to have properties likely to result in primitive cells. Fox's (1970) "proteinoids" result from appropriately treated polypeptides synthesized by thermal copolymerization. Proteinoids can be composed primarily of proteins containing amino acids found in naturally occurring proteins, and have been demonstrated to possess over twenty protein properties. Most remarkably, proteinoids easily form stable, cell-like structures which possess double membranes, catalytic activity, and which, under the influence of changes in the pH and temperature of their environment, can be induced to increase in mass through accretion, to divide, and to grow once more in the completion of a primitive life cycle. Similar cell-like properties have been demonstrated with coacervates by Oparin (1965). Coacervates, derived from the Latin 'acervus' meaning aggregation, with the 'co' signifying the aggregation of colloidal particles, result from a mixing of solutions of proteins with various high molecular weight substances to produce droplets. This phenomenon, which can occur in solutions containing but one part of protein per 100 million parts of water, can lead to spheres which, after absorbing enzymes from their environment, can be made to increase in size due to the assimilatory properties of their component enzymatic activities. Coacervates, though less stable than proteinoids, have metabolic properties reflecting their enzymatic composition and thus provide a model for the chemical dynamics of precellular systems. The implication from observing the behavior of such systems is that once macromolecules form, cellular organization will follow spontaneously.

In this brief review of "spontaneous generation", we have pointed out the achievements in this area of investigation without emphasizing areas of controversy. Virtually everything presented has been and still is the subject of debate. Of the yet unresolved problems concerning the gap between primitive atmospheric gases and living cells, some questions probably result from minor technical disagreements that would involve a change in gas composition or some other reaction parameter; others, such as the problem of asymmetry, appear to involve fundamental shortcomings in existing theory. Graf and Cole (1967), introduced a new set of theoretical environmental parameters when they theorized the availability of enormous quantities of electromagnetic energy arising from an extra-low frequency (ELF) planetary resonance phenomenon postulated to have occurred on the primitive Earth and possibly occurring now on Jupiter.

This theory, originated by the authors, proposes that a planet with the appropriate composition and axial rotation to possess a magnetic field and its associated radiation belts forms a vast concentric spherical resonator between its electrically-conducting core and ionospheric charge layer at an early point in its evolution. Such a planetary resonator would manifest a coherent electromagnetic field configuration and remain active for a substantial period of time after its initiation. In our solar system this resonance phenomenon could have existed or may now exist on such planets as Earth, Jupiter, and Saturn, though not on Venus and Mars. In the case of Earth, which has a conducting core approximately one wavelength in circumference at 10 Hertz (Hz), the planet is envisioned to have functioned as a gigantic ELF oscillator with a 10 Hz eigenfrequency. The time-changing component of the Earth's magnetic field, as diagrammed in Figure 1, served the critical function of closing the feedback loop which energized the oscillator.



Note: Ⓐ - Magnetic field lines from North. See Figure 6.

Figure 1. A cross section of the electromagnetic fields of the Precambrian Earth.

This planetary resonance phenomena could only occur when the ionosphere-core cavity of the primitive Earth had evolved to within the range of the functional electrical geometry. If, as we have postulated (Graf and Cole, 1967), planetary resonance was crucial to life formation, then evidence from Precambrian paleobiology suggests that this geometry must have been attained between 3.5 and 4.5 billion years ago. Fossil records 3.5 billion years ago contain evidence of life forms that have already undergone extensive evolution and thus had their genesis at an earlier period (Schopf, 1972). The Earth is believed to have been solid for 4.6 billion years (Sutton, 1968). Rasool's (1972) prediction of the Earth's atmosphere at this earliest stage of existence was shown in Table 1. Such an atmosphere would have been several orders of magnitude more extensive than the Earth's present one and of similar composition to that proposed for Jupiter and Saturn today (Rasool, 1972). The Earth's Precambrian ionosphere was thus thousands of miles from the planet's surface, as is Jupiter's presently. As the lighter, more volatile components escaped, carbonates formed, water condensed, etc. (Rasool, 1972), the atmosphere then, long after life was established, underwent a transition from reducing to oxidizing. Our present atmosphere, greatly reduced in extent, subsequently arose from outgasing during continued volcanic activity as well as from photosynthetic, respiratory, and other biologic activities. Electrical oscillation was attainable within the Earth's original atmosphere by means of fluctuations that exist in the currents of the van Allen belts due to pulsations of the geomagnetic field and solar winds. Such phenomena would have generated enormous equatorial currents (at frequencies from 0.1 Hz to 100 Hz) in the ionosphere by closely-coupled induction from the van Allen belts. These currents in turn excited a resonant electromagnetic field within the conducting core-ionosphere cavity which, during the shrinking of the planet's atmosphere, attained the preferred electrical separation of $\lambda/2$ (about 9,000 miles), which would permit resonance at 10 Hz. The loops of the resonant magnetic field (Hr) run parallel longitudinally from pole to pole between the two containing spheres of the Earth's ionosphere and conduction core. The maximum strength of the resonant magnetic field (Hr) was at the surface of the two spheres and the maximum strength of the electric field (Er) was electrically equidistant between them. The static electric field (Es), between the Earth's surface and the atmosphere, existed then as it does now, with its relative positive pole

above the Earth's surface.

This oscillator, thus conceived, was active at about 10 Hz with other frequency components rapidly attenuated. The high intensity resonant magnetic fields penetrated to the Earth's magnetic core, thereby enhancing the fluctuating component of the Earth's primary magnetic field in a "feedback phenomenon", which permitted an exponential increase in the strength of the 10 Hz eigenfrequency component in the equatorial driving current (Iv) of the van Allen belts. Hence, there developed a voltage potential in the mid-equatorial zone of the planetary resonator sufficient to break down the primitive reducing gas atmosphere and permit enormous electrical discharge.

An examination can now be made on some of the possible consequences of these events in terms of the environment of the primitive Earth.

ATMOSPHERIC GAS COMPOSITION

Though the earliest known rock formations from the early Precambrian sediments contain carbonate units, indicating that carbon dioxide, not methane, was the dominant form of carbon some three billion years ago (Ramsay, 1963), few disagree that the atmosphere 1 to 1.5 billion years earlier can be approximated by that shown in Table 1. All agree that such a mixture would have to be reducing with respect to carbon for only in such reducing atmospheres have organic compounds with more than one carbon unit been synthesized (Abelson, 1953). It is clear that the planetary resonance phenomena we have described above could have only occurred had the Earth's atmosphere been much larger than it is now. No one denies that the atmosphere of the primitive Earth, containing its abundance of hydrogen, must have been much larger.

ENERGY

In considering the potential environmental energy sources for abiogenic organic syntheses, most investigators have settled on that region of the electromagnetic spectrum where the light quanta contain sufficient energy to make and break chemical bonds, with most attention centering on ultraviolet (U.V.) wavelengths. As can be seen in Table 2, other sources of energy for abiogenic synthesis have been considered negligible by comparison.

The energy source for synthesis on the primitive Earth is still the subject of debate. Fox and his supporters (1970) propose heat to be a critical energy factor in polymerization. Oparin (1972) has pointed out that U.V. possesses energy sufficient to break as well as make chemical bonds, and thus newly formed chemical precursors must be shielded from the very radiation required for their formation. Rasool (1972) points out the possible opacity of the primitive atmosphere to U.V. due to NH_3 absorption. Others question whether chemicals formed high in the atmosphere by U.V. can survive long enough to reach the earth's surface (Hull, 1960). Recently, Bar-Nun et al (1970), have demonstrated an extremely efficient synthesis of amino acids from a reducing gas mixture subjected to shock heating followed by a rapid thermal quench. It is suggested that these conditions could have occurred on the primitive Earth either by microcometary meteorites entering the Earth's atmosphere or by thunder associated with lightning.

Though Byk (1904) considered the effects of the Earth's natural magnetic field as an asymmetric force producing dextro-circularly polarized light and Presman (1970) has appreciated the pervasive omnipresence of this environmental force, only Graf and Cole (1967) have presented a theoretical case for its potential in abiogenic chemical synthesis. In view of the fact that the direct energy from this low frequency field does not exceed random thermal noise, the omission is understandable. In the "Planetary Resonator Theory" as presented above, it is evident that the energies available for abiogenic synthesis are only indirectly attributable to the Earth's magnetic field.

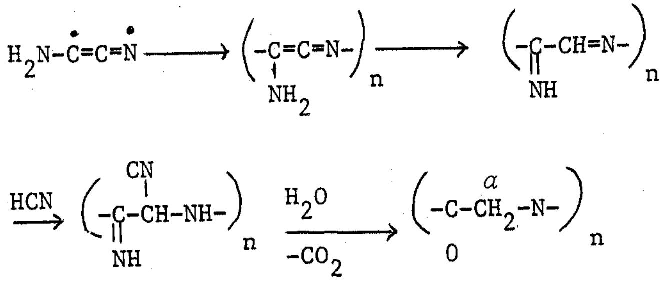
The effect of electrical phenomena described earlier on chemical synthesis in the postulated resonant cavity of the primitive Earth would be remarkably uncontroversial since virtually all of the energy sources postulated to be involved in chemical abiogenesis would be provided: Heat and U.V. arising respectively from the arc and its corona, with shock waves and quench resulting from the subsequent thunder. Perhaps as important is the fact that all radiation within the resonant cavity would show the effects of modulation at the basic 10 Hz frequency. Moreover, these energies would have been available within the Earth's atmosphere at its surface, and as we will see later, were probably confined to a relatively small region, thus allowing products to migrate from these potentially destructive forces.

Thus, within the conducting core-ionosphere cavity of the primitive Earth, there would have existed enormous electrical activity, similar perhaps to that occurring within "The Great Red Spot" on Jupiter today, which would permit the formation of almost boundless quantities of organic compounds. Such activity would have prevailed until the further condensation of water vapor, the loss of volatile gases, and the conversion of the atmospheric gases into denser organic forms reduced the dimensions of the conducting core-ionosphere cavity such that it was no longer resonant near 10 Hz.

ORGANIC SYNTHESIS

Our discussion here will be confined to macromolecular synthesis since, as we have pointed out, organic syntheses of micromolecules by exposure of reducing gases to a variety of energy sources has been particularly successful (Gabel et al, 1972).

In conducting our own arcing experiments in a reducing gas mixture of methane, ammonia, hydrogen, (40:40:20 mole percent) and water vapor in which reactants and products were circulated at room temperature with a tubing pump to avoid heating, we have obtained apparent polypeptide material. Our data are consistent with the hydrogen cyanide polymerization mechanism proposed by Matthews and Moser (1966) shown below.



$$H_2N\text{-}\dot{C}\text{=}C\text{=}\dot{N} \longrightarrow \left(\text{-}\underset{\underset{NH_2}{\downarrow}}{C}\text{=}C\text{=}N\text{-}\right)_n \longrightarrow \left(\text{-}\underset{\underset{NH}{\parallel}}{C}\text{-}CH\text{=}N\text{-}\right)_n$$

$$\xrightarrow{HCN} \left(\text{-}\underset{\underset{NH}{\parallel}}{C}\text{-}\overset{\overset{CN}{|}}{C}H\text{-}NH\text{-}\right)_n \xrightarrow[-CO_2]{H_2O} \left(\text{-}\underset{0}{C}\text{-}\overset{a}{C}H_2\text{-}N\text{-}\right)_n$$

In the hydrogen cyanide polymerization mechanism for prebiotic protein synthesis a "stereoregular helical polymer" of polyglycine forms. According to the authors, the polyglycine protein precursor would have tended to form an alpha helical structure, either right- or left-handed, given a symmetric external environment. Secondary reactions on the alpha carbon would have led to a protein polymer, yielding either D or L amino acids upon hydrolysis, since by this mechanism the direct synthesis of alpha amino acids does not occur.

As shown in Table 3, free amino acids were not present in quantity in our reaction products until after HCL hydrolysis. The glycine to alanine ratio in these peptide-like materials was 2:1, similar to that obtained by Miller (1953), but with a greater spectrum of amino acids. A similar spectrum of amino acids has been reported by Grossenbacher et al (1965) in arcing experiments.

The oligomeric nature of these possible peptide materials from our experiments was further suggested by their elution pattern from Sephadex, as shown in Figure 2, where some of the 254 mμ absorbing material was eluted close to the high molecular weight marker Blue Dextran. Grossenbacher et al (1965) also suspected peptide products. It is

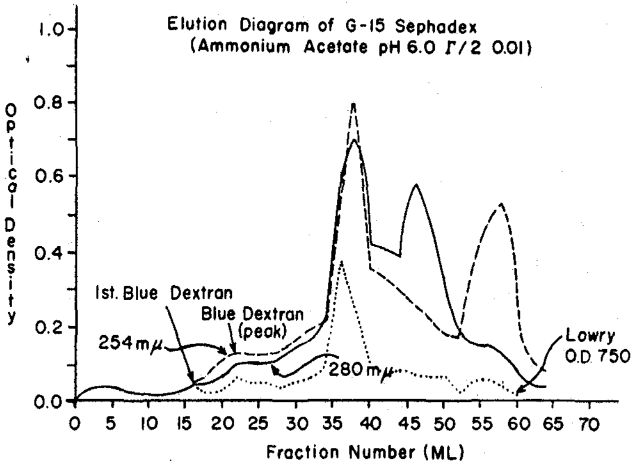


Figure 2. Elution pattern of reaction products from Sephadex indicating their possible peptide nature.

TABLE 3

PRINCIPAL NINHYDRIN REACTIVE PRODUCTS*
VALUES IN μMOLES/L REACTION MIXTURE

	Exp. 1		Exp. 2	
Amino Acids	HCL Hydrolyzed	Unhydrolyzed	HCL Hydrolyzed	Unhydrolyzed
Asp	26	.6	93.2	54
Thr	--	--	97.2	--
Ser	70	5.8	16	2
Glu	7.6	--	34	--
Gly	1656	58.8	826	23.2
Ala	840	20.6	450	14.4
*α*ab	84	--	48	--
Met	16.8	3.4	2.6	--
Leu	--	--	2.0	--
Orn	62	--	15.4	--
His	6.4	4	17.6	--
Lys	2.4	--	53.2	--
Arg	2.0	--	13.2	6

*The amino acids listed represent the ninhydrin peaks of whose identity we were most certain. There were many unidentified peaks in both hydrolyzed and unhydrolyzed samples.

interesting to note that simply mixing hydrogen cyanide and ammonia apparently yields a near pure glycine homopolymer with only traces of other amino acids (Matthews et al, 1967). Miller's failure to demonstrate peptides may be a result of his refluxing his reaction products.

The above mechanism for peptide synthesis has been criticized recently by Gabel and Ponnamperuma (1972) on two points: (1) that the mild basic conditions postulated for the primitive Earth would not be favorable for hydrolysis of the cyano groups (step 4 of the reaction sequence); (2) that hydrogen cyanide polymerization reactions would be of minor importance in <u>gas</u> phase reactions.

They propose the polymerization mechanism suggested by Akabori (1955), where aminoacetonitrile forms polyglycine, though apparently only diglycine and triglycine have been synthesized (Hanafusa and Akabori, 1959). It should be noted that neither mechanism proposes peptide synthesis from free amino acids. Our failure to demonstrate quantities of free amino acids while simultaneously demonstrating intermediate molecular weights with our products would seem to be most consistent with the data and mechanism of Matthews and Moser (1967). Clearly, in our laboratory, polymerization reactions of HCN are significant since amino acids are released only after HCL hydrolysis. This discrepancy may be explained if the HCN polymerizes in liquid rather than gas phase. The question as to whether they are truly amino acid polymers can be approached in future experiments utilizing enzymatic rather than acid hydrolysis of the polymeric products.

Other indirect evidence in support of a prebiotic polymerization mechanism for proteins that does not involve amino acid monomers is the observation that 80 percent of the carbon in sedimentary deposits is in a highly polymeric form called kerogen, "...which is not extractable with ordinary solvents" (Chang et al, 1972). In their analysis of a chert sample from the Fig Tree series, Kvenvolden et al, (1969) found only glycine and a trace of alanine as free amino acids, but after HCL hydrolysis, they found glycine, serine, threonine, leucine, alanine, valine, proline, aspartic and glutamic acids, isoleucine, and phenylalanine. No analysis was performed to detect basic amino acids.

FIELD ASYMMETRY AND POLYMER ASYMMETRY

The formation of highly charged molecules such as peptides, proteins, nucleic acids, and their precursors in an environment in which unique electromagnetic phenomena were the dominant characteristics clearly must have had a decisive influence in determining their subsequent properties. Naturally occurring biopolymers always demonstrate a preferred direction of structural rotation. However, laboratory synthesis of these molecules fails to produce this preferred rotation without resorting to the use of asymmetric reagents. In protein, a right-handed helical structure predominates. This structural asymmetry results from asymmetry in the component amino acids, with L forms occurring nearly exclusively. It is proposed here that unique electromagnetic conditions, present at the time of the evolution of the first primitive molecules of this type, caused this asymmetry. These conditions in turn were dependent upon the planetary resonance conditions described earlier.

We will take for purposes of illustration the hydrogen cyanide polymerization mechanism, in which a stereoregular polymer or oligomer of polyglycine forms; however, the considerations to follow would exert their asymmetric influence on prebiotic peptides or proteins regardless of their mechanism of polymerization.

The electrical structure of a protein molecule with a volume dipole moment can be represented by three orthogonal dipoles. At the carboxyl terminal end of the molecule, a negative charge would exist due to the ionization of this group in the alkaline environment of the primitive seas; and thus, newly synthesized polyglycine polymers and oligomers would first tend to orient at the water's surface with the carboxyl terminal end of the molecule pointed upwards toward the positive pole of the Earth's static electrical field. As additional reactions take place along the surface of the helix, it becomes progressively dipolar across the helix, bearing a net negative charge overall due to its alkaline aqueous environment. Thus a molecule with a relatively strong heliaxial dipole moment (z) and relatively weak radial dipole components (x and y) would be synthesized. Such a molecule is chematically represented in Figure 3. In a resonant cavity of the type described for the primitive Earth, the field configuration would be as follows: the strong static electric field (Es) and static magnetic field

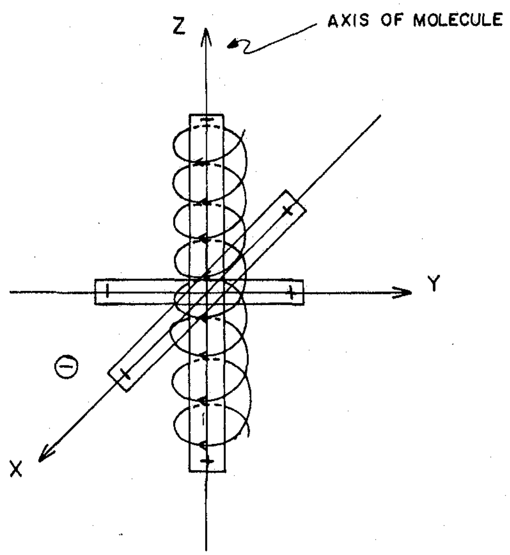


Figure 3. Molecule with a strong heliaxial dipole moment along the z axis. Note relatively weak radial dipole moments (x and y axes).

(Hs) act in parallel directions while, simultaneously, sinusoidally time-varying electric (Et) and magnetic (Ht) fields act perpendicular to the static fields. The static electric field is much larger in magnitude than the sinusoidal electric field. These fields define a coordinate system as in Figure 4.

Suppose the protein or peptide molecule under consideration were placed in this field system. Since the axial dipole is much stronger than the radial dipoles, it would tend to align itself with the strong static electric field. The sinusoidal fields, however, would tend periodically to rotate the molecule around its axis, as the radial dipoles attempt to align themselves with this field. With no other fields present, the direction that the molecule rotates on each change of polarity would be random, as shown in Figure 5.

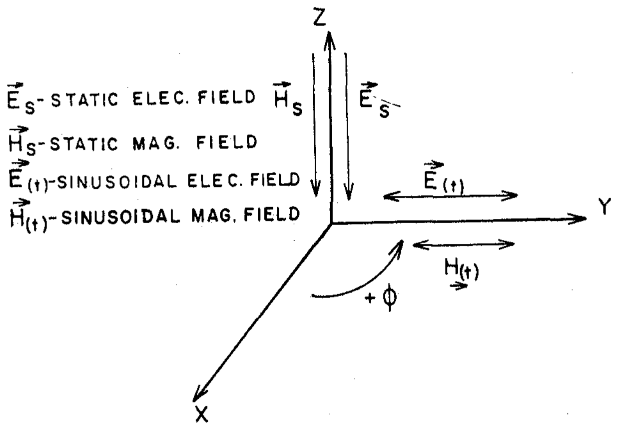


Figure 4. Coordinate system defined by the Earth's electromagnetic fields.

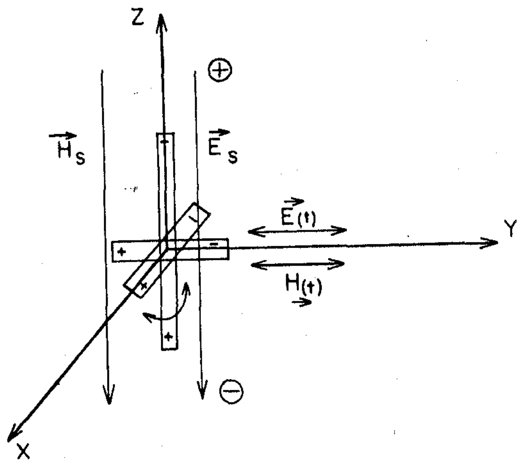


Figure 5. Direction of molecule rotation under applied electric fields.

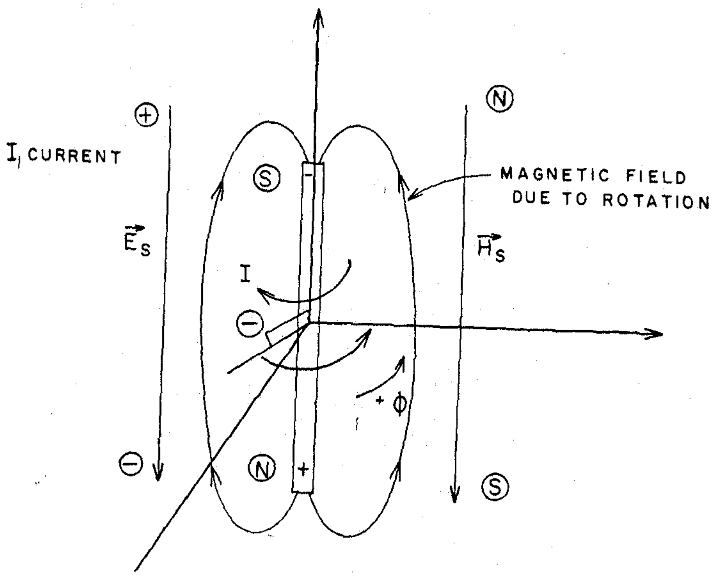


Figure 6. Induced H field caused by rotation in $+\phi$ direction.

However, a rotation in the $+\phi$ direction would constitute a current (I) in the $-\phi$ direction due to the excess negative charge, and a magnetic field (H) would be induced in the protein molecule as shown in Figure 6. This would create an axial magnetic dipole with a north pole at the positive end of the axial electric dipole.

Since the current-generated H field is in a direction parallel to that of the static H field, there is an induced magnetic north pole at the positive end of the axial electric dipole. The magnetic field set up by this particular molecular rotation will therefore tend to keep the molecule aligned with the Earth's static electric field.

A rotation in the other direction ($-\phi$), however, would create a magnetic south pole at the positive end of the axial electrical dipole, and the molecule will attempt to reverse its axial alignment in the field. This will be in opposition to the static electric field, and the balance of the system will be upset. There is, therefore, a

preferred direction of rotation for a dipolar protein molecule in this system. Since the movement of a charged particle in the fields defined above would describe a helix, we would expect this form to predominate as well in the structure of other charged polymers such as nucleic acids. Of course, if the static magnetic field were reversed, the opposite direction of rotation would be preferred. It is proposed that during the Precambrian period the polarity of Earth's static magnetic field was identical to that used in Figures 4-6, with the polarity of the field having subsequently reversed itself many times.

It is suggested, therefore, that an asymmetric field configuration of this type would serve as a bias providing resolving energy to select protein molecules with a right handed structural rotation. HCN is symmetric so it would have no bias for forming exclusively left or right-handed helices. Such a balance can be easily upset, just as a balanced, double-pan scale can be upset in either direction, by adding either a gram or a kilogram weight to one pan. By comparison, all that is necessary to produce exclusively L or D amino acids would be a small energy bias making either a right or left-handed HCN helix preferred respectively. This energy could be in the range of a small activation energy. Certainly it could be much less than covalent bond-breaking energies. Such a phenomenon would produce virtually all-or-none results with a minimal energy input.

The bias in the proposed fields, for a ($+\phi$) rotation, could give an additional minute energy advantage to the right-handed helix as follows: It was indicated in Figures 4 through 6 that the preferred spin ($+\phi$) in the Earth's fields is counterclockwise. Right-handed helical polymers would thus be forced by their spin to unscrew themselves from an aqueous medium, remaining at the surface where their net minus charge and induced magnetic south pole would hold them as close as possible to the positive pole of the Earth's static E field and the north pole of the Earth's static H field. On the other hand, left-handed helices, should they attempt to form, would tend to screw themselves deeper into their aqueous environment opposing the Earth's static fields and become subject to increasing effects of shearing forces at greater depths. Right-handed helices would thus have a greater stability and a clear survival advantage.

Thus, the HCN polymerization mechanism would be admirably suited for the task of asymmetric amino acid production since D or L amino acids form only as a result of the hydrolysis of left- or right-handed helices, respectively. L amino acids would result simply from addition reactions at the alpha carbon on the preferred right-handed helical polyglycine protein precursor. Such a resolving mechanism avoids the costly expenditure of bond-breaking energy that would be necessitated by a mechanism involving selection or destruction and then polymerization of one of the two amino acid stereoisomers.

PROTEIN PRECURSORS

The field configurations we have described would have a maximum effect upon relatively short peptides, ones with a heliaxial dipole at a pH near 8 which Miller et al (1959) have predicted for the pH of the primitive seas.

There are several lines of evidence that lead us to believe peptides of low molecular weight were the precursors of primitive proteins. Proteins are composed of short helical peptide segments joined together. The longest segment of α helical structure in most proteins does not exceed 30 amino acid residues (Haurowitz, 1963). The catalytic center of most protein enzymes are short peptides. It has long been known that much of the polypeptide structure of some enzymes, such as enolase and ribonuclease, can be removed without lowering catalytic efficiency (Mahler and Cordes, 1966). A significant amount of the involved tertiary structure of modern proteins has therefore evolved for other purposes such as control, specificity, or stability in unusual environments. Their forerunners could have functioned adequately as peptide enzymes using the vitamin coenzymes in lieu of greater protein complexity. It should be noted that the most conservative regions of protein structure are the active site regions, and these sequences may even be common to enzymes which catalyze different reactions (Goodwin et al, 1964). This conservatism in active site sequence strongly suggests a primitive origin.

The results of arcing experiments also demonstrate that most of the amino acid carbon is contained in peptides of rather low molecular weight (Matthews and Moser, 1967, Fig. 2), and lastly, if one assumes that polymer composition reflects the stoichiometry expected from a statistical increase in precursor amino acid complexity, then proline, a structurally simple amino acid which interferes with helix formation, should occur often enough to prevent long α helical segments.

GEOGRAPHY OF FIELD DISTRIBUTION

The particular field configurations diagrammed in Figures 4 through 6 would have been localized rather than distributed over a wide geographic area within the conducting core-ionosphere cavity. The Earth's static electric field strength is highest in the central latitudes and decreases toward the poles and equator (Presman, 1970). Its average value today is $E_0 = 130$ V/m on a clear day. With cloud cover this value increases to thousands of volts per meter. Further, with an increase in distance from the Earth's surface, the value decreases exponentially. Thus the E component in Figures 4 through 6 was maximum at the surface of the Earth in the middle latitudes. The field strength of this component must have been thousands of volts per meter due to the dense cloud cover that would have probably existed during the Precambrian period.

The magnetic field has a similar uneven distribution over the Earth's surface. The vertical component is high at the poles where it equals 0.6 to 0.7 oersteds (Oe) and almost zero at the equator and middle latitudes (Presman, 1970). There is also a strong vertical component over surface iron fields which exist almost exclusively in central latitudes. For example, in the Kursk region of Russia, the value is nearly double that of the poles, with $H = 1.0$ to 1.5 Oe. Thus the maximum effect of the static H field in Figures 4 through 6 would be at the poles and over iron deposits that cause "magnetic anomalies". The combined effects of both static fields would be most apparent at the Earth's surface near vast surface iron deposits in the central latitudes.

The time-changing E field in Figures 4 through 6 would also be significant near the Earth's surface. In a resonant cavity, E_t is maximum at the electrical center, with H_t maximum at the the reflecting surfaces. In the case of the Earth's cavity, with conducting core-ionosphere surfaces, the resonant electric field would have a large value near the Earth's surface, when one takes into consideration the dielectric properties of the Earth's crust and the depth of the conducting core below the surface. Thus with these considerations, one is led to conclude that the maximum resolving effect of all of the field components diagrammed in Figures 4 through 6 would be near the Earth's surface over iron deposits in central latitudes. Further, arcing activity and associated shock wave effects would also be concentrated in this region, and thus atmospheric breakdown and resulting organic synthesis would be local rather than general.

OTHER FIELD EFFECTS

The theoretical conclusions above concerning the biologic and chemical effects of these fields lead to other hypotheses, several of which can be supported on the basis of the observations of other investigators.

Life formation and asymmetry should be geographically related. Most of the world's major iron deposits are concentrated in central latitudes, the largest being near the Greak Lakes in Canada. We have mentioned that the Earth's atmospheric disturbances and their consequent organic synthesis would have been local rather than general. The "Great Red Spot" of Jupiter might represent a contemporary manifestation of this phenomenon where several investigators have reported conditions compatible for organic synthesis (Michaux, 1967; Sagan, 1964). Evidence about the primitive Earth is limited due to the paucity of early fossil forms, less than 50 to date that are of sufficient age. However, there is a clear association between the earliest fossil forms and sedimentary iron deposits (Schopf et al, 1965). All of these which have been examined contain proteins which are composed exclusively of L amino acids. Another association of potential importance is that the proteins believed to have evolved in early life forms, ferrodoxin and cytochrome C, both contain iron. Ferrodoxin, universally distributed in higher and lower plants, is the protein with an oxidation-reduction potential closest to that of molecular hydrogen which was the dominant gas in the Earth's early atmosphere.

An interesting, perhaps related, observation is the association of morphological and chemical asymmetry with central latitudes, whereas racemic morphology predominates at equatorial regions as seen in Table 4 (Klabunovskii, et al, 1959).

TABLE 4

GEOGRAPHICAL DISTRIBUTION OF DISSYMMETRIC FORMS

<u>Contemporary forms</u>	High Latitudes	Found in the equitorial zone and areas of slight polarization
Colonies of B. mycoides	L	L and D
Molluscs--Prosobranchia		
Lonistes,	D	D and L
Planorbis	D	D and L
Partula saturnalis	---	D and L
Achatinella mustelina	---	D and L
<u>Ancient forms</u>		
Molluscs--Fusus antiquus	---	L and (D?)
Gastropoda (protoconch)	---	L and (D?)
Petroleums	D	D and L

The occurrence of asymmetry in central latitudes would be predicted if the resolving forces described above are expressed at the morphological level.

Biologic macromolecules should have heretofore unrecognized physical properties reflecting their sensitivity to the field configurations described above. Proteins, for instance, may exhibit electromagnetic structural features that are not apparent from their gross physical appearance as indicated by x-ray crystalography. The similarities of structure between the subunits of the iron-containing proteins, myoglobin and hemoglobin, may represent a case illustrating a preferred electromagnetic configuration. X-ray studies of hemoglobin by Perutz (1965) have shown that each of the hemoglobin chains has the same overall shape as the myoglobin molecule even though 80 percent of the amino acids have changed. These data clearly suggest a preference for conformation that is independent of primary structure. Further, the similarity in structure extends to hemoglobin chains of such divergent species as worms and insects. These complex twistings and foldings of tertiary structure in proteins, which have thus far eluded a consistent explanation, may represent an overall electrical helix or some other structure influenced by unappreciated features in their present electromagnetic environment and that also existed at the time of their formation and during their evolution.

NUCLEIC ACIDS

Nucleic acids seem to us to be an evolutionary development for preserving evolutionary advancement. Being removed by several steps from continual catalytic function, they would not be as subject as proteins are, to continual evolutionary pressure. Primitive cells could have been nearly self-sufficient. If cells had an impetus for mass maintenance, then there were enzyme peptides and coenzymes to do the work catalytically, and adequate foodstuffs in their environment for their heterotrophic nutrition. Peptides were in no shorter supply than other molecules of comparable complexity such as ATP; thus, reproduction among coacervate-like forms could take place with some guarantee that each coacervate globule would acquire all of the enzymatic components it needed for its relatively simple tasks of survival and reproduction.

We believe that the synthesis of nucleic acids may have acquired catalytic or structural assistance from preexisting proteins. Only the peptides have been synthesized in arcing experiments at basic pH's. Nucleic acids at this pH would not be dipolar but rather strongly negative and attracted to basic proteins of opposite charge. Lacey et al (1969) and Woese (1968) have demonstrated the preferential interactions between poly-L-arginine and poly-L-lysine and certain nucleotides, and Woese has speculated that these interactions might represent a rudimentary, primaeval translation system. Lacey and Pruitt's (1969) observations on the origin of the genetic code support this scheme. Wald (1957) has pointed out that the preferred right-handed direction in nucleic acid helices may result from their association with proteins.

POLYPHOSPHATE AND PHOSPHATE ESTERS

The arguments for the central role of polyphosphates and phosphate esters in biogenesis (Gabel, 1965), based upon the near universal distribution of polyphosphates and their ability to aid in polymerization, suffer from several deficiencies. Polyphosphate and phosphate ester catalyzed polymerizations are acid catalyzed and therefore of questionable compatability with the primitive Earth Conditions. Phosphate, in spite of its obvious importance in biochemistry, is relatively rare in the environment. Polyphosphate might represent no more than a storage reservoir of this critical substance. Baker and Schmidt (1964) demonstrated in Chlorella pyrenoidosa that ^{32}P is mobilized from polyphosphate during nuclear division into the nucleotide pool only in a phosphate deficient medium. This study clearly demonstrates that at least in Chlorella, polyphosphate does not serve as a phosphagen or energy source during the most active period of nucleic acid synthesis, except when cells were starved for phosphate.

PRE-CELLULAR ORGANIZATION

The dynamic field forces of the planetary resonator should also have had effects on cellular organization. In addition to the proteinoids of Fox (1970) or the coacervates of Oparin (1965, 1972), both of which require protein for their formation, cell-like forms have also been obtained by an unknown mechanism as products from arcing in primitive-Earth gas mixtures. Grossenbacher and Knight (1965) observed a turbidity in their liquid phase which upon microscopic examination of stained material "looked vaguely suggestive of bacteria". Examination under the electron microscope revealed solid bodies which ranged in size from 800 Å to 50 Å or less. These materials appear only after arcing. Upon analysis the dense spherules (1.8 density) were found to contain large amounts of mineral, 10 percent carbon, and ninhydrin reactive material. The high mineral content might represent silicates produced from the action of ammonia on glass. We obtained similar structures in our arcing experiments, some of the more interesting representatives of which are shown in Figure 7 (a-d). Note in Figure 7a and b the apparent tear in the "membrane". We have not analyzed our "spherules", but we would agree with Grossenbacher et al (1965) that they are probably organics adsorbed by silicates. This observation would be consistent with a prediction of an early formation of diatomaceous life forms with outer coatings of silica, since aqueous ammonia in contact with silica would have been widespread in the primitive Earth environment. Further, fossil forms of living organisms are most commonly found entrapped and embedded in rapidly deposited colloidal silica which infilled the cell lumens of microorganisms leaving their organic cell walls intact (Schopf, 1972).

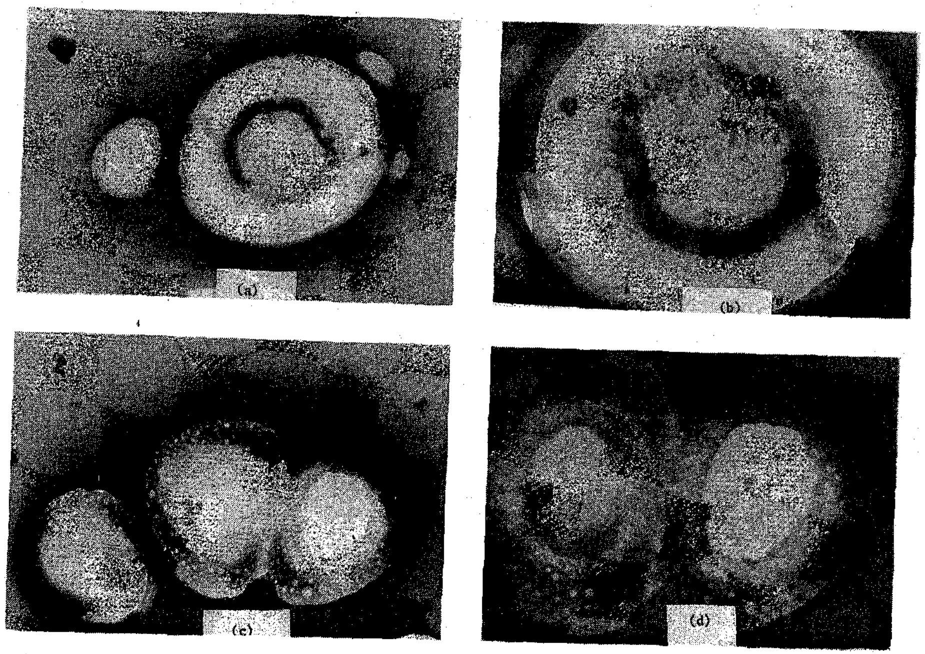


Figure 7. Electron micrographs of cell-like forms obtained as products from arcing in primitive Earth gas mixtures. Note tear in "membrane" in (a) and (b).

ELECTRICAL CONTROL OF CELL DIVISION

The implication of the observations in the preceding section is that once proteins and other polymers form, cellular formation and evolution are inevitable; but evolution is a dynamic event. Changes do not occur without an impetus from the environment which makes change advantageous. According to Simpson (1965), an opportunity for change must exist in the environment which evolution exploits to the benefit of subsequent generations. The accretion of mass for its sake alone would be pointless and random. Oparin (1972) comments, "...It is important to have in view that the above-mentioned external sources of energy not only cause synthesis of organic substances but also their decomposition. Thermodynamic equilibrium does not in general contribute to the advantage of synthesis. Thus, the organic materials that arose abiogenically on the surface of this or that cosmic body did not have to evolve further, as on Earth." On the other hand, uniformity of mass presupposes an environmental constraint on size. There must be an impetus to grow and, once size is obtained, a stimulus for mass reduction through division. In the proposed electromagnetic fields of the primitive Earth such an impetus is provided. Charged polymeric cellular constituents, and thus cells themselves, would have had to strive for an electromechanical mass equilibrium in an external time-changing electromagnetic field. That such phenomena exist is demonstrated in the measurements of relaxation times of proteins in alternating fields (Haurowitz, 1963); whereas, amino acids respond at higher frequencies, proteins, being larger, require longer times or slower frequencies to complete their oscillations. Aggregations of proteins of cellular size would require correspondingly longer times or yet slower frequencies. At 10^7 cycles per second and faster, proteins no longer increase the dielectric properties of water. Larger proteins will not respond at frequencies above 10^5 cycles per second. Presumably, cells would require frequencies several orders of magnitude lower in order to respond. The estimate of minimum cell diameter, conservatively 1000 Å (Margulis, 1972), based upon space requirements for genetic material to code for the enzymes necessary for reproduction, is several orders of magnitude larger in volume than the largest proteins. Thus an environmental factor such as the 10 Hz field we have described might have been a crucial determinant of cell size and thus an impetus for both growth and division. Such a conclusion at first may seem tenuous, but then what is metabolism in its simplest form but the maintenance of mass balance? Under the influence of a dynamic external field, microstructures would have the time and impetus for the selection of proteins that had an attendant catalytic property to aid in the maintenance of mass, i.e., catabolic and anabolic enzymes. Certainly, some external force was necessary to allow time for proteins to evolve to use alternate forms of energy such as solar radiation. In short, there had to be a greater difference between the "quick and the dead" than simply time.

The speculation above, of the electrical control of cell division, is not without support by observations of other investigators. In the most primitive cell models, Booij (1967) has shown that coacervates may show a creeping motion and internal circulation when placed in an electrical field. Other investigators have observed electrical field changes correlated with cellular necrosis and hyperplasia as pointed out in a review of the subject by Ravitz (1962). The relationship between cellular damage and necrosis and a "current of injury" has been observed for at least a century. Singer (1954) demonstrated that the ability to regenerate limbs in animals is related to nerve supply. He induced limb regeneration in two non-regenerating species by surgically increasing the nerve supply to newly severed limbs. Recently Becker (1972) has stimulated cellular activity and partial limb regeneration electrically using minute currents.

Neuman and Katchalsky (1972) have performed an experiment that might elucidate some of these experiments at a molecular level. They were able to induce a partial unwinding of a multistranded polynucleotide with a 20 kV/cm applied electrical field, which as the authors point out, is comparable to the potential across the 100 Å nerve membrane after excitation. These long-lived conformational changes may provide the vector for changing nerve impulses into protein synthesis since unwinding of the nucleic acid helix is the first step in code translation that results ultimately in the synthesis of new protein. Persina and Geynisman (1972) have data consistent with this hypothesis. They have shown that protein content diminishes in inhibited neurons but increases in those subjected to stimulation. Thus, there exists a large body of observations, from which we have selected but a few, to illustrate that the concerted growth and division of cells in multicellular organisms is still dependent upon electrical fields, and thus the necessity of the evolution of an electrical nervous network to produce such fields.

PROTEIN OR PEPTIDE TRANSDUCTION

Though many of the above cited electrical phenomena are not clearly connected with low-frequency time-changing fields, at least one observation requires a physiologic transduction mechanism for this region of the electromagnetic spectrum. Human subjects placed in an underground bunker showed a gradual desynchronization of circadian kidney excretion and body temperature, both of which were resynchronized by exposure to a 10 Hz 25mV/cm externally applied field (Wever, 1968).

As is well known, the Hertzian dipole is considered to be the most basic of all radiating or receiving elements of electromagnetic radiation. By definition, a dipolar protein molecule, excited by a 10 Hz electromagnetic wave, approaches being a theoretical Hertzian dipole. However, it must be recalled that the protein charges are bound and not allowed to move freely over the length of the molecule. In view of the elasticity of the protein molecule, however, it is quite possible for a 10 Hz mechanical vibration to be set up in the molecule due to the impinging field. If the molecular vibration at low frequency resulted in a conformational change in the protein, then this could have far-reaching biological effects. It was pointed out in an earlier paper (Cole and Graf, 1973) that proteins, aside from exerting functional control as enzymes, a transport mechanism, structural units, etc., occupy the ultimate level of control in higher organisms in the form of pituitary and hypothalamic hormones. As control becomes more ultimate, the peptides become simpler. As an illustration of this mechanism, conformational changes in these hormones could affect their ability to combine with their membrane receptors and thus these hormones could operate as a transduction system bridging the gap between absorption of radiation and physiologic change.

We have described in an earlier paper a mechanism by which proteins and peptides might act as an ultrasensitive biocommunications system by acting as transreceivers of ELF radiation (Cole and Graf, 1973) through protein resonance phenomena.

EVOLUTION OF THE ELF RESPONSE

Biologic response to ELF radiation would represent an evolutionary advancement for the organism since the ability of ELF to penetrate biologic material provides an instantaneous "deep level" control system. Presman (1970) pointed out that such a deep level control and communication system would be of survival advantage as a warning system and, as he pointed out, animal fright and flock behavior could be a manifestation of this system. In addition, such control systems could be regulated ultimately by a phenomenon no less stable than the ELF time changing field of the Earth and thus could serve as the master clock or Zeitgeber (Konig, 1962). An invariant timing device would obviously be helpful in the complex coordination of the various physiologic processes.

SUMMARY

We have presented a theoretical case for the origins of biologic sensitivity to low-frequency electromagnetic radiation (ELF) and electromagnetic events in the 10 Hz region which date from the origins of life itself. As the eye has an evolved sensitivity to the major region of the electromagnetic solar spectrum reaching the Earth's surface, the visible, so it could be with an ELF biological response of a living organism. This response could be no more than another example of an organism's adaption to a pervasive environmental factor: The 10 Hz component of the Earth's natural electromagnetic fields.

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ELF ELECTRIC AND MAGNETIC FIELD EFFECTS: THE PATTERNS AND THE PROBLEMS

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Whether ELF and VLF electric and magnetic fields influence biological systems to any significant extent and are consequently of practical importance per se will not be determined from the contents of this text. No doubt the *implications* of biofrequency magnetic and electric field effects are interesting, and there is strong evidence presented in this text that some behavioural-biological changes are associated with the presence of either environmental or experimentally produced ELF fields. However, there are still many control problems that must be resolved. In such a complex research area with limited available data, unjustified, irrelevant and often misleading interpretations can be made about the implications of results. Data collected by a small group of observers from different disciplines and conclusions drawn from data collected on one discourse level but generalized to another, must be taken with some reservation when the subject matter is new or apparently contradictory.

The object of this text was not to establish proof that ELF fields produced in the environment or in laboratory settings are important or effectual. At present the data are still insufficient in number. This may be due to factors intrinsically related to the problems mentioned. On the other hand, contradictory results may only suggest that the *stimulus characteristics of ELF fields to which the organism responds are much more complex than expected* and are presently being ignored or not measured by the experimenters. Further data collection must follow.

GENERAL SUMMARY OF RESULTS

The data collected and presented for this text as well as data reported from other sources, indicate that the presence of ELF electric and magnetic fields (when animals are exposed to test situations) do not significantly affect behaviours which are specific to particular stimulus operations, in any consistent manner. The chapter by de Lorge and Marr, which included a number of superbly executed and controlled operant methodologies, demonstrated little evidence that low intensity ELF electric or magnetic fields were detectable by the organism or affected the strong stimulus control of the operant schedules used. König's chapter on ELF-RT changes for human subjects, whose behaviours were maintained by operations other than food-deprivation or shock avoidance, indicated that significant field-related results were possible, but that a number of controlling variables had not been measured. The implications of these results will be discussed later.

On the other hand, more diffuse behaviours, such as ambulation or emotional responses, which are controlled by a variety of environmental stimuli, have been reported to vary as a function of ELF electric or magnetic field application. The chapters by Persinger, Lafrenière and Ossenkopp, and Altmann strongly suggested that changes in motoric activity were reliably associated with ELF field exposures. It is interesting that changes in activity levels associated with ELF field exposures have been reported for primates who otherwise had not demonstrated field-related response changes in operant or discrete responding situations (de Lorge, 1973a).

Chapters by Wever and Altmann indicated that ELF electric and magnetic fields may not primarily control specific task related behaviours but involve diffuse and long-term behaviours. Both Wever and Altmann found that shielding of ambient ELF and VLF field components was associated with deviations in circadian functions and a number of behaviourally and physiologically related measures. Such aberrant conditions could, however, be attenuated when artificial 10-Hz electric fields were applied to the experimental situation. Comparable results were reported by Persinger, Lafrenière and Ossenkopp. In their studies, rats that had been exposed perinatally to an ELF field, with a dominant magnetic component, were observed to display behaviours different than control rats. However, such differences could be reduced by re-exposing the perinatally RMF-exposed rats (as adults) into the field condition in which they had been born. Such data are commensurate with the theories and experiments presented in the chapter written by Cole and Graf. These authors suggest that ELF resonance fields were temporally contiguous with and instrumental in life formation. Consequently, some of the primitive life support systems in life forms may have an endogenous tendency to respond to variations in the external ambient ELF fields. Complete removal or shielding of these fields has been presumed to have undesirable side effects, especially if the fields are functioning as Zeitgebers.

The physiological bases of the behavioural observations seem to involve the autonomic-endocrine systems. Fluctuations in endocrine tissue weights as well as those behaviours known to be associated with endocrine function have been reported. Corresponding changes in water consumption (the chapters by Altmann and Persinger, Lafrenière and Ossenkopp), oxygen consumption, cation distributions and related changes may occur concomitantly or following ELF magnetic field or electric field exposures. Selective effects on enzyme systems and resonance interactions with liquid crystals, specific protein structures, or intraorganismic structures, have been suggested as the mechanism of interaction. However, the actual mechanism, or more probably mechanisms, are not clear.

CONSIDERATIONS, INTERACTIONS AND IMPORTANT CONTROL VARIABLES

ELF electric field and magnetic field effects are not uniform in their manifestations. Instead, they seem to be complicated with several unspecified variables or specific conditions. Cognizance of these problems is important.

Stimulus Characteristics

It is important to control stimulus characteristics of ELF fields precisely. Parameters which now seem important may be shown to be control features of the effect. We have seen the confusion in ionizing radiation research before the variables of dose rate, cumulative dose, inter-dose intervals or radiation sources were specified.

Stimulus shape. If indeed ELF external fields mediate their putative effects on life systems through a resonance interaction with bioelectrical processes, then the shape of the applied field configuration would be critical. From the data presented in Ludwig's and König's chapters, it is apparent that ELF signals from the environment can occur as ELF waves, per se, or as ELF pulses from higher frequency waves. Often laboratory experiments which involved different wave shapes are compared or considered as equivalent. However, direct comparison of the efficacy of different stimulus shapes must be made within the same experiment before any such conclusions can be made. These experiments have not been completed.

That different field shapes are preferentially effective can be demonstrated for fish. Bullock (1973) reported experiments with fish that are selectively responsive to pulsed fields while others are more sensitive to sinusoidal fields. Pulsed magnetic fields (10 to 20 gauss), with waveforms similar to electrical discharge patterns of the fish, can significantly influence its behaviour (Werber, Sparks and Goetz, 1972). According to Flanigan and Caldwell (1971), pulsed fields would have more neurophysiological effects than sinusoidal or d.c. fields. Recent data indicate that pulsed fields within the ELF range can influence oxygen consumption more effectively at lower intensities (1 V/m) than sinusoidal or square wave frequencies (Lotmar, Ranscht-Froemsdorff and Weise, 1969). However, sinusoidal wave forms can presumably be important at very low intensities for some behavioural tasks (see König, p. 86).

Frequency. The frequency of the applied field would be theoretically important for at least two reasons. First, at lower ELF regions, a shift in electric/magnetic components take place. Pierce (1960) states that below 20-Hz, which includes the majority of important bioelectrical-behavioural correlates, there is probably a change-over in nature from dominance of the electromagnetic to the magnetic component. From Ludwig's chapter, it can be seen that the electric component of ELF fields is shielded with relative ease; however, the magnetic component still has significant penetrability (and potential bioeffectiveness) in this frequency range. Secondly, if the applied ELF field influences biological structures with similar biofrequencies, then different applied frequencies would influence different structures and consequently different behaviours.

Sensitivity to narrow frequency bands has been demonstrated for fish. Bullock (1973) reports that most non-electrogenic, electroreceptive fishes are sensitive to electric fields between 0.1-Hz and 10-Hz. Sensitivity falls off rapidly above 10-Hz. Narrow band sensitivity to high ELF or low VLF signals, especially those which are of social or individual significance, also have been demonstrated for fish (Werber, Sparks and Goetz, 1972). Applied fields which are outside this range are less effective or ineffective.

In mammals similar differential responding to very small frequency changes have been reported for ELF fields. Whereas 1.75-Hz or 5-Hz electric fields suppressed activity in birds, a 10-Hz field increased activity (Altmann's chapter). Similarly, 10-Hz electric fields are associated with different directions of human reaction time changes than 3-Hz electric fields, according to the data of König and Hamer (p. 81). Differential changes in RT variability for human subjects were also noticed with 3-Hz and 10-Hz electric fields in short term (40 minute) exposure experiments (Persinger, Lafrenière, Mainprize, 1974).

The width of effective frequency bands and the number of effective bands have not been determined. König (p. 94) suggests that the shift in field frequency might also determine the intensity at which the organism best responds. Fish and perhaps human primates could be sensitive to changes of 0.1-Hz (Bullock, 1973; Friedman, Becker and Bachman, 1967). It is difficult to understand how such small frequency changes would be associated with different effects. However, many aberrant physiological conditions and even "consciousness" in human subjects are associated with only brain frequency shifts of < 1-Hz to ∿ 3-Hz.

One would also expect a number of effective frequency bands that reflect field interactions with the harmonics of fundamental bioelectrical frequencies. Presman (1970) reports a number of experiments that indicate possible harmonic (higher frequency) components of fundamental cardiofrequencies and brain frequencies. Harmonic-like responses have been reported to photic frequencies (Holubar, 1969, p. 83-84). Unfortunately, few experimenters have approached life forms from this point of view.

Existence of narrow band sensitivity to either experimentally or naturally applied ELF fields is expected within the framework of Cole's and Graf's model. The apparent similarity between well-known brain rhythms and ambient ELF weather related signal patterns (König, p. 84) are interesting in this context. Responses to a small range of frequencies are not unusual within the nervous system and have been demonstrated with photic driving of the alpha rhythm, motion sickness and similar frequency dependent problems.

Until data have demonstrated otherwise, quick and indiscriminate comparisons of experiments which have dealt with different frequencies within the ELF range should be avoided. This restraint should be especially applied to comparisons of effects from fields within major biofrequency ranges (1 to 10-Hz) relative to those within minor biofrequency ranges (> 50-Hz). Some experimenters have prematurely dismissed the importance of biofrequency time-varying magnetic and electric fields by generalizing from results collected with higher frequency bands (e.g., 45 to 100-Hz).

Intensity. In the first chapter it was mentioned that invertebrates and perhaps birds may be maximally responsive to ambient static magnetic fields around natural intensity levels. One could argue that such "key-hole" intensity effects (Persinger, 1974) reflected the narrow band effective current intensities (around 1 mμA) discussed by Becker (1972). Reille's (1968) experiments with cardiac conditioning in birds presumably used field levels of 0.15 gauss. Lotmar, Ranscht-Froemsdorff and Weise's (1969) ELF-pulsed VLF electric field effects upon tissue respiration presumably occurred at natural intensity levels. The Frank Brown effect can be achieved with intensities between 0.05 gauss and 4.0 gauss (Brown and Park, 1965).

The sensitivity of organisms to a narrow band of ambient field intensities would be an important limit to many studies. Studies which employed 10 gauss fields (for example) may not be at optimal levels unless less intense field values were also produced that fell within effective ranges (e.g., heterogenous fields). Future experiments should deal with the effects of small incremental changes at intensity levels approximating geomagnetic disturbances or the magnetic component of ELF fields. Although such selective responses to small intensities are presently without apparent mechanism, they are quite consistent with the models of Cole and Graf. If ELF fields were involved with abiogenesis, then sensitivity to those appropriate field levels should still be existent. This does not mean, however, that the organism would not respond to higher intensity fields by different mechanisms. The potentially low energy associated with ambient ELF fields should not be used as evidence against their possible effectiveness. Less than twenty years ago, before the mechanisms of selective isotope concentration were known, the possibility that low (background) level radiation could produce infant mortality or leukemia was also considered highly unlikely (Sternglass, 1972).

Electric vs. magnetic fields. Some experimenters have employed ELF fields with relatively large electrical components while others use fields with predominant magnetic components. The selection of the component is important since it will also determine the field's penetrability at ELF frequencies (Ludwig's chapter). The efficacy of the two components is yet to be established. Werber, Sparks and Goetz (1972) indicate that fish behaviour in a pulsing magnetic field is markedly different from that in a pulsing electric current, indicating that sensitivity to induced current is only one component of the electromagnetic stimulus complex. On the other hand, McCleave, Albert and Richardson (1974) claim that ostensible ELF magnetic field sensitivity in fish and eels is actually due to the electric field produced by motion of the magnetic field. Such electric fields would produce very low currents, but their intensities would still be within Becker ranges. Similarly, Lotmar, Ranscht-Froemsdorff and Weise (1969) found that only the electric field component was important for these tissue respiration changes in their experiments. Further direct comparison experiments are required.

Interaction with Ambients

Very few experimenters working with ELF electric or magnetic fields have attempted to shield ambient ELF signals. Such shielding would be difficult anyway for magnetic components according to the data from Ludwig's chapter. Certainly, magnetic storms or local weather variations would contribute to incident ELF signals. Extra electrical charges, associated with transient high electric fields or local ionization, upon skin surfaces would alter the resistivity and consequently the penetrability of at least the electric field components.

Analagous possibilities can be seen in the experiments by Mikolajczyk (1963). He found that decreases in hexosamine levels in rabbits occurred when they were placed in experimental atmospheric pressure-reduced chambers. However, the degree of the decrease in hexosamine levels was a function of the ambient atmospheric pressure before the animals were placed into the experimental chambers. It seemed that treatment of animals with reduced air pressure at the time of a natural tendency for increasing atmospheric pressure resulted in a more significant decrease of hexosamine levels than for periods typified by decreasing atmospheric pressure.

The orientation of the experimental field also would be important. It is known that horizontal static magnetic fields are associated with different effects than vertical static magnetic fields (Barnothy, 1964). In nature, horizontal magnetic field variations and concomitant vertical electrical changes are presumably more frequent than the alternate combination. Consequently, relative orientation of experimental components with respect to local magnetic and electric field configurations should be considered. Seasonal or daily variations in ambient EMF stimuli would not be irrelevant. Yearly amplitude ranges can be quite large and may be responsible for some of the seasonally-dependent ELF phenomena.

Effect vs. Detection: Long Term vs. Short Term Exposures

Although the concept is a simple one, many experimenters seem to confuse the results of experiments which were concerned with detection of ELF fields by test organisms and the effects of ELF fields upon test organisms. An organism does not have to detect a stimulus in order to be influenced by it. Fishes and invertebrates do seem to detect ELF fields within a brief period of application. However, the experiments by de Lorge and Marr indicate that rats and non-human primates cannot detect ELF field presence within short periods (of a few minutes to hours), whether it be associated with aversive stimuli or merely concomitantly applied during operant responding.

With human subjects, the problem of detection and effect becomes even more complex since the role of "consciousness" becomes an important factor. König (p. 92) has mentioned that subjects exposed to 3-Hz ELF fields report subjective complaints during and after the periods associated with RT decrements. Such subjective sensations were not reported as intensely by subjects tested by Hamer (1968). Persinger, Lafrenière and Mainprize (1974) who have tested more than 80 subjects for 40 minute intervals in 3-Hz/10-Hz (0.3 V/m or 3.0 V/m) situations, have never found a single case where there was strong evidence that the subjects' private experiences were coincident with field frequency changes. In fact, the type of private experiences did not vary from those reported by subjects in sham field situations. Nevertheless there were weak, but statistically significant, effects on reaction time variability within 10 minutes of field application. Latencies in this order of magnitude occur with ELF magnetic field effects (e.g., Travkin, 1972).

Implicitly involved with the problem of detection vs. effect and the different changes that take place with varying durations of ELF field exposures. There may be some argument that short term exposures, e.g., six to eight hours, may not significantly influence behavioural or physiological responses. On the other hand, long term exposures are associated with more positive reports. Depending upon a number of field parameters, e.g., pulse width, field intensity and pattern of field presentation, exposures of more than two to five days have been reported to be associated with a number of internally consistent behavioural, physiological, morphological and biochemical changes. It is not surprising that exposure length would be an important control factor for the field effect. Even with relatively simple behavioural responses, the consequence of a single stimulus presentation is markedly different from the effects of repeated and protracted presentations of the stimulus. If ELF field effects are mediated through some long latency system, e.g., thyroid, then time is required for the response to be initiated.

Operant vs. Respondent Measurements

The chapter by de Lorge and Marr succinctly describes the differences between operant and respondent paradigms. Essentially, the operant procedure requires the test subject to emit (or display) some response after which a reinforcer is delivered. In most experimental situations the response is a discrete movement. The respondent procedure (or Pavlovian conditioning) involves the presentation of the reinforcer, only the delivery is not contingent upon the animal's behaviour. The presentation of the reinforcer is instead programmed by the experimenter or the environment. Respondent procedures generally work best for responses associated with the autonomic-endocrine system, and are typically more diffuse in nature. Some theorists have argued that operant conditioning is more involved with skeletal muscles while respondent conditioning is more concerned with smooth muscle autonomic networks, although these distinctions are less exact since the discovery of biofeedback phenomena.

The distinction between the two types of conditioning and their structural substrates is an important one. A stimulus which effects one system may not necessarily affect the other. As any operant behaviourist knows, the behaviour of a test organism maintained by one of the fundamental reinforcement schedules is under strong stimulus control. Even variations in the environment, which physiologically may have significant consequences, may not alter response patterns maintained by these schedules. In experiments where changes in responding are coincident with the presentation of an external stimulus (e.g., drugs, ionizing radiation), direct changes in the mediating brain chemistry or indirect detection by specie-specific sense modalities (e.g., enhanced olfaction in the rat) are involved. Since data indicate that ELF magnetic and electric fields influence the autonomic nervous system, de Lorge and Marr's failure to detect ELF effects may indicate the response measure was not sensitive to the systems which mediated the stimulus effect. Such a result or statement should not be taken as an indictment against operant procedures; rather, it should be understood that some measurements may not reflect ELF magnetic or electric field presentations.

In one series of de Lorge's and Marr's experiments, the conditioned suppression paradigm was used, where response suppression during CS (conditioned stimulus) periods preceding aversive stimuli was attempted with ELF fields as the CSs. Their results were negative. However, again the dependent variable (lever pressing) was not one directly associated with the autonomic nervous system but instead with the discrete skeletal response system. Furthermore, in some of the experiments a standard CS (a light) was used to indicate shock presentation before the ELF fields were used as CSs. As a result the animals may have learned to use another stimulus as the CS. That learning may influence detection of weak stimuli has been demonstrated, e.g., the specific hunger controversy. Animals have a hierarchy of stimuli to which they respond. For a weak stimulus like an ELF magnetic field, the presence of, or previous conditioning with other stimuli could have a masking effect. For example, Walcott and Green (1974) and Lutsyuk and Nazarchuk (1971) reported that pigeons respond to natural horizontal magnetic field cues when more obvious cues, e.g., the sun position or star sky, were not available.

Experiments which have involved ELF fields as CSs in respondent paradigms have been more successful. Kholodov (1964) could condition electrodefensive responses in fishes with static magnetic fields (10^2 gauss) as CSs, while Yakovleva and Medvedeva (1972) have demonstrated cardiac conditioning in birds to a constant magnetic field of 520 gauss presented before electric shock. Reille (1968), who used both static, ELF and VLF magnetic fields (< 1 gauss) as possible CSs before shock, found that increased heart rate conditioning was more effective with 0.2-Hz and 0.5-Hz fields rather than 300-Hz, 500-Hz or static fields. Similar paradigms for cardiac conditioning have been reported for eels and fish when ELF electric fields were used as CSs (McCleave, Albert and Richardson, 1974). Further experimentation with respondent models, preferably without electric shock as the UCS, are suggested.

Antecedent Operations and Individual Differences

One of the most interesting and complicated features of biological feedback systems is the response dependence upon background activation of the system at the time of stimulation. Principles like Wilder's law of initial values are instrumental to the understanding of biological phenomena. It is known, for example, that excessive stimulation of the sympathetic nervous system when it is already stimulated near asymptotic levels, may actually produce a decrease in activation, or parasympathetic "overshoot". Stimuli which contribute to resting levels of these systems can be either of exogenous or endogenous origin. Their importance can be exemplified by results associated with brain chemistry fluctuations. Margules et al (1972) found that norepinephrine applied to the perifornical medial forebrain bundle (ventral andrenergic bundle) suppressed eating when applied during the night. The opposite effect (enhanced eating) occurred when it was applied during the day. Many behaviours are a function of parasympathetic (night) or sympathetic (day) dominance (e.g., Brezowsky and Ranscht-Froemsdorff, 1966).

The importance of antecedent treatments of test organisms used in ELF experiments cannot be overemphasized. In fact, much of the apparently contradictory findings may involve these variables. As noted in the chapter by Persinger, Lafrenière and Ossenkopp, variables that are highly coupled to systems which seem to be most probably mediating the main field effects, can mask or confound results. Age of the organism, a factor which is highly correlated with thyroid activity--a tissue apparently influenced by the 0.5-Hz rotating magnetic fields, often influenced the direction of the field effect. Sex, another factor which is linked to endocrine function, was another variable that interacted with the field effect. Ambient temperature was still another. Particular effects of ELF magnetic fields on *groups* of food-deprived animals has interesting implications.

Other treatments that may influence relevant systems that mediate ELF magnetic field effects and hence influence the system's susceptibility to experimental effects would certainly involve previous emotional conditioning. It would be expected that the manner in which the test subjects were housed before or during the experiment would be important. Unfortunately many experimenters, upon receipt of test subjects from suppliers, quickly expose the subjects to experimental conditions. As pointed out by Grant, Hopkinson, Jennings and Jenner (1971), about four weeks in a constant environment are required for stability to occur (in rats).

<u>Individual differences</u>. Williams (1956) has cogently pointed out that in some situations assumptions of uniformity in group responding are weakly based. If responses to ELF signals are as precise as some authors maintain, then individual differences in responding would be an important issue. One would expect ELF exposed groups not to vary with respect to control groups in <u>mean</u> values of the response measured, but in the *variance* (standard deviation)

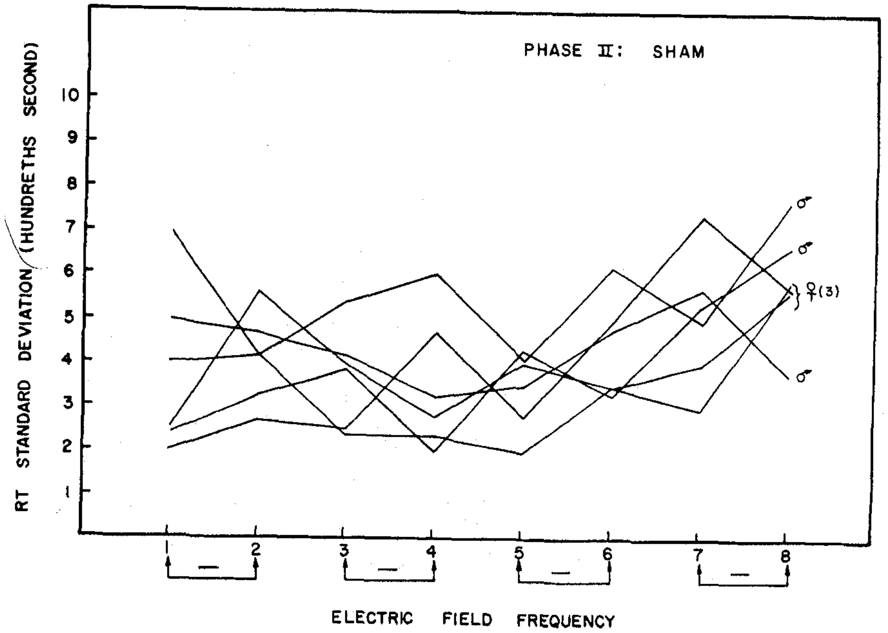

Figure 1. Reaction time (RT) standard deviations per block of 10 trials for different human subjects exposed to sham-field conditions. The RT task was to press a lever following the semi-random presentation of a light (unpublished data, Persinger, 1973).

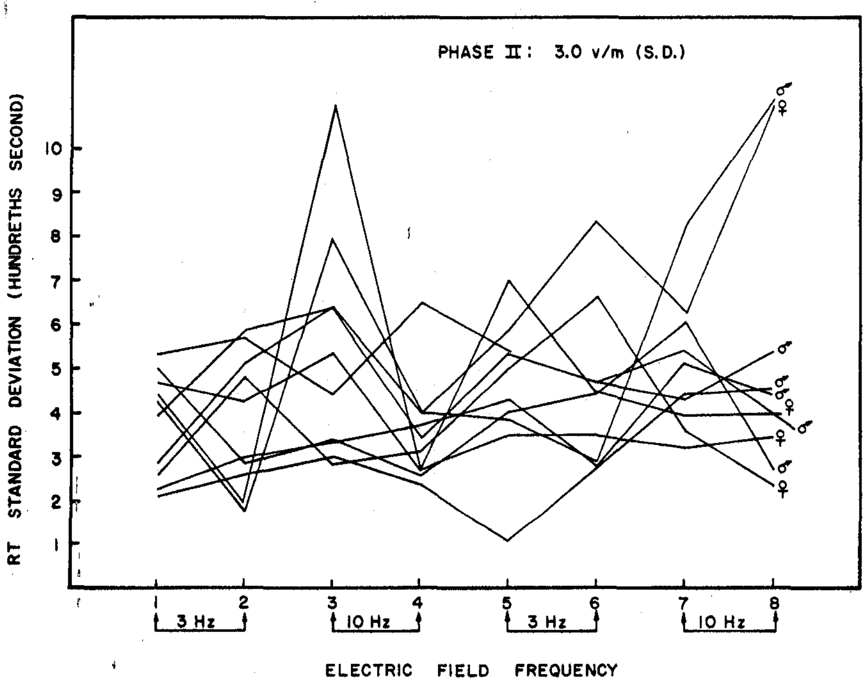

Figure 2. Reaction time (RT) standard deviations per block of 10 trials for different human subjects exposed to successive 10 minute presentations of either 3-Hz or 10-Hz 3.0 V/m electric fields. Total experimental time was 40 minutes (unpublished data, Persinger, 1973).

of the response measured. The measurements of different individuals, responding in different directions, would be expected to average out despite increased response *variability*. König (p. 98) also suggests that one should look at variability as an important ELF field effect. Figures 1 and 2 indicate some of the individual differences in responding that may occur during ELF experiments with human subjects.

The variables responsible for individual differences to ELF fields are not clear. Ludwig and Mecke (1968) have suggested that subjects should be classified on the basis of the degree of sympathetic or parasympathetic dominance (see Gellhorn and Loofbourrow, 1963) and autonomic lability or stability. Presumably, these individual differences would influence the subject's response sensitivity, response pattern and the frequency range to which he optimally responds. Both indirect and direct interactions with ELF fields could be expected. For example, autonomic instability could be associated with increased moistness of the skin boundary. When the skin is wet, average resistance drops from about 100,000 ohms (dry skin) to less than 1000 ohms. Such resistance changes could influence surface conductivities to ambient signals. Little data has been collected to support or reject the Ludwig model.

A further complication is that ELF fields, similar to natural levels, may be effective because they behave essentially as conditioned stimuli (CSs). In nature there is a tendency for ELF signals to precede fluctuations in barometric pressure. Stimulation of baroreceptors in response to barometric pressure fluctuations has been interpreted as a natural UCS (unconditioned stimulus) - UCR (unconditioned response) sequence. Since ELF signals may, in some localities, consistently precede atmospheric pressure changes, ELF signals could act as CSs which would evoke similar pressure-related behaviours. Such passive conditioning to the environment would not be incompatible with known respondent paradigms; it is known that some parasympathetic responses can precede barometric pressure changes by some hours. Consequently, successive presentations of ELF (CS) signals to the organism without UCS contiguity, would result in a gradual loss of the ELF field's effectiveness, i.e., extinction.

Stimulus and Response Patterns

Perhaps the most invaluable models for understanding biological servomechanisms has been produced by the systems approach. One aspect of the systems approach involves the critical role of change in stimulus input upon adjustment responses of the system. Step-, ramp- or impulse-like changes in stimulus input can produce a number of predictable adjustments in the system stimulated. Step-like changes in stimulus input (demand) result in *response transients* that are typified by oscillatory over- and under-compensatory adjustments that are slowly dampened as a function of several parameters of the system, over time. Ramp-like input changes may not necessarily be associated with the transient oscillatory adjustments. Similarly, impulse input changes may not influence the feedback system if the duration of the impulse is less than the system's response latency. If the impulse stimulation does affect the resting system, it may only produce mild stimulation, but no great instability. These models have been applied to hormone systems as well as to behavioural networks (Halasz, 1968).

Experiments using ELF fields have indicated that the stimulus application pattern is an important control variable of the results. When test subjects are suddenly placed in an ELF field and maintained there (step-like change), different results would be expected from situations where the field is applied intermittently for a brief amount of time. In addition, the time at which the measurements are taken after animals are placed in a step-like manner within the field may influence the results, depending upon which phase of over- or under-compensation the systems are displaying. In the chapter by Persinger, Lafrenière and Ossenkopp, it was mentioned that short, daily ELF stimulation was associated with increased eosinophil levels, while long term continuous ELF exposure was associated with decreased eosinophil levels. Tumors that were inhibited during the first 30 days of magnetic field exposure may actually show facilitated growth afterward. An experiment by Khananaev and Borodaikevich (1973) aptly demonstrated these effects. Whereas a 220 μsec pulsed magnetic field (14,000 Oe) delivered for 30 minutes accelerated chick embryonic development, one hour exposures inhibited embryonic development.

Initial stability of the system is also an important influence upon the systems adjustment or response to a new

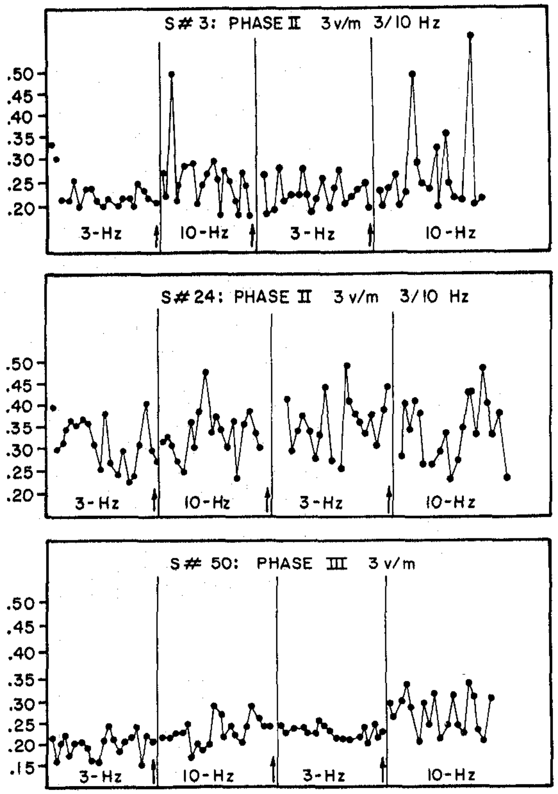

Figure 3. Individual reaction times (hundredths of a second) to semi-random presentations of a red light for subjects exposed to successive 10 minute presentations of 3-Hz or 10-Hz, 3.0 V/m electric fields (unpublished data, Persinger, 1973).

stimulus. The importance of this variable is demonstrated in Figure 3, which shows the reaction times of human subjects to light stimuli during successive 10 minute exposures to either 3-Hz or 10-Hz electric fields. Subject #3, who did not respond to the first 3-Hz field presentation, demonstrated significant RT variability when the 10-Hz field was instituted in a step-like manner. During the second 3-Hz field presentation, the RT variability did not return to normal, but was attenuated. Subject #24, on the other hand, who was relatively unstable during the 3-Hz presentation, did not show any significant oscillations when the 10-Hz field was presented. From a systems point of view, the system was already unstable. Consequently, a weak stimulus did not produce any observable perturbation. Subject #50 emitted patterns that indicated stabilizing effects from repeated frequency changes, followed by an oscillatory response upon the last 10-Hz presentation.

It is interesting that the mean reaction times of the subjects exposed to different field frequencies were not drastically altered. For those subjects which did show oscillatory changes in their RTs, the periodicity was around the normal maximum of 2.2 minutes (Stebel and Sinz, 1971). From these data one might conclude that the 10-Hz electric fields did not initiate oscillatory changes, but merely amplified endogenous rhythmicities already present in the system.

Stage of Development

The chapter by Persinger and his colleagues indicated that the developing fetus may be a sensitive model for testing ELF field effects. In a system with a myriad of critically timed processes in progress, the probability of an indirect or direct effect from a weak stimulus is increased. In fact, a number of chemical properties (e.g., immature astrocytic networks, high hyaluronic acid levels) in the fetus and neonate alter the electrical characteristics from those of the adult. The possibility that short term, developmentally-dependent sensitivities to local electric and magnetic stimuli may permanently alter the organism's response is suggested by the re-exposure experiments (p. 209) and by those changes which occur when natural ELF fields are removed (Altmann and Wever). The developing organism has been and will be an important experimental model for testing ELF field effects.

COMPARISONS TO HIGH INTENSITY STATIC ELECTRIC AND MAGNETIC FIELDS

Considerable research has been completed with static field intensities in the order of 10^3 to 10^4 gauss or 10^3 to 10^5 V/m. Most theorists have argued in favour of direct effects upon chemical or molecular processes. However, there may be ELF components interacting with the static field effects. König (p. 95) has pointed out that natural 8 to 12-Hz mechanical vibrations of the body (Rohracher vibrations) can produce significant ELF electric fields when the body is placed in a high intensity electric field. Similarly, high intensity magnetic fields would be expected to produce induced currents during animal motion through the field or in association with endogenous time-varying processes, e.g., heart beat, blood flow.

Although a complete review of high intensity static electric and magnetic field effects is beyond the scope of this book, general comparisons can be made. High intensity static magnetic fields are associated with endocrine changes (Barnothy, 1969, 1964), oxygen changes (Pereira, Nutini, Fardon and Cook, 1966), oxidative enzyme changes (Shyshlo and Shimkevich, 1966), attenuation of traumatic edema and pain (Degen, 1970; Hansen, 1938) in human patients, inhibition of tumor cell growth (Weber and Cerilli, 1971), and a number of immunological responses (e.g., Katola, 1970). Electrical changes in activity and morphology of glial cells have been reported (Kholodov, 1964) following static magnetic field exposure, but these effects may be indirectly evoked (Friedman and Carey, 1969). Deviations in blood clotting and similar histamine/connective tissue-correlated processes have also been reported.

Fewer investigations have been concerned with high intensity static electric fields. This statement does not include possible indirect effects from induced currents (Herin, 1968). In addition to the usual reports of deviations in blood clotting and variations in "colloid" suspensions, repeated 5-6 hour daily exposures of 400 V/cm electric fields are associated with decreased background firing of neurons (Shlyafer and Yakovleva, 1970). Constant electric fields of 100 V/cm can enhance silk production (Luca, Rosca, Chitan and Rusu, 1970). Presumably, human subjects who work for long periods of time around static electric fields displayed decreased immunological resistance and increased nervous system disorders (Minkh, Nepomnyaschkii and Portnov, 1971).

Qualitatively, the types of reports associated with high intensity static electric and magnetic fields do not differ significantly from those associated with low intensity ELF electric and magnetic fields. The quantitative differences between experimental groups exposed to high intensity static magnetic or electric fields and their control groups are generally not large (i.e., > 100%), and are within the same order of magnitude as those differences described in some ELF field experiments. Moreover, the total effects of either static or time-varying field treatments are rarely immense, but seem to fall within the normal adaptive range of biological potential and can be simulated by other agents, e.g., drugs. Many of the quantitative changes at various levels of measurement during high intensity static field or low intensity ELF field exposures are within the limits of endocrine function. Equivalent changes in endocrine equilibria can produce many behaviours at the same levels of magnitude as those associated with field exposure. Even phase shifting in circadian clocks can be induced by weak thyroid stimulation (Wahlstrom, 1965).

GENERAL CRITIQUE OF ELF RESEARCH AND SUGGESTIONS

Correlational Studies

Geomagnetic disturbances and ELF fluctuations have been correlated with a number of phenomena, many of which have been replicated in the laboratory with artificially produced fields. Fluctuations in the horizontal component of the geomagnetic field are associated with acute attacks of glaucoma (Zhokhov and Indeikin, 1970), oxygen changes (Barnwell, 1960), changes in bee activity (Lindauer, and Martin, 1968), blood clotting relationships, leukocyte counts (Alvarez, 1935), heart failures (Novikova, Gnevyshev, Tokareva, Ol, and Panov, 1968), and even emotional disturbances (Traute and Düll, 1935; Friedman, Becker and Bachman, 1963). Daily magnetic field deviations may influence invertebrate activity and orientation. Removal of the earth's magnetic field can modify orientation (G. Becker, 1966) or circadian rhythms of invertebrates (Bennett and Huguenin, 1969). Similarly, peripheral disorders such as smooth muscle spasms and allergic reactions supposedly are attenuated by placing the patient in magnetic and electric field shielded rooms (Novak, 1969).

Natural ELF field fluctuations are also correlated with similar processes. Variations in oxygen consumption (Lotmar and Ranscht-Froemsdorff, 1968), heart failures (Brezowsky and Ranscht-Froemsdorff, 1966), blood clotting, time perception, reaction time (König's chapter) and related phenomena are examples of such correlations.

A serious limitation of these correlations is that the phenomena measured are not under experimental control, and are occurring in a complex milieu of environmental variations. As de Lorge (1973b) aptly points out, barometric pressure changes also occurred with the now classic reaction time experiments at the Munich transportation fair reported by König. Many of the effects associated with variations in ELF fields are also known to be correlated with barometric pressure (e.g., Teng and Heyer, 1955). Changes in barometric pressure (and more importantly rate of change in barometric pressure) are correlated with biochemical processes that are ostensibly produced by ELF fields (Mikolajczyk, 1967; 1963).

Recently, geophysicists and meteorologists have shown that significant variations in atmospheric pressure and increased frequencies of low pressure air masses occur within one to five days following geomagnetic storms or passages of solar magnetic sector boundaries (Roberts and Olson, 1973; Wilcox, Scherrer, Svalgaard, Roberts and Olson, 1973). The role of non-magnetic stimuli must be considered when the significant correlations with biological phenomena occur some days after geomagnetic or ELF disturbances. Certainly they may reflect lag-response times of organismic systems, but they may also indicate that the organism is responding to other stimuli. That normal fluctuations in atmospheric pressure can be potent stimuli has been demonstrated by Mikolajczyk (1963).

Future studies involved with correlations between environmental magnetic field changes and biological systems should also include other ambient variables in their analyses. The application of multiple regression or analagous models would help determine which variables are most consistently related to variations in the biological measurement. As special precautions, those studies which show weak correlations between biological measurements and magnetic field variables on the same day, should also complete auto-correlations and lag-correlations to determine the role of more common weather factors (e.g., temperature, barometric pressure) that were fluctuating days or hours before. Even very impressive (but selected) data (Dubrov, 1970) could be coincidence or artifact in this context.

On the other hand, one should not dismiss all data on geomagnetic or ELF wave correlations as artifactually related to barometric pressure. Barnwell's (1960) data showed significant correlations between oxidative metabolism and the geomagnetic disturbance one to two days later. This suggests that more direct processes associated with the solar flares, including ELF fluctuations (Ormenyi, 1972), were more important than the corpuscular phases reaching the earth days later.

Experimental Studies

Lab levels vs. natural levels. There has been a tendency to generalize experimental data collected with lab-level field intensities to natural conditions. The assumption that "weak" magnetic or electric fields produce the same effect as naturally produced fields, has not been firmly supported with data. Although effects associated with weak magnetic (∿ 10 gauss) and electric fields (∿ 100 V/m) are interesting for a number of theoretical and academic reasons, they may not be representative of effects associated with natural conditions. Similarly, long term exposures to simple wave forms or time-varying field configurations (e.g., a 0.5-Hz rotating magnetic field) do not simulate natural ambients. ELF waves or geomagnetic disturbances last only for a few hours to a few days and demonstrate a more statistical pattern in both temporal distribution and field shape.

Apparatus artifacts. A common criticism against weak ELF field effects is that they are apparatus artifacts or due to experimenter biasing. The latter can only be remedied by replications in other laboratories. The former can be attenuated by designing experiments which directly compare effects from different field frequencies or intensities generated by the same apparatus. The use of apparatus with different designs but similar field configurations would be another control feature.

The possibility of artifact contribution must still be considered a viable explanation for some of the reported ELF field effects. Despite controls against vibration, noise, temperature and other ambients as well as a field intensity dependent effect, some of Persinger's studies did not employ sham field comparisons. Experimenters who have used ELF electric fields or magnetic fields generated by coils or plates must control for contamination from mechanical stimuli. Ultrasonic noise, infrasonic noise or coronal discharges generated by the equipment (Roberts, 1969) may be detectable by the test subject but not by the experimenter. Long forgotten experiments (Williams, 1931) indicate that some electromagnetic field designs can generate both audible and inaudible mechanical vibrations in the air. Mikolajczyk (1974) indicates that human urinary protein polysaccharide levels can be influenced by weak hand-transmitted mechanical vibrations from the human body. Control for these possible contaminants may be obtained by verifying orientation-, vector- or component-dependent phenomena in the presence of ELF electric and magnetic fields.

MECHANISMS

General Theories and Levels of Discourse

Different experimenters have presented different explanations for ELF field effects. Most of the theories are a function of the author's competence in a particular level of discourse or discipline. Whereas a behaviourist would be satisfied with an explanation based upon stimulus operations and known behavioural patterns, a physiologist prefers discussion at his level of expertise. However, when most scientists ask the question "how?", they are usually referring to the physical mechanisms with a physiochemical reference. Comments from scientists outside and within ELF research indicate that satisfaction only will be possible when a physical mechanism is demonstrated. This is not unreasonable since ELF fields are magnetic and electric stimuli; the primary level of effect would be expected in this mode. Mechanisms at other levels of discourse have been discussed by Persinger, Ludwig and Ossenkopp (1973).

The basic physicochemical mechanisms of ELF magnetic and electric field interaction have involved:

1) effects on dipole moments of macromolecules;
2) resonance interaction with some molecular species; or
3) coupling with time-varying electric or magnetic fields in the brain - body.

It usually has been assumed that the molecular species involved exhibits some susceptible property, such as weak ordering (e.g., liquid crystals or "colloids") that can be significantly influenced by particular weak forces. Unfortunately, the dynamics of the molecular or intramolecular species selected as the foci of interaction are as unclear as the ELF effects themselves.

Direct effects of ELF pulsed fields upon nerves by summation of sub-threshold oscillations have been suggested by the experiments of Bromm (1971). Intra-axonal dipole orientation would contribute to these effects (Schubert, 1974) as well as conformational changes along intracellular fibers which also have electric components (Hejnowicz, 1970). Other theorists have argued less specific reactions which involved "elastic" deformations of the oscillating microelements (Kevanishvili and Zhgenti, 1971). Biochemical "flip-flop" inductions in enzyme activities described by Comorosan (1971) could account for the frequency and intensity specificity of some ELF magnetic field effects.

Recently, more specific mechanisms have incorporated developments in solid state physics. Cope (1973) has suggested that organisms can detect weak magnetic fields (0.1 to 5.0 gauss) through electrons tunneling across junctions between superconductive micro-regions of living systems. The existence of such superconductive Josephson junctions in living systems would allow exceptional sensitivity to weak electromagnetic forces. In fact, peripheral nerve bundles have been reported to show unexpected attraction to magnetic fields (Kolta, 1973). However, this attraction is eliminated if the nerve bundles are immersed in lipid solvents.

Ludwig (Persinger, Ludwig and Ossenkopp, 1973) has directly calculated that bioeffective energies may be available at the synapse by a 10^{-4} second, 1 V/m, VLF pulse. Membranes resonating at the same frequency as an applied ELF field can presumably absorb energy from the field and increase the amplitude of oscillation. Stretch-like conformational changes in the membrane could then occur and changes in ion distributions would result. More detailed descriptions have been given elsewhere (Ludwig, Persinger and Ossenkopp, 1973). An analagous model has been postulated by Russo and Caldwell (1971). Using the neuroglial semiconductor model described by Robert Galambos, they argue that crystal properties of the neuroglial complex would allow directional and amplification effects from applied weak magnetic fields.

Interface Mechanisms

In the past biological scientists primarily have studied reactions which include single responses to single stimuli. Yet there are important diffuse reactions in the body which are initiated by a large variety of different stimuli and mechanisms. The famous Selye stress patterns are examples of such reactions. ELF electric and magnetic field effects are included within the latter category. According to Ludwig, the electric component of ELF fields would have little organismic penetrability, but could still influence peripheral receptors in the skin. Similar arguments could be made for VLF fields. Magnetic components of ELF fields would have greater penetrability and presumably affect other systems. Ludwig, in fact, has stated that VLF fields would affect the peripheral nervous system while ELF fields would affect the central nervous system. However, the consequences could be quite similar. Direct coupling effects of external ELF magnetic or electric fields with bioelectrical fields are options which have received little attention.

An Integrated Mechanism

If ELF electric and magnetic fields were involved with the formation of life forms (Cole and Graf), then these fields should still influence those diffuse but essential processes that were available to life-forms at that time. Reflexively catalytic reaction series (reflexive cycles), an emergence condition for origin of life (Hanson, 1966), would be specifically affected because of their time variation. One of the most common properties of biological systems is the ability to maintain ion-molecular concentration disparities through the use of membrane selective permeability. Such selectivity is in large part governed by a precariously balanced structure of lipoproteins that has been called the liquid crystal condition. There is strong evidence that lipids and lipoproteins are involved with other basic life processes relevant to ELF field interactions. Rhythmicities in heart cells are intrinsically related to lipid levels (Masoro, 1968). Lipid solvents, which change membrane selectivities to the ionic milieu, are important anesthetics and toxicants. The reported intense attraction of peripheral nerves to magnetic fields also seems dependent upon lipid structure (Kolta, 1973).

The liquid crystal condition of lipids at life temperature, water concentration, and pH (charge) exhibit a lamellar structure that is characterized by selective permeability. In this narrow band of environmental conditions, the bilamellar or "smectic mesophasic" structure is quite stable. Theoretical calculations indicate that when local variations in charges are increased (1.25 to 2.0 charges per phospholipid molecule), the "cylindrical miscelle" has lower free energy than the bilayer which consequently becomes unstable (Papahadjopoulos and Okhi, 1970). With greater numbers of cylindrical micelles, increased numbers of "holes" occur in the membrane and permeabilities are changed.

Certainly this model could explain many ELF field research results. Weak electromagnetic forces that produced localized changes in charge density could alter the conditions required for liquid crystal conditions, and consequently produce small changes within the viable limits of the system. Changes in phospholipid membrane properties or variations of specific cations, e.g., Na^+, K^+, Ca^{++}, known to be controlled by membrane properties have been frequently reported in ELF research (Travkin, 1972; Müller and Jitariu, 1971; Dubrov, 1970). However the species which mediates the change in charge density has not been isolated.

One group of candidates is the macromolecules involved with the connective tissue and ground substance of living organisms. Connective tissues include the tendons, cartilage and most important, the intercellular matrix around the cell or ground substance. Ground substance contains large proportions of proteins with covalently-bound carbohydrates that give it a gel-like character. Such support tissue would be phylogenetically quite old and a coincident condition for life formation. The connective tissue have invaluable structural and functional roles and are involved with homeostasis (Mikolajczyk, 1963).

The ground substance is interesting for ELF field research since it contains proteinpolysaccharides (mucopolysaccharides) that include the chondroitin sulfates, hyaluronate and heparin. Proteinpolysaccharides, like the chondroitin sulfates, are actually polyanions and are typified by straight chained structures which carry large numbers of negative charges (McGilvery, 1970). Hyaluronate, on the other hand, is known for its greater conformational mobility. Heparin, a compound contained within mast cells which are concentrated throughout the body (but primarily in the liver and lungs), is the well known proteinpolysaccharide associated with clotting (in most species). These substances are found along the linings of nerve membranes, at the nodes of Ranvier, and in the synovial fluids of the joints. Viscose mucopolysaccharides also comprise the humours of the eye. Possible high concentrations of these substances may occur in the pituitary and subcommissural organ in the brain (Friede, 1966).

These polyanions, with branch-like electron nets, are likely candidates to be influenced by Becker currents induced within the ground substance by ambient ELF magnetic (or at times electric) fields. Mikolajczyk, Allalouf and Ber (1968a,b) have reported the sensitivity of mucopolysaccharides to many natural and experimental variations. Changes in the electronic capacity of polysaccharides adjacent to phospholipid membranes would alter those conditions associated with membrane permeability. Redistributions of cations and anions relevant to resting membrane potentials would follow. Polysaccharides can function as ion exchanges since they facillitate K^+ and Na^+ absorption (Friede, 1966). At more complex ("higher") levels of measurement, changes in neuron firing, topographic shifts in brain frequency, alterations in reaction time, or diffuse subjective emotional reports might be expected.

At peripheral levels, perturbations in polysaccharides like hyaluronate or heparin could influence joint complaints and blood-clotting properties. Both phenomena are commonly associated with ambient ELF fields and experimental ELF fields applied in the laboratory. Consequent changes in other parts of the connective tissue system, such as the mast cells, would allow histamine and related reactions to be stimulated. The role of mast cells and ground substance materials in immunological reactions is known, but the mechanisms are not readily apparent. However, one of the most frequent experimental ELF results are involved with immunological responses. Histamine-related diseases such as arthritis, allergies, asthma, smooth muscle spasms, emboli, angina pectoris or edema are the most frequent diseases which are supposedly influenced by electric field and magnetic field shielding (Novak, 1969; Ranscht-Froemsdorff, 1968), or excessive production.

Systems (e.g., pituitary) which have high mucopolysaccharide concentrations predictably would be most affected by ELF-EM stimuli. The increased susceptibility of the fetus, neonate and migrating cell to ELF magnetic field may only indicate the high hyaluronate levels recently reported for this developmental period (Polansky, Toole and Gross, 1974). Reactions at other measurement levels would merely reflect functional connections of these systems to the more fundamental changes. More precise development of these models are now in progress.

Comment on natural ELF signals. The precise roles of ambient ELF electric and magnetic fields upon life systems seem to be involved with regulation of primitive homeostatic processes. The particular sensitivity of life systems to a narrow frequency band or deviations in ELF signal circadian variations may indicate the importance of these fields during abiogenesis. With the exception of some fishes which may use ELF signals for communication, natural ELF fields seem to act as diffuse zeitgebers of some biocyclic phenomena. Shielding or masking of these signals, such as during geomagnetic storms or during weather perturbations, can desynchronize some individuals and produce undesirable side effects. Whether these effects are of any real practical importance has yet to be established.

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