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INFLUENCE OF MAGNETIC FIELDS
ON BIOLOGICAL OBJECTS

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INTRODUCTION TO THE PROBLEM

[Yu. A. Kholodov, Institute of Higher Nervous Activity and Neurophysiology, USSR Academy of Sciences]

Interest in the influence of magnetic fields on biological processes developed in ancient times. Those interested in the initial history of magnetobiology* can be referred to books published at the end of the last and the beginning of the present centuries [18, 62, 78].

There is no single opinion among our contemporaries regarding the beginning of scientific approach to magnetobiological problems. Some believed [283] that the year 1600 may be considered as the year of the birth of magnetobiology because of the publication of a book by a British court physician, a classic of magnetism, Gilbert, "De Magnete," which was recently republished in our country [57]. Others [62] believe that the report of the committee of the French Royal Medical Society regarding therapeutic effects of magnets presented in 1780 by Abbot Lenoble did not contain any mysticism characteristic of that time. Finally, some others [287] consider the year 1934, when Lengyel's [346] article was published, as the beginning of magnetobiology.

We shall adhere to the golden mean and, just as our countryman, consider that magnetobiology was conceived in 1780. Referring to the influence of magnetic fields on the human organism, the members of the above-mentioned committee wrote:

"This influence, evidently, consists in a direct effect of the magnetic fluid on the nerves, on which its influence is as certain as its influence on iron. But it, evidently, has no direct or special effect on tissues, on the viscera of the human body, or on the functions of the organism.

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*The frequently encountered, particularly in American literature, synonym of "magnetobiology," the term "biomagnetism," in connection with the established scientific biological terminology, must include the registration of magnetic fields generated, for example, by the heart [173, 276], the brain [295], or a nerve [317] rather than the study of the influence of external magnetic fields on biological objects.

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Thus, the cause of the influence of the magnet on the human body is not its ferrous substance, not in its attraction of iron, and not any other properties attributed to it by empiricism. It is possible to assume that, in time, it will be no less useful in medicine than it is now in physics, although, we should not, of course, believe all the miracles which are told about it and the praises with which it is showered" (Bine and Fere [18]).

It is clear from the above passage that its authors did not overestimate the potentialities of magnetotherapy and expressed the necessity for further investigation of the influence of magnetic fields on the organism.

However, scientific studies in magnetotherapy were hindered by external events. In 1784, a committee of French scientists condemned Mesmer's theory of animal magnetism, which is now called hypnosis, as unscientific. This judgement affected everything that was connected with magnetism in medicine. Strangely enough, many people still connect magnetobiology with Mesmer's name and believe even now that magnetobiology was condemned by formal science.

In the 19th century, investigations were started on the effects of magnetic fields on animals and plants (see this collection). Magnetotherapy was revived in connection with increased interest in metallotherapy [62]. Italian physicians headed by Mazziorani and French physicians of the Charcot school observed that the influence of magnetic fields was manifested most clearly in hysteria patients.

The appearance of electromagnets resulted in increased magnetobiological studies. It was discovered in the Charcot school that magnetic fields of solenoids have the same influence on the organism as a constant magnet.

However, magnetotherapy proved to be less effective than the newly developed methods of electrotherapy (darsonvalization, diathermy, ultrahigh frequency fields, and so on). Therefore, the number of magnetotherapeutic studies started to decrease at the beginning of the 20th century.

The clearest formulation of the problem of the effect of electromagnetic fields was given in 1900 by V. Ya. Danilevskiy [63], who spoke of the effects of "electricity from a distance." The term was put in parentheses by the author himself, since, for the sake of convenience, the term "electricity" included all types of inductive effects. V. Ya. Danilevskiy's general problem included "the influence of a magnetic flux, electric and electromagnetic fields, the effect of electric beams in their various forms and combinations, including the influence (from a distance) of high-frequency and high-voltage currents, and so on. Not only cut-out nerves and muscles, but also whole organisms, from the lowest (microbes), had to serve as objects*." It was pointed out that the formulated problem was of great interest for general biology, hygiene, and electrotherapy.

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*V. Ya. Danilevskiy. ISSLEDOVANIYA NAD FIZIOLOGICHESKIM DEYSTVYEM ELEKTRI-CHESTVA NA RASSTOYANII (Studies on the Physiological Effect of Electricity from a Distance), Vol 1, pp 6-7, Kharkov, 1900.

In our century, people were skeptical of magnetobiology. The scanty reports on the presence of one or another biological effect of constant magnetic fields did not correct the situation.

However, since 1961, interest in this problem started to increase. In the sixties, three international biomagnetic symposiums in Chicago (1961, 1963, 1966) and an international conference in Rome (1964) were held. In our country, the problems of magnetobiology were discussed in Moscow at a symposium on the biological effects of constant magnetic fields and static electricity (1963), at the conferences of the Central Scientific Research Laboratory of the Tomsk Medical Institute (1964, 1965), at a conference on the effects of magnetic fields on biological objects (Moscow, 1966), at all-union (1963, 1965, 1968) and republican (Minsk, 1967; Kiev, 1968) conferences on bionics, as well as at conferences on the hygiene of work and biological effects of radiofrequency electromagnetic waves (1968). This problem is included in the agenda of conferences on biophysics and space biology.

During the 66 years of the 20th century, we can count about 900 scientific reports on magnetobiology, but most of them belong to the last 6 years, and approximately 400 to the last three years. Thus, magnetobiology is forming in front of our eyes, although interest in it continued throughout this century (Figure 1).
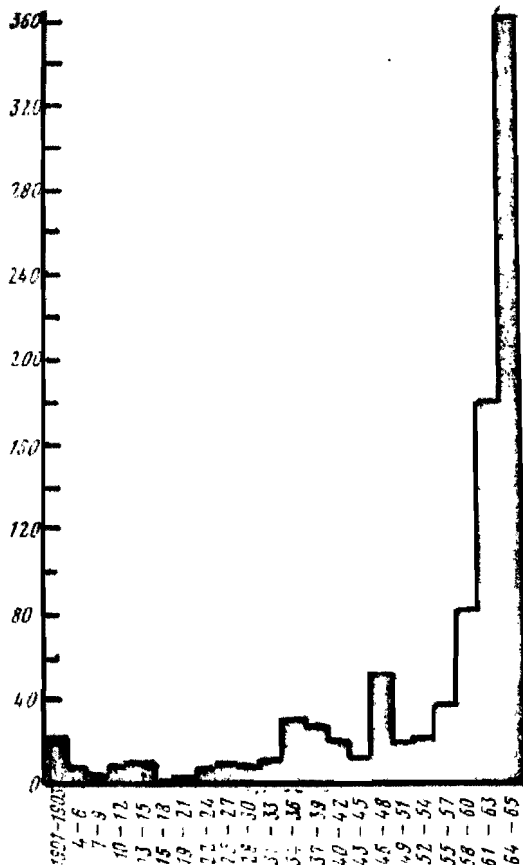
Figure 1. Publication of Articles on Magnetobiology During the 20th Century

Ordinate -- number of articles, abscissa -- years.

In our opinion, the reasons for increased interest in magnetobiology are as follows.

The creation of powerful magnetic fields in various industries resulted in complaints on the part of the maintenance personnel with regard to disturbances in their nervous and cardiovascular systems. Space explorations require the knowledge of the effects of very strong magnetic fields on living systems in order to protect spacecrafts from ionizing radiation, as well as the knowledge of very weak fields which may be encountered in space.

Investigations of problems of the biological orientation and periodicity of some processes showed that the geomagnetic field (GMF) is not an indifferent factor for biological systems. Interest in therapeutic effects of magnetic fields (MF) revived again, particularly in connection with studies pertaining to their effect on malignant growths. Finally, an important motive power in magnetobiological studies is the assumption that, by using magnetic fields as an instrument of study, it will be possible to study the fundamental principles of living things. Now, if a biologist builds up his theory on a biochemical basis, it should be remembered that chemistry itself is based on electrodynamics and quantum mechanics, and that MF play an important role in these disciplines.

The appearance of a large number of publications on magnetobiology required generalization of the obtained data. This is the goal of this collection and some other publications of this nature which appeared in recent years [39, 46, 67, 74, 119, 136, 137, 153, 200, 219, 221, 223, 286, 289, 315, 333, 349, 395, and others].

It should be mentioned that the achievements of magnetobiology are not proportional to the number of published articles, whose scientific value varies greatly. There have been more descriptive articles. Of course, they contribute to the solution of the formerly disputable problem of the presence of the biological effects of magnetic fields. However, the greatest contribution to the development of magnetobiology will be made by those works which will reveal clear quantitative regularities between the intensity of constant magnetic fields and the values of biological responses. Then, what do we know about the biological influence of magnetic fields?

The majority of works on magnetobiology studied the effects of artificial constant magnetic fields, considerably more intensive than geomagnetic fields, on various biological objects. This collection includes only this kind of studies.

The most evident proof of the presence of a biological action of any factor is lethal termination. Such facts were obtained on Drosophila in a nonuniform constant magnetic field of 20-40 kilo-oersteds [281, 351] and on young mice in a field of up to 10 kilo-oersteds [268]. It is interesting that only male mice died from the influence of the constant magnetic field, while female mice survived under the same conditions.

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A uniform constant magnetic field (CMF) of 140 kilo-oersteds, acting in the course of one hour, disturbed the development of the eggs of sea urchins, but did not affect Drosophila and mice [286]. One hour exposure to a field of 70 kilo-oersteds resulted in a sharp decrease of the frequency of heart contractions in the monkey, an increase in the T-wave of the electrocardiogram (EKG) and a considerable change in the electroencephalogram (EEG) [284].

CMF of lower intensities (up to 10 kilo-oersteds) had varied effects on biological objects. Morphological changes in animals and plants exposed to CMP are particularly demonstrative.

It was shown that guinea pigs exposed to a CMF of 200 oersteds for six hours and to a CMF of 7,000 oersteds for 6 and 500 hours develop disturbances in their hemodynamics and lymphodynamics, and there appear sections of emphysema in the lungs, hyperplasia of the lymphoid tissues, and necrobiosis chiefly in the differentiated cellular elements (spermatazoids, neurons) (see this collection). In white mice exposed to a CMF of 200 oersteds, necrobiotic changes in the liver, kidneys, and the motoneurons of the front horns of the spinal cord increased sharply when these organs had a functional load [156, 157]. The observed morphological changes were reversible and were expressed clearer under the effect of AMF (alternating magnetic fields). The combination of all these changes occurring under the effect of CMF under the conditions of whole organism makes it possible to speak of the specificity of the pathologoanatomic picture. Detailed morphological studies on various organs of animals exposed to magnetic fields have been conducted for several years by Tomsk medical researchers under the direction of I. V. Toroptsev ([200] and the present collection).

Mice exposed for a long time to a CMF of from 2 to 13 kilo-oersteds showed atrophy of the fascicular zone of the suprarenal glands [395].

Narcissus and onion roots placed in a CMF of 500-5000 oersteds grew slowly and produced side shoots. Retardation of cell division was observed. This resulted in death of embryonic tissues and was accompanied by the aging of all root tissues. The length of one division cycle was retarded by 3-4 hours even in a CMF of 20 oersteds (see this collection).

High sensitivity of embryonic tissues to CMF was mentioned by many researchers. It was shown that pregnant mice placed in a field of 2,500 oersteds gave birth to healthy offsprings, but the young mice were about 20 percent smaller than the newborn mice of the preceding litters from the same mothers. When pregnant females were exposed to a field of 3,100 oersteds, their newborn babies lived only a few days, and when they were exposed to a field of 4,200 oersteds, the embryos dissolved in the womb. Little mice placed in a field at the age of 3-4 weeks grew slower than the control animals, and males grew slower than females. A strong field (5,000 oersteds) inhibited the growth more intensively. Magnetic fields had almost no effect on the weight of adult mice.

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If mice were placed in a field before reaching puberty, they could adapt themselves and develop in the magnetic field, but matured 7-week old males died after 10 days in the field. Not a single female died in the same experiments.

In the males which died in the field, the weight of the liver was 50 percent less than in the control animals, although the weight of the lungs, heart, kidneys, and testes did not change. Mice exposed to a field of 4,200 oersteds for 5 weeks and killed 3 months after the completion of the experiments showed neoblasts in the spleen [268, 286, 395].

In a CMF from 60 to 7,000 oersteds, the death rate of tadpoles was higher than in the control group [180]. In CMF from 450 to 7,000 oersteds, there was an increase in the fertility and survival rate of drosophila flies [180], and in a CMF of 20 kilo-oersteds, when only reproductive organs were exposed, their development was retarded [351].

A heart tissue culture of the embryo of a chicken placed in a CMF showed atypical cells, sometimes multinuclear and gigantic [246], migration of cells in the direction of electromagnet poles [331], and sometimes only a weak tendency toward protoplasmic disintegration [372]. A kidney tissue culture of a mouse embryo used 87 percent less oxygen in a magnetic field, although the field did not have any effect on the tissues of an adult mouse [387].

The presence of an inhibiting effect of CMF on embryonic growth compels us to assume that this factor may have an inhibiting effect on cancerous tumors. Positive effect were obtained in several cases on human beings, rodents, and on tissue cultures of tumor cells (see this collection).

In their experiments on one-celled animals, some researchers observed a decrease in the intensity of motion, inhibition of growth and reproduction, while some others did not find any biological influence of CMF. These problems were studied in detail by S. A. Pavlovich ([51, 180] and this collection).

It was shown by P. F. Savostin in a series of his studies that magnetic fields change the movement rate of protoplasm in plant cells. It was also found that CMF increased the sprouting rate of roots and the permeability of cellular membranes. It was found in experiments on plants that the roots of corn, while sprouting, turn to the south pole of the magnet, the roots of cress shifted in the direction of a lower intensity of the CMF, and seeds of many plants sprouted sooner in magnetic fields, particularly when they were oriented along the magnetic lines of force.

Exposure to a magnetic field increased the yield and accelerated the ripening of tomatoes, lowered the intensity of photosynthesis in the leaves, and changed the orientation of volvox. Detailed studies of magnetobotanical problems are conducted by Yu. I. Novitskiy et al ([137, 138] and this collection).

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According to the data of individual authors, magnetic fields could cause chromosomal changes in cells, both alone and particularly against the background of irradiation effect. However, this important problem cannot as yet be considered solved, and its detailed discussion is given in the article by A. A. Pozolotin (this collection).

In recent years, there have been only isolated articles on the therapeutic effect of magnetic fields which describe their favorable effects on human beings in cancer [359, 393], in cases of phantom pains after the amputation of limbs, in nephritis and eczema cases, in internal and cardiovascular diseases [19, 206], in thrombophlebitis [129], and in obliterating endarteritis [100].

In recent years, there have been reports on using magnets for treating the hypertonic disease (Tyagin [180], Andreyev et al [180]).

Experiments on animals revealed a favorable effect of magnetic fields in inflammatory processes [182], in radiation sickness [272, 273, 286], and in experimental tumors (Ukolova, in this collection).

However, the therapeutic effect of CMF cannot be used successfully until we have a clear knowledge of the physiological and physicochemical mechanism of the biological influence of CMF.

This conclusion also refers to the studies on magnetic fields as a harmful industrial factor. Such studies are widely conducted only in the USSR by the Moscow Scientific Research Institute of Hygiene imeni F. F. Erisman. A preliminary summary of these studies is given in the article by A. M. Vyalov (in this collection).

Among the physiological effect of CMF on the organisms of animals, a great significance is attached to the changes in the nervous system (Kholodov [217, 220, 222-224] and this collection) and the blood system.

Unfortunately, this collection does not contain an article by a hematologist and we have to limit ourselves to references to literary sources.

It was shown that CMF slows down the erythrocyte sedimentation rate (Mogendovich et al [19, 126, 127], [14, 65, 66, 191, and others]), changes the number of leukocytes [245, 286, and others] and phagocytal activity of leukocytes (PhAL) [49, 169, 180, 244, 245, and others] and their luminescence [180, 186, 187, and others]. Orientation of sickle-shaped erythrocytes of human blood across magnetic lines of force was discovered [365].

The influence of magnetic fields on immunogenesis has been studied intensively by N. V. Vasil'yev ([39] and this collection).

It was shown that magnetic fields change osmotic processes in muscles [19, 180, and others], affect the permeability of the cellular membrane [19, 324, and others], and disturb the hydration ability of tissues in animals [74, 75, 119, and others] and plants [202].

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The influence of magnetic fields on biochemical processes has been studied by many researchers. Changes in the enzymal activity and oxidation processes in animal organism have been discussed by M. A. Shishlo (this collection).

Various mechanisms are suggested as a possible route of the realization of the influence of CMF on biological objects: changes in the orientation of large molecules in strong fields [69], the inhibiting effect of CMF on the rotational diffusion of large molecules, changes in the angle of the chemical bond in the molecules, changes in the rate of proton tunneling in hydrogen bonds between nucleotides making up a desoxyribonucleic acid molecule [286], the influence of CMF on pulsating biocurrents, which may cause mechanical shifts of the sources of biopotentials [72], and changes in the properties of water in CMF [11, 49, 180, and others]. The mechanism of the biological influence of magnetic fields is intensively studied in experiments by A. B. Kogan et al (this collection), while a theoretical treatment is being developed successfully by Ya. G. Dorfman (this collection).

The above mentioned studies indicate that artificial magnetic fields influence the entire organism, its systems and organs, cells, subcellular formations, and molecular structures. It is appropriate to mention here that CMF of the same characteristics have a stronger effect on a school of fish than on an individual fish from this school. This fact leads to a conclusion regarding the presence of "collective reception" of CMF [180]. Thus, the sphere of magnetobiology includes all levels of biological organization: from a molecule to a population. It is characteristic that the reactions of biological objects to magnetic fields are often of a nonspecific nature, common for all damaging factors.

In changing to the discussion of problems of the biological influence of GMF, it should be mentioned that the number of studies on this subject was about 10 percent of the total number of magnetobiological studies.

In 1855, Russian Academician A. T. Middendorf, while studying the periods of arrival of some birds in spring in Siberia, expressed an opinion regarding the possibility of the orientation of birds by GMF.

American physicist Yeagley [404, 406] succeeded in showing experimentally that pigeons orientate themselves by GMF and Coriolis acceleration. He trained pigeons to return to their pigeon-house from distant places. Then, the pigeons and the pigeon-house were moved thousands of kolometers away to a place where the indexes of GMF and Coriolis acceleration were identical to the corresponding indexes of the training area. When pigeons were released at an unfamilar place, they were able to find their house.

The possibility of perceiving GMF by pigeons was checked in experiments where magnetic plates were attached to the wings of experimental pigeons and copper plates -- to the wings of the control pigeons. The pigeons with the copper plates, who were released at an equal distance from the pigeon-house, returned home sooner than the pigeons with the magnets. Similar results were obtained

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recently by A. R. Sakayan [170], although it was not possible to confirm Yeagley's conclusions in other experiments.

Other migrating animals -- fish -- were found to be more sensitive to magnetic fields. Fish released at an unfamilar place, in the absence of orientators, started swimming in the direction of a magnetic meridian [147].

Orientation with respect to GMF was also discovered in insects [277, 391, 395, and others]. Unlike the traditional statement of the problem of the possible orientation of birds and fish by GMF during distant migrations, modern studies indicate that GMF orientation is present in such biological objects (one-celled animals, plants, snails) which do not migrate [29, 154, 395, and others] or do not even move, such as plants [80, 104, 105, and others].

Consequently, the GMF orientation is a general biological problem. It is not excluded that, on the basis of general biological sensitivity for GMF, birds, fish, insects, and other animals developed some very sensitive receptory formations. However, we do not have any facts supporting this assumption. In some instances, which have not as yet been confirmed, it was mentioned that GMF orientation changes the sensitivity of human tissues [13] and can influence the formation of sex in plants and animals [1, 180].

It should be mentioned that GMF can serve for biological systems not only for their orientation in space, but also for their orientation in time. Here again, we should be speaking not only of the traditional correlation of the rhythm of biological processes with the 11-year cycle of solar activity [233, 254, and others], but also of shorter cycles of the GMF fluctuations which are also correlated with biological activities.

Probably, this section should include the results of experiments on the influence of very weak CMF. For example, the influence of a CMF of 280 gammas inhibited the opening of flower clusters, and a longer exposure caused the fading and death of dandelions [368].

A small group of works published in recent years indicate that reducing GMF by screening or creating of a counter-field by means of Helmholtz coils may lead to biological effects. For example, a reduced magnetic field inhibited the development of a staphylococcus culture [278], accelerated the sprouting of roots of some plants [395], reduced the frequency of the confluence of light flashing in man [283], and caused other biological effects [51, 289, and others].

Studies on the biological influence of GMF and fields of lower intensities lead to an important conclusion regarding the ecological significance of this physical factor.

It is possible to assume that in the course of their evolution biological systems became adapted to a definite range of magnetic field intensity, just as they became adapted to a definite temperature, atmospheric pressure, and

so on. Decreases or increases in the intensity of magnetic fields may re-
flect on the biological processes.

An important condition for further work is to summarize what has been done
in this area, because there has been a certain degree of dissociation among
individual authors in their studies. It is just as important to raise the
level of methods for magnetobiological experiments. For this purpose, the
present collection includes an article by physicist A. A. Shul'pekov. Only
a close cooperation of biologists and physicians with physicists and engin-
eers will help to understand the primary physicochemical mechanisms of mag-
netobiological effects and to provide a solid theoretical basis for further
development of magnetobiology.

PHYSICAL PHENOMENA OCCURRING IN LIVE OBJECTS UNDER THE EFFECT OF CONSTANT MAGNETIC FIELDS

[Ya. G. Dorfman, Institute of History of Natural Sciences and Technology, USSR Academy of Sciences, Moscow]

I

In recent years, attention of biologists and physicians has been strongly attracted by the problem of the influence of external magnetic fields on live objects.

It is natural to term this area of biophysics as magnetobiology by analogy with electrobiology. In the U.S.A. and in France, it is termed "biomagnetism" [286]. This term is obviously inappropriate, since living beings do not create any specific magnetisms.

At the present time, a large number of observations have been accumulated in literature on various biological effects caused by CMF and AMF in man, animals, and plants [286].

Along with this, many papers have been published on the therapeutic use of magnetic fields, and foreign countries are advertising widely magnetic field sources on sale for the treatment and prevention of various diseases. Some Japanese firms even advertised the possibility of treating all diseases by means of magnetic fields.

At the same time, there are no sufficiently convincing attempts in literature for a critical scientific analysis and generalization of all these data with respect to the biological and physical aspects.

It is caused, primarily, by the fact that most of the published experimental studies described the physical conditions of the experiments extremely superficially and indefinitely. Quite frequently, the authors of articles do not even differentiate between CMF and AMF or between sinusoidally changing fields and pulsating fields, and so on. They often ignore the possible physical or

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biological effects of side factors and disregard specifically high sensitivity of biological objects. For example, they often forget about induced electromotive force (EMF) which, for instance, occurs at the moment of switching off or on CMF and about the local heating of the object during a short period of time in this connection. In the case of low-frequency AMF, these secondary effects may play a considerable role, and for the high-frequency fields they, evidently, have a fundamental and decisive significance*.

From the few works in which physical conditions are described more clearly and the strongest side effects are almost eliminated, it is, evidently, possible to conclude that CMF exert some influence on the cardiovascular activity of the organism and on the nature of brain biopotentials in man and animals, and also affect the rate and direction of growth in plants.

As for the available information regarding therapeutic results, it is difficult to separate facts from delusions, enthusiastic ideas, or even simply from sensations and advertising. Moreover, it is particularly difficult to eliminate psychogenic factors in them.

Some physicists are of the opinion that, with this state or magnetobiological studies, physicists should not engage themselves in such doubtful problems. In our opinion, this viewpoint is wrong especially because many other areas of biology and medicine had been in an analogous condition until physicists joined the research. The problems of magnetobiology interest not only biologists and physicians, but also wide circles of healthy and sick people, therefore, the physicist should also think of this problem.

It should also be remembered that in our time increasingly greater numbers of people are exposed to magnetic fields in the course of their professional activities. Incidentally, such people include physicists themselves.

However, it is necessary to find such a scientific approach to this problem with which physicists could examine its physical aspect regardless of certain inadquacies of the biological experiments which are still present. From this viewpoint, it seems to me possible and useful to state a purely theoretical problem of what basic physical phenomena must take place in a living matter under the effect of CMF.

II

In order to solve this physical problem, first of all it is necessary to have in mind at least schematic physical model of a live biological object.

We conceive it in the form of a nonuniform electrolytically conducting system in which complex biochemical reactions progress in liquid solutions with the participation of certain specific types of molecules. Along with this, the biological object has continuous circulation of blood or other fluids.

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*Experiments with radio-frequency EMF have chiefly to do with internal heating of objects.

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Finally, there occur the generation of bioelectric potentials and propagation of bioelectric pulses over the nerve and other fibers.

First let us consider the macroscopic and then the microscopic effects which should be expected in the presence of CMF.

III

The simplest macroscopic magnetic effect that may reflect on the biological object is the ponderomotor, i. e. mechanical, influence of a constant but not uniform magnetic field on a plant or animal tissue. A volume unit of the tissue substance is subjected to the effect of force

$$\vec{f} = \varkappa H \frac{dH}{dx},$$

where $\varkappa$ is the magnetic susceptibility of the volume unit of substance, and H is the intensity of the magnetic field. As a rule, plant and animal tissues are diamagnetic, i. e. $\varkappa$ is an essentially negative value. Consequently, force $\vec{f}$ corresponds to the ejection of the tissue from the place where the magnetic field is the most intensive in the direction of the field gradient dH/dx. Numerical values of $\varkappa$ could differ somewhat at various points of the tissue.

The presence of the mechanical force, regardless of the origin of this force (field of gravatation, magnetic fields, wind pressure, and so on), have the same effect on the cells in the process of growth: it becomes easier in the direction of the action of force $\vec{f}$ and more difficult in the opposite direction. This results in a deformation of the growing live tissues. Some authors are inclined to see a certain specific biomagnetic effect in this "magnetotropism" [407], but this viewpoint is not substantiated physically. For example, this is proved by Audus' experiments [265] in which all organs of a plant changed identically the direction of their growth in a magnetic field.

In other words, "magnetotropism" is a trivial macroscopic effect which does not require any new hypotheses for its explanation. However, there may be some cases when "magnetotropism" is connected simultaneously with the influence of a magnetic field on vital processes, which will be discussed later, and then it must, probably, be expressed not only in the changes of the direction of growth, but also in some other peculiarities.

IV

The basic macroscopic effect should be, evidently, considered to be the possibility of the magnetohydrodynamic inhibiting influence of CMF on the circulation of conducting fluids in a live object. This problem is a very complex problem of magnetic hydrodynamics (the so-called Hartmann's problem). It was analyzed in 1965 by L. Ye. Belousova [15] and by E. M. Korchevskiy and L. S. Marochnik [102]. They examined a problem on the influence of a magnetic field on the laminar flow of a fluid characterized by electric conductivity σ and viscosity factor η if the flow occurs in the space between

two planes which are removed from each other at a distance 2a, and if field H is perpendicular to the direction of flow. This model is sufficiently close to the case when the same fluid flows along a tube 2a in diameter. The change in the flow rate caused by field H depends on the so-called "Hartmann number"

$$M = \frac{aH}{c} \sqrt{\frac{\sigma}{\eta}},$$

where c is the velocity of light. Here σ is expressed in the CGSE system. The inhibiting effect of the field becomes noticeable when $M \gtrsim 1$. For blood vessels 2 cm in diameter at $\eta = 10^{-2}$ poise and $\sigma = 2 \cdot 10^{10}$ units CGSE (which corresponds to the properties of human blood). $M \gtrsim 1$ at

$$H \gtrsim \frac{c}{a} \sqrt{\frac{\eta}{\sigma}} \approx 2 \cdot 10^4 \text{ oersteds (Oe)}$$

L. Ye. Belousova's calculations yield the following values for the relative decrease in the blood flow rate $\Delta V/V$ under the effect of the field

H, Oe	$\Delta v/v$, %
$2 \cdot 10^3$	0,1
$2 \cdot 10^4$	9,0
$2 \cdot 10^5$	55,0
$2 \cdot 10^6$	94,0

Thus, L. Ye. Belousova came to a conclusion that fields or $2 \cdot 10^3$ - $2 \cdot 10^4$ oersteds could have a very strong effects on the blood flow in the aorta of a man (2 a = 2-3 cm). The smaller the diameter of the vessel, the lesser is this influence with other equal conditions.

In most biological and therapeutic studies, the intensity of the applied magnetic fields does not exceed $2 \cdot 10^3$ oersteds and usually they are not applied to the area of the heart (i. e. not to the aorta), therefore, it is possible to assume that the magnetohydrodynamic effect did not play the decisive role in these experiments.

It should be mentioned that this inhibitive effect should lead to a decrease in the local gradient of the blood pressure, since the magnetic field creates a kind of counterpressure which slows down the flow of blood.

The above theory makes it possible to assess the value of the lowering of the blood pressure which can be caused in the blood vessels of a human hand by the well-known Japanese "magnetic bracelets" which are believed to have a therapeutic effect.

A CMF created by such a bracelet near the blood vessels of the hand does not exceed 10^3 oersteds. The diameter of these vessels is 2-4 mm. Thus, the local lowering of the blood pressure caused by the magnet bracelet must not exceed 0.03 percent. Such an insignificant local change in the pressure in the vessels of the hand is comparable to changes occurring from a multitude of incidental causes and cannot be felt at all. In the meantime, for example,

the blood pressure of a hypertonia patient must be lowered at least by 10-20 percent, and not only in one of his hands. It is evident that such an effect cannot possibly be achieved by means of a "magnetic bracelet." Therapeutic application of magnetic bracelets for treating hypotonia patients, whose blood pressure must be increased, is even more unfounded from the physical point of view.

In order to eliminate the psychogenic factors, it would be important to conduct experiments with "magnetic bracelets" on anthropoid apes, placing them in cages made of nonmagnet metals.

The above problem is a clear example of the difficulty of the analysis of the available information on the therapeutic effects of magnetic fields which we mentioned before, therefore, we shall not touch upon them further.

V

Among possible macrascopic effects of CMF, some works [286] mentioned the influence of a field on bioelectric currents, particularly, Hall's effect was mentioned. However, it is well known that the Hall effect in electrolytes is negligibly small because of the mobility of the ions of both signs. Experimental studies on the effects of CMF on nerve fibers carried out by Ye. A. .Liberman, M. N. Vantsvayg, and L. N. Tsofina [111] showed directly that even the fields of the order of 10^4 oersteds had almost no effect on electric resistance or on the potentials of fiber excitation.

Until recently, no attention was given to the possibility of a macrascopic ponderomotor effect of a field on the conductors of bioelectric currents -- nerve fibers [72]. The pulsating nature of these currents and some peculiarities of the fiber structure were not taken into account. The pulsation frequency varies from 10 to 10^3 per second, but, evidently, higher pulsation frequencies also occur. The biopotential amplitude reaches from 10^{-4} to 10^{-1} volts. The most detailed studies have been done on pulsating currents in the so-called myelinated nerve fibers. Schematically, such a fiber is a flexible, electrolytically conducting inner vein covered by an insulating myelinous layer and submerged in a liquid electrolyte. The myelinous insulation is interrupted at equal intervals. The spots where the insulation is interrupted and the inner vein is bare are called nodes of Ranvier. On the whole, the nerve fiber resembles sections of a coaxial cable connected in series with a liquid external coating. The electric biopotential appears in the excited node of Ranvier. A discharge occurs along the inner vein between two adjacent nodes, and the circuit closes through the surrounding liquid. Then, the next node is excited, which creates a current pulse in the next section of the conducting vein, and so on. According to the Ampere law, at the moment of the passing of the current pulse, the current-carrying section of the vein must experience a bending ponderomotor force from the magnetic field.

The propagation of an electric pulse along the nonmeylinated nerve fibers, along muscle fibers, and along plant fibers progresses in a similar manner.

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Consequently, all of them must also bend in a magnetic field under the influence of the Ampere force.

Evidently, when an electric pulse propagates along a fiber in the presence of a magnetic field, all of its sections must bend consecutively during the passage of the discharges. Thus, a peculiar elastic wave with a frequency equal to that of electric discharges must propagate along the fibers. Keeping in mind that the amplitude values of the discharge currents vary from 10^{-7} to 10^{-5} amperes and taking reasonable values for the elastic properties of the fiber, it is possible to show that the amplitude value of the bending deflection of the fiber in the field of $H = 10^3$ oersteds may be from several microns to hundreds of microns for a section length of 1-2 mm. Thus, in the presence of a magnetic field, a fiber works as a peculiar string instrument. As far as we know, this fact has not been given attention in scientific literature.

In the meantime, the bending of a fiber must cause an induction EMF distorting the current pulse. The bending of the fibers is equivalant to the appearance of self-inductance in the electric circuit of the fiber which must inhibit the propagation of the pulse. Evidently, this effect will show itself more at high frequencies than at low frequencies, which may reflect, for example, in the suppression of high frequency component in an EEG.

From the biological studies described in literature, it is, evidently, possible to conclude that magnetic fields have a certain effect on the nature of the EEG of experimental animals. It follows from these data that CMF indroduce noticeable distortions in the bioelectric potentials of the brain.

From time to time, French journals run advertisements of a certain private enterprise located in Nice referring to itself as the "Center for Dissemination of Biomagnetics." The center fills orders for constant magnets with special instructions for their therapeutic application. It is interesting to note that the scientific-like text of the advertisement states that "this new scientific method regulates the electric currents running through the body." This statement is hardly scientifically sound. However, we believe that this entire problem deserves a careful and critical scientific clarification.

The considerations presented here regarding the ponderomotor influence of CMF on the nerve, muscle, and plant fibers lead to a very interesting conclusion.

Let us imagine a special case when the natural frequency of the mechanical oscillations of the nerve fiber coincides with the frequency of the electric discharges occurring along the fiber. In this case, the fiber may be particularly sensitive even to weak external magnetic fields causing elastic oscillations of the resonance frequency in it. This means that under certain conditions this fiber may become a kind of a magnetometer or a compass permitting the live system to orientate itself in the GMF.

It is known that the problem of the ability of certain animals, birds, and fish to orientate themselves in the GMF has been often discussed in literature.

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However, the physical mechanism of this effect remained unclear. All the hypotheses so far proposed regarding the structure of the corresponding magnetic organs were unsound. The considerations stated above seem to point to a new route for solving this problem. However, it should be mentioned that, although many studies have been published in recent years on the orientational ability of fish, birds, and even insects, the utilization of the GMF by the animals has not been proven convincingly in any of these cases.

VI

Let us now turn to the microscopic effects. Biological objects contain diamagnetic and weakly paramagnetic substances which become magnetized in a CMF. Some authors maintained [21, 22, 364] that the living matter also has ferromagnetic macromolecules and biopolymers. However, it was clearly shown by us that all these statements were based on misunderstanding and were not true [70, 71].

Further, it is necessary to stress that any orientational and concentrational effects of paramegnetic atoms or molecules (whose μ moment depends on the presence of one or several unpaired spins) are negligible in the fields of the order of 10^3 - 10^5 oersteds because their magnetic energy μH is considerably smaller than the mean energy of the thermal motion kT at usual temperatures.

The situation is different with diamagnetic macromolecules because their magnetic energy under the same conditions may be comparable to kT. The orientation of anisotropic diamagnetic molecules was examined for the first time by P. Lanzheven [107] in his theory of the magnetooptical effect of Cotton-Mouton. However, since Lanzheven limited himself to the examination of very small molecules, he was compelled to stress that the degree of their orientation was so neligible, that it could be established experimentally only with very sensitive optical devices. The same can be said regarding the changes in the concentration of small diamagnetic molecules in nonuniform magnetic fields.

However, anisotropic macromolecules with a very large molecular weight $\geqslant 10^6$ in a not very viscose liquid solution at the same usual temperatures and in the fields of the order of 10^4 - 10^5 oersteds must show a very noticeable alignment in a uniform magnetic field, and a considerable concentration gradient in the case of a nonuniform field with a gradient of 10^3 - 10^4 oersteds/cm [69].

These effects are determined by the Boltzmann factor $e^{-\gamma_1 x}$, where

$$\gamma_1 = \frac{\bar{\chi}' H \frac{dH}{dx}}{2kT}$$

for a nonuniform field, and factor $e^{-\gamma_2} \cos \theta$, where

$$\gamma_2 = \frac{\Delta \chi' H^2}{2kT}$$

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for a uniform field (here, X' is average magnetic susceptibility of one molecule over the directions, and $\Delta_{X'}$ is its magnetic anisotropy).

If γ_i and γ_k are close to 1, then both of these effects can show themselves not only in optical phenomena, but will also reflect in various other processes (chemical kinetics, passage through membranes, viscosity, and so on) [69], which has been given little attention until recently. Since such molecules (enzymes, nucleic acids, etc) participate in biochemical reactions, it can be expected that the influence of a magnetic field through these effects will be noticeably reflected on the vital activity of the biological objects.

Our hypothesis regarding the influence of external magnetic fields on the kinetics of chemical reactions progressing with the participation of macromolecules has been recently tested experimentally in GDR by W. Haberditzl et al [325-327]. They showed that, for instance, a reaction progressing in vitro with the participation of the enzyme glutamate dehydrogenaise slows down by 15-20 percent in a nonuniform magnetic field of the order of $2 \cdot 10^2$ oersteds, evidently, because of a sharp decrease in the concentration of diamagnetic macromolecules with a molecular weight of about 10^6 in the interpolar volume.

In the fields of the order of $7 \cdot 10^4$ oersteds, this effect exceeded 90 percent. An analogous effect is also observed in solutions containing molecules of nucleic acids. This effect has an independent significance because the effect of magnetic fields on the kinetics of chemical reactions is, evidently, shown here clearly for the first time.

Along with the changes in the orientation in the magnetic field concentration of biologically active macromolecules, we should, of course, expect analogous effects in the supermolecular structures: organoids, viruses, and so on. W. Neurath [366] pointed out the possibility of the orientation of the erythrocytes of human blood. However, since erythrocytes have almost a spheroidal shape, this effect can hardly be considerable. But the latest works on blood circulation [404] show that, in the thin capillary vessels erythrocytes form piles of considerable lengths which slide as an integral mass along the walls due to the presence of lubrication from the blood plasma. The ponderomotor influence of the magnetic field on such piles of erythrocytes may prove to be a very serious factor and, in our opinion, deserves a special study. We are dealing with capillaries 10-12 microns in diameter (the diameter of an erythrocyte is about 8 microns).

It should be stressed that the possibility of the alignment of supermolecular biological structures in magnetic fields opens new routes for their detailed study by means of orientated influences (for example, radiation) and can make a considerable contribution to microbiology and cytology.

Summing up all that has been said above, we come to a conclusion that three basic types of physical effects can occur in live objects under the effect of CMF: magnetohydrodynamic inhibition of the circulation of blood and other fluids; elastic oscillations of nerve, muscle, and plant fibers during the

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propagation of bioelectric pulses which, in turn, cause the distortion and inhibition of the pulses themselves; orientational and concentrational changes in biologically active macromolecules and solutions reflecting on the kinetics of biochemical reactions and other physicochemical processes.

Depending on the condition, some of these processes prevail. The observed magnetobiological effects must, evidently, depend on the above-mentioned physical factors. Therefore, the formulation of the basic physical effects enumerated above opens a real route for the clarification of the mechanisms of the basic magnetobiological phenomena. But investigation of this problem is possible only with a very thorough and careful consideration for all active physical factors and elimination of side phenomena.

INFLUENCE OF MAGNETIC FIELDS ON ENZYMES, TISSUE RESPIRATION, AND SOME ASPECTS
OF METABOLISM IN AN INTACT ORGANISM

[M. A. Shishlo, Central Scientific Research Institute of Health Resorts and
Physical Therapy, Moscow]

The modern stage of magnetobiology is characterized by further accumulation
and systematization of the facts regarding the biological influence of mag-
netic fields and by a transition to the generalization of the obtained re-
sults and searching for the primary mechanisms of the interaction of magnetic
fields and live structures.

The experimental data which is presently available led a number of researchers
to an assumption regarding the changes in biochemical processes in magnetic
fields. Firstly, biochemical studies make it possible to have a more profound
understanding of the qualitative changes occurring under the effect of mag-
netic fields and, secondly, to reveal certain quantitative regularities neces-
sary for the understanding of the primary mechanisms of the influence of mag-
netic fields on biological objects.

This report discusses:

1. The influence of magnetic field (chiefly CMF) on: a) enzymes and reac-
tions catalyzed by them; b) respiration and energetics of the tissues and
some aspects of metabolism in an intact organism of animals.

2. Hypotheses proposed for explaining the influence of CMF on biochemical
processes.

Influence of Magnetic Fields on Enzymic Reactions

To date, the first, sometimes contradictory, experimental data have been
accumulated on this problem.

Thorough investigations were carried out by Cook and Smith [286, 395] on the
influence of CMF (8-13 kilo-oersteds) on trypsin. The enzyme activity was

evaluated by the hydrolysis rate of benzoyl chloride-dl-arginine-p-nitroanilide determined spectrophotometrically. The experimental error did not exceed one percent. The studies were done with preincubation of the enzyme in a CMF at pH 3 in the course of 1-4 hours with subsequent incubation at pH 8.

The CMF increased the activity of the enzyme, which was determined by the reaction product, by 6-20 percent. This effect depended on the preincubation time of the enzyme in the CMF. A one-hour exposure to the CMF caused insignificant changes, and an exposure of 2-3 hours increased the activity of the enzyme by 15 and 17 percent, respectively, with a level of significance of (1:1000). Such experiments were conducted with trypsin which had the highest stability at pH 3 and showed an optimum activity at pH 8. Thus, if the trypsin was at pH 3 at the time of the influence of the CMF and then reacted with the substratum at pH 8, then, as was mentioned above, an increase in its activity was observed. However, when the trypsin solution was in its most unstable state at pH 8 at the time of the influence of the CMF, its activity decreased by 10 percent. The increases and decreases of the trypsin activity under the effect of CMF were connected by Smith [395] with various degrees of orderliness of the enzyme structure at various pH and the orientation by the CMF of electronic dipoles in the protein molecules.

It was shown in the same experiment that CMF do not increase the amount of the SH-groups of enzymes (do not break the disulfide bonds) and do not restore the disulfide bonds after they are broken under the effect of ultraviolet radiation. At the same time, the ultraviolet absorption spectrum of trypsin changed after the influence of CMF, which was expressed in decreased absorption in the region of 250-290 millimicrons, while the qualitative changes caused by ultraviolet radiation were opposite.

The influence of CMF was also studied on partly inhibited trypsin [286]. The obtained data indicated that, with certain types of inactivation, CMF reactivates (by 4-12 percent) trypsin. The highest reactivation was when the activity of trypsin was inhibited with an inhibitor from the white of an egg and it was exposed to a CMF for 1008-1106 minutes. The authors believed that the influence of CMF could be dependent on the redistribution of hydrogen bonds or some dipole structures in the protein molecules. At the same time, it is not expected to have any disturbances of chemical bonds in a CMF.

Along with the above results, there have been recent data regarding the absence of any influence of CMF on enzymic reactions, and, in particular, on trypsin [383, 384]. No changes were discovered in studying the influence of very strong CMF (208 kilo-oersteds) on reactions catalyzed by ribonuclease, peroxidase, tyrosinase, aldolase, succinate-cytochrome-C-reductase. However, in the first series of these experiments, firstly, the exposure time was only a few minutes, and, secondly, enzyme-substratum complexes were exposed to a CMF, and not preincubation of enzymes in a CMF, as it was in the experiments by Smith and Cook. In the second series of experiments, the conditions of Smith's reaction were reproduced. The only exception was that the maximum time of enzyme preincubation was only 65 minutes, although the intensity of

the CMF was considerably higher: 208 kilo-oersteds against 8 and 12 in Smith's experiment. Negative results were also obtained [384]. It can be mentioned in this connection that the above-mentioned negative results could be connected with the fact that statistically significant effects in Smith's experiments were observed at 120-240 minutes of exposure to a CMF, while in the experiments described in [383, 384] the maximum time of exposure was 65 minutes. However, the authors compensated the shorter time of exposure by increasing the intensity of the CMF. However, if we assume that a CMF changes the denaturation of the enzyme in the course of time and the latter reaches the experimentally determined differences only in the course of 2-3 hours, then the "compensation" by reducing the exposure time and increasing the CMF intensity becomes unjustifiable.

In connection with the above-mentioned variance of the results of the experiments conducted with trypsin at various intensities of the CMF, I would also like to mention that many experiments did not show a linear dependence, but a complex and often multioptimal dependence of changes in the indexes on the intensity of the CMF.

The results obtained by Akoyunoglou [262] in studying the influence of a CMF (20 kilo-oersteds) on carboxydismutase demonstrated that the activity of the enzyme increased by 14-20 percent when it was exposed to the field for 1-196 hours and when the enzyme was kept as 4 degrees C. In these experiments, the activity of the enzyme decreased in the course of time, which was due to the denaturation of carboxydismutase, and this inactivation was expressed more in the control preparation of the enzyme than in the enzyme which was exposed to the CMF.

It was characteristic that no differences were found from the control when the reaction mixture was exposed to a CMF for a short time (25 minutes).

Akoyunoglou also studied the effects of CMF on carboxydismutase under the conditions when the same enzyme solution was exposed periodically to a CMF and served as a control at the same time. The activity of carboxydismutase increased when the electromagnet was turned on and dropped rapidly shortly after it was turned off (Figure 2).

Experiments were also conducted on the influence of CMF on carboxydismutase which was partially or completely inhibited by ultraviolet radiation. Just as in the experiments of other authors, it was shown that a CMF did not reactivate the enzyme in this case.

Interesting results were obtained in studying the effects of a nonuniform CMF of 60 kilo-oersteds on enzymal reactions catalyzed by catalase and glutamate dehydrogenase [326]. Samples were placed in a CMF for 17-60 minutes. A uniform CMF did not change the activity of the enzyme very much, while a nonuniform field inhibited the activity of glutamate dehydrogenase to 92.7 percent and increased the activity of catalase to 52 percent. The author considers the effects of CMF on these reactions proceeding from the theoretical premises

of Ya. G. Dorfman [69]. The author explains the increase in the activity of catalase in the nonuniform CMF by its action on the acceleration of the removal of paramagnetic oxygen from the areas of the reaction. This could be probable if we consider the data on the fact that magnetic fields increase the liberation of gaseous products during chemical reactions and electrolytic processes (cited from [268]).
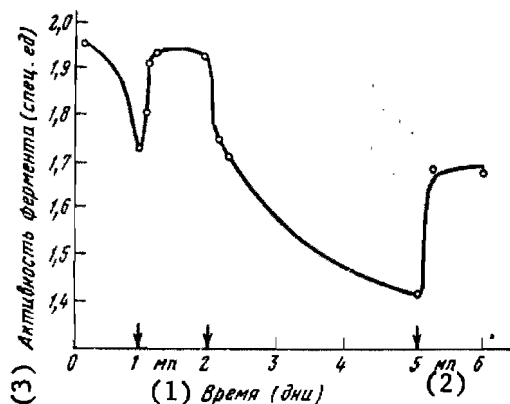

Figure 2. Effects of a Magnetic Field on the Activity of Carboxydismutase.

The same enzyme solution served as a control and an experimental samples. The ordinate is the enzyme activity in relative units, and the abscissa is the time in days; the arrows mark the moments of the turning on and turning off the electromagnet.
Key:
    1. Time (days)
    2. Magnetic field
    3. Enzyme activity (special units)

The last results clearly show the significance of the nonuniformity of CMF in a number of magnetobiological effects.

Other works include studies on the activity of histidase (from an acetone powder of rat liver) and asparaginase (from the blood serum of guinea pigs) in a nonuniform CMF of 17 kilo-oersteds. In these experiments, the field was weakly pulsating. The authors [247] discovered an increase in the activity of asparaginase by 24.5 percent and its decrease in histidase by 24.9 percent. A short (1 hour) preincubation in a magnetic field did not change the activity of the enzymes in their next incubation.

Effects of Magnetic Fields on the Respiration and Energetics of Tissues and Some Aspects of Metabolism in an Intact Animal Organism

All studies on the processes of tissue respiration can be divided into those during the influence of a magnetic field and those after the influence of

this factor. It is important to note that studies of tissue respiration during the action of a CMF in the Warburg apparatus, as well as by the polarographic method involve some   difficulties. In the first, the most widespread method of studying the consumption of oxygen by cell suspensions, homogenates, sections, and mitochondria, it is necessary to observe carefully the mixing of the gaseous and the liquid phases in order to ensure a sufficient rate of oxygen diffusion to the preparation. In the polarographic method of registering the oxygen consumption, the mixing of the incubation medium is also necessary. This fact limits the application of these methods directly at the moment of the CMF action. The electrometric method of registering oxygen consumption, unlike the above-mentioned methods, can be, evidently, used for these purposes [83]. It is also possible to use microrespirometers of various modifications, for example, like those which were used in the refined experiments of Reno and Nutini [387], and, finally, to study with substances labeled with radioactive isotopes, as for example in the experiments by A. I. Zabotin [49, 180] on the effects of CMF on the processes of photosynthesis.

In studying the aftereffects of CMF, all methods can be used equally successfully and the selection is determined by the purpose of the experiment.

The first problem which arose in studying tissue respiration was to detect the changes at those intensities of the CMF and in those objects in which changes in the morphology and growth of cells had been discovered. A sharp inhibition of growth and the destruction of cells were shown, in particular, for tumor cells of sarcoma-37 and an embryo at a CMF intensity of 10^3-10^4 oersteds. Studies of tissue respiration on these objects were carried out by Reno and Nutini [286, 387] at a CMF intensity of 7,300 oersteds on microrespirometers which made it possible to take very small amounts of tissues (1-4 mg) for the experiment. The control respirometers were in the same conditions with the exception of the CMF. Constant temperature was maintained with accuracy of up to 0.01 degree C. It was found that at 37 degrees C the CMF inhibited the consumption of oxygen by the cells of sarcoma-37 and Ehrlich's tumor by 34.4 and 33.7 percent, respectively. The consumption of oxygen by the kidney tissue of a mouse embryo dropped in the CMF to 87.2 percent (Table 1). As it can be seen from the table, there is an inverse correlation between the degree of the inhibition of oxygen consumption and the dimensions of the embryo: the smaller the embryo, the greater the degree of inhibition of oxygen consumption by the kidney tissue of the embryo. This fact gave the authors the basis to assume that there existed a dependence between the metabolic activities of the tissues determined by their age and the degree of inhibition of oxygen consumption by the CMF.

At the same time, the CMF did not have any substantial effect on the oxygen consumption by the kidney tissues of an adult animal (12-18 week old mouse). Average indexes of QO_2 in the control and in the experiment were 2.6 ± 0.14 and 2.5 ± 0.16, respectively. It can only be said that QO_2 under the effect of the CMF in these experiments was not higher than in the control.

Table 1

Inhibition of Tissue Respiration of Kidney Tissues of a Mouse Embryo Under
the Effect of a Magnetic Field of 7,300 Oersteds

(1) Размер эмбриона, мм	(2) Время воздействия, мин.			
	60	120	180	240
	(3) Процент угнетения			
15	86,6	86,6	86,0	86,4
15	81,5	90,6	93,5	88,3
17	33,9	37,6	37,7	37,5
19	49,3	24,0	13,2	37,2
20	47,2	42,1	39,8	36,2
20	47,0	42,5	29,4	40,4
23	21,5	25,1	30,1	25,9
23	5,9 *	6,0	7,8	2,9
24	4,2 *	0,0	1,5	0,7 *
25	10,1	11,9	6,0	9,2
27	2,4	12,8	15,5	10,3

$N = 33$ $t = 4,84$ $p < 0,001$

* Stimulation

Key:
1. Size of embryo, mm
2. Time of exposure, minutes
3. Percentage of inhibition

The temperature dependence of the inhibition of oxygen consumption of a cell
suspension of sarcoma-37 by a CMF (by 34.4 percent at 37 degrees C and 37.9
percent at 32 degrees C) discovered by Reno Nutini deserves special attention.

After the data of Reno and Nutini [286, 387] had been obtained, it became
necessary to conduct an experimental study of the dependence of changes in
tissue respiration on the intensity of CMF. These studies were carried out
by Pereira et al [375,395]. The experiments were conducted on differential
microrespirometers at a temperature of 37+0.01 degrees C with an electromag-
net whose CMF intensity could be changed from 40 to 10,000 oersteds. The
scheme of the experiment was as follows: the chamber of the microrespirometer
was placed between the ends of the electromagnet for 40 minutes; after the
equilibrium was established and the consumption of oxygen by the cells became
stable, the electromagnet was turned on for 10 minutes (experimental period)
and then it was turned off for the same period (control period). This pro-
cedure was repeated in the course of 2 hours and made it possible to obtain
6 control and 6 experimental readings in each experiment. The residual field
intensity between the end pieces was 40 oersteds and, as was shown before,
did not change the consumption of oxygen.

The conducted experiments made it possible for the author to conclude that
the influence of a CMF with an intensity greater than the threshold 80-85
oersteds caused a substantial lowering of the respiration in the cell suspen-
sion of sarcoma-37, kidney and liver sections of a mouse embyro by 28.3, 29.3,

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and 20.6 percent, respectively; did not influence the respiration of kidney and liver sections of an adult mouse, and increased it in baker's yeast by 40 percent. The reaction on the field was fast and reversible. A CMF with an intensity lower than the threshold level did not have any influence, and increasing the intensity from 80 to 10,000 oersteds did not produce a greater effect than the threshold level. Statistical treatment conducted by the authors according to the average values in the intensity interval of 80-10,000 oersteds showed the reliability ($p < 0.05$) of the obtained results.

However, it is necessary to note that the authors' conclusion that the effect of the CMF did not depend on its intensity is, evidently, not sufficiently founded, since they did not have a sufficient number of experiments at various intensities which would permit them to compare the effects. Moreover, in earlier experiments [387], it was shown that changes in the tissue respiration depended on the CMF intensity. A weak CMF (80 oersteds) stimulated respiration, and a field of 400 oersteds and higher slowed down the oxygen consumption rate. When the intensity was increased from 400 to 7,300 oersteds, the oxygen consumption kept decreasing.

Thus, the problem of the dependence of oxygen consumption by tissues in vitro on the intensity of the CMF has not yet been completely solved for animal objects.

The discovery of the fact that the influence of a CMF of the same intensity, in various objects (tissue homogenates of warm-blooded animals, tumor cells, and baker's yeast) and in the same tissues, depending on the age, causes inhibition or increase of the oxygen absroption rate, or does not change it at all, in our opinion is of great interest. Evidently, stimulation, inhibition, or absence of the CMF effect on the absorption of oxygen is determined by the biological object itself, particularly by the peculiarities of its metabolism and its level.

Much information has been accumulated regarding the fact that the level of oxygen consumption by cells, tissues, and the entire organisms is a value regulated by many factors among which the degree of conjugation of oxidation and phosphorylation plays an important role.

Confirmation of the possibility of changes in the ratio of free and phosphorylated respiration under the effect of CMF in vitro was obtained in studies on its direct effect on the functional state of isolated mitochondria [180, 246, 250]. The experiments were done after a 40 minute action of a CMF of 4.5×10^3 oersteds on mitochondria isolated from the livers of white rats which were obtained by differential centrifugation. Respiration was recorded by the polarographic method at a temperature of 26 degrees C.

Glutamic acid, a mixture of glutamic and malic acids, or succinic acid were used as oxidation substrata. Adenosinediphosphate (ADPh) was used as a phosphate acceptor. Dinitrophenol was used as a disconnector. Respiration stimulated by the substratum in a medium without the phosphate acceptor was

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considered free (nonphosphorylated), and phosphorylated when the phosphate acceptor was added [292, 345].

The first noticeable fact in the CMF effects on isolated mitochondria is the dependence of its influence on the rate of nonphosphorylated respiration on succinic acid on its initial level (Figure 3). As the rate of nonphosphorylated respiration increased due to the aging of the mitochondria preparation, the influence of the CMF led to an increased lowering of the oxygen absorption rate. The obtained results indicated that the influence of the CMF led to the lowering of high levels of nonphosphorylated respiration of isolated mitochondria. This conclusion was also supported by the lowering of the oxygen absorption rate on a mixture of glutamic and malic acids in a medium without the phosphate acceptor which was shown most clearly in the action of the CMF on aged mitochondria preparations.
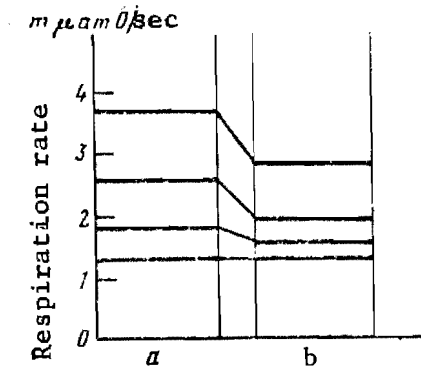

Figure 3. Various Levels of Respiration on Succinic Acid and the Influence of a Constant Magnetic Field Against this Background. Mitochondria of the liver of a white rat (from 200 mg of tissue per sample). Volume of incubation medium -- 1 ml: 20 micromoles of KH_2PO_4; 2.5 micromoles of $MgCl_2$; 15 micromoles of KCl; 10 micromoles of versene, 200 micromoles of saccharose, added 10 micromoles of succinic acid per sample; a -- control mitochondria; b -- mitochondria after the exposure to CMF.

The second special characteristic is the dependence of the CMF effect on the rate of phosphorylated respiration on the degree of its conjugation in various oxidation substrata. The influence of the CMF increased the rate of oxygen absorption on glutamic acid, increased it slightly on the mixture of glutamic and malic acids, and, finally, lowered it on succinic acid. It is known that the oxidation of glutamic acid is strongly conjugated with phosphorylation, the oxidation of a mixture of glutamic and malic acids is conjugated less strongly and, finally, the oxidation of succinic acids is conjugated still less strongly; free oxidation is 30-50 percent of the phosphorylated oxidation [178, 382].

Comparison of the changes in the state of the respiratory chain of mitochondria discovered in various oxidation substrata after the effects of CMF

with the published data on various degrees of the conjugation of oxidation of these substrata [109] made it possible to assume that a CMF, evidently, changes the ratio of the free and phosphorylated oxidation in the respiratory chain: reduces the electron flux along the free route of oxidation without the accumulation of energy and raises insignificantly the electron transfer along the phosphorylated route.

Analyzing the conditions under which these experiments were conducted, it is necessary to stress that the exposure to CMF was carried out on mitochondria in the state of "rest" at a temperature of from 0 to +4 degrees C. The latter evidently intensified the CMF effects. Secondly, the control and experimental preparations of mitochondria aged during the experiment and, finally, it should be mentioned that the functional changes in the respiratory chain of mitochondria were studied after the action of the CMF.

It is worthy of notice that the same preparation of mitochondria, depending on the initial level of oxidation and its conjugation at various substrata, showed an increase, a lowering and absence of changes in the absorption of oxygen under effect of CMF (Figure 4). As can be seen from the figures, a CMF narrows the range of possible rates of the electron transfer along the respiratory chain of mitochondria. This effect of the CMF is opposite to the effect of low concentrations of cysteine, which facilitates the disulfide-dithiole transitions in mitochondrial proteins when their conformation changes [98, 99]. The latter gave a basis to assume that a CMF "conserves" the dithiole groupings of mitochondrial proteins and thus lowers the probability of disulfide-dithiole transitions [246], which, proceeding from the idea of the alternating conjugative operation of the respiratory chain [99, 134], may result in the limitation of the possibilities of electron transfer.

In connection with the assumption regarding the conservation of SH-groups under the effect of CMF, it is interesting that in studies on a homoginate of cardiac muscles the lowering of the temperature leads to a decrease in the reactive ability of the SH-groups [205].

Thus, the presence of the reactions of tissue respiration and changes in the activity of some enzymes in vitro make it possible to expect some changes in the progress of biochemical processes under the influence of a CMF on an intact organism. In the last studies, it is important to consider the fact that an important role in the reaction of tissue respiration under the effect of a CMF on an intact organism is played by the changes occurring in the regulating systems of the integral organism (nervous system, endocrine system, and so on).

The first data on the changes of the general gaseous interchange in intact animals with a short exposure to a CMF (5 kilo-oersteds) were obtained by V. F. Tishan'kin [197], who reported that a CMF lowered the consumption of oxygen in mice and that this effect was expressed the most in young animals.
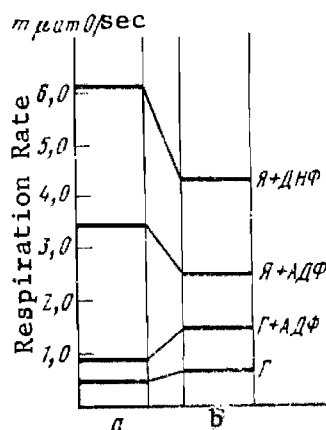
Figure 4. Various Levels of the State of the Respiratory
Chain and the Effects of a Constant Magnetic Field Against
this Background.
Incubation medium (see Figure 3). Я -- succinic acid (10
micromoles); АДФ -- adenosinediphosphate (100 micromoles),
ДНФ -- 2.4-dinitrophenol $(4 \cdot 10^{-5}$ M); Г -- glutamic acid
(10 micromoles); a -- control mitochondria; b -- mitochon-
dria after the influence of the CMF.

The data on the lowering of the general gaseous interchange by 16±9 percent
with longer (up to 16 days) exposures to CMF (4.2 kilo-oersteds) were re-
ported by M. Barnothy [286]. The inhibition of the oxygen consumption in his
experiments correlated with the lowering of the hemoglobin content by
5.4±1% (p = 1:6000) against the background of an unchanging amount of ery-
throcytes.

Further studies on white mice [248] showed that a CMF (4.2 kilo-oersteds)
with short exposures (about 1 hour) caused an insignificant lowering of the
general gaseous interchange in the mice by 5.9 percent $(p > 0.05)$. The de-
gree of the lowering of the gaseous interchange by the CMF increased when
its initial level was higher. And, on the contrary, animals with relatively
low initial level of the gaseous interchange almost did not change it in the
CMF.

In order to study the levels of oxidative processes in intact animals with
short exposures to a CMF of 4.5 kilo-oersteds, studies were made on the re-
storation of the body temperature in mice after an acute hypothermia whose
rate is, evidently, a direct function of oxidative processes.

The obtained results showed the lowering of the restoration of body temper-
ature in the animals after an acute hypothermia, and the maximum of this in-
hibition (1.5 degrees) ooincided with the highest level of general gaseous
interchange at the 90th minute of the restoration period. As the body tem-
perature approached the initial temperature prior to cooling, the degree of
the differences between the control and the experiment leveled out [249].

In studying the sensitivity of the general gaseous interchange in white mice to amytal, it was found that the resistance of the animals was increased. According to the authors, this indicated an intensification of glycolytic processes in the tissues of the animals under the effect of a CMF of 4.2 kilo-oersteds [248].

In studying longer influences (24-72 hours) of CMF (4.5 kilo-oersteds) on an intact organism by histochemical methods, considerable changes were discovered in the activity of a number of oxodative enzymes in the livers of white mice [250]. The first fact that was noticeable was a substantial change in the activity of mitochondrial enzymes (succinate-, glutamate-, and malate-dehydrogenase) and relatively insignificant changes in the activity of enzymes localized in the cytoplasm of liver cells (lactate-and glucose-6-phosphate dehydrogenase). Secondly, the nature of the discovered changes in the activity of metochondrial enzymes made it possible for the authors to assume that these changes were based on the disturbances in the permeability of mitochondrial membranes and not on the primary effect of the CMF on the enzymal reactions.

And, finally, different degrees of sensitivity to CMF in different types of tissues were discovered. Moreover, the changes in the enzymal activity in the elements of the connective tissues of the liver where less expressed than in the liver cells.

Studies on oxidative phosphorylation in animal tissues during the influence of a magnetic field on the complete organism are treated in a few works where intermittent low-frequency magnetic fields were used. When a weak magnetic field (16 oersteds, 50 hertz, 3 sec - pulse and 1 sec - pause) in the course of 6 or 9 days for 5 minutes a day, the livers of guinea pigs showed an intensification of the esterification of inorganic phosphorus and a decrease in oxygen absorption. The R/0 coefficient increased accordingly. With longer periods of exposure, the observed changes were more expressed [337].

Under the effect of exposure to a CMF (300 oersteds, 7 kilohertz) daily for 1.5 hours, the lowering of the coefficient of oxidative phosphorylation was registered in the muscles of rats during the first month, and in the brain and liver only during the third month of exposure. It is characteristic that a lowering of the level of creatine phosphate and the accumulation of lactic acid in the brain and muscle tissues were discovered under tha same experimental conditions. The lowering of the coefficient of oxidative phosphorylation was accompanied by an increase in the preformed ammonia in the muscle tissues of rats [56]

Changes in the nitrogenous metabolism of the brains of white rats were discovered under the effect of a CMF by A. B. Kogan and G. V. Shcherbakova [180].

Experiments described in [180] deserve attention. It was established that, after exposing a rabbit (head) to a nonuniform CMF (100 - 1000 oersteds)

in the course of 20-60 minutes daily from 1to 3 weeks, the peroxidase acti-
vity (determined by I. V. Simakov's method) lowered gradually, and it was not
possible to determine this activity in most of the rabbits. The peroxidase
activity in this part of the rabbits could be determined only after a three-
seven-day interval. According to the authors' data, the value of the effects
of a CMF within the above-mentioned intensities depends on the time of exposure
of the animals to the CMF.

A decrease in the peroxidase and catalase activities of rat blood was revealed
under the effect of a low-frequency pulsed magnetic field [56].

Hypotheses Proposed for the Explanation of the Effects of CMF on Biochemical
Processes

In analyzing the possible variants of the influence of CMF on chemical reac-
tions, it is possible to isolate, first of all, the direct effect of magnetic
fields on the equilibrium and rate of chemical reactions; secondly, the di-
rect effect of magnetic fields on chemical bonds and, finally, the indirect
effect of magnetic fields on chemical processes [286].

The CMF influence on the rates of chemical reactions was studied by Indian
chemists Batnager and Methur [285], who established an empirical rule: if
the sum of molar susceptibilities of the reaction products is greater than
the same sum for the initial reagents (with consideration for the complete
number of gram-molecules with respect to the reaction equation), then the
magnetic field will increase the reaction rate; otherwise its rate in the
magnetic field decreases. A field does not affect the reaction rate if the
sums of the molar magnetic susceptibilities of the initial and final reaction
products are equal*.

A brief review of works regarding the influence of CMF on chemical reactions
can be found in a book by P. Selvud [174]. A more up-to-date and complete
review of works on the influence of magnetic fields on reactions in liquid
and gaseous media on polymerization, catalysis, and electrochemical reactions
is offered by J. and L. Mulay [286]. However, evidently, the equilibrium and
rates of the majority of chemical reactions do not change significantly in
CMF.

In examining the interaction of CMF with paramagnetic and diamagnetic mole-
cules, which make up the bulk of a cell, attention was drawn to the fact that
the energy of the action of a magnetic field was smaller by many orders than
the thermal motion [69, 286]. Even the energy of such a weak chemical bond
as the hydrogen bond (3-7 kilocalories/mole) is considerably smaller than
the energy of the CMF action. Thus, it is impossible to expect that a CMF
will change or, especially, upset the nature of chemical bonds in general
and in a biological system in particular [286]. The results of studies on
the effects of CMF on the reactivation of enzymes after ultraviolet denatur-
ing do not contradict this conclusion (see above).

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*Thermodynamic substantiation of this rule was given by R. Delhez [302].

At the same time several hypotheses have been offered now for explaining the effects of CMF of up to 10^4-10^5 oersteds on certain biochemical processes.

The first theoretically substantiated indication of the possibility of changes of enzymal processes in CMF was a report by Ya. G. Dorfman [69]. The calculations given in this article showed that, firstly, uniform CMF of 10^4-10^5 oersteds are capable of causing an almost total alignment of dissolved macromolecules, which could reflect, for example, on the kinetics of the corresponding chemical reactions (due to the steric action). Secondly, in nonuniform CMF of the same orders, apart from the orientation of macromolecules, there is a possibility of the appearance of considerable concentration gradients which also could have a substantial effect on the progress of physicochemical or biochemical processes in the solution. These conclusions were obtained in calculations under the condition that the molecules had a rod-like shape and, correspondingly, a sharply expressed diamagnetic anisotropy (see this collection). As experiments have shown [326], CMF noniniformity plays an important role. At the same time, there are considerable difficulties in explaining the causes of different directiveness of the effects of nonuniform CMF in reactions catalyzed by catalase and glutamate dehydrogenase.

In connection with the theoretical premises stated by Ya. G. Dorfman, it is possible to add that many substances of biological origin may have a liquid crystalline structure. For example, myosin, a protein which is a part of many membranes, is capable of forming liquid crystals. There are hypotheses that many structural elements of the cytoplasm, for example, mitochondria, have a liquid crystal structure.

Liquid crystals possess anisotropy of magnetic properties [230, 231]. Diamagnetic anisotropy is chiefly due to the presence of benzene rings in the molecules and is proportional to their number. In sufficiently strong CMF, the long axes of nematic liquid crystals are oriented parallel to the lines of force of the magnetic field. Smectic liquid crystals, because of their great viscosity, are not oriented by CMF up to 3,000 oersteds. However, it is possible to orient a smectic substance by cooling an isotropic melt in a CMF. When the field is switched off, the orientation of the preparation is preserved, which does not occur in nematic preparations [240]. There still is a possibility that liquid crystals are those magnetically anisotropic structures of the cell which orient themselves under the influence of CMF. The latter, being localized in the membrane structures of the cell, are, possibly, responsible for the changes in the permeability of the membrane, which, in turn, regulates the progress of biochemical processes.

In recent years, there appeared many theoretical studies in the field of magnetobiology. For example, Valentinuzzi [286] arrived at an assumption that Brown's rotation of molecules (rotational diffusion) could be responsible for the number of chemically effective collisions, when a molecule involves successively its specific reactive groupings in the course of a reaction. If such molecules are paramegnetic, then the influence of an outside CMF can either slow down or stop their rotation. As a result of this, the possibility of effective collision will decrease and, consequently the corresponding biochemical reaction will be slowed down. Valentinuzzi's work treats

the problems of CMF effects on rotational diffusion and applies this theory to the influence of CMF on the rates of biochemical reactions progressing with the participation of strongly paramagnetic molecules, for example, ferrihemoglobin. On the basis of the author's calculation, a field of $5 \cdot 10^3$ oersteds at a temperature of 300 degrees K must reduce the reaction rate by 1 percent, and a field of $8 \cdot 10^5$ oersteds must stop completely a chemical reaction progressing with the participation of molecules whose magnetic susceptibility is of the same order as that of ferrihemoglobin.

The hypothesis proposed by Gross [286] for explaining certain magnetobiological effects is based on the assumption that they could be caused by the inhibition of the enzymal activity resulting from a change in the angle of bond (orbital) of paramagnetic molecules in a CMF. The author points out that, as was shown experimentally, the energy necessary for the deformation of the tetrahedral bond angle of carbon is equal to $E_\theta = \frac{1}{2}K_\theta(\Delta\theta)^2$, where K is a constant equal to 0.035 and $\Delta\theta$ is the angular deflection in degrees from the tetrahedral bond angle $109°28'$. The energy necessary for the deformation of the bond angle by one degree is 0.0175 kilocalories/mole. On the basis of the low energy requirement for changing the tetrahedral angle of bond, Gross developed theoretically the possibility of the CMF influence on certain chemical processes and assumed that magnetic fields would have a substantial effect on the production rate of desoxyribonucleic acid and ribonucleic acid by polynucleotide pholphorylase, and would also affect the reactions progressing with free radicals in solid media, for example, isomerization caused by radiation and radiation-induced polymerization of monomers in crystaline state.

Conclusions based on the quantum mechanics theory of the formation of supermolecular structures from simpler high-molecular compounds developed by L. Ya. Kobelev [88] deserve attention. This theory is based on the assumption that collective interactions produced by quantum forces of exchange nature play a basic role in the formation of supermolecular structures. The author made a qualitative analysis of the causes leading to a possible increase in the parameters of exchange interaction and came to the conclusion that a magnetic field can possibly control this value.

When hypotheses are offered for the explanation of the biological influence of CMF, it is, evidently, necessary to consider the fact of CMF effects on certain physicochemical properties of water, which has been established in many works: surface tension, viscosity, electric conductivity, dielectric constant, light absorption [31, 123, 211, and others]. Changes in the properties of water must necessarily cause changes in the united system of water with the molecules of proteins, nucleic acids, polysaccharides, and lipids.

It is not simple to answer the question of what are the real mechanisms of this bond, since the role of water and its structure in biological processes is one of the most complex problems and important discoveries must be made in the course of solving this problem. However, it is possible to imagine the simplest of these mechanisms.

It was shown that CMF change the dielectric constant of water [211]. As is known [177], not only the energy of electric interaction of two charges, but also the weak interactions of dipoles depend on the value of the dielectric constant of the medium. Moreover, unlike the Coulomb interaction, the dipole-dipole interaction and the interaction of constant and induced dipoles are inversely proportional not to the value of the dielectric constant, but to its square. Consequently, we can rightly expect the highest effect from the changes in the dielectric constant of water under the influence of a CMF on the energy of the weak interaction of the dipoles. Moreover, the increase in the dielectric constant of water under the effect of the CMF must lead to the weakening of the interaction energy of the electric charges and, even to a greater degree, of the interaction energy of the dipoles. It is possible that similar changes take place when the incubation temperature of biological objects drops, since the value of the dielectric constant of water increases when the temperature drops [212].

There are, evidently, many ways to realize the influence of CMF on weak interactions, and it is possible to assume that CMF will change the frequency of the formation and destruction of weak bonds experiencing a relatively strong action of thermal perturbations, and will influence the fluctuation of the electron clouds of the molecules inducing dipoles participating in weak interaction. The latter is probable, since the fluctuation frequency of electron clouds is 10^{15} times per second, which is approximately equal to the oscillation frequency of the visible or ultraviolet light [177], and the absorption spectra in the ultraviolet and visible regions change under the influence of CMF on water and proteins [31, 286].

Enzymes do not participate in the destruction and appearance of weak bonds, but these weak interactions play an important role in the supermolecular organization of many cellular structures, including membranes [301]. Such supermolecular formations as the membranes of the nuclei, mitochondria, and the cells are the regulators of many biochemical processes [55, 131, 158, and others].

On the basis of these assumptions, it seems probable that, by changing the energy of weak interactions, CMF influence the supermolecular organization of live structures which, in turn, leads again to quantitative changes in chemically specific reactions (including those with the participation of enzymes) leading to disturbances in the macroscopic characteristics by which experimentators judge the biological effects of CMF. Along with the above-mentioned possible effects of CMF on the supermolecular organization of biological structures, it is possible to assume that changes in the dielectric constant of water under the effect of a CMF will also affect the rate of some chemical reactions.

The rate of a reaction is determined by the value of the activation energy, which, in turn, often depends on the value of the electrostatic forces of the interaction among the reacting molecules. When the dielectric constant decreases, the reaction between oppositely charged ions progresses more

rapidly, while the reaction between analogously charged ions slows down. Since the forces of the electrostatic interaction are significant in many enzymic reactions, the dielectric constant can influence the rate of some enzymic reactions, changing either the affinity of the enzyme to the substratum, or the disintegration rate of the enzyme-substratum complex, or both simultaneously. The effects of the changes in the dielectric constant of the medium with the addition of organic solvents to the water on the overall rate of enzymic reaction were shown experimentally for several cases [212].

It is important to note that, since the greatest changes in the dielectric constant of water are observed when CMF act upon moving water, and not on still water, it is natural to expect that the suggested mechanisms of the CMF influence will be more expressed in the first instance.

In examining the hypotheses proposed for the explaination of the CMF influence on biochemical processes, it may be mentioned that in most of them magnetic fields of 10^4-10^5 oersteds are used.

However, experimental materials indicate that changes in biochemical processes in vitro, and particularly in vivo, can be detected with the field intensities by several orders lower. These changes are chiefly nonspecific, such as: changes in the aging rate of enzymes in vitro, changes in the ratio of free and phosphorylated oxidation, intensification of glycolysis, stress reaction of the entire organism, and so on.

It seems probable that studies on the mechanism of the CMF influence on live structures are closely connected with the studies on the nature of nonspecific reactions of the protoplasm to external influences, which is one of the most important tasks of biochemistry and biophysics.

It is possible that further magnetobiological investigations will broaden and deepen our understanding of many urgent problems of modern biology and medicine.

THE INFLUENCE OF MAGNETIC FIELDS ON MICROORGANISMS

[S. Z. Pavlovich, Ivano-Frankovsk Medical Institute, Ivano-Frankovsk]

Unlike other physical factors of the environment, the influence of magnetic fields on microorganisms has not been sufficiently studied. This is, evidently, connected with many circumstances. First of all, the nature of magnetic fields as physical phenomena has not yet been fully explained, Secondly, their influence on live objects has specific characteristics depending on the experimental conditions and, finally, microbiological studies on the effects of magnetic fields   encounter some technical difficulty.

There are some contradictory reports in the literature on the problem of the influence of magnetic fields on microorganisms. The reliability of these reports can be assessed with the consideration for the dates of the studies, the level of knowledge of the biological effects of magnetic fields, study methods, the nature of the microbiological test objects exposed to a magnetic field, and other reasons.

Among the earliest investigations on the effects of magnetic fields on microorgamisms belonging to the end of the XIX and the beginning of the XX centuries, the reports by Dubois, R. [307], Sheneveau and Bohn [293,294], and Grenet [319] deserve attention.

Dubois described the influence of a high-intensity magnetic field on the development of a culture of Micrococcus prodigiosus. Growing this species of bacteria on the surface of solid nutrient media, the researcher noticed some changes in the formation and orientation of the microbe colony under the influence of CMF on the inoculated culture. According to the author's description, the colonies of the microorganisms growing in the magnetic field had a dry, consolidated center of elongated shape whose longitudinal diameter was three times greater than the transverse diameter. There were also some changes in the structure of the peripheral part of these colonies, and their edges became uneven. The major axis of the central zone of such colonies was directed chiefly from northeast to southwest. In some colonies situated in the middle part of the system of magnets, the author observed four

consolidated punctate formations oriented toward the four poles of the two opposite magnets.

Sheneveau and Bohn showed the influence of magnetic fields of 5000-8000 oersteds on several species of infusorians developing in a favorable liquid medium at 18-19 degrees. The experiments were carried out on mobile carnivorous (Loxophyllum maris) and herbivorous (Colpidium), slightly mobile freshwater (Stylonichia) and marine (Oxytrichides), as well as immobile (Vorticella) infusoria. The authors observed an inhibiting effect of magnetic fields on the protozoans. For example, in the beginning the magnetic field slowed down the movement rate of the cilia of the infusoria, and 4-5 days later, the resorption of motor organs was observed. The growth of protozoans was inhibited. In the course of several generations, individual infusoria were atrophied, and their growth declined by one-third or even by one-half in compariton with the size of the initial population. The multiplication process of the infusoria also stopped.

Particularly clear results were obtained under the influence of magnetic field on the immobile species of protozoans, which died rapidly before their division. After one day, their number decreased by one-half, and 4 days after the moment of study, 100 percent of Vorticella died. This is explained by the inability of such infusoria to move into the areas of lower intensities.

When Grenet [319] studied the effects of magnetic fields on paramecia, he observed a more rapid biological effect than the preceding researchers. In this experiment, Paramaecium aurelia were exposed to an intermittent magnetic field whose intensity was always below 100 oersteds. Half an hour from the moment of the application of the field, the movements of the paramecia slowed down or they became immobile. By the end of the 1.5-hour period of observation, all infusoria lost their ability to move. Most of the protozoans exposed to the field became rounded, spherical, and only some of them preserved their characteristic ovoidal shape. In many of them even the membranes burst and the content of the protoplasm poured out.

Further studies by Leusden [350], who studies the growth of Bacterium coli and Staphylococcus aureus on laminated agar, when the medium was inoculated with identical amounts of fresh subcultures of microbes, did not reveal any effects of the CMF on the microorganisms. He found the same numbers of microbe colonies in the dishes exposed to the field and in the control.

In a work by Jennison [332], which was published in the form of theses, the growth of bacteria, yeast and mold in a strong magnetic field was studied. Among the 25 species of microorganisms studied by the author, 12 species belong to the class of bacteria, and the remaining to fungi. Unfortunately, the author did not enumerate the specific composition of the microbes. In his experiment, he studied the influence of a uniform magnetic field of 3000 oersteds on the growth of microbes in Petri dishes placed in the gap of an electromagnet, so that in most experiments the applied field was perpendicular to the surfaces of the nutrient media. The experimental dishes were

kept in the magnetic field in the course of 48 hours while the microorganisms were grown at a temperature of 25 degrees C.

The results of the studies did not reveal any influence of the magnetic field on the growth rate or the size of the colonies of the test microbes and there were no changes in the structure and pigmentation of the colony, in the size and shape of the individual cells or in their behavior with respect to the Gram staining and the process of spore formation. The attempts of the author to reveal the effects of the magnetic field by changing its direction toward the surface of the nutrient medium or after repeated 2-3-time passages of the culture in electromagnets failed just as before.

Luyet [353] studied the effects of a magnetic field of 524 oersteds on the process of sprouting and further development of the spores of the mold Rhizopus nigricans in Cohn's agar at a temperature of 22 degrees C. Having studied the growth rate, the direction of aerial mycelium and the morphological structure of the mold, he established a normal development of the aerial hyphae of the fungus and its sporangia. He did not detect any influence of matnetic field in other experiments, where soft iron plates were placed in the vessel with the nutrient medium for thickening the lines of force of the field.

The results of Lenzi's experiments [347] contradict the conclusions made by Leusden and Jennison. Unlike these authors, he used the rods of blue-green puss as a microbiological test object, exposed them to an alternating magnetic field (AMF), and discovered the inhibition of the culture growth. By growing Saccharomyces cerevisiae for a long time in a constant, pulsating and alternating magnetic fields of various frequencies, Lenzi also showed the changes in the enzymic ability of the yeasts expressed in the inhibition of this function, which showed itself particularly sharply in the pulsating field.

An analogous influence of magnetic fields on the development of yeasts was described by Kimball [340]. This author studied the budding process of yeast cells by inoculating a bud-free culture of the microorganisms in nutrient media, after which they were grown and placed in Petri dishes for a certain period of time on the poles of a constant horseshoe magnet.

As a result of this study, he discovered a considerable inhibition of the budding of the yeasts under the poles of the magnet creating a nonuniform field. On the average, the process of bud formation was inhibited by 20-30 percent. The squares of the nutrient medium toward the periphery of the dish which were farther removed from the magnet poles contained more yeast cells. The experiments showed that the most sensitive stage of the development of the yeast to the effects of the magnetic field was the end of the lag phase measured by the 1.5-hour period of the preliminary growing of the microbes at a temperature of 30 degrees. The magnetic field did not affect the budding process of the yeast during the first hour from the moment of inoculation or after 2 hours of the culture's growth. An inhibition of the

multiplication of the inoculated yeast was observed after a 20-30-minute action of the magnetic field. The author also showed that the inhibition process of budding depended on the characteristics of the magnetic field. Having discovered the inhibiting effect of a nonuniform field with respect to the multiplication of yeast, he did not observe such an effect from the application of a homogeneous field. According to Kimball, the effect is produced not by the magnetic field as such, but by the changes in the strength of the field, or its gradient. This explains both the unsuccessful experiments of scientists who used homogeneous fields, and the expressed effects from the application of heterogeneous fields of even weak magnets.

The works by Magrou and Manigault [355, 366] are of particular interest. They showed an inhibiting effect of magnetic fields on Phytomonas tumefaciens causing the development of swellings in pelargoniums (Pelargonium zonale). The studies of these authors were based on an earlier discovery by Remy [386], who showed that magnetic fields have an inhibiting effect on the development of tumors in pelargoniums caused by chemical agents. Since Remy's report did not give the physical characteristics of the magnet and the histological picture of the tumor, Magrou and Manigault decided to fill in this gap. They inoculated Phytomonas tumefaciens into a pelargonium stem and placed the infected cuttings of the plant in constant magnets or electromagnets whose magnetic field intensities were 550, 900, and 1500 oersteds. Dimensions of the induced tumors were measured 67 days after the beginning of the experiment. In the plants exposed to the magnetic field, the swellings did not exceed 1 mm, i.e. they were in an embryonic state of their development, while the stems of the control specimens had a wart-like formations of 8-12 mm. The authors observed that the inhibition of the tumor depended on the field gradient: when the gradient diminished, the growth of the tumors in the magnetic field became more rapid in comparison with what was observed when the field gradient increased. The inhibition of the tumors or their slower development caused by a magnetic field with a high gradient were also connected with the moment of the application of the magnetic field: an expressed effect of inhibition was observed when the plant was exposed to the magnetic field during the formation of a diamond-shaped scar. It was not possible to change the characteristics of the growth of the tumor under the influence of a uniform magnetic field with a high gradient on an already formed scar of the plant. Cytological studies did not reveal any qualitative peculiarities in the cell structure of the experimental and control tumors.

In connection with the application of high-intensity magnetic fields in science the technology in recent years, there have been more studies on their influence on live organisms, particularly, on unicellular organisms.

For example, Buksa [32] compared the biological effects of magnetic fields, ultrahigh frequency fields, and ultraviolet radiation, and showed that these agents caused similar effects with respect to food yeasts expressed in the inhibition of their multiplication. For this purpose, suspensions of fresh subcultures of the yeast in various nutrient media were placed in a CMF of 750 oersteds at room temperature for 2-8 and more hours, and in studying

the effects of short exposure, for one hour in an incubator at a temperature of 22-29 degrees C. For the control, there was a series of experiments at an optimal temperature for the multiplication of the yeast (30 degrees) and in an optimal medium (hopless wort with 1 percent of glucose). By counting the microbe cells in Goryayev's chamber, the inhibiting action of the CMF on the increase of the yeast culture was established in more than 100 various experiments. The inhibiting effect of magnetic fields on the multiplication of the yeast showed itself at various temperatures and in various nutrient media. The increment of cells in the yeast suspensions exposed to a magnetic field for one hour was one-third of the increment of the control, and after 2-hour exposure of the culture to the same field, it was approximately 50 percent less. When the exposure time was lengthened (over 8 hours), The intensity of the inhibition of cell division did not increase. The inhibition of the yeast multiplication took place only during the period of the action of the magnetic field. After the termination of the action, the rate of increase in the amount of cells in the experiment and the control was the same.

Platunova and Korotkova [146] studied the effects of AMF and CMF on Paramaecium caudatum developing in a hay infusion. In this brief and a very poorly presented report, where the characteristics of the magnetic fields are not even mentioned, the authors concluded that CMF influence the vital activity of paramecia only after 3 days. After this time in a CMF, the movement of the slipper limpets was noticeably inhibited.

Indirect indications regarding possible effects of external magnetic fields on the development of unicellular organisms are contained in the work by O. P. Samoylova and L. A. Blyumenfel'd [172]. This work studied the appearance and changes in "pseudoferromagnetism" in a biological object (Saccharomyces cerevisiae) at various states of its biological activity and is in agreement with the above-mentioned experiments by Kimball and Buksa. For a better understanding of this, the following should be stressed. Samoylova and Blyumenfel'd established that preparations of the initial yeast, as a rule, practically did not produce an EPR [electron paramagnetic resonance] signal. Growing the yeast as an object of study by the air-flow method on a 10-hour schedule, 30 minutes after the beginning of the experiment the authors registered an extremely intensive signal of magnetic resonance. Later, as the culture developed, the intensity of the signal changed regularly and periodically in the course of the experiments up to 6.5-7 hours. Beginning with 7-7.5 hours the intensity of the signal dropped sharply and returned to the initial level by 8-10 hours. The processes of cell division and culture growth generally ended by the same time. Let us remember that Kimball used the same test object and showed an inhibition in the budding of yeast in a magnetic field during the final moment of the lag phase, which, in the usual method of the microbe development, coincides with the beginning of the registration of an extremely intensive signal of magnetic resonance. Buksa, however, could not detect any inhibition of the division of yeast under the effect of a magnetic field, as he pointed out, "above 8 hours", i.e., during those study periods when the intensity of the signal of the growing culture begins to drop.

One of the most thorough studies is the work done by Gerencser et al [286, 318]. Their conclusions, judging by the faultless techniques and mathematical analysis of the results, testify with a high degree of reliability to the biological influence of magnetic fields on unicellular organisms. The authors studied the growth rates of two species of microorganisms in magnetic fields: Serratia marcescens and Staphylococcus aureus. The growth rate of the microbes was studied in electromagnets creating a magnetic field of 15,000 oersteds with a constant gradient of 2,300 oersteds/cm in the center of the growing culture (the paramagnetic strength of this field was 34.5 megaoersteds/cm). The count of viable cells (colonies) in dishes with agar was expressed numerically and graphically. All three experiments with Serratia marcescens exposed to the magnetic field first showed a slight acceleration of the culture growth (by 5 percent in the lag phase, i.e., during the first 3 hours of the field action. On the contrary, during the logarithmic phase, the magnetic field caused a considerable inhibition of the growth rate of the microbe. After the 10th hour since the beginning of the action of the magnetic field, the growth intensity (the number of colonies) was the same in the experiments and in the control. It was mentioned in the generalization of these experiments that the amount of the isolated colonies on the media during the period of the highest activity of the magnetic field (between the 6th and 9th hours) was 36 percent smaller than in the control. These observations made it possible for the authors to conclude that magnetic fields had an insignificant effect on the metabolism and growth of cells, but changed sharply the process of their division. The magnetic field of the above-mentioned intensity did not have any effect on the other test object (Staph. aureus). However, when the magnetic field was changed in such a way that its strength remained the same, but the paramagnetic strength was more than double, then the "magnetic" culture of Staph aureus grew faster than the control culture between the third and sixth hours. An obvious inhibition of the multiplication of the staphylococcus (by 42 percent) was observed between the sixth and seventh hours, and the difference in the intensity of the growth of the experimental and control cultures disappeared by the end of the ninth hour. Finally, the authors stated that the inhibition of the growth of the staphylococcus was caused by the paramagnetic force.

Hedrick's report [286] presented the results of studies on the effects of homogeneous CMF on the the growth rate, and physiological and morphological functions of Staph aureus, Sarcina lutea, and Escherichia coli. These cultures were grown on a broth at a temperature of 37 degrees in an electromagnet whose magnetic field intensity was 14,000 oersteds and the paramagnetic force was 0.14 megaoersteds/cm, or in a uniform field of a magnet of 700 oersteds. As a result of these studies, it was established that the growth intensity of the culture of Staph aureus during the first 15 hours of the action of the magnetic field did not differ from the control. The growth rate was inhibited during the 16th hour and up to the completion of the experiment (24 hours). Thus, the influence of a homogeneous CMF of 14,000 oersteds showed itself only in the maximum stationary phase of the development of the culture. A microscopic study of a hanging drop exposed to a field of 700 oersteds revealed a disorganization in the typical arrangement

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of the staphylococcus ("grape clusters"). In the opinion of the authors, this phenomenon was caused by the possible changes in the charges of individual cells. They were unable to detect any inhibiting effect of the magnetic field on the growth rate of Sarcina lutea. There was also no quantitative difference in the growth of E. coli exposed to a magnetic field.

Interesting studies were carried out by Kogan et al [49, 91, 93, 395]. They studied biological effects of a homogeneous magnetic field on various functions of microorganisms. Their attempts to establish the influence of magnetic fields on the multiplication rate of paramecia and the growth of Azotobacter chroococcum. Saccharomyces cerevisiae, Sarcina lutea, Bac. mycoides, Bac. Subtilis, Proteus vulgaris and other microbes yielded negative results. In the available literature, this is presented in the form of brief reports and resumes without any details of the experiment and the analysis of the obtained data and leaves this problem open. However, the above-mentioned works proved sufficiently fully and systematically the influence of magnetic fields on Paramaecium caudatum. Some experiments showed the effects of magnetic fields on the movement rate of infusoria, and others revealed cytological changes in the structure of protozoans. In their first study, the authors placed an elongated glass capillary (100 x 1 mm) filled with water and infusoria between the poles of a constant magnet of 400 oersteds in such a way that its long axis was parallel to the lines of force of the field and observed an asymmetry in the movement of the protozoans with a delay at the south pole. In another study, they determined the influence of a homogeneous magnetic field on the nucleus and the distribution of nucleic acids. In this case, the infusoria were exposed to a field of 600 oersteds in the course of 30 minutes. The magnetic field caused a displacement of the nucleus of the protozoans in relation to the long axis of the cell by approximately 15-30 degrees. There was a decrease in the amount of the cytoplasmic ribonucleic acid in the magnetic field, but the total amount of the nuclear desoxyribonucleic acid did not change.

Valentinuzzi and Vasquez [395] studied the development of a culture of Tetrahymena pyriformis, strain SH, and showed that homogeneous CMF of various intensities (2,000, 4,000, 6,000, and 8,000 oersteds) acting 6 hours daily in the course of 3 days of the experiment produced, in most cases, an inhibiting effect on the growth and multiplication of the protozoans.

Shakhov and Dushkin [243] studied the possibility of using an external magnetic field in the process of water disinfection. For this purpose, special electromagnets were designed with the magnetic field intensity within 40-720 amperes/cm. They studied artificially contaminated water, as well as water from an open reservoir. Water of both types was passed between the poles of electromagnets at the rate of 0.5-2 m/sec and was treated by a magnetic field in the course of 0.4-1.6 sec. The experiments revealed bactericidal effect of the magnetic field: the microbic number and the coli index decreased sharply in the treated water.

Studies on the oxidation processes of microorganisms subjected to the influence of magnetic fields deserve special attention.

In 1909, Gaule [316] established that a magnetic field of a solenoide intensified the enzymal activity of yeast. In comparison with the control cultures growing under normal conditions or subjected to a mechanical stimulation and electrolysis, the splitting of grape sugar by yeast to carbonic acid increased in the magnetic field (depending on the experimental conditions) by 31-61 percent.

Reno and Nutini [286] studied tissue respiration and showed that a CMF of 7,300 oersteds activated the cellular respiration of an yeast culture in all their experiments.

In another work, Pereira et al [395] observed a similar effect under the influence of intermittent magnetic fields on the same test object. It was observed that magnetic fields of 80-85 oersteds and higher (to 10,000 oersteds) had almost identical stimulating effects on the respiration of Saccharomyces cerevisiae. According to the authors, the bioeffects of magnetic fields do not increase in high-intensity fields, and the response reaction of the cells shows itself immediately, but remains reversible.

Moskwa and Rostkowska [362] discovered disturbances in the enzymic activity of yeast in CMF of 2400—3200 oersteds, which was expressed as a decrease in the amount of carbonic acid liberated by it. In their experiments, such poisons as atebrin, urethan, and dehydrocholic acid, had a much weaker effect on the "magnetic" yeast than on the control yeast. Analogous results were obtained in trial experiments with protozoans on the influence of CMF.

The activating influence of a homogeneous CMF of 14,000 oersteds on the enzymic activity of E. coli was also observed in the above-mentioned work by Hedrick. This observation was established during spectrophotometric studies on hydrogen liberation.

Finally, we [180] determined sharp shifts in the metabolic functions of a number of microorganisms after long passages in various magnetic fields.

In connection with the development of space biology, studies on the biological influence of strong magnetic fields, as well as the effects of magnetic fields on chlorella, are becoming very important.

Beischer [286], Knepton et al [341, 343] did not discover any influence of the magnetic field of 140,000 oersteds on the luminescence of Photobacterium fisheri and on the mutation rate of Neurospora crassa. However, the same field inhibited the division rate of fertilized eggs of the sea urchins Arbacia punctulata during the first stage of development.

Halpern and Konikoff [328] showed that, by the end of the 7th day of exposure, a magnetic field accelerated the growth of Chlorella pyrenoidosa, and that the intensity of growth increased when the field intensity increased. Thus,

magnetic fields of 750 and 1,000 oersteds did not have any obvious effect on the microorganisms, while a magnetic field of 4,000 oersteds increased the yield of the biomass by 6 percent, and the field of 20,000 oersteds increased it by 38 percent.

Rodicheva et al [49] studied the biosynthesis of chlorella which was cultivated continuously and showed that AMF of 100 and 200 oersteds did not have any noticeable effect on the productivity of Chlorella vulgaris and its other characteristics in the course of 12-24 hours.

Having summarized briefly the results of the above-mentioned studies of microbiological nature, it should be said in conclusion that the various views of individual researchers on the nature of the biological influence of magnetic fields, in the final analysis, confirm the notion of magnetic fields as active physical factors of the environment. This is also supported by our studies on some functions of the vital activities of microorganisms subjected to the action of CMF, AMF, and PMF [pulsed magnetic field] whose intensity were 6,000, 180 oersteds, respectively, and also 22,000 or 45,000 oersteds.

In order to study the biological effects of magnetic field, we took various microorganisms which were different in their biological properties and belong to different taxonomic groups. More precisely, we used the set of microorganism species which is usually used for testing the antibacterial activity of actinomyces, antibiotics, chemical preparations, phytoncide, and so on. This list of species included:E. coli, Shigella sonnei, Bac. subtilis, Bac. anthracoides, Bac mycoides, Staph aureus 209, its mutant -- Staph aureus UF-3, Candida albicans, Mycobacterium B-5, and Proteus vulgaris. As test objects, we used pathogenic, conditionally pathogenic, and saprophytic forms of microorganisms, Gram-positive, Gram-negative, sporogenous and asporous, mobile and immobile microbes, bacteria, bacilli and cocci, fungi, mycobacteria, and a mutant with a respiratory defect proposed for preliminary selection of actinomyces possessing an antitumoral effect.

In various experiments, we studied a prolonged action of magnetic fields on the nature and rate of the growth of microorganisms, oxidation processes, biosynthesis of nucleic acids,inducing effects of magnetic fields on lysogenic bacteria, thermal resistance, and some other phenomena of the vital activities of "magnetized" microbes.

a) The Effect of Magnetic Field on the Multiplication and the Nature of Growth of Microorganisms. The influence of magnetic fields on the growth rate was studied for 10 species of microorganisms growing in 15 continuous passages in electromagnetsof direct and alternating currents or subjected twice daily to a treatment in a pulsed magnetic field. During the first day of the experiment, the broth cultures were exposed to a CMF or AMF for 9-10 hours, and to PMF immediately after the inoculation and 3 hours after the beginning of growth.

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The results of the study showed that, after 15th subinoculation of the micro-organisms, CMF activated the multiplication process of the cultures of E. coli, Staph. aureus 209, its mutant UF-3, and three sporogenous bacilli. In comparison with the control strains grown outside the magnetic field, the development rate of "magnetized" cultures was faster by 21.2-48.6 percent (P<0.05). The AMF caused statistically certain changes in the multiplication in Shigella sonnei, Bac. subtilis, and Staph. aureus 209: the growth rate of the first culture increased and in two others it lowered. The PMF at this stage of study had a stimulating effect only on two cultures. The amount of microbe cells in the broth culture of Proteus increased by 22 percent and in the yeast by 43.9 percent (P<0.05).

In making further subinoculations of the microorganisms in magnetic fields and studying the characteristics of their growth on various nutritive media, we noticed that the process of prolonged "magnitization" of the cultures was accompanied by a great variability of the cultural and biochemical properties of the tested microbes. The influence of various magnetic fields changed the structure and shape of the colonies and the relation of the microbes to sugars.

The biological influence of PMF on the cultures of mutants of Staph. aureus UF-2 and UF-3 deserves particular attention. When they were "magnetized," there was a clearly expressed depigmentation of the colonies. The phenomena of the microorganism variability observed in other fields were just as interesting. The greatest effect was produced by a CMF on a culture of Bac. subtilis whose "magnetized" strain considerably lost its ability for spore formation after 50th subinoculation in the CMF. Specific characteristics of the colonies of E. coli and Bac. mycoides changed sharply during this subinoculation.

A considerable influence of the fields was also revealed in studying the saccharolytic and proteolytis properties of "magnetic" cultures of microbes in the Hiss series, which made it necessary to make a thorough study of their biochemical activity.

b) The Influence of Magnetic Fields on the Enzymic Systems of Microorganisms. This section presents the results of studies on the catalase, peroxidase, and dehydrase activities of microorganisms after prolonged subculturing in magnetic fields. For the quantitative determination of the catalase of the bacteria, we used a modification of the Bakh and Zubkova method. The peroxidase determination was done by Boyarkin's method. The dehydrogenase activity was studied by three methods: Tunberg, Wilson and Kalish, and Kun and Ebud.

Studies on the enzymic activity in the microorganisms were always done in the same phase of growth corresponding to the logarithmic stage of cell development. Microbe cultures were grown on a beef-extract agar and a beef-extract broth at 37 degrees, and Candida albicans at an optimal temperature of 29-30 degrees. The catalase activity was determined after 50 continuous subinoculations of microbes in a magnetic field in the course of one and a half months. The peroxidase and dehydrogenase activity was determined after 50 subinoculations three months after the beginning of the exposure to the magnetic field.

Analysis of the obtained data subjected to statistical treatment makes it possible to conclude that a magnetic field can cause biological shifts in the oxidation-reduction processes of microorganisms.

We established that various magnetic fields acting continuously on microbes, as a rule, inhibit the activity of the catalase. The most active field with respect to catalase was CMF, while PMF and AMF produced lesser effects.

After 50 subinoculations in CMF, the catalase activity did not change only in three species of microorganisms out of the 10 studied caltures. Cultures of Bac. antracoides and Staph. aureus 209 were found to be very sensitive to the action of CMF. The percentage of the catalase activity in the "magnetized" variant of the first species of microbes decreased by more than one half and was 44 ± 2.16 against 90 ± 1.58 in the control (P $<$ 0.001), and in the second species it decreased to 64 ± 1.28 in comparison with 90 ± 0.73 of the control strain (P $<$ 0.001). A smaller but statistically certain degree of decrease in the catalase activity was observed in "magnetic" cultures of Bac. subtilis, Bac. mycoides, Candida albicans, and Staph. aureus UF-3. The opposite effect was produced by CMF only on a culture of Proteus vulgaris, whose catalase activity increased considerably.

AMP affected the catalase activity of 6 species of microorganisms. The catalase activity of the "magnetic" cultures of E. coli, Shigella sonnei, Staph. aureus 209 and its mutant UF-3, and Bac. anthracoides decreased to various degrees (P$<$0.01), while it increased in Candida albicans (P $<$ 0.01).

The effect of PMF was accompanied by the inhibition of the catalase activity in 5 species of microorganisms: E. coli, Bac. mycoides, Staph. aureus 209, Staph. aureus UF-3, and Myeobacterium B-5.

The peroxidase study of the "magnetized" strains of microorganisms revealed the same directivity of the changes in their biochemical activity as in the catalase studies. In other words, the influence of various magnetic fields, in the majority of cases, was expressed in the inhibition of the peroxidase activity.

After the 50th subinoculation in the CMF, the activity of peroxidase dropped by 15.9-35.4 percent in the cultures of Proteus vulgaris, E. coli, Mycobacterium B-5, and yeast-like microorganisms (P $<$ 001), and at the same time increased by over 20 percent in the cultures of Bac. subtilis, Bac. anthracoides, and Staph. aureus UF-3 (P $<$ 0.01)

Statistically certain inhibition of the peroxidase activity under the influence of PMF was observed in E. coli, Staph. aureus strain 209, Mycobacterium, Proteus vulgaris, and Bac. mycoides. The same shifts in the peroxidase activity were caused by AMF in Shigella sonnei, Bac. subtilis, Candida albicans, Mycobacterium B-5, and Bac. anthracoides. On the contrary, PMF stimulated the peroxidase activity in Bac. subtilis and Bac. anthracoides, while AMF activated perioxidases in Bac. anthracoides and Staph. aureus UF-3.

The most sensitive to PMF were the cultures of E. coli and Proteus vulgaris. The peroxidase activity in them was inhibited by 37.6+4.36 percent (P < 0.001) and 32.2+3.13 percent (P< 0.001).

AMF was the most effective with respect to Bac. anthracoides and Candida albicans; in the first microbe species, the peroxidase activity increased by 25.1+2.4 percent (P < 0.001) in comparison with the control culture, and in the second it dropped by 25.6+7.35 percent (P < 0.05).

The variability of the dehydrogenase activity under the influence of external magnetic fields had its own characteristics which depended on the specific properties of the tested microorganisms, the nature of the field, its intensity, and the length of its action upon the test microbes. Just as in the studies on other anzymes, CMF had the greatest effect on the dehydrogenase of the microorganisms. Among all cultures treated with this field, the dehydrogenase activity did not change only in Mycobacterium B-5.

After 50 subinoculations in CMF, dehydrogenase activity increased regularly with various methods of study in E. coli, Shigella sonnei, Bac. anthracoides, and Bac. mycoides, and was inhibited in the "magnetic" cultures of Staph. aureus 209 and its mutant UF-3, Bac. subtilis, Bact. proteus vulgaris, and Candida albicans. The CMF had a particularly strong effect on the spore-forming microorganisms and Candida albicans. For example, when we studied dehydrogenization by the method of Kun and Ebud, the "magnetic" cultures of Bac. anthracoides and Bac. mycoides formed 15+0.93 micrograms and 13.5+1.1 micrograms of formazan per 1 mg of dry weight, which was 1.5-2 times the amount of formazan in the control cultures (P < 0.01 and P< 0.002). In determining the dehydrogenase activity in the "magnetized" culture of Bac. subtilis (P < 0.001), the amount of the forming formazan decreased by 2.5 times in comparison with the control, and the dehydrogenase activity in Candida albicans was completely suppressed.

AMF inhibited the dehydrogenization process in various degrees in Staph. aureus 209, Proteus vulgaris, and Bac. subtilis, while Candida albicans (in studying the dehydrogenase activity by the ability to reduce 2,3,5-triphenyl tetrazolium chloride) showed an almost total suppression of the enzyme activity. On the other hand, AMF had a stimulating effect on the dehydrogenases of Bac. anthracoides, and the "magnetic" variant of the culture formed twice as much formazan than the control variant.

PMF caused a statistically certain increase in the dehydrogenase activity in Bac. anthracoides, Bac. mycoides, and, what is particularly interesting, in Candida albicans. The following should be stressed regarding the changes in the enzyme activity of yeast-like microorganisms. The amount of formazan formazan forming in the control culture in 30 minutes of the reaction did not exceed 1.1+0.1 micrograms per 1 mg of dry weight, while 5+0.25 micrograms/mg was found in the "magnetic" culture. When the reaction mixture was kept for 1.5 hours, the amount of formazan in the "magnetic" variant of the yeast increased to 17.3+0.56 micrograms per 1 mg of weight against 2.3+0.31 micrograms in the control culture (P< 0.001).

An opposite effect was observed when PMF acted upon three other species of microbes. The dehydrogenase activity was inibited in the "magnetized" cultures of Staph. aureus 209, Preteus vulgaris, and Bac. subtilis. It was notable that after 50 exposures of Staph. aureus UF-3 to PMF, the index of the dehydrogenization rate (method of Wilson and Kalish) decreased in all 5 experiments by 92.4 percent ($P < 0.001$).

This observation led to the investigation of the effects of magnetic fields on dehydrogenases of other mutants with respiratory defects (Staph. aureus UF-2, Bac. subtilis 168, Bac. subtilis SC-22, and E. paracoli 52-1). It was interesting to study this problem in connection with the published information regarding the antiblastomic effect of magnetic fields. The analysis of the results of these studies confirmed the earlier conclusion regarding a high sensitivity of microbic dehydrogenases with oxidation defects to the influence of CMF.

c) The Influence of Magnetic Fields on the Biosynthesis of Nucleic Acids in Microorganisms. Studies on the quantitative composition of nucleic acids were done by the color reaction method. The content of ribonucleic acid (RNA) in the extract was determined by the orcin test (Meybaum, 1945), and the composition of desoxyribonucleic acid (DNA) -- by means of the diphenylamine test (Dishe, 1930). RNA and DNA were studied after the 50th subinoculation of cultures in magnetic fields in the phase of the logarithmic growth of the microorganisms.

The results of our studies indicated that prolonged exposure of microorganisms to magnetic fields changed the synthesis of nucleic acids. This effect of magnetic fields showed itself only in the RNA exchange, because the insignificant changes in the DNA amounts in a number of the "magnetic" variants of the microbes proved to be uncertain after statistical processing. The amount of RNA increased under the effect of CMF in comparison with the control by 11-52.3 percent in Shigella sonnei, Bac. mycoides, Proteus vulgaris, and Staph. aureus 209, and decreased by 18 percent in Bac. subtilis. When the cultures were subinoculated in AMF, the RNA content increased, on the average, by 16.7-30.4 percent in Bac. subtilis, Bac. mycoides, Staph. aureus 209, and Proteus vulgaris. PMF stimulated the RNA synthesis to the same degree in the last three microorganisms and still more intensively in Candida albicans. On the contrary, when this field acted upon Staph. aureus UF-3, the amount of RNA in the dry residue of the "magnetized" culture decreased by 26.7 percent in comparison with the control cultures.

d) The Inducing Effect of Magnetic Fields on the Lysogenic Systems. The induction of phages under the influence of magnetic fields was studies on lysogenic bacteria E. coli K-12 (λ) and E. coli K-12 (λ^+). The results obtained by us indicate that magnetic fields can produce the phenomenon of phage induction.

The most powerful inducer was CMF. Under its influence, the production of phages λ and λ^+ exceeded spontaneous induction by more than 7 times ($P < 0.01$)

The effect of AMF on lysogenic bacteria was not equivalent. This field induced the conversion of a prophage into a phage in a lysogenic culture of E. coli (λ+). After the treatment of this lysogenic system with an AMF, the amount of phage plaques increased by 6 times ($P < 0.01$). We did not succeed in causing the phenomenon of phage induction by exposing lysogenic bacteria E. coli K-12 (λ) to an AMF.

In our experiments, PMF did not have any inducing effect, and the number of phage plaques on the experimental dishes was the same as in the control.

e) The Influence of Magnetic Fields on the Resistance of Microorganisms to High Temperatures. The work consisted in studying the thermotolerance of 10 species of microbes exposed to CMF in 25 subinoculations. Broth cultures of microorganisms were placed between the poles of an electromagnet heated to 50 degrees, and the control cultures were placed in a water bath (of the same temperature) outside of the magnetic field. Then, the temperature in the electromagnet and in the water bath was evenly raised to 65 degrees in the course of one hour and stabilized at this level for the entire time of the experiment. The effect of the temperature factor on the microbes was registered three hours after the moment of heating of the cultures.

The following details should be mentioned regarding the thermal stability of the "magnetic" cultures. The initial gram-negative species of microorganisms E. coli, Shigella sonnei, and Proteus vulgaris died after an 1.5-hour exposure to high temperatures, while the "magnetic" variants continued to grow even after a three-hour high-temperature treatment. Among the gram-positive bacteria and bacilli, the initial strain of Candida albicans was the most sensitive to high temperatures. It endured the selected temperature conditions only in the course of the first hour. Its "magnetic" strain survived even two hours after the beginning of the thermal action. CMF also increased the thermal resistance of the staphylococcus cultures. The control strains died after being heated for two hours, and their variants which had been exposed to CMF in 25 subinoculations endured the high temperature in the course of 2-2.5 hours. Similar results were obtained in studying the thermal stability of a culture of microbacteria B-5. Three spore-forming microbes exposed to CMF in 25 subinoculations had a number of specific peculiarities with respect to their behavior under the effect of high temperatures. Unlike the "magnetic" cultures of Bac. subtilis and Bac. mycoides, whose thermal resistance increased sharply, the temperature resistance of a similar strain of Bac. anthracoides, on the contrary, decreased. The initial strains of the first two species of bacilli withstood the destructive effect of high temperatures in the course of two hours, and the "magnetic" cultures survived during all periods of study. The high-temperature endurance time of the "magnetic" variant of the anthracoid was shortened by 30-60 minutes in comparison with the initial culture.

The analysis of our data makes it possible to make a number of generalizations. Firstly, magnetic fields can influence the vital activity processes of microorganisms, and their effect depends on the nature of the field, exposure time, and the biological characteristics of the test objects. This

is particularly obvious in the case of a relatively short exposure to a magnetic field.

Secondly, the differences in the nature of the biological phenomena in magnetic fields can be explained by the differences in the experimental conditions which determine the final result.

Thirdly, a long exposure of microorganisms to magnetic fields determines clearly expressed biological effects, and the specific action of magnetic fields is often leveled, so that the observed changes have the same diretivity.

The experiments conducted by us also show that the variability of the organisms is, evidently a result of the influence of magnetic fields on the enzymic systems and RNA. In particular, this can explain the effects of magnetic fields on the nature and rate of growth of microorganisms and the increase in the thermal tolerance of "magnetized" cultures. This does not rule our that magnetic fields cause some other shifts in the metabolism of microorganisms.

THE MECHANISM OF BIOLOGICAL EFFECTS OF A CONSTANT MAGNETIC FIELD

[A. B. Kogan, T. S. Sachava, L. I. Dorozhkina, V. M. Pavelko, and I. N. Gol'-
tseva, Rostov-on-the-Don State University, Rostov-on-the-Don]

Considerable progress has been made in the last ten years in the investigation
of the effects of magnetic fields on live organisms. It has been shown that
magnetic fields influence living things of any degree of organization --
from the simplest to the highest. This influence is characterized by a vari-
ety of effects -- from changes at the molecular level to the reactions of the
entire organism.

The Department of Human and Animal Physiology of the Rostov Order of the Red
Banner of Labor State University has been studying for a number of years the
influence of CMF on the organisms of various evolutionary levels in order to
understand the physiological mechanism of this phenomenon.

It has been shown in our works that magnetic fields produce a certain effect
on the movements of the infusorians Paramaecium caudatum. Uniform movements
of infusorians along a capillary tube filled with water undergo regular changes
in a CMF. With a definite latent period, there occur a delay near the south-
ern pole and asymmetry of motion, which gradually disappears after the field
is removed [93, 94]. An important fact which was of fundamental significance
for the understanding of the mechanism of the CMF influence was discovered
during observations on the behavior of infusorians placed in water which was
first exposed to a magnetic field. There were the same changes in their mo-
tor activity as when infusorians are exposed to the action of a CMF under
the usual experimental conditions [49].

Cytochemical studies revealed a rearrangement and a decrease of RNA in infu-
sorians placed in a magnetic field [49].

It was found that CMF had a definite effect on the territorial distribution
of the fruit flies Drosophyla melanogaster and, particularly, on the topo-
graphy of their egg laying [91].

Studies on the influence of CMF on microorganisms showed that a magnetic field of 400 oersteds inhibits the growth and development of staphylococci. However, a field of this intensity did not cause any noticeable changes in the morphological, biochemical, and cultural properties of E. coli. A CMF of 3,000 oersteds inhibited the growth and development of Echerichia coli, which was expressed by a decrease in the number of colonies [16].

In recent years, studies have been carried out in order to clarify and refine the cellular, subcellular, and physicochemical mechanisms of the influence of CMF in which cells of the fresh-water alga Nitella flexilis, nerve cells of crustaceans, and isolated hearts of cold-blooded animals were used as the test objects.

In view of the fact that the influence of magnetic fields shows itself in the changes in the properties of excitable tissues, experiments were conducted for studying the effects of fields on an important excitability index -- the electrical potential of a membrane. For the sake of convenience, the studies were done on a simple object frequently used in electrophysiological experiments: Nitella. The first apical cells of the internode 7-14 mm long and 0.4-0.5 mm in diameter were usually taken for the experiment. The membrane rest potential (RP) of these cells was measured between the environment and the cell protoplasm by introducing into it a glass microelectrode filled with a 3M solution of KCl and having a diameter of the end of 1-1.5 micron. The potential difference was sent through a cathode follower to the d-c amplifier of a S1-19B oscillograph and was registered on the screen of an electron tube. A magnetic field was created by means of ring-shaped magnets (alloy YuNDK-24).

Measurement of RP in the initial state, during the action of the CMF, and during the aftereffect period were done on the same Nitella cell. Therefore, a preliminary series of experiments was carried out in order to establish possible effects of repeated (at 20-20-40 minute intervals) introduction of a microelectrode into the cell on the value of RP (Table 2). The results of these experiments showed that the repeated pucturing of the cell for the introduction of the electrode at the above intervals practically did not change the RP value. Therefore we were justified in considering that the changes occurring in the CMF were the result of its influence.

In the second and third series of our experiments, we studied the influence of CMF of 1,000 and 1,600 oersteds on the RP of Nitella cells. In each experiment, we first measured the RP in the initial state, then after 20 minutes of the CMF action, and then 40 minutes after it was stopped. All experiments were repeated during various seasons (spring, summer, and autumn).

As a result of these experiments, we established definite seasonal variations in the effects of the CMF on the Nitella cell. It was found that the reaction to the CMF (Table 3) was expressed the most during the spring period.

Table 2
Mean Value of the Rest Potential of the Nitella Cell in Repeated Meazurements

(1)Условия наблюдения	(5) Число измерений	(6) Среднее ариф.ПП, мв	(7) Уровень значимости различия по критерию Стьюдента между:		(8)
			I и II	I и III	II и III
(2) I — через 20 мин. пребывания нителлы в камере	62	—83	P>0,1		
(3) II — через 20 мин. после I	62	—83		P>0,1	
(4) III — через 40 мин. после II	62	—83			P>0,1

Key:
1. Observation conditions
2. I -- after 20 minutes of Nitella's stay in the chamber
3. II -- 20 minutes after I
4. III -- 40 minutes after II
5. Number of measurements
6. Arithmetic mean of RP, millivolts
7. Level of significance of the difference by the Student criterion
8. and

Table 3
The Effects of Constant Magnetic Fields of 1000 and 16000 Oersteds on the Rest Potential of a Nitella Cell in the Spring Experiments

(1) Условия наблюдения	1000 э (5)			1600 э (5)		
	(6) число измерений	(7) среднее ариф. ПП, мв	уровень значимости различия по критерию Стьюдента (8) между	(6) число измерений	(7) среднее ариф. ПП, мв	уровень значимости различия по критерию Стьюдента между (8)
(2) I — исходное измерение ПП	57	—82	I и II P<0,01	55	—88	I и II P<0,01
(3) II — через 20 мин. действия поля	57	—70	I и III P>0,1	55	—76	I и III P<0,01
(4) III — через 40 мин. после снятия поля	57	—78	II и III P<0,05	55	—79	II и III P>0,1

Key:
1. Observation conditions
2. I -- initial measurement of RP
3. II -- after 20 minutes of the field action
4. III -- 40 minutes after removal on the field
5. Oersteds
6. Number of measurements
7. Arithmetic mean of RP, multivolts
8. Level of significance by Student criterion between
9. and

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It can be seen from the Table that, when a CMF of 1,000 or 1,600 oersteds acted upon a cell in the course of 20 minutes, there was a statistically certain decrease in the RP value, on the average, of 12 millivolts. It should be noted that, when the CMF of 1,000 oersteds was removed, there was a more complete restoration of the RP value than after the removal of the CMF of 1,600 oersteds. However, in the course of 40 minutes and at a lower intensity of the CMF, the RP did not reach the initial level. There was only a relatively small statistically uncertain shift in the RP toward its initial level 40 minutes after termination of the action of the CMF of 1,600 oersteds.

In the summer experiments, the changes in the CMF were less expressed. The results of these experiments are shown in Table 4.

Table 4

The Influence of Magnetic Fields of 1000 and 1600 oersteds on the Rest Potential of the Nitella Cells in the Summer Experiments

(1) Условия наблюдения	1000 э (5)			1600 э (5)		
	(6) число измерений	(7) среднее ариф. ПП, мв	(8) уровень значимости различий по критерию Стьюдента между	(6) число измерений	(7) среднее ариф. ПП, мв	(8) уровень значимости различия по критерию Стьюдента между
(2) I — исходное измерение ПП	28	—84	(9) I и II P > 0,1	50	—103	I и II P < 0,05
(3) II — через 20 мин. действия ПМП	28	—85	I и III P > 0,1	50	—96	I и III P < 0,05
(4) III — через 40 мин. после снятия поля	28	—86	II и III P > 0,1	50	—96	II и III P > 0,1

Key: 1. Observation conditions
2. I -- initial measurement of RP
3. II -- after 20 min of CMF action
4. III -- 40 min after the removal of the field
5. Oersteds
6. Number of measurements
7. Arithmetic mean of RP, millivolts
8. Level of significance of the difference by the Student criterion between
9. and

It can be seen from the Table that the changes of the RP in the CMF of 1000 oersteds were statistically uncertain. When the CMF of 1600 oersteds acted upon the cell for 20 minutes, it brought about a statistically certain decrease in the value of the RP, on the average, by 7 millivolts. Moreover, 40 minutes after the termination of the field action, the RP did not show any tendency for returning to the initial level.

Similar results were also obtained in the autumn (Table 5).

The results presented in Table 5 show that the CMF of 1,000 oersteds caused a decrease in the RP value of 4 microvolts. However, it was statistically uncertain. When the CMF of 1,600 oersteds acted upon a cell, there was a statistically certain decrease in the RP value, on the average, by 7 microvolts, just as in the summer series of experiments.

Table 5

The incluence of Constant Magnetic Fields of 1000 and 1600 oersteds on the Rest Potential of the Nitella Cells in the Autumn Experiments

(1) Условия наблюдения	1000 э (5)			1600 э (5)		
	(6) число измерений	(7) среднес ариф. ПП, мв	(8) уровень значимости различия по критерию Стьюдента между	(6) число измерений	(7) среднее ариф. ПП, мв	(8) уровень значимости различия по критерию Стьюдента между
(2) I — исходное измерение ПП	41	—74	(9) I и II P > 0,1	50	—100	I и II P < 0,05
(3) II — через 20 мин. действия ПМП	41	—70	I и III P > 0,1	50	—93	I и III P > 0,05
(4) III — через 40 мин. после снятия поля	41	—70	II и III P > 0,1	49	—94	II и III P > 0,1

Key: 1. Observation conditions
2. I -- initial measurement of RP
3. II -- after 20 min of CMF action
4. III -- 40 minutes after the removal of the field
5. Oersteds
6. Number of measurements
7. Arithmetic mean of RP, millivolts
8. Level of significance of the difference by the Student criterion between
9. and

The obtained results show that CMF of 1,000 and 1,600 oersteds affected the thin structures of the membranes of the Nitella cells, which was expressed in the changes of the membrane's electrical properties. The changes were more expressed in CMF of the higher intensity. It was interesting that the CMF effects were different during different seasons.

As has been mentioned earlier, CMF have a strong effect on infusoria [68]. It is quite evident that such facts as changes in the motor activity, redistribution and decrease of the protoplasmic RNA, and increase in the phagocytal activity must be connected with the changes in the cellular metabolism. In particular, there are some data on the fact that the energy necessary for phagycytosis is provided by the processes of glycolysis. Substances activating the phagocytal activity, first of all, intensify glycolysis [28]. Therefore, we made a study of the effects of CMF on aerobic glycolysis in infusoria.

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To solve this problem, we determined the content of glycogen and lactic acid in them.

The study was carried out on clone cultures of Paramaecium caudatum on the Lozin-Lozinskiy medium [115]. Yeast was used as the food. The study was done in the stationary phase of growth. Glycogen was detected cytochemically by the Shabadash method, which has the advantage of high sensitivity and makes it possible to register the amount of glycogen by the cytophotometric method [241]. Cytophotometric measurements were taken diretly from the preparation by means of a sounding photometer. The photometric measurements were done on 100 infusoria in the control, and after the exposure to the CMF, in each clone. The amount of glycogen was judged by the light absorption index. Moreover, a qualitative evaluation of the glycogen content was done by Polyanskiy's method [151]. The infusoria were divided into classes with respect to the glycogen accumulation levels. The first class corresponded to a total absence of glycogen, and the fifth class corresponded to a compact filling of the endoplasm by glycogen grains. Since, in our experiments, the light absorption indexes did not follow the normal distribution law, the statistical processing of the material was done by the sign criterion.

Lactic acid was determined by the biochemical method of colorimetry with the use of paraoxydiphenyl. This method made it possible to measure the coloration intensity of the compound forming in the process of the reaction of acetaldehyde with paraoxydiphenyl. For each test we took 1,000 infusoria. Statistical processing of the data was done by Student's criterion.

The CMF was created with a bar magnet (alloy ANKO-4). The exposure time was 30 minutes.

Preliminary experiments showed that infusoria of different clones cultivated under identical conditions differed in their glycogen content. The glycogen content also varied rather widely within the limits of one clone -- from a complete filling of the endoplasm to an almost total absence. This is explained by the fact that glycogen is a very labile substance and its accumulation depends on a number of factors: oxygen tension, individual age, food, temperature and so on [151]. Three clones were studied: "A", "B", and "D". The assessment of the glycogen content by Polyanskiy's classification revealed that the individuals of clone "B" had the highest level of glycogen content, and the smallest amount of glycogen was found in clone "C". The glycogen content in cells within the limits of one clone is shown in Table 6. Although the visual evaluation of the classification of infusoria may be a source of errors, a large number of observations yeilds a sufficient objective picture which is repeated when the same material is examined many times. Cytophotometric measurements confirmed the evaluation of glycogen content by Polyanskiy's classification.

The influence of CMF leads to a definite changes in the dynamics of glycolysis. First of all, the endoplasm shows a lack of glycogen. The grains become smaller, distances between them become larger, while the glycogen

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grains are distributed evenly and there appear some areas without any polysaccharide. The decrease in the glycogen content was revealed clearly by the evaluation according to Yu. I. Polyanskiy's method (Table 6).

<p style="text-align:center">Table 6
The Influence of a Constant Magnetic Field on the
Glycogen Content in Three Clones of Infusoria</p>

(1) Классы накопления гликогена	(2) Распределение числа особей инфузорий по классам накопления гликогена, %					
	(3) контроль			(4) после воздействия ПМП		
	(5) клон «А» 633 особи	(6) клон «Б» 401 особь	(7) клон «С» 720 особей	(8) клон «А» 825 особей	(9) клон «В» 965 особей	(10) клон «С» 610 особей
I	0	0	1,4	0	0	2,5
II	7,5	1,2	16,2	14,6	7,0	33,0
III	25,1	5,0	36,7	41,3	21,0	39,8
IV	58,5	31,8	39,8	36,9	36,0	23,2
V	8,9	62,0	5,9	7,2	36,0	1,5

Key: 1. Glycogen accumulation classes
2. Distribution of the numbers of infusoria by the glycogen accumulation classes, percent
3. Control
4. After the CMF action
5. Clone "A", 633 individuals
6. Clone "B", 401 individuals
7. Clone "C", 720 individuals
8. Clone "A", 825 individuals
9. Clone "B", 965 individuals
10. Clone "C", 610 individuals

The decrease in the glycogen content was expressed most clearly in Clone "B", which had the highest content in the normal state. The changes were less expressed in Clone "C". Comparison between the light absorption indexes of the endoplasm of the infusoria in the normal state and after the influence of the CMF by the sign criterion indicated a practically certain decrease in glycogen in Clones "A" and "B", while only a slight tendency toward decrease was detected in Clone "C". The error probability does not exceed 1 percent. Changes in the glycogen content were reversible: restoration of the initial level took place in all clones after 4 hours (Table 7).

Table 7 shows the return of the glycogen content to the normal state after the termination of the CMF action.

Table 7

Glycogen Content in Infusoria of Clone "B" at Various
Times after the Action of the Constant Magnetic Field

(1) Классы накопления гликогена	(2) Распределение числа особей инфузорий по классам накопления гликогена, %						
	(3) контроль	(4) сразу после прекращения воздействия ПМП	(5) через 1 час	(6) через 2 часа	(7) через 3 часа	(8) через 4 часа	(9) через сутки
I	0	0	0	0	0	0	0
II	1,2	7,0	19,0	10,0	6,0	0	2,0
III	5,0	21,0	31,0	31,2	15,5	2,0	4,5
IV	31,8	36,0	36,0	20,8	34,8	48,0	37,2
V	62,0	36,0	14,0	38,0	43,7	50,0	56,3

Key: 1. Glycogen accumulation classes
2. Distribution of the numbers of infusoria by the glycogen accumulation classes, percent
3. Control
4. Immediately after the termination of exposure to CMF
5. After 1 hour
6. After 2 hours
7. After 3 hours
8. After 4 hours
9. After 24 hours

Thus, the CMF caused a regular decrease in the glycogen content in all clones
of the infusoria. As is known, infusoria have a mixed metabolism consisting
of the activity of Emden-Meyerhof enzymatic systems and the Krebs cycle. The
respiration-glycolysis ratio changes depending of the age [171, 369] and on
various conditions under which the culture is kept. The decay of glycogen
is an indication of the intensification of glycogenolysis, but it is possible
that the decrease in the glycogen content is connected with the inhibition of
its synthesis. It is also possible that synthesis does not keep up with the
expenditure of glycogen, because it is known that its restoration progresses
even when the glycogen content is decreasing intensively. On the other hand,
the content of the lactic acid in the cells is a direct indication of the
levels of glycolytic processes (Table 8)

Table 8 shows the amounts of lactic acid in gammas per 1000 individuals deter-
mined in 10 experiments. It can be clearly seen that, under the same condi-
tions, infusoria in their normal state are characterized by approximately the
same content of lactic acid in the stationary phase of their growth. Infu-
soria exposed to the CMF, in all 10 cases, showed the statistically certain
$(P < 0.01)$ increase in their lactic acid content.

Table 8

CMF Effects on Lactic Acid Content Infusoria

(1) № опыта	(2) Содержание молочной кислоты в гаммах		(5) Достоверность различия между контрольными группами (1000 особей) и подвергнутыми действию ПМП
	(3) в норме	(4) после воздействия ПМП	
1	14,25	23,75	P < 0,01
2	12,50	20,75	P < 0,01
3	13,50	21,50	P < 0,01
4	14,75	22,75	P < 0,01
5	14,25	27,80	P < 0,01
6	13,75	20,75	P < 0,01
7	14,25	27,30	P < 0,01
8	14,06	27,00	P < 0,01
9	14,29	27,60	P < 0,01
10	14,00	27,50	P < 0,01

Key: 1. Number of experiment
2. Lactic acid content in gammas
3. In the normal state
4. After the CMF action
5. Difference certainty of control (1000 indiv) and groups exposed to CMF

The average amount of lactic acid in 30 experiments under normal conditions was 13.7 ± 0.05 gammas, and after the CMF action it was 24.5 ± 0.21 gammas $(P < 0.01)$.

The fact of the sharp increase in the amount of lactic acid leaves no doubt that exposure to CMF intensifies the aerobic glycolysis in infusoria. Paramecia are, generally, characterized by switching from one kind of enzymatic systems to another under the effect of various extreme factors, which makes it possible for them to minimize harmful effects. Intensification of glycolysis occurs most frequently when the chain of aerobic respiration is disturbed. The level of glycolysis is controlled by a special "intensifying factor" which is located in the mitochondria [132]. The control of the glycolysis rate depends on the structure of the mitochondrial membranes and on their permeability. The lowering of the ATPh (adenosinetriphosphate) level within the mitochondria is one of the causes of increased glycolysis. This is accompanied by the deformation of membranes, their permeability increases, and the "intensifying factor" has a free exit. Thus, the directivity of the oxidative phosphorylation is closely connected with the structural state of the mitochondria [96].

A number of researchers showed the presence of the influence of magnetic fields on the nervous activity [113, 180, 223, 278, 305, 342, and others]. However, it is still unclear whether the observed changes are due to the processes occurring in the nervous tissue itself, or they are a result of other mechanisms, for example, neuroglia or the reactions of the blood vessels. Therefore, we conducted a study on the influence of magnetic fields on the activity and structure of a single isolated surviving cell -- a receptor of muscular stretching of the river crayfish.
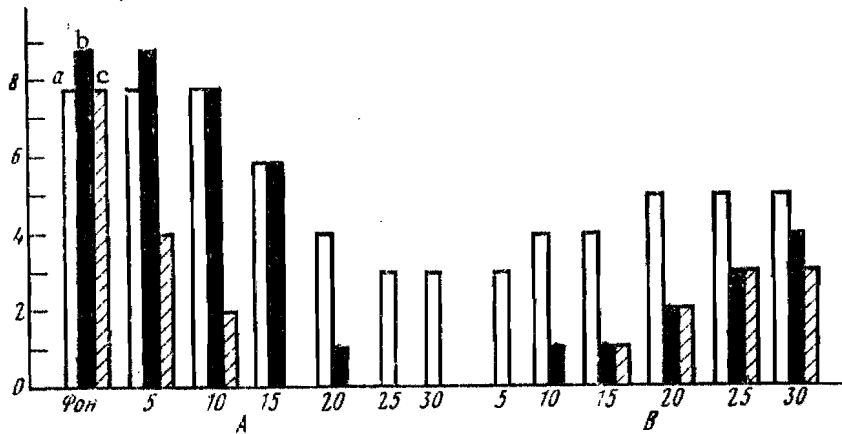
Figure 5. The Dynamics of the Electrical Activity of the Receptory Neuron of a Crayfish Under the Conditions of a Constant Magnetic Field.
Ordinate -- pulse frequency, sec; abscissa -- time, min.
A -- during CMF action; B -- after removal of CMF;
a -- summer season; b -- autumn-winter season; c -- winter

In studying the influence of CMF on the neuroreceptor, we studied not only its functional activity, particularly by the indexes of its impulse activity, but also the nature of those metabolic changes which could be connected with this physiological index.

According to modern notions, nucleic acids play the main role in the processes of protein synthesis in the cells. At the same time, it has been proven by numerous studies that there is a close connection between metabolism, particularly the RNA exchange, and the functional activity of the nerve cells [30, 47, 89, 90, and others]. Therefore, we took RNA as a cytochemical index for our experiments on the effects of CMF on the neuroreceptor of the crayfish.

Our studies were carried out with the application of complex electrophysio-logo-cytochemical methods [89, 92]. For each experiment we prepared two preparations of isolated stretching neurons from the symmetric receptory apparatuses of one of the abdominal segments. The preparations were placed in a stretching device. The neurons were prestained in a specially adapted dish with acridine orange diluted $1:10^5$ for 20 minutes. Then the stretching device was placed on the microscope stage. The potentials were tapped off with platinum electrodes and, after amplification, were photographed from the screen of a vectorelectrocardioscope VEK-01. The structure of cells was photographed by means of a microphotoattachment MEN-4.

By stretching the muscles 10-20 percent of the initial length, the neuron was stimulated to a frequency of 6-12 pulses per second. This frequency was taken as the initial frequency.Then the preparation was exposed to a constant magnet creating a CMF of 500 oersteds. The magnet was installed so that lines

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of force would cross the neutron at a right angle to the line connecting the shovel-like dendrite with the axon. The registration of the electric activity and the photographing of the neutron structure were done simultaneously before the exposure to CMF every 5 minutes in the course of 30 minutes during the CMF action and for 30 minutes after. A second preparation outside of the CMF served as the control. A total of 96 such experiments were carried out.

As a result of these studies, it was established that a CMF of 500 oersteds with an exposure of 30 minutes caused an inhibiting neutron reaction which was expressed   differently depending on the seasons. In the summer, the neutrons reacted to the CMF by a moderate decrease in the frequency of their impulse activity, with an average latent reaction period of 13 minutes. During the winter period, their electric activity was sharply inhibited. The latent period was, on the average, 5 minutes. During the autumn-winter and winter-spring periods, which were isolated by us as "intermediate," the inhibition of the impulse activity occurred with an average latent period of 9 minutes and was accompanied by arrhythmia with fluctuations of the peak amplitudes. When the CMF was removed, the frequency of the impulse activity of neurons was restored during all seasons, however, the electric activity was not restored to the initial state up to 2 hours of observation. The dynamics of the electrical activity of the stretching neurons is shown in Figure 5. The columns represent the measurements of the pulsation frequency during the exposure to the CMF (A) and after the removal of the CMF (B).

The structural changes of the neurons under the effect of the CMF were characterized by changes in the lumps of RNA, its decrease along the cell periphery, and accumulation in the perinuclear region. The changes in the lumps and the spindles of RNA is characteristic of the excited state of these neurons. During their excitation, the RNA grains are distributed evenly over the entire cytoplasm [82, 92]. Under the effect of a CMF, changes in the RNA grains are accompenied only by a partial disturbance of the spindle-shaped structures. RNA was not distributed evenly in the cytoplasm. It was observed that it accumulated in the perinuclear region and there was less of it over the cell periphery. By the 30th minute after the removal of the CMF, only a partial restoration of the structures was observed with a more even RNA distribution over the entire cytoplasm.

In studying the RNA distribution by the microphotometric method, we observed some changes which were expressed particularly sharply in the departure zones of the dendrites and the axon, The characteristics of the RNA density distribution before, during, and after the exposure to CMF are shown in the form of curves of neurons measrued photometrically with a beam passing along the center of the nucleole from the dendrites to the axon (Figure 6) and along the transverse diameter of the cell (Figure 7). As can be seen from the photometric curve, by the 30th minutes of the exposure to the CMF, the density of RNA decreased in the departure zone of the dendrites, while, on the contrary, it increased in the departure zone of the axon. The initial picture was somewhat restored 30 minutes after the removal of the CMF. Photometric measurements of the neuron body along the transverse diameter revealed an increase

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in the RNA density by the 30th minute of the CMF action in the perinuclear region, which was leveled after the termination of the CMF action.
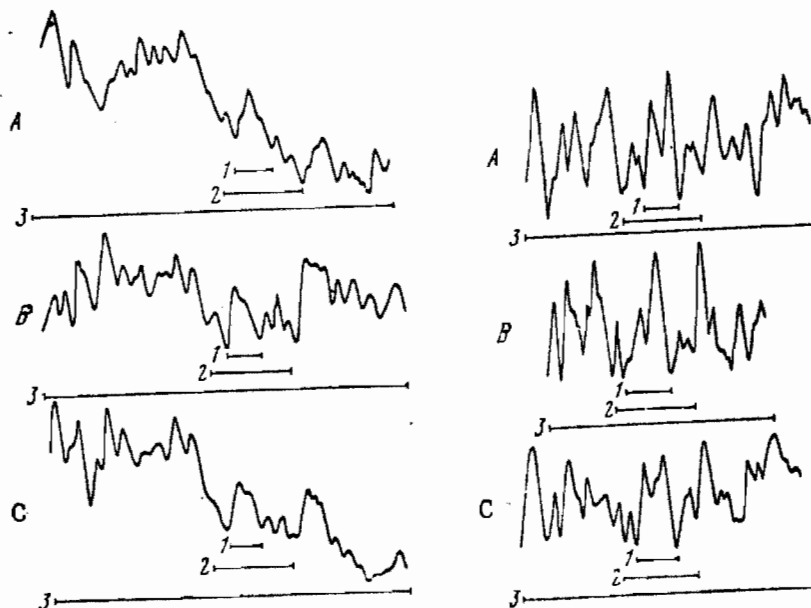

Figure 6. Photometric Measurements of the Neuron Body During the Beam Movement along the Center Line from Dendrites to the Axon.
A -- initial background, B-- at the 30th minute of CMF action,
C -- 30 minutes after the exposure;
1 -- nucleole; 2 -- nucleus; 3 -- cytoplasm.
Upward beam deflection -- increase in the RNA density.

Figure 7. Photometric Measurements of the Neuron Body During the Beam Movement along the Transverse Diameter of the cell.
A -- initial background; B -- at the 30th minute of CMF action;
C -- 30 minutes after the exposure;
1 -- nucleole; 2 -- nucleus; 3 -- cytoplasm.
Upward beam deflection -- increase in the RNS density.

The results of these experiments show that the reactions of the nerve tissues to CMF may be based on the changes in characteristics of the generation of pulses by neurons. Disturbances in the functional activity of neurons are, evidently, the reflection of changes in the nature of their intracellular metabolism which we observed in this case by the RNA dynamics indexes occurring under the effect of CMF.

In connection with the facts of changes in the cellular metabolism in magnetic field described above, there arises the question of how CMF affect

directly the chemical properties of some physiologically active substances.
Adrenalin was taken as one of such substances.

We studied the physiological activity of adrenalin pretreated in a CMF of 1300
oersteds for 30 minutes and in a CMF of 4500 oersteds for 1 hour by the indexes
of its influence on a frog heart isolated by Straube's method. The cardiogram
was recorded on a kymograph. The initial heart activity was recorded, then
0.01 ml of adrenalin processed in a magnetic field in a concentration of
1:10,000 was introduced, and heart contractions were registered for 5-10 min-
utes, during which time the response to adrenalin was observed. If there was
no return to the initial state, the heart was washed with Ringer's solution
and its activity was recorded again. The amplitude and frequency of heart
contractions were counted on the average for each minute of recording. In
the control experiments, the usual adrenalin without preliminary treatment
in a magnetic field was introduced.Table 9 shows average values of amplitudes
of heart contractions for all 3 series of experiments.

Unlike the control experiments in which adrenalin increased the rate of heart
contractions, the experiments with adrenalin exposed to a magnetic field did
not show such an increase in the cardiac activity. On the contrary, there
was a decrease in the amplitude of heart contractions which was not always
restored to the initial level after washing the heart with the physiologic
solution. This inversion effect of the adrenalin action from increasing to
weakening was more expressed after the influence of a CMF of 1300 oersteds
for 30 minutes. In these experiments, there were instances of the inhibition
of the cardiac activity, up to cardiac standstill. However, these changes
were reversible, and it was sufficient to replace the physiologic solution
once or twice to restore the cardiac activity in such cases.

Table 9

The Effect of Adrenalin Exposed to a Constant MF on the
Strength of the Contractions of an Isolated Frog's Heart

(1) Условия опытов	(5) Коли-чество опытов	(6) Амплитуда, мм (среднее значение в 1 мин. из всех опытов)									(10) Уровень значимости различия по критерию Стьюдента между	
		(7) исход-ный фон	(8) время после введе-ния адреналина в 1 мин						(9) после отмыв. раствором Рингера	(11) I и II	I и III
			1	2	3	4	5	6			
(2) I серия Контроль	48	12	17	17	15	13	13	12	—	P<0,01	
(3) II серия H—1300 э —30 мин	57	12	11	10	9	9	9	9	13		P<0,01
(4) III серия H—4500 э —1 час	51	11	11	10	10	10	10	10	10		

Key: See next page

Key: 1. Experimental conditions
     2. I series, control
     3. II series, H -- 1300 oersteds -- 30 minutes
     4. III series, H -- 4500 oersteds -- 1 hour
     5. Number of experiments
     6. Amplitude, mm (average value in 1 minute from all experiments).
     7. Initial background
     8. Time after the introduction of adrenalin in 1 minute
     9. After washing with Ringer's solution
    10. Level of significance of the difference by Student's criterion between
    11. and

When adrenalin was treated in a CMF of 4500 oersteds for 1 hour, its weakening effect was less expressed, but was practically nonreversible. No regular changes were established in the frequency of cardiac contractions under the effect of adrenalin exposed to a magnetic field and in the control experiments.

The detected influence of a CMF on the activity of such an important hormone as adrenalin is, possibly, accomplished through changing the orientation of its molecules in a CMF.

THE INFLUENCE OF CONSTANT MAGNETIC FIELDS ON THE GROWTH OF PLANTS

[Yu. I. Novitskiy, V. Yu. Strekova, and G. A. Tarakanova, Institute of Plant Physiology, USSR Academy of Sciences, Moscow]

In 1966, at the 8th International Oceanological Congress, the biological role of the geomagnetic field (GMF) was discussed. An opinion was expressed to the effect that it hinders the penetration of charged radiation particles into the biosphere and lowers the mutating radiation background [17]. Thus, the GMF was assigned a purely passive role. However, the numerous facts accumulated by biologists regarding the sensitivity of plants and animals to CMF make it possible to assert that the GMF could be a direct, biologically active and significant factor, not to mention high-intensity fields.

In principle, the problem of the significance of the GMF fluctuations was raised by Reinke [385] in 1876 and was analyzed by him on the example of the growth of the marsh reed. Reinke believed that the nonuniformities of the growth observed by him and a number of physiologists in plants during a 24-hour period could be determined by the diurnal variations of the GMF. However, as a result of a thorough analysis of the material collected by him, he came to a conclusion that this nonuniformity is determined by some unknown intrinsic causes hidden in the plant itself. But now we will, evidently, have to reexamine this problem, because the investigations by Dubrov and Bulygina [180] compel us to examine closely the causes of the correlated dependence between the state of the GMF and the excretory activity of plants connected with the intensity of growth.

In 1886, D'Arsonnval [298] observed intensified growth of the garden cress under the influence of a CMF. Then Tolomei [397] reported that geotropism of kidney bean roots was disturbed by a CMF. A little later, Errera [312] established the absence of CMF influence on mitosis observed on the staminal filaments of the spiderwort. In the XIX century, there were few works on the growth response of plants to CMF. Most frequently, studies were done on the protoplasm of plant cells and on suspended cells themselves. Amici, Welten, Becquerel, Reinke, and others (see [164]) found no dependence between the action of a strong (several thousand oersteds) CMF and the movement of protoplasm (in this connection, it was hoped to confirm the electric

nature of the protoplasm movement). As was shown later by Savostin [164] and confiemed by Ambrose [263], CMF, actually, affect this movement (with the introduction of quantitative methods for evaluating its velocity), which depends on the intensity of the magnetic field, the direction of movement of the protoplasm, relative arrangement of the cell and the field, as well as physiological peculiarities of the object. Thus, the necessary attribute of the growth process -- the movement of protoplasm -- is affected by CMF, and in an individual suspended cell it even determines its fundamental magnetic properties. This means that a cell with moving protoplasm in a homogeneous CMF of the order of 20,000 oersteds is positioned across the lines of force, i.e., behaves like a paramagnetic, while a dead cell, or a cell with nonmoving protoplasm is arranged along the lines of force, i.e., behaves as a diamagnetic (studies were done on the cells of Nitella, Elodea, Chara, and others). Moreover the application of the statistical methods of analysis to the results of the experiments on the influence of weak (20 oersteds) CMF on the movement of protoplasm (Elodea) made it possible for us [180] to detect the action of such a field and to show its dependence on the seasons (Figure 8). The problem of the mechanism of this influence still remains unresolved. The mechanism of the CMF influence proposed by Savostin, which was based on theoretical calculations and brilliantly confirmed by him in practice (calculations required acceleration in 25 percent of cases, and the experiment showed 21 percent) is chiefly the magneto-mechanical effect appearing in a charged rotating plasma in a CMF. It is essential only for CMF of the order of 5-10,000 oersteds, with which Savostin was dealing, and can never occur in our case. Of course, it would be tempting to connect this effect with the appearance of a force bending a growing organism under the influence of a magnetic field and thus to explain the phenomenon of magnetotropism which will be discussed later. Unfortunately, a simple analysis of the directions of moving protoplasm in neighboring cells of Elodea showed us that if they were not mutually compensating one another, than there could not be any significant resultant force.
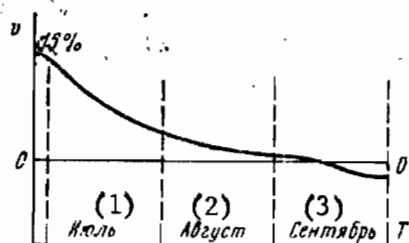

Figure 8. Changes in the Average Movement Rate of Chloroplasts in Elodea under the Effect of a Magnetic Field of 20 oersteds Depending on the Season. The control rate is zero.

Key:
1. July
2. August,
3. September

The works of Savostin [164, 165, 166] on the effects of CMF on the movement of plasma and growth of plants will, for a long time, serve the experimenters in the field of magnetobiology as a source material for criticisms, verification, and further development of his ideas.

Savostin [167] was first to observe that a CMF of 1600 oersteds has a less noticeable effect on the growth of wheat sprouts than a field of 60 oersteds (he studied coleoptiles of pure-strain wheat sprouts grown in the dark).

In fact, the popular opinion that CMF of lower intensities have a weaker effect on the physiological object often is not confirmed. Reno and Nutini [286] were convinced that there could not be any physiological effect from a CMF below 80 oersteds. However, if we consider a CMF not merely as a mechanically acting factor, but as a physiological stimulant, than its influence must, generally, be determined by a certain irritability curve whose concrete form may differ, but the general points pertaining to the lower threshold, stimulation zone, and the zone (or phase) of inhibition must be observed.
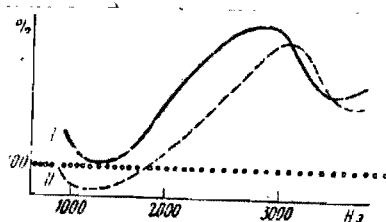
Figure 9. Growth Rate of "Gatchinskaya" Winter Rye Depending on the Intensity of the Applied Magnetic Field [128] for Two Identical Experiments.
Ordinate -- growth rate in percent; abscissa -- magnetic field intensity in oersteds.

The growth rate curve of "Gatchinskaya" rye exposed to a CMF on an EPR unit at various field intensities which was published by Mochalkin et al [128] in 1962 may serve as an example of such curves. Curves of this type were also obtained by the authors for a number of other crops (Figure 9).

However, it is also not at all clear from this work whether fields of lower intensities than 2000 oersteds can affect the growth rate. It appears that the problem of the influence of magnetic fields on the intensity of growth is closely connected with the problem of the primary orientation of the growing object with respect to the direction of the lines of force of the CMF.

A few years ago, we compared the growth responses of various germinating seeds to the orientation with respect of a relatively horizontal component of the GMF; we could only establish what had already been known from the work by Krylov and Tarakanova [105]: the overall length of the roots of some crops grown in the dark whose germ was oriented to the north (i.e., toward the magnetic south) was greater in the first 3-4-7 days than when the orientation was in the opposite direction.

As the next step, it would be natural to confirm that this ability of responding to the orientation by changing the growth rate is connected with the sensitivity to magnetic fields. In the experiments by Krylov and Tatakanova [105], this was achieved by studying the growth and germination rates in artificial magnetic fields created by permanent magnets arranged in such a way that the horizontal component of the GMF coincided in its direction with the intensity vector of this artificial magnetic field (400 oersteds). But this did not solve the basic problem of the possibility of the orientation toward the sun.

In our experiments, Helmholtz rings arranged next to each other -- sources of a homogeneous magnetic field -- gave the directions of the horizontal components along and against the direction of the GMF with identical orientation of the grain germs with respect to the sun (Figure 10).

<div align="center">

Table 10

Germination Rates of Seeds in a Magnetic Field of Helmholtz Rings
(20 oersteds) under the Conditions of Natural Light Status
Control -- magnetic field of the earth (in percent of the sown material)

</div>

(1) Культура	(6) Дни после посева								
	0	1	2	3	4	5	6	7	8
(2) Ячмень «Винер»									
(3) опыт	—	—	32	87	100				
(4) контроль	—	—	17	89	100				
(5) Бобы «Кузминские»									
(3) опыт	—	—	—	—	—	24	72	—	97
(4) контроль	—	—	—	—	—	13	54	—	90

Key: 1. Culture   4. Control
     2. Rye "Viner"   5. Beans "Kuzminskiye"
     3. Experiment   6. Days after sowing.

We believed that in this way the response to a weak CMF and its direction would be proven, which we did achieve [194]. Thus, the intensification of growth was characteristic of sprouts whose seeds were initially oriented toward the south. This response of intensified growth continues when the field intensity is increased to 60 oersteds [190], but fields of 4,000 and 12,000 oersteds [193] inhibit the growth rate (Figure 11). Since we did not place Helmholtz rings in a strictly vertical position, but in such a way that the direction of their field coincided with the direction of the natural field, i.e., at an angle of 74 degrees to the horizon, therefore, generally speaking, we had two components -- vertical and horizontal -- which intensified the GMF in proportion to the natural ratio of the vertical and horizontal components of the GMF. Thus, although the results of these experiments can be used in further studies, they cannot answer the question: is the response to the magnetic field determined by one or by both of its components?

<div align="center">

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</div>

The above-mentioned studies were done on sprouts grown in the dark. Let us note that the germination rate in the light in a magnetic field directed along the GMF was higher than without it (Table 10). This more intensive growth rate of the root system in comparison with the control continued for over 30 days.
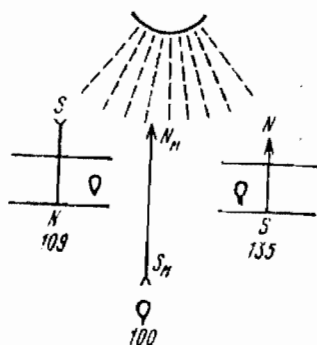

Figure 10. Scheme of an Experiment Proving the Significance of the Primary Orientation of Seeds in the Magnetic Field of Helmholtz Rings (20 oersteds).
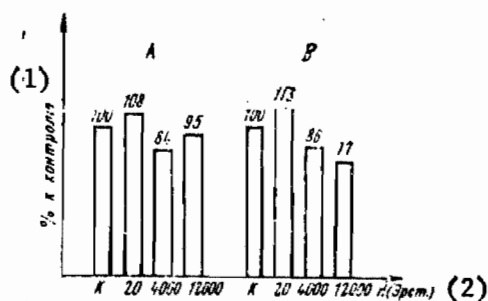   The figures show the relative length of the root system of a 4-day-old Rye "Vyatka."

Figure 11. Influence of Magnetic Fields of Various Intensities on the Length of Roots (B) and Stems (A) of 4-Day-Old Bean Sprouts.
Key: 1. percent of the control
    2. Oersteds

How fast is it possible to observe the acceleration of growth in a root under the effect of the applied field? Experiments show [49] that 30 minutes are quite sufficient for observing the change in the growth rate under the influence of a field by means of a horizontal microscope (Figure 12).
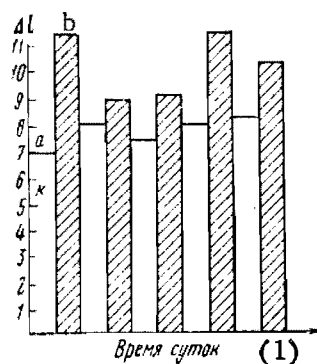
69

Δl b
11
10
9
8 a
7
6 к
5
4
3
2
1

Время суток (1)

Figure 12. Overall Increase in the Length of the Root
of Rye "Vyatka" Visible in a Horizontal Microscope with
a Constant Magnetic Field of 20 Oersteds Alternately
Turned On and Off. The CMF is Directed Along the Magnetic
Field of the Earth.
Ordinate -- increase, mm; eyepiece micrometer scale;
Abscissa -- time, hours; K -- control; a -- field turned off;
b -- field turned on.
Key: 1. Time of day

Thus, if the magnetic field coincides with the direction of the GMF, the
growth rate increases at first when the field intensity increases, then it,
evidently becomes stabilized, and, finally, at 4,000 oersteds, and particu-
larly over 12,000 oersteds, the field inhibits the growth of the root. It
is appropriate to mention here that, according to Montgomery and Smith [395],
only a root not detached from the plant is so highly sensitive to CMF, and
this limit rises to several thousands of oersteds for an isolated root. How-
ever, our experiments conducted together with A. M. Smirnov in 1965 showed
that the growth of isolated kidney bean roots grown for 7-10 days in Helmholtz
rings (20 oersteds) was inhibited in comparison with the control palnts grown
at the same temperature [179].

Unfortunately, there are no convincing studies which would have it as their
goal to show the sensitivity of isolated (cultural) roots, and not roots de-
tached from the plant, to magnetic fields. It is believed that the root is
no less sensitive than the coleoptile, because the problem of the different
sensitivity of detached and undetached roots to magnetic fields presupposes
either a high sensitivity of some other plant organs to magnetic fields (the
cleoptile base -- Savostin [168], Montgomery and Smith [395]), or an increase
in sensitivity due to the presence of a mechanism integrating the metabolism
in the entire plant. In any event, as it follows from the work by Dycus and
Shultz [310], plants are capable of reacting not only to increases in the field
intensity, but also to its lowering by 10,000 and 1,000 times against the
GMF. Moreover, some plants respond by the acceleration of growth (cucumbers
and radishes), some by the inhibition of growth (corn, rye), and some do not
react at all. In most cases, this was a temporary phenomenon, and it was
studied only in the course of one month.

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In 1967, Chuvayev et al [57] described their experiments in which the GMF intensity in the test (in darkness) dropped by almost 50,000 times. They obtained the first interesting results indicating certain disturbances in the growth of the roots. The roots became thicker, shorter, bent, and formed knobs.

It will be recalled that Savostin [168] believed that the magnetic field is one of the coordinates (along with the force of gravity) necessary for a normal development of a plant in time and space. This explains why the disappearance of this coordinate or the lowering of the sensitivity to the field (which, for the object, is the same as the disappearance of the coordinate) can bring about the above-mentioned aftereffects. At the same time, what should be the mechanism ensuring the sensitivity to a magnetic field which is hundreds and even thousands of times weaker than the GMF? It is known that, in the history of the Earth, there were not only periods when the GMF had a different direction, but also those when it was tens of times weaker than now. From this point of view, it is not possible that temporary intensification and inhibition of growth in plants with a lowering of the field (Shultz, Smith, and Dycus [395]) is a reaction of a temporaty loss of sensitivity to the field which is restored later and the absence of any response of some plants to the lowering of the magnetic field intensity -- just the fact that the "magnetic" coordinate still exists for them?

From this viewpoint, it is not so much the value of the magnetic field intensity, but the very fact of the presence of a field above the minimum intensity that must be important. But this, in turn, presupposes the presence of a special mechanism of response to magnetic fields which is very sensitive to the fact of existance of the field, but not very sensitive to the increases in the intensity (of course, with certain limits).

It should be mentioned that acceleration and inhibition of growth by magnetic fields show themselves as a statistical reaction, i.e., include instances of its extremely strong manifestation. In this sense, the variability of the reaction is not only a consequence of different physiological states of the objects, but also the variability of external conditions.

With all these reservations, it must be said that the nonuniformity of magnetic fields is the factor facilitating the manifestation of these reactions. The presence of the gradient facilitates the response to the magnetic field and makes it more effective in the case of lower intensities. This was pointed out by Cotton [397] in his analysis of Perakis' work [374], who did not detect any effect when he treated sea urchin eggs with a homogeneous magnetic field of 30,000 oersteds, while a field of 8,800 oersteds, but with the gradient, produced a definite inhibiting effect. This role of the gradient in suppressing the growth of tumors on Pelargonium plants was shown by Magrou and Manigault [355, 356]. Audus [265] succeeded in showing that the bending of roots of garden cress in a magnetic field of 4,500 oersteds, with a gradient of 4,500 oersteds/cm, can be registered on the movie film after several minutes, and that the root moves from the region of the highest gradient to the region of the lowest gradient, showing negative magnetotropism.

Audus and Vish [286] showed that this response is based on the translocation of starch grains in the cells of the zone of stretching in the directions of the highest gradients. As a result of the appearance of the irritation center when the grains press on the boundary layer of the plasma, auxin gets on the corresponding side, causing the stretching of the wall and the bending of the root in the opposite direction. Unfortunately, the authors were not able to confirm the fact of the translocation of starch grains later.

Audus [265] based his notion of magnetotropism on the fact of the bending of the root end along the gradient.

A. V. Krylov and G. A. Tarakanova [104, 105] gave an entirely different interpretation of the concept of magnetotropism. They considered that magnetotropism was the fact of the bending of the primary root during sprouting in the direction of one of the poles, i.e., along or against the intensity vector of the magnetic field, which they discovered.

And, finally, the third interpretation of magnetotropism was given by Pittman [377-380], who understands it as the phenomenon of orientation of root systems under the influence of the GMF in nature. In this case, root systems orient themselves either along a magnetic meridian, or across it, in the latitudinal direction. Wherever the directions of the magnetic and geographic meridians are close, this direction of stretching of the root systems coincides with the N-S or W-E direction. However, in those regions of Canada where the azimuth is sufficiently large, this direction, for instance, in sugar beets, as was described by Schrieber [392], corresponds to the NE-SW direction. Pittman [377] succeeded in showing that changes in the direction of a magnetic field change the direction of orientation of the root system.

Table 11
Orientation of Branch Roots in Some Root Crops under Field Conditions

(1) Сорт растений	(5) Всего	(6) Число обследованных растений									
		(7) Характер ориентации									
		(8) С — Ю		(9) З — В		(10) СЗ — ЮВ		(11) ЮЗ — СВ		(12) неопреде-ленный	
		(13) абс.	%	(13) абс.	%	абс.	%	абс.	%	абс.	%
(2) Сахарная свекла «Белоцерковская»	10220	5550	54	3719	36	325	3,0	200	2,0	426	5,0
(3) Сахарная свекла несортовая	1221	687	56	490	41	9	0,7	5	0,4	24	2,0
(4) Редис «Дунганский»	1160	711	61	403	35	17	1,5	—	—	29	2,5

Key: 1. Plant variety
  2. Sugar beet, Belotserkovskaya"
  3. Low-quality sugar beet
  4. Radish, "Dunganskiy"
  5. Total
  6. Number of studied plants
Key continued

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7. Nature of orientation   11. SW-NE
8. N-S   12. Indefinite
9. W-E   13. Absolute
10. NW-SE

Let us show on the example of our data obtained in 1967 how root grooves of sugar beets and radishes are distributed under field conditions (Table 11). As can be seen from the table, two main directions are predominant: N-S and W-E, which constitute 90 percent of the cases. The roots of these plants are the heaviest, although their sugar content is not known.

Pittman [381] pointed out that the absorption activity of root systems (for example, with respect to phosphorus) is expressed stronger in the preferential direction. Consequently, the practical conclusion would be to introduce fertilizers across the preferential distribution of the root system (Schreiber [352] came to the same conclusion with respect to sugar beets over 10 years ago).

Thus, magnetotropic responses occur in nature and are connected with the active absorption activity of the root system. Moreover, the orientation with respect to the lines of force of magnetic fields is so important that plants reorient their root system if, for some reason, the mutual arrangement of the field and the root system changes.

So far, we have been discussing the external manifestations of growth as a response to magnetic fields, which was expressed in changes in the growth rate of the roots or in the direction of growth. As is known, the cytological basis of growth is the division and distension of cells. Consequently, changes in these two processes under the influence of a magnetic field must precede the morphological shaping of growth. Moreover, the majority of works, with the exception of interesting studies by Celestre [290] and Dunlop and Schmidt [308, 309], mention only the final result of the field influence on the growth of plants and do not analyze what cytological processes are responsible for this effect.

In our studies on the influence of magnetic fields, we tried not to limit ourselves to studying the effect of the field on the growth of sprouts [190]. The goal of the cytological study was to solve the problem of which phase of growth -- embryonic or distension -- is affected by magnetic fields, changing the rate of growth. Due to the great importance of nucleic acids in the growth processes, we connected the growth intensity with studies on the content of nucleic acids.

The obtained data -- greater intensity of staining by methyl green pyronin, increase in the size and number of nucleoles -- indicate a higher content of RNA in plants grown in a weak nonuniform magnetic field (60 oersteds). No noticeable difference was established with respect to the DNA in the experimental and control plants.

Based on the notion that nucleic metabolism is one of the fundamental biochemical mechanisms of mitosis, the different levels of the RNA content in plants grown in a magnetic field and in the control would reglect on the mitotic activity of the cells.

In fact, the mitotic coefficient of plants grown in a weak magnetic field was higher than in the control plants [180].

It has been established that magnetic fields influence not only the zone of cell dividion, but also the distension zone, increasing the size of the cells and the RNA content.

Under the influence of high-intensity fields (12,000 oersteds), which obviously hindered the growth rate (4,000oersteds -- by 17 percent, 12,000 oersteds -- by 30 percent), we observed [189] a considerable decrease in the mitotic coefficient (from 10.65 percent in the control to 5.11 percent in the experiment) (Table 12).

Table 12

Mitotic Coefficient and the Occurrence Frequency of the Cellular Cycle Phases in the Root Cells of Beans Grown for 4 Days in a CMF of 12,000 oersteds

(1) Вариант	(2) Митотический коэффициент	(3) Встречаемость фаз цикла клеточного деления				
		(4) Интерфаза	(5) Профаза	(6) Метафаза	(7) Анафаза	(8) Телофаза
(9) Контроль	10,65±0,67	89,35±0,65	5,95±0,59	1,89±0,23	1,93±0,14	1,51±0,18
(10) ПМП	5,11±0,51	94,89±0,52	2,71±0,36	0,89±0,15	0,56±0,09	0,95±0,17
(11) ПМП к контролю, %	48	106	46	47	43	63

Key:
1. Variant
2. Mitotic Coefficient
3. Occurrence Frequency of the Phases of Cell Division Cycle
4. Interphase
5. Prophase
6. Metaphase
7. Anaphase
8. Telophase
9. Control
10. CMF
11. CMF-Control Ratio, percent

As can be seen from the table, the inhibition of mitosis in a magnetic field takes place from the earliest phases and is registered even in the prophase. This, evidently, suppresses mitosis during the subsequent division stages and inhibits the process as a whole. The validity of this assumption is supported by the fact that the values of mitosis suppression are very close in its different phases. As was shown by further studies of Strekova, magnetic fields of 12,000 oersteds increased the number of chromosomal aberrations (8.1 percent) consisting in the formation of bridges, fragments, and microneuclei. So far, we cannot tell whether or not the chromosomal aberrations

induced by CMF differ qualitatively from those caused, for example, by irradiation or exposure to high temperatures.

The manifestation of the field effects even in the initial stages of cell division makes it possible to assume that CMF influence chiefly the preparatory stages of the cellular cycle (the interphase). The data obtained on chromosomal aberrations make it possible to judge with more certainty which period of this stage is effected by strong magnetic fields. It is known that chronosomal aberrations occur when some factor acts on the presynthetic period of the interphase (g_1). Therefore, the chromosomal aberrations observed by us can be connected with the action of the field on this period.

If we compare these data with the earlier results obtained by Celestre [290], we shall find many similarities. Whan hyacinth and tulip bulbs were exposed to a magnetic field of 15,000 oersteds for a shorter period of time (2 hours) than in our experiments, the mitotic aberrations were manifested as the adhesion of chromosomes and the appearance of free and bound fragments; when the exposure time was 5 hours, there was a strong inhibition of the spindle activity with 8.6 percent chromatic bridges with fragments and free fragments. Resting cells showed pycnosis and degeneration. Agglutination and breakage of chromatin fibers resembled those caused by irradiation and action of an AMFor an electric field [291]. Celestre, just as Pirovano [376], believes that all above-mentioned phenomena are a result of the disturbance and incoordination in the movement of charged masses of the nuclear material in the process of mitosis or its preparation under the effect of a magnetic or electric (direct or alternating) field. Thus, they consider it a consequence of direct nonspecific interference of a magnetic field in the process of cell division.

Dunlop and Schmidt [308, 309] studied the influence of CMF of 500-1,000 and 5,000 oersteds (nonuniform) on narcissus, onion, and amaryllis bulbs in the course of 2 months. The overall pictures of the inhibition of the growth of roots at the anatomo-morphological level is conceived by them as the appearance of flexures in the roots, thickening of the roots, appearance of additional branch roots from the initial area, and the appearance of tumors in the apical region. At the cytological level, the authors observed the inhibition and stoppage of mitoses, then the destruction and dying of the meristematic zone accompanied by general enlargement of the cells in the region of the field, and an accelerated maturing of the tracheal elements in the apex.

Thus, cytological changes in magnetic fields lead to that visually observed picture which manifests itself as inhibition of root growth in magnetic fields.

It seems to us that one of the possible causes of the lowering of the mitotic coefficient could be the lowering of effectiveness of respiration in strong magnetic fields (4,000-12,000 oersteds) which was established by Tarakanova [180]. It is even more probable since there are indications in

literature that the blocking of oxidative phosphorylation can inhibit or even stop completely the progress of mitosis [103].

Thus, it seemed to us that it was possible to connect the observed cytological changes with biochemical and physiological processes. A few years ago, we notices a strange incongruity between the intensification of growth in weak magnetic fields when seed germs were oriented toward the magnetic south and the comsumption of oxygen. Oxygen consumption lower than in the control corresponded to a more accelerated growth than in the control [194]. When the seeds were turned with their germs toward the magnetic north, this incongruity was not expressed so clearly. In general, the lowering of oxygen consumption in magnetic fields is a well-established fact [197, 387, and others]. However, we were interested in the unusual relation of these processes -- accelerated growth and lowered respiration.

For stimulating doses of pulsed EMF (electromagnetic fields), similar data were obtained by Jitariu et al [335] on chicks. They succeeded in connecting their results with the processes of energy metabolism and showing that EMF increase the conjugation of the oxidation and phosphorylation processes whenever surface (in relation to mitochondria) enzymes, which usually do not produce the conjugation of oxidation and phosphorylation, penetrate within the mitochondria due to increased permeability of the membranes caused by the electromagnetic action.

In our case, which was very similar with respect to superficial results (although we were dealing with CMF), it was also possible to assume that the changes observed in the nature of the gaseous interchange were connected, first of all, with the changes in the nature of conjugation of the oxidation and phosphorylation processes accompanied by a general shifting of metabolism under the effect of the magnetic field in the direction of anaerobiosis [138, 194]. A similar conclusion was made by Jitariu et al [334] when they studied the influence of pulsed EMF on the hatching rate of chicks, as well as by Tarchevskiy [195] and Zabotin et al [81] when they studied unfavorable effects on photosynthesis (drought, magnetic fields, electric fields) with respect to photophosphorylation.

In fact, it was shown by Tarakanova's dinitrophenol method [180, 193] that, whenever the growth is accelerated by the influence of a magnetic field (20 oersteds), oxygen consumption by the roots of experimental plants with stimulating doses of dinitrophenol increased considerably more than in the control plants (Table 13), which could, possibly, be interpreted as strengthening of the connection between oxidation and phosphorylation. When growth was inhibited (by CMF of 4,000 and 12,000 oersteds), this connection was weaker. A prolonged action of a CMF (30 days) did not change the directivity of the processes, but only intensified them.

The earlier assumption regarding the shifting of metabolism in the direction of anaerobiosis in CMF made it necessary for us to broaden the ideas of the

influence of CMF on the respiratory gaseous interchange by determining the value of the respiratory quotient(RQ) in the process of action and after-effects of CMF.

Studies [192] showed that the action of strong (4,000 and 12,000 oersteds) magnetic fields on detached roots (exposure -- 1 hour) was also expressed as decreases in the amounts of consumed oxygen accompanied by a lowering of the amounts of liberated carbon dioxide. The RQ increases somewhat in this case. On the other hand, one-hour exposures of detached roots to a weak (20 oersteds) magnetic field did not produce any effect. Let us mention for a comparison that oxygen consumption by seeds in the process of germination in a weak magnetic field is accompanied by the lowering (in comparison with the control) of oxygen consumption by 15-20 percent. Thus, by this index, just as by the growth response, the magnetic field sensitivity of isolated parts of the plant and that of the whole plant are different. In our opinion, it is interesting that the aftereffects of strong magnetic fields (particularly, with long exposures) cause an opposite effect -- increased intensity of respiration (Figure 13). The value of RQ also increases considerably in this case. A similar picture was observed by Jitariu et al [335] on the example of the metabolism of K, Na, Ca, and other elements during some exposures to PMF. All this is very similar to a nonspecific compensating response to an unfavorable stimulant [220, 270, and others].
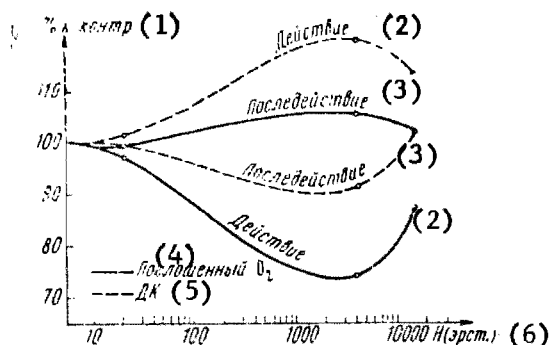

Figure 13. The Dependence of the Respiration of Roots of 4-Day Beans on the CMF Intensity for an Exposure of 1 Hour (Action and Aftereffect) Expressed in Logarithmic Scale.
Key:
1. Percentage of control
2. Action
3. Aftereffect
4. Absorbed O_2
5. RQ
6. (oersteds)

Along with this, we,in cooperation with the Department of Biophysics of the Moscow State University [73], studied the influence of magnetic fields of various intensities on the intensity of the extremely weak spontaneous hemiluminescence of bean roots. According to modern notions, this method makes it possible to obtain information on the energy metabolism at the submolecular level.

It was established that the intensity of the extremely weak spontaneous hemiluminescence of the roots changed after the sprouting beans had been exposed to a magnetic field: a weak magnetic field (62 oersteds) caused intensification of luminescence, and a strong field (4,000-12,000 oersteds) inhibited it. The inhibition effect was more expressed in a magnetic field of 12,000 oersteds. The influence of a magnetic field on the intensity of of luminescence had a clearly expressed aftereffect (Figure 14).
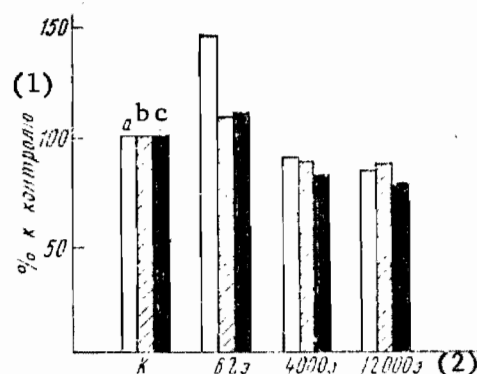

Figure 14. Extremely Weak Spontaneous Hemiluminescence, Energy Effectiveness of Respiration, and the Growth Response of Bean Roots grown in CMF of various Intensities. a -- intensity of extremely weak spontaneous hemiluminescence; b -- energy effectiveness of respiration; c-- growth response.
Key:
    1. percentage of control
    2. oersteds

The obtained data completely correlate with the changes in the intensity of the growth process and the energy effectiveness of respiration in magnetic fields. Evidently, this means that CMF disturb the steadiness of the biological oxidation processes in the cell, changing the intensity of luminescence. Changes in the nature of the chain process of oxidation under the influence of CMF is, probably, manifested in the disturbance of the synthesis of nucleic acids and proteins, which is reflected on the progress of cell division and on the growth rate.

The modern biochemical data on the influence of magnetic fields on plants are characterized by their nonspecificity, i.e., disregarding the nature of the factors causing these changes, it is impossible to determine by the progress of the biochemical changes what physical factors was responsible for them. This nonspecific nature of the manifestations of the influence of magnetic fields at various levels was first stressed by Tarchevskiy [195], as well as by other authors [220,270,336, and others]. Tarchevskiy pointed out that the so-called "alanine effect" in photosynthesis, as well as the shifting in the quantitative distribution of the marking between saccharose and monosaccharides could be a result of drought, as well as the effect of

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electric or magnetic fields, or a result of the introduction of certain substances. Evidently, the general cause of the nonspecificity of the response reaction is the ability of protoplasm to "generalize" stimulants. It is in the property of the protoplasm to respond very sensitively, but in a standard way, to any stimulant.

Thus, if the state of the protoplasm determines the possibility of perceiving stimuli of various strengths, then the rhythmic changes in the sensitivity of the protoplasm to the stimuli will play an important role in perceiving magnetic fields. However, since this "rhythmic sensitivity" is determined by the physiological state of the object, it is not advantageous to separate them.

Savostin [168] believed that the periodic sensitivity of growth in plants to magnetic fields is caused by the periodicity of mitoses. However, the problem of the daily periodicity of mitoses is still under discussion, just as the daily periodicity of matnetic fields.

On the other hand, the influence of CMF on spatial rhythmic phenomena is clearly presented. Savostin [165] showed that nutations of pea tendrils were disturbed when they were exposed to a CMF. The rhythm of root secretions was upset when the horizontal component of the GMF was changed in the experiments by Dubrova and Bulygina [77]. Even in the experiments by Novak and Valek, which should be treated very critically because of absence of recurrence, the rhythm of dandelion clusters was sharply disturbed under the effect of a weak CMF. In general, under the effect of weak magnetic fields, the connection between these effects and the periodic phenomena outside the plant, such as the movement of the sun and moon, is registered more clearly than under the influence of strong magnetic fields [29, 370, and others].

All this, evidently, testifies to the fact that a weak magnetic field similar to the GMF is somehow connected with the determinition by the plant of its spatial-temporal position in the environment (of course, it is even more significant for moving objects).

Savostin's opinion [168] regarding the fact that the GMF could be a coordinate (others are the rotation of the earth and gravitation) on which "heredity is based in its realization in ontogenesis" deserves attention. This, in turn, presupposes the existence of a mechanism highly sensitive to CMF, which has been mentioned before. In fact, many works [51, 395, and others) say a decrease in the intensity of the GMF by hundreds and thousands of times would have definite physiological aftereffects for a number of plants. The acceleration or inhibition of growth (with subsequent return to the normal state) [310] with a great degree of compensation of the field (exact to 10^{-5} oersteds) -- all testify to the fact that the GMF is an important factor of the normal vital activity of plants. However, the very value of the response to a magnetic field is, to a considerable degree, a consequence of this phyciological state. We only have to give some examples illustrating this statement (Figure 15).

Table 13

The Influence of Dinitrophenol (DNPh) of the Oxygen Consumption of Roots of Four-Day-Old Beans Grown in Magnetic Fields of Various Intensities

(1) Напряжен- ность МП, э	(2) Варианты	(3) Поглощено кислорода за 1 час на 1 г сырого веса тиани, мкл		(6) Стимуляция от ДНФ, %	Р
		(4) вода	(5) ДНФ		
20	(7) Магнит	331,6	521,3	57,2	< 0,05
	(8) Контроль	327,8	454,3	38,6	
4000	(7) Магнит	386,2	458,2	18,6	< 0,05
	(8) Контроль	337,2	455,6	32,1	
12000	(7) Магнит	401,0	469,2	17,0	< 0,005
	(8) Контроль	314,5	420,5	33,7	

Key: 1.   Magnetic field intensity, oersteds
2.   Variants
3.   Oxygen absorbed, 1 hour per 1 g of raw weight of tissue, microliters
4.   Water
5.   DNPh
6.   Stimulation from DNPh, percent
7.   Magnet
8.   Control
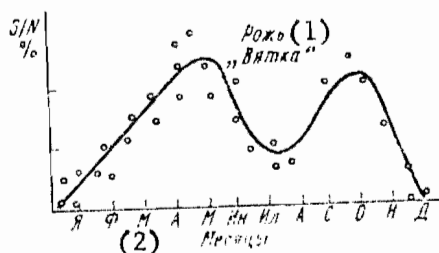
Figure 15.   The Influence of the Orientation of Seeds on the Ratio of the Length of Roots of 3-4-Day Sprouts Grown in the Dark for Several Days Depending on the Season
Key: 1.   Rye "Vyatka"
2.   Months

As can be seen from the figure, the response of the rye seeds "Vyatka" to the orientation with respect to the poles of the magnetic field disappears prectically by the moment of the winter solstice and increases again by the spring and fall. The number of positive responses to artificial magnetic fields changes in exactly the same way.

Moreover, the reaction of the chloroplast movement to CMF has a clearly expressed seasonal rhythm, which, to a certain degree, is the reflection of the state of protoplasm.

It is possible to assume that the principle of limiting factors known in plant physiology holds true in respect of the influence of CMF. We have already mentioned that the maximum growth response to magnetic fields takes place at optimal temperature conditions. However, the maximum inhibiting action of high temperatures takes place under the conditions of the action of high-intensity magnetic fields inhibiting the growth of plants [242].

This does not mean, however, that any growth inhibiting factor will prevent the manifestation of the stimulating effect of low-intensity magnetic fields. Evidently, this will depend on whether the magnetic field and the controlling factor are acting on different or the same sections of the general mechanism of the growth process, as well as on the strength of their action.

However, this means that further experiments on the combined action of CMF and other factors will help to reveal the mechanism of the CMF influence on plants. At the present time such works yield very contradictory data.

For example, Conger and Flasterstein [296], while studying the effects of radiation against the background of a magnetic field of 4-10 kilo-oersteds on the sprouting of barley, came to the conclusion that they did not discover any independent effect of magnetic fields. On the other hand, Mericle et al [360], after having done a thorough statistical analysis of the effect of a magnetic field of 3,000 oersteds (also on sprouting barley), discovered an increase in the variability of the objects exposed to a magnetic field, as well as the fact that magnetic fields lowered the influence of radiation on the size and total number of roots. This effect of the magnetic field was strictly specific for each index and proportional to the radiosensitivity of the organ. For example, they discovered synergism in the effects of radiation and the magnetic field on the germination rate and the number of roots, and antagonism (a protective action) of the field with harmful effects of radiation on the germinating seeds.

It deserves mentioning that radiation itself affects differently the polymerization effects in organic gels depending on the dose. In the case of oriented polymerization under the influence of some factor, it, consequently, must shift the sensitivity of the polymer system toward this factor [239, 256], no matter what it is, light, a foreign body or an electric or magnetic field. It is possible to assume that the destructuralization and structuralization of the protoplasm elements in the process of growth and development could be that magnetic-field-sensitive reaction which can ensure the majority of (if not all) the effects observed by us in magnetic fields and their seeming nonspecificity. In this sense, the temperature, by nature of its action, unlike the action of a field, must be a disorganizing factor. And in those cases when metabolism is low, it is possible to expect that the magnetic field will have a protective effect (in terms of the preservation of the

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orientation of the structure, if this structure is sufficiently sensitive to the magnetic field). A similar picture was observed by us when a magnetic field of 450 oersteds acted upon dry seeds at high temperatures. The field protected longitudinally oriented seeds against the inhibiting temperature effects. However, when the magnetic properties of seeds are not clearly expressed, this phenomenon needs further studies. It should be mentioned that the protective effect of the field against temperature was observed by us only on dry seeds and in the first stages of development (germination energy). However, since the field acts along many channels, it is quite possible that the protective action could be exhausted during the first stages and change to the opposite, if the genetic apparatus is involved, or those of its parts which control the coordination of metabolism in ontogenesis. Of course, in the above example, we are dealing with the first stages of the aftereffects of the magnetic field which are realized as a possible consequence of the field's action both upon the bud and upon the endosperm. As regards the mechanism of the action of the field on dry seeds, it is of interest that the protective influence of the magnetic field shows itself the most at 40 degrees and 85 degrees, i.e., at the temperatures when the sharpest changes in the electric conductivity of the seeds were observed, which was, evidently, connected with the disturbance of the ion-water structure and, consequently, the colloid stability [19]. The latter must reflect on their accessibility to enzymic processing during the sprouting of the seeds.

In essence, the above examples of changes in the hemiluminescence under the influence of magnetic fields are also the aftereffects.

Thus, the magnetic field acts through many channels, and it is not always easy to distinguish its effects from aftereffects.

Let us try to evaluate the possible routes of this action.

Savostin [164] believed that the effect of a CMF is determined by: 1) its effect on the biochemical reactions; 2) its effect on the magnetic masses of substances in the cell; 3) its effect on the biocurrents. On the basis of the modern concepts of the effects on the biochemical reactions developed by Dorfman (see this collection), it is possible to consider that the decisive factors here will be the molecular weights of the reagent and the substratum, the intensity of the magnetic field, and its nonumiformity. In general, this thesis was confirmed well by Haberditzl's works [326, 327]. However, if we consider that studies by Conley et al [395] on the changes in the trypsin actively in a weak magnetic field are convincing, then we must propose some other alternative to the above hypothesis.

It should be mentioned that the translocation of the organelles and particles within the cell as a basis of the mechanism of response to the magnetic field is hardly probable because of the high viscosity of the protoplasm even at high intensities of the field and the gradient. On the other hand, the development of pressure on the boundary layers of the protoplasm is so real that it can be registered as a signal.

For approximately the same reason, the turning of individual chromosomes, and especially of nucleic and proteic compounds, in a uniform magnetic field is also unlikely. However, it is not ruled out that at certain moments -- during the time of weakening and separation of the chromosomes -- conditions are created when the viscosity decreases locally, the fragmental bonds weaken, and then strong magnetic fields could have an effect. It is no coincidence that many authors observed a particular sensitivity of mitosis to strong magnetic fields.

The problem of the effects on magnetic masses includes also the effects on the paramagnetic substances of the cell. At one time, Savostin attached much importance to this matter, believing that the content of paramagnetic elements in the cell determines its sensitivity to CMF. The highest content of paramagnetic elements in an organ or tissues [164, 180, and others] also is the reason why this organ or tissues are the most sensitive to the field. Evidently, Khvedelidze et al [51] are of the same opinion. They stated that they established a connection between the strength of the response of wheat seeds to a CMF and the content of paramagnetic elements in the caryopses. However, in our opinion, it is difficult to interpret the observed biological effects in the magnetic field on the basis of the paramagnetic phenomena. Of course, such paramagnetic elements as Fe and Co are connected with the most important enzymic and coding systems, but, unfortunately, these systems do not have such "outstanding" magnetic properties [394] that it would be possible to explain biological responses through them as a result of a special behavior of these substances in magnetic fields of sufficiently strong, medium, and particularly, weak intensities. Moreober, due to the viscosity of the protoplasm, this mechanism in the cell, is, in general, doubtful.

In our opinion, more attention should be given to Dorfman's theory [72] regarding the effect of the appearance of a resonance between the frequency of the biopotentials and the frequency of the mechanical oscillations induced by the magnetic field, as well as when the frequency of the natural mechanical oscillations of an organ (or particles) coincides with the natural frequency of free oscillations. As Dorfman points out, this could explain the presence of biological effects in very weak magnetic fields (of the order of 0.5 oersteds). However, this area in magnetobiology has not yet been studied at all. It is only known that the mechanical oscillations (vibrations), actually, bring about the phenomena which closely resemble the effect of a constant magnetic field (Karmilov et al [19]).

According to this hypothesis, sensitivity of magnetic fields is connected with the generation and the natural purpose of biopotentials in a plant. It follows from this that studies on bioelectricity and biomagnetism should be done, as far as possible, simultaneously, in which we fully agree with Dorfman.

Summing up what has been said, we can assume with a certain degree of caution that the effects of magnetic fields on plants, on their physiological functions, can show themselves either as a result of their influence on the genetic apparatus, for example, through cell division (directly on the code or the transmission of information), or as a result of direct interference in the

metabilism or in the coordination phenomena connected with the orientation in space and time.

Since in the fields of great intensities and gradients, we are dealing with many of these phenomena at once, at the present time it is impossible to isolate any of these mechanisms. At the same time, the connection between the effects of CMF with the last of the above-mentioned phenomena shows itself clearly in the fields of the order of the earth's field (and lower), which in our opinion, can be explained not only by the resonance effects, but also by a particular sensitivity of the transitional structural states of organic gels to external effects.

THE INFLUENCE OF MAGNETIC FIELDS ON RADIATION-INDUCED CHROMOSOMAL ABERRATIONS IN PLANTS.

[A. A. Pozolotin, Institute of Plant and Animal Ecology of the Ural Branch of the USSR Academy of Sciences, Sverdlovsk)

It follows from the analysis of the data on the biological effects of electro-magnetic fields (EMF), that magnetic fields (MF) are weak stimulants in the majority of the known effects [153, 220]. First of all, it is indicated by the examples when MF were used against the background of a strong stimulant [37, 220]. The EMF effects against the background of such a well-studies factor as ionizing radiation are of special interest.

A brief summary of the data on the changes in radiation effects under the influence of MF is given in an article by Vilenchik [46]. The first work in this direction was Forssberg's study [313] on eggs of Drosophyla melan-ogaster. Pretreatment of eggs with an MF of 6,000 oersteds increased their radiosensitivity: the death rate from irradiation with a dose of 165 roent-gens was 16.8 percent higher than in the control, which was five times higher than the average error of the experiment. In M. Barnothy's experiments [272, 273, 286], MF treatment also preceded the irradiation, The mice kept for 14 days in a field of 4,200 oersteds with a gradient of 30 oersteds/cm before their irradiation were found to be less radiosensitive to gamma-radiation, which was indicated by their weight curve, hematologic indexes, spleen weight, and death rate.

It is logical to assume that the MF effect will differ depending on whether the organisms are exposed to the field before, during, or after the irradia-tion.

We know of an experiment [264] when an MF was applied at the moment of irra-diation. Tribolium confusum pupae were irradiated with roentgen rays in a dose of 1200-2500 roentgens in an MF of 3,000 oersteds, and the abnormali-ties in the wings of the adult insects were studied seven days later. The control insects were kept under identical conditions. The experimental group yielded 54.1±1.5 percent of flies with abnormal wings as compared to 93.4±1.4 percent in the control group. The death rate of the pupae in both groups did not exceed 3 percent.

It should be noted that the above experiments were done on animals. There are still less published data on the effects of preliminary or simultaneous exposure to MF and ionizing radiation on plants. In the experiments by Santha [390], Vicia faba seeds in various stages of development were used. The growth rate of the roots in the course of 10 days served as the criterion. Prior to irradiation with three different doses of roentgen rays, the object was placed in a uniform MF of about 3,000 oersteds. No significant effect of the MF pretreatment on the resting seeds was observed. The "premagnetizing" of the sprouting seeds had a protective effect against the exposure to ionizing radiation.

Exposure to MF after irradiation is of particular interest. Such studies were done chiefly on plants. The results obtained by different authors even on the same experimental material were often different. In Conger's experiments [296] on barley seeds irradiated with doses of from 1 to 40 kiloroentgens, the MF in the interval of 4.1-10.1 kilo-oersteds did not change the radiation injury. In a series of experiments [286, 360, 361], the action of an MF of the order of 3,000 oersteds on irradiated seeds and sprouts of barley reduced the radiation effect of growth inhibition, and the degree of protection was lower when the radiation injury was greater.

Malz [357] used a uniform CMF of 40,000 oersteds in his experiments on the yeast Saccharomyces vinii irradiation with gamma-rays in a does of 100,000 roentgens. Numerous repeated experiments showed clear acceleration of the response of the yeast to irradiation. A negative result was obtained with a field of 25,000 oersteds.

This article describes my experiments on the modifying influence of EMF on radiation injuries of the chromosomal apparatus of cells.

The study was done on meristematic cells of the roots of peas, "Capital" variety, from the experimental plant selection station Bishkil, Chelyabinskaya Oblast! Chromosomal aberrations of the type of bridges and fragments in the anaphases of the first postradiation mitosis were selected as the criterion of radiation injury. With a few exceptions, which are specially mentioned in the appropriate parts, resting pea seeds were irradiated with Co^{60} gamma-rays. Their exposure to EMF was done at various stages of their development. The applied PMF was of 200 kilo-oersteds, a frequency of 3,000 hertz, and a length of about two periods obtained by discharging battery capacitors on a solenoid and a uniform CMF in the gap of a direct current electromagnet from a generator. More detailed descriptions of the methods, as well as the cytobiological part, are given in earlier works[148].

Results and Discussion

Before describing the results of the main experiments on the influence of PMF on the cytological effect of irradiation, we shall briefly describe the results of experiments on the effects of a PMF on nonirradiated seeds and sprouts of peas. These experiments were expected to answer the question whether or not an MF by itself, without additional influences, can cause

chromosomal aberrations in the cells of meristemic tissues. This was particularly important because there were individual reports [290, 201, 312, 357] on the cytological influence of CMF and AMF, but there were no published data on the effects of PMF on chromosomes. Studies were done on the influence of PMF on resting seeds, seeds swelling in water, seeds beginning to sprout, and on sprouts. The results of these studies are given in Table 14. It can be seen from the table that in the control variants, i.e., in the roots which were not exposed to MF, there were some cells with chromosome aberrations when the anaphases were analyzed. The percentage of these anaphases varies between 1 and 3.5, and the variations depend on many uncontrolled experimental condition [229]. The statistical processing of the data given in the table showed that the number of cells with chromosomal aberrations in the variants with the application of PMF did not differ with certainty from the number of cells with aberrations in the control variant. The same picture was also obtained for resting seeds for a swelling seeds, for the seeds beginning to sprout, and for the sprouts.

Thus, no harmful effect was detected by a strong PMF on the chromosomes of cells after the exposure to a field at various stages of the development of pea seeds. It was pointed out by us earlier (49, 149] that a uniform CMF of about 8 kilo-oersteds also did not cause any chromosomal aberrations in the seeds of peas and pine. In both cases, the cells of the first mitosis after the exposure to the field were analyzed. The cytogenetic effects of MF described in literature [290, 291] were observed during long exposures to MF (during several mitotic cycles) and on other objects.

The next series of experiments was on the application of PMF after the irradiation of sprouts. In selecting the most suitable dose for our purposes, we proceeded from the data obtained by Tsarapkin [229] for determining the dependence of the development of the pea plants of the "Capital" variety on the irradiation dose. The dose of 400 roentgen selected by us did not inhibit noticeably the development of sprouts in the following days, and caused a moderate number of chromosomal aberrations per one cell with aberrations. The number of cells with chromosomal aberrations at a dose of 400 roentgens is convenient for calculations. The same work showed that the lowest variability of the radiation effect was observed at a dose of 400 roentgens.

Pea sprouts were placed within a solenoid in special funnels inserted into a Dewar flask. The sprouts were arranged in such a way that the pea itself was outside the field, and the ends of the roots about 10 mm long were in the middle of the solenoid where the field was uniform. The series consisted of three experiments which differed only in the time they were done. Preliminary dispersion analysis showed that the differences between the data of these experiments were statistically insignificant, therefore Table 15 gives averaged results.

Table 14
The Number of Anaphases with Chromosomal Aberrations in the First Mitosis after the Exposure to a Pulsed Magnetic Field

(1) Вариант		(6) Воздействие	(9) Просчита-но анафаз	(10) Повреждение анафаз (11)		t	P
				число	%		
(2)	Покоящиеся семена	7) Контроль	200	2	$1,0\pm0,71$		
		8) Магнит	100	2	$2,0\pm1,40$	0,64	0,5
(3)	Набухающие семена	7) Контроль	400	4	$1,0\pm0,49$		
		8) Магнит	400	6	$1,5\pm0,61$	0,64	0,5
(4)	Наклевывающиеся семена	7) Контроль	200	7	$3,5\pm0,30$		
		8) Магнит	250	9	$3,6\pm0,18$	0,06	0,95
(5)	Проростки	7) Контроль	150	2	$1,3\pm0,93$		
		8) Магнит	250	3	$1,2\pm0,69$	0,08	0,9

Key:
1. Variant
2. Resting seeds
3. Swelling seeds
4. Seeds beginning to sprout
5. Sprouts
6. Influence
7. Control
8. Magnet
9. Anaphases counted
10. Anaphase damage
11. Number

Table 15
Effects of PMF on the Number of Anaphases with Chromosomal Aberrations in Gamma-Irradiated Sprouts

(1) Вариант	(4) Число иссле-дованных анафаз	Анафаз с хромосомными аберрациями (5) (6) число	%	t	P
(2) Контроль	1100	400	$36,4\pm1,4$		
(3) Магнит	1000	488	$48,8\pm1,6$	5,82	0,0002

Key:
1. Variant
2. Control
3. Magnet
4. Number of studied anaphases
5. Anaphases with chromosomal aberrations
6. Number

It follows from the table that the exposure to the field under the experimental conditions increased the number of cells with chromosomal aberrations. This effect was due to the disturbances in the general cellular mechanism of the restoration of potential radiation injuries [148]. It should be noted that no special study of the dynamics of this effect was done in these experiments, and the data of Table 15 characterize only one point of time in the development of the irradiated sprouts, namely, 20 hours after irradiation. Thus, in the experiments on irradiated pea sprouts with the application of a PMF, we obtained a significant change in the radiation injury expressed in the number of cells with chromosomal disturbances.

The next series consisted of experiments on the influence of EMF on radiation
injuries of chromosomes in pea seeds. Seeds were irradiated with a dose of
10,000 roentgens of Co^{60} gamma rays. Immediately after irradiation, part of
the seeds was exposed to a PMF of the described parameters. For this, the
seeds were placed in a Dewar flask within a solenoid coil. The series con-
sisted of three experiments. The first experiment was done on seeds with a
moisture content of 9.3 percent, the second -- with a moisture content of
16.7 percent, and the third -- with a moisture content of 20.3 percent. The
particular moisture content of the seeds was obtained by keeping them in a
desiccator over sulfuric acid. Cells in the first mitosis after irradiation
were studied. The criterion was the absence of micronuclei characteristic
of the stages of the second mitosis. The results of the experiments for the
fixation point 45 hours after the end of the soaking of the seeds are shown
in Table 16. The table reveals, first of all, the dependence of the number
of damaged anaphases on the moisture content of the irradiated seeds. This
dependence has been known in literature [152]. The difference between the
variants (magnetized and nonmagnetized seeds) for each index was statistically
insignificant in all experiments. It is known from literature [152, 229]
that fragments are the most sensitive to additional influences. For a com-
parison, Table 7 shows the data of our experiments on the number of bridges
and fragments for two fixations. The dispersion analysis of the total number
of fragments in the experiments and the fixation points showed that the vari-
ation in the number of fragments between the magnetic and nonmagnetic vari-
ants can be considered incidental (p = 0.5). It should be noted that the
moisture content of the irradiated seeds affects greatly their radiosensitiv-
ity (the yield of chromosomal aberrations), but does not influence the MF
effect (p = 0.5).

Table 16
The Influence of a Pulsed Magnetic Field on the Number of Anaphases
with Chromosomal Aberrations in Irradiated Resting Seeds

(1) № опыта	(2) Вариант	(5) Число анализиро- ванных анафаз	(6) % повреждсн- ных анафаз	(6) % анафаз с мостиками	(7) % анафаз с фрагментами
1	(3) Контроль	350	52,6±2,17	19,4±2,11	45,5±2,66
	(4)Магнит	200	60,5±3,45	19,5±2,80	55,5±3.51
2	(3)Контроль	150	38,7±3,97	24,7±3,52	19,3±3,21
	(4)Магнит	200	47,0±3,52	22,0±2,93	30,5±3,24
3	(3)Контроль	300	11,0±1,81	5,7±1,34	6,3±1,40
	(4)Магнит	200	15,6±2,52	7,6±1,80	9,6±2,02

Key: 1. Number of experiment
    2. Variant
    3. Control
    4. Magnet
    5. Number of analyzed anaphases

6. Percentage of damaged anaphases
7. Percentage of anaphases with bridges
8. Percentages of anaphases with fragments

Table 17
The Influence of a Pulsed Magnetic Field on Various Types of Chromosomal Aberrations in Gamma-Irradiated Pea Seeds

(1) № опыта	(2) Вариант	(5) Фрагментов на 100 клеток		(6) Мостиков на 100 клеток	
		I	II	I	II
1	(3) Контроль	139,5	118,3	27,5	32,0
	(4) Магнит	154,5	208,5	26,5	39,0
2	(3) Контроль	169,5	47,3	38,0	42,7
	(4) Магнит	121,0	69,0	32,5	35,5
3	(3) Контроль	32,0	15,3	15,5	10,3
	(4) Магнит	49,5	18,5	29,0	13,0

Notes: I -- fixation 35 hours after the end of the soaking
of the seeds

II -- fixation of 45 hours after the end of the soaking
of the seeds

Key:

1. Number of experiment
2. Variant
3. Control
4. Magnet
5. Fragments per 100 cells
6. Bridges per 100 cells

The results of the experiments with PMF described above show a clear influence of the field on the sprouts and a total or nearly total absence of effects on the resting seeds. From the resting seed to a sprout, the bud of the seed passes through a number of physiological states which are characterized by physicochemical, colloidal, and other indexes. Approaching this problem in a strictly practical way, it is possible to distinguish four early stages of ontogenesis: the resting of the seeds, swelling, the beginning stage of sprouting, and sprouting. Naturally, the question arises which of the above development stages of the gamma-irradiated seeds will show a substantially noticeable influence of MF on radiation injuries.

Table 18 shows the results of the experiments on the dependence of the effect of PMF on the cytogenetic influence of gamma radiation on the stage of the development of irradiated pea seeds. The effect is manifested only at the very end of the soaking of the seeds and remains unchanged when the field acts upon the seeds beginning to sprout. Table 18 gives the results of anaphase analysis 45 hours after the end of the soaking of the seeds, which corresponds, in time, to the end of the first mitosis. Although some individual cells dividing for the second time after irradiation can be registered.

It is known from radiobiological literature that there exists a regular dynmics of the number of cells with gamma-induced aberrations throughout the first postradiation mitosis [101]. On this basis, we analyzed the number

Therefore, in the experiments on seeds, we obtained a diversified manifestation of changes in the number of chromosomal aberrations in the direction of increase or, on the contrary, of decrease. In the course of the first post-radiation mitosis at the beginning of it we have a larger number of cells with chromosomal aberrations in the magnetic variant in comparison with the control, and a smaller number at the end of mitosis. The first of this manifestations is, probably, observed in the experiments with sprouts. Unfortunately, detailed studies of the time-effect curves on sprouts are difficult because of a great heterogeneity of the phases of mitosis in growing roots.
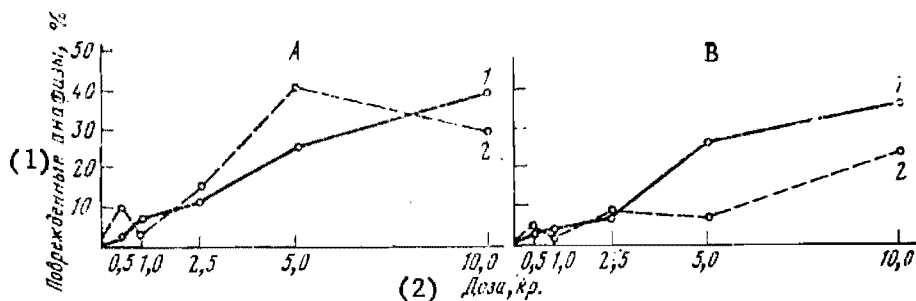

Figure 16. The Influence of a Dose of Preliminary Gamma-Irradiation of Seeds on the Effect of a Magnetic Field.

A -- Fixation 30 hours after magnetizing; B -- Fixation 40 hours after magnetizing; 1 -- Control; 2 -- Magnet
Key:
1. Damaged anaphases
2. Dose, kiloroentgens

In order to study the dependence of the MF effect on the dose of the preliminary gamma irradiation of seeds, experiments were conducted with a CMF of 8 kilo-oersteds. Pea seeds were irradiated on a Co^{60} gamma source with doses of 500, 1,000, 2,500, 5,000, and 10,000 roentgens. Since it is known from the preceding experiments that the total number of cells with chromosomal aberrations changes at different times of fixation after the end of the soaking period (at different times of the first mitosis), two points of time during the first postradiation mitosis were selected in the experiments with different irradiation doses. The results of the experiment for two points of time, namely, 30 and 40 hours after the end of the 24 hour soaking period, are shown in Figure 16. First of all, it can be seen from the figure that a significant effect of the MF of the above intensity shows itself at sufficiently large doses of preliminary gamma irradiation. In our case these doses were 5 and 10 kiloroentgens. Then, there was a clear manifestation of the effect described above, when during the earlier part of the first mitosis we observed an increase in the number of cells with chromosomal aberrations in the magnetic variant in comparison with the control, and a decrease in their number at a later period (in our case, 40 hours after the end of soaking).

The following conclusions can be made on the basis of the experiments on the effects of EMF on radiation-induced chromosomal aberrations in the meristematic tissues of peas. EMF influence the yield of chromosomal aberrations induced by gamma radiation in the meristematic cells of the ends of pea roots. The MF effect is manifested only when the field is applied since the stage of the end of the soaking of the irradiated seeds and depends on the dose of the preliminary gamma irradiation of the seeds in such a way that the effect becomes significant only when the seeds are irradiated with a sufficiently large dose (in our case, beginning with 5 kiloroentgens). Then, the effect is not uniform in the course of the first mitosis, which means that MF affect the restoration rate of the primary potential injuries of chromosomes. The obtained results confirm the conclusion that EMF are weak biological stimulants.

Under the effect of an AMF of 200 oersteds, 50 hertz, and 6.5-hour exposure, there were microscopically clear signs of disturbances in the hemodynamics and a weakly expressed hemorrhage in the lungs and on serous membranes. Testicular edema, as well as the phenomena of emphysema in the lungs, were observed constantly.

Microscopic studies yielded a picture of universal disturbances in the blood and lymph circulation, which was expressed in spastic contractions of some arteries, and, on the contrary, paretic dilatation of the capillary network, veins, and lymph vessels with signs of stasis.

Comparison of all morphological changes in this relatively short period of the AMF influence made it possible to reveal that the "shock" organs were the testes, which had a striking variety of changes. Along with normal tubules, there were always many tubules filled by detritus from decomposed cells or with sharply discomplexed epithelium. There was a clear and regular picture of the death of differentiated cellular elements particularly spermatozoa. Cytological analysis of the dying spermatogenic ephthelium and spermatozoa revealed combined changes in the cytoplasm in the form of signs of disturbances in the water metabolism (vacuolization) with various morphological manifestations of nuclear necrobiosis. Spermatozoa suffered various stages of swelling of the heads, as far as the formation of club-shaped figures described earlier for radiation sickness.

Of particular interest was the appearance of multinuclear cells originating from the epithelium of the tubules (Figure 17).
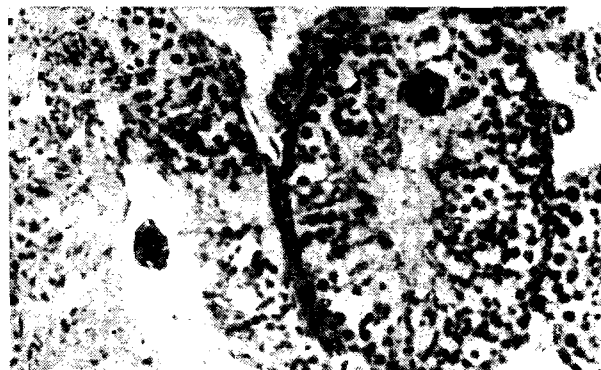

Figure 17. A Testis 24-Hours after the Exposure to an EMF. Discomplexing of spermatogenic epithelium;giant cells. Hematoxylin-eosin. 20 x 7.

Ovaries were found to be less sensitive than testes. However, necrobiological processes were also found in them, both in the follicular epithelium and in the ova, with various degrees of manifestation.

Histochemical studies of nucleic acids -- DNA and RNA -- in the epithelium of the testis tubules showed a complete correspondence in the degree of lack of nucleic acids with the manifestation of necrobiotic changes in the cells. This picture was in contrast with the preserved epithelium, where the amount and distribution of nucleic acid was as usual.

The central nervous system was also not intact. In some gangliar cells of subcortical nodes and in the cornua of the spinal cord, it was possible to observe the swelling and vacuolization of the nuclei and cytoplasm, down to the formation of "shadow cells."

Changes in the lungs were characterized by the presence of emphysema and distelectasis. They appeared rapidly and remained present for a long period of time. Sometimes there appeared small hemorrhages in the lungs, and it was possible to detect prismatic crystals of hemoglobinogenic nature in those areas. The enrichment of the lung tissues by light substances of mucopolysaccharide nature and almost total loss of the tinctorial properties of the argyrophilic substance deserve attention.

As for other organs, we should mention weak destructive changes in the epithelium of the tubules of the kidneys and liver, hyperplasia of lymph nodes and enrichment of the bone marrow by eosinophils.

Changes in the organs of sight were characterized by vacuolization of the cytoplasm of the epithelium and the endothelium of the cornea, hyperchromatosis of the epithelial nuclei, edema of the stroma with the separation into fibers and swelling of its lamellas. Along with this, we found edema of the ciliary body stroma, and hyperemia in the iris and the choroid. In the crystalline lens, there were hydropic changes in the cytoplasm of the epithelium in the area of the front pole. We observed chromatolysis and swelling of the nuclei in the cells of the germinal epithelium, the appearance of fissure-like structureless formations and vacuoles in its cortical fibers.

In the retina, in ganglion cells, we discovered swelling of the nuclei, chromatolysis, decrease in the Nissl substance, in some cells coarsening of the tigroid represented in the form of grains; isolated "shadow cells" were present.

Histochemical studies on nucleic acids revealed a lack of RNA content in the ganglion cells of the retina, particularly where there were signs of necrobiosis after usual staining in the first two weeks after the exposure, with a gradual restoration of RNA by the 30th day. Swelling of the interstitial substance of the retina was discovered by Foot's argentation method. There were clear accumulations of acid mucopolysaccharides in the stroma of the cornea, particulary in the location of edema (Figure 18).

The dynamic aspect of studies in this series showed that morphological changes in the organs were still preserved after 2-4-7 days. Signs of neuronophagia appeared in the central vervous system. Changes in the kidneys and the

crystalline lenses became clearer. In the kidneys, macroscopically anemic sections appeared, and microscopic studies revealed a more widespread necrobiosis of the epithelium, its desquamation and the formation of peculiar cylinders forming from the fragments of the cell cytoplasm. In the crystalline lens, the fissure-like formations in the area of the front pole enlarged in size considerably, and in some instances had a shape of large ovals. The vacuolization in the cortical fibers of the crystalline lens was preserved and was visible in large areas. During these days, for the first time and only in one instance, we discovered transudate in the eye in a small section between choroid and the retina.

By the 30th day of observation, there were almost no signs of damage except the coarsening of the argyrophil substance in the lungs.
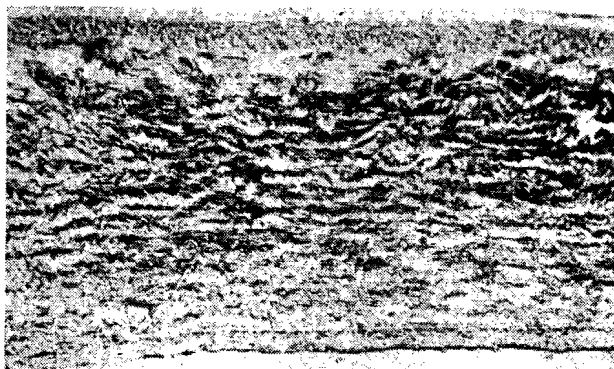

Figure 18. Cornea Seven Days after the Exposure to an Alternating EMF. Accumulation of acid mucopolysaccharide in the stroma of the cornea. Stained by Hale's method. 20 x 7.

Under the influence of a single 24-hour action of an AMF of 200 oersteds and 50 hertz, changes in the organs and tissues were qualitatively of the same nature but were more widespread. The appearance of multinuclear giant cells in the epithelium of the crystalline lens was an interesting peculiarity. Optic nerve edema was discovered in individual guinea pigs.

Repeated action of the AMF (50 hertz, 200 oersteds) daily in the course of 24 days with exposures of 6.5 hours and studying four hours after the last exposure showed that the macroscopic picture was analogous to the short exposures to the AMF. The clearest microscopic changes were found in the kidneys, testes, liver, and lungs, and they were less expressed in other organs.

In the kidneys, expressed disturbances in the blood and lymph circulation were combined with clear changes in the epithelial part of the nephron which gradually attenuated in the straight tubules and the collecting tubules.

Changes in the testes were also localized in the zone of differentiated cells and were of the same qualitative nature, but were more widespread.

In the liver, a pecular destruction of the cytoplasm was observed and, as histological studies showed, this was due to the disappearance of fat, as well as of acid and basic proteins.

In the lungs, the picture repeated the changes of the preceding observations, but in the testes and other organs there were differences only in the quantitative aspects. It should be noted that the signs of disturbances in the lymph and blood circulation were respresented clearer than in the experiment with a single 6.5-hour exposure.

Changes in the eyes, basically, remain the same, but transudate was found more frequently between the choroid and the retina, and the processes of necrobiosis in the ganglion cells of the retina were expressed more. Argentation by Foot's method revealed the weakening of the argyrophil properties of the intersitial substance of the retina, perivascular tissues of the retrobulbar space and ciliary body. Along with this, clear accumulation of acid micropolysaccharides at the areas of edema was observed.

Morphological Changes in the Organs and Tissues of Guinea Pigs Induced by CMF

Under the effect of a CMF of 200 oersteds with exposure time of 6.5 hours, morphological changes in the structural elements of organs and tissues were, basically, of the same nature but less expressed, and the restoration processes developed earlier.

This series of experiments was characterized by the appearance of basophilia of the back layers of the cornea which continued for rather long period of time. Histochemical studies revealed clear accumulation of acid mucopolysaccharides in these areas.

The group of young guinea pigs in which the affection of the epithelium of the testes was expressed very sharply deserves attention. This group revealed an almost total devastation of all tubules with the appearance of a large number of multinuclear cells, and there were no signs of regeneration during the studied period.

Changes occurring in the organs and tissues under the effect of a CMF of 200 oersteds with single 24-hour exposure and after exposures of 6.5 hours for 24 days were of the same type with the analogous groups of AMF of 200 oersteds, 50 hertz, but their degree of expression was considerably lower. The eyes in the last series (24 days, 6.5 hours daily) again showed the presence of multinuclear cells in the epithelium of the crystalline lens (Figure 19).

A CMF of 7,000 oersteds with the exposure length of 6.5 hours caused, after 24 hours, changes whose macroscopic and microscopic picture was also identical

to the picture described during this period for an AMF of 200 oersteds, 50 hertz, and 6.5 hour exposure.

Figure 19. Crystalline Lens on the 24th Day of Exposure to a Constant EMF of 200 Oersteds. A multinuclear giant cell in the epithelium of the crystalline lens. Hematoxylin-eosin. 40 x 7.

The effect of a CMF of 7,000 oersteds in the course of 500 hours (12 hours daily for 42 days) was characterized by clearly expressed disturbances in the hemodynamics and lymph circulation. We constantly encountered plethora of the viscera, hemorrhages in the lungs and edema which was more expressed in the testes. Particularly clear changes were observed in the testes, which were striking not only because of the variety of the morphological pictures but also because they were strongly expressed and widespread. Most of the tubules were damaged and their lumens were filled with cellular detritus. An interesting peculiarity of this group of experiments were giant cells lying amidst the detritus and sometimes in the tubules with the preserved epithelium and in the tubules of epididymides (Figure 20). The amount of spermatozoa either decreased sharply, and in this case they are characterized by swelling of the heads, or it was not possible to detect them at all.

In the spleen, against the background of general intactness of the structure of the organ and a moderate hemosiderosis, in all instances, there was a striking increase in the follicles due to the accumulation in their peripheral sections of a slightly oxyphil mass replacing cellular elements sometimes down to their total disappearance (Figure 21). With the usual methods of staining, this substance resembled an amyloid, but none of the reactions known to us yielded a clear positive result. The lymph nodes and bone marrow were hyperplastic, and the bone marrow was strikingly rich in eosinophils.

In this group of experiments, we also revealed some changes in the suprarenal glands, where atypical patterns of mitosis (Figure 22) and very rare microsections with signs of necrobiosis occurred sometimes in the cortex cells. In the medulla, a picture of perivascular edema and lysis of the nuclei of individual cells was observed. In the eyes, the greatest changes, just as in the preceding series, showed themselves in the crystalline lens. Just as before, they were characterized by hydropic changes in the epithelial cytoplasm in the area of the front pole, and the appearance of fissure-like structure-less formations. Moreover, there were destruction foci in the substance of the crystalline lens sometimes with the formation of flakes and lumps which took staining weakly. Similar changes were found after 24 hour exposures to AMF. The detected changes also showed themselves against the background of clear histochemical shifts. But still they were less expressed than under the effect of AMF, in spite of a higher intensity of the CMF, which was 7,000 oersteds, and continuous and long exposure of animals to it.
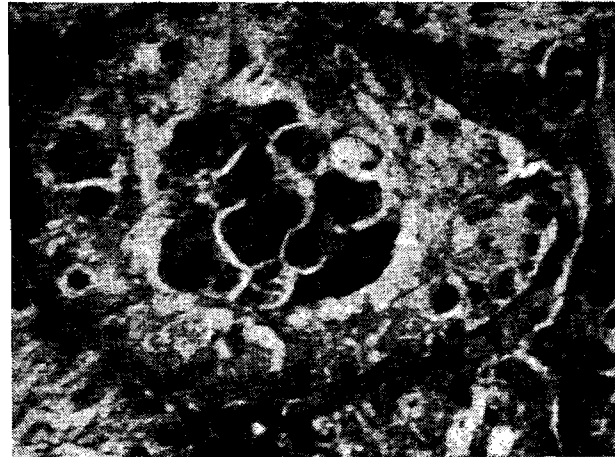

Figure 20. A Testis on the 42nd Day of Exposure to a Constant Magnetic Field of 7,000 oersteds. Necrobiosis of spermatogenic epithelium. Multinuclear giant cells. Hematoxylin-eosin. 40 x 10.

In our studies on the peculiarities of the biological effects of PMF, we also used a horseshoe electromagnet with a high degree of uniformity of the field in the gap between the poles whose intensity was changed sinusoidally, and was, at the maximum, 1,200 oersteds with a frequency of 5 pulses a minute. The length of each pulse was 84 milliseconds.

At 6.5-hour stay of the animals in the gap between the poles, the total exposure to the PMF was only 2.73 minutes, however, morphological changes in the organs 24 hours after the termination of exposure, in their nature and expression, in 80 percent of the animals were close to those after 6.5-hour
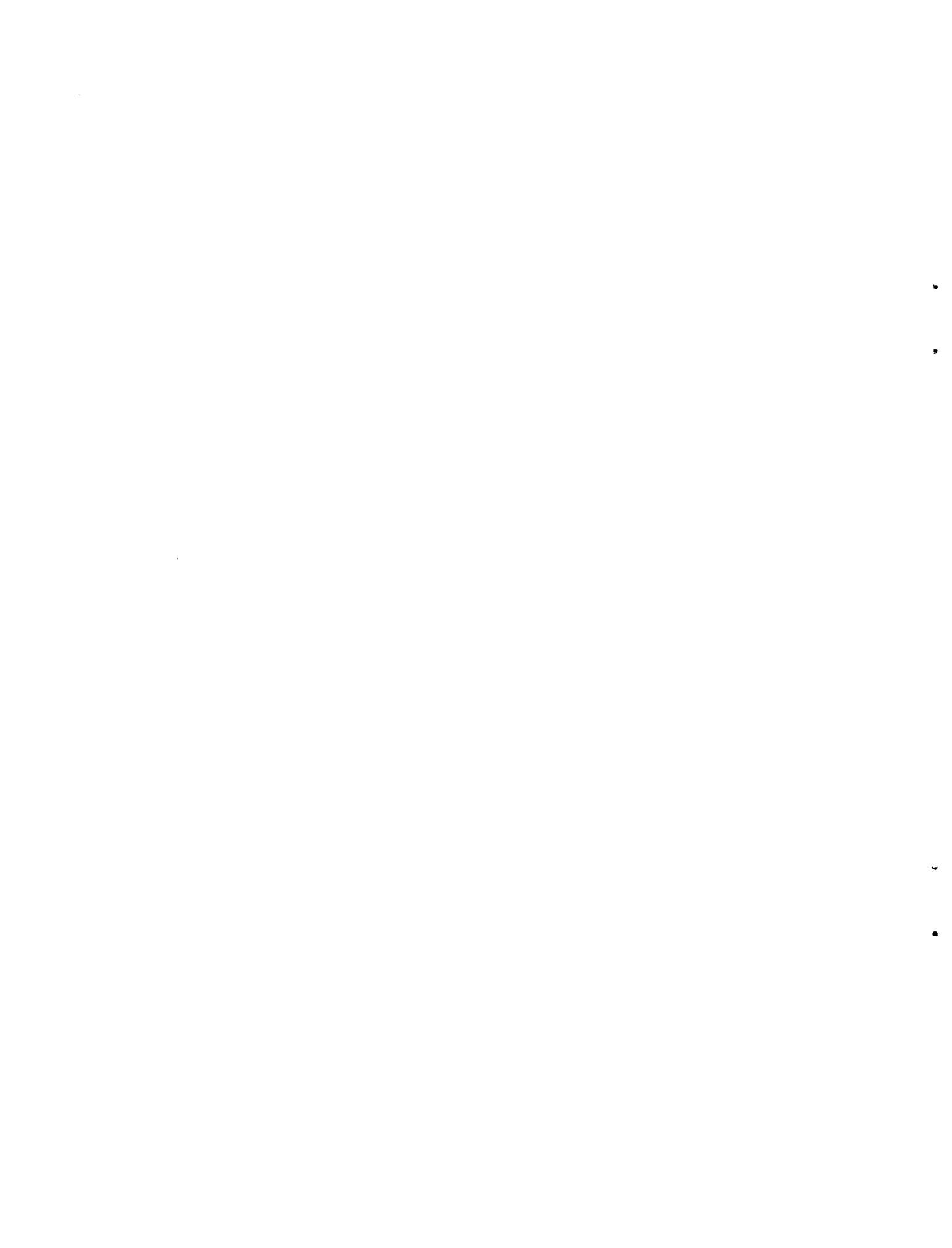
single exposure to an AMF of 200 oersteds, 50 hertz, and only in 20 percent of the animals these changes were more expressed.
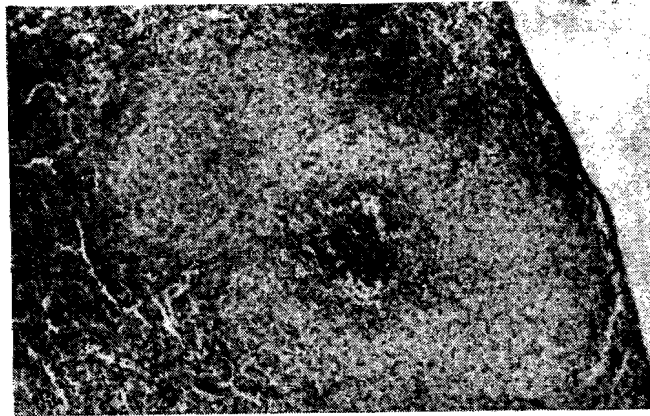
Figure 21. The Spleen on the 42nd Day of Exposure to a CMF of 7,000 Oersteds. Disappearance of lymphoid elements and accumulation of an amorphous mass along the periphery of the follicle. Hematoxylin-eosin. 9 x 10.
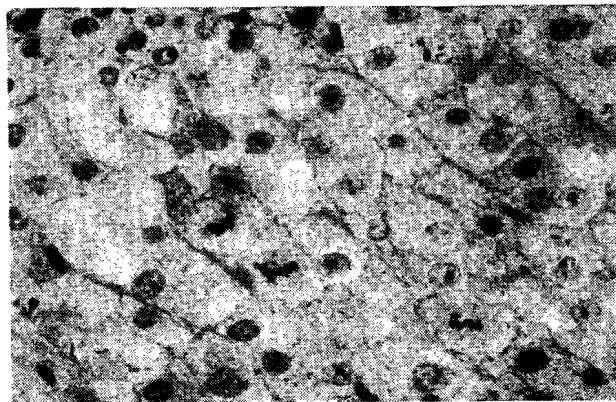
Figure 22. A Suprarenal Gland on the 42nd Day of Exposure to a CMF of 7000 Oersteds. Atypical patterns of mitosis in the adrenal cortex. Hematoxylin-eosin. 40 x 10.

The above observations indicate that the pathological changes developing under the conditions of the tested intensities of magnetic field in a number of organs and systems are not of a catastrophic nature. These changes build up during the first 24 hours and progress much slower as the exposure time gets longer. When the action of the magnetic field is stopped, there appears

a tendency toward the normalization of structures. However, this factor is far from being "harmless," particularly for certain organs and systems, and primarily for gonads.

The obtained experimental data showed convincingly that PMF, CMF, and AMF of the tested intensities had an expressed biological effectiveness. The biological effectiveness of AMF and PMF was higher than that of CMF.

Comparison of all morphological changes in the organs and tissues revealed the highest sensitivity of male gonads to the action of magnetic fields.

Magnetic fields have a disturbing effect on mitosis, as a result of which there appear giant multinuclear cells in a number of organs (testes, liver, kidney, suprarenal glands, and the epithelium of the crystalline lens).

The combination of the morphological charges caused by magnetic fields under the conditions of the entire organism makes it possible to speak of the specificity of the pathologoanatomic picture.

Studies of the morphological changes in their dynamics revealed a marked tendency toward normalization of the disturbed structures in the organs and tissues after the termination of the MP action.

MAGNETIC FIELDS, INFECTION, AND IMMUNITY

[N. V. Vasil'yev, I. B. Shternberg, and L. F. Boginich, Tomsk State Medical Institute, Tomsk]

One of the aspects of magnetobiology is the problem of the influence of MF on the reactivity of the organism, particularly on its immunity mechanisms.

Studies in this area were started only about eight years ago. At the present time there are about 20 publications on this subject, and a considerable part of them is based on the studies carried out in the Tomsk Medical Institute, Tomsk Scientific Research Institute of Vaccines and Serums, and the Tomsk Scientific Research Institute of Nuclear Physics, Automation, and Telemechanics of the Tomsk Polytechnic Institute.

There is a need to sum up the preliminary results of this work and to determine the most promising directions of work for the future.

Magnetic Field Effects on the Infectious Process

There is some published information on the effects of magnetic fields on infectious processes caused by bacteria, protozoans, and viruses.

Odintsov [49, 139, 140, 141] studied the effects of this factor on the progress of experimental listeriosis. The experiments were conducted on 1200 white mice and 15 guinea pigs placed in an AMF of 200 oersteds and a frequency of 50 hertz. He tested a single field effect (exposure -- 6.5 hours) and a continuous exposure in the course of 15 days. The animals were studied for LD_{50}, the distribution of the microbes in the organism, the amount of leukocytes and their phagocytal activity, and changes in the white blood and in the titer of agglutinins. The animals were infected after the influence of the magnetic field.

Immediately after the stay of the animals in the MF, there was a relative increase in the number of segmentonuclear neutrophils (without nuclear shifts) and monocytes, and a decrease in the percentage of lymphocytes. No changes were discovered in other indexes.

After a long exposure, the LD50 for the experimental mice decreased by 50 times and was 81,000 microbe cells against 422,000 for the control animals. There was no difference in the yield of Listeria in the experimental and control groups in the first two days after infection, but on the third day, the infestation of the organs in the animals exposed to the field was more than twice as high.

The PhAL (phagocytal activity of leukocytes), which was determined immediately after MF action but before infecting, was three times lower than in the control groups. It remained low (2.5 times) for 18 days after the animals had been infected. The amount of leukocytes after the chronic influence was 76.5 percent of the initial amount.

Morphological studies on blood which were conducted immediately after the exposure to the MF (but before infecting) showed slight neutrophilesis, monocytosis and lymphopenia. During the first 24 hours after the infection, the amount of segmentonuclear neutrophils and lymphocytes increased, and remained the same throughout the infection in comparison with the indexes of the control group. But the amount of monocytes, after some decrease during the first 24 hours, was increasing and stayed at a considerably higher level than in the control for 6 days.

The titer of the agglutinins of the experimental mice increased extremely insignificantly throughout the observation period, and differed from the control group by four times at its maximum.

Thus, Odintsov showed that the infectious process caused by the bacterial agent was aggravated under the effect of prolonged exposure to an AMF. It was also established that some mechanisms of the congenital and acquired immunity change under these conditions.

An analogous result was obtained by Vasil'yev, et al, [41], who worked with an experimental viral infection (acarid-bite encephalitis). In this case, preimmunized animals were infected.

The experiment was done on white mice (1,000 animals) which were immunized with an antiencephalitis vaccine three times at 2-3 days intervals. Fourteen days after the last injection of the antigen, the active virus was introduced into the animals. The survival rate was registered on the 15th day after the experiment. The animals were exposed to an AMF (200 oersteds, 50 hertz) before the first or second or third immunization, or, finally, daily through the vaccination period. Apart from the AMF, in some series of experiments a CMF of 7,000 oersteds was used.

The results of the experiments can be seen in Table 21.

Table 21
Effects of AMF and CMF on the Resistance of White Mice to the Virus of Acarid-Bite Encephalitis and on the Antibody Production in them

(1) Вид воздействия	(8) Группа	(11) Резистентность		(12) Реакция нейтрализации		(13) РСК	(14) РТГА
		(9) опыт	(10) контроль	(9) опыт	(10) контроль		
(2) Переменное магнитное поле							
(3) Перед 1-м введ.	(9) Опыт	1,6	8,0	5,9	7,8	1:6	1:10
	(10) Контроль	1,8	8,0	6,3	7,8	1:16	1:20
(4) Перед 2-м введ.	(9) Опыт	1,0	7,7	6,2	7,5	1:4	1:40
	(10) Контроль	1,3	7,6	6,7	7,5	1:20	1:40
(5) Перед 3-м введ.	(9) Опыт	2,2	7,6	6,7	7,5	0	1:60
	(10) Контроль	1,3	7,6	6,7	7,5	1:32	1:70
(6) Длительное воздействие	(9) Опыт	2,5	8,2	6,2	8,0	1:5	—
	(10) Контроль	2,1	8,2	5,5	8,0	1:16	—
(7) Постоянное магнитное поле	(9) Опыт	2,0	7,0	7,0	8,0	1:8	1:160
	(10) Контроль	1,0	7,0	6,4	8,0	1:16	1:160

Note: The table shows negative indexes of LD_{50} 0.03 ml.

Key:

1. Types of influence
2. Alternating magnetic field
3. Before first introduction
4. Before second introduction
5. Before third introduction
6. Prolonged action
7. Constant magnetic field
8. Group
9. Experiment
10. Control
11. Resistance
12. Neutralization reaction
13. Complement-fixation reaction
14. Hemagglutination inhibition test

It was shown that the application of an MF during the immunization period sharply inhibited the resistance of the animals to the subsequent infection with the virus of acarid-bite encephalitis. This can be seen by the resistance index, the virus neutralization reaction, and by the antibody titer in the complement-fixation reaction. The antibodies revealed in the hemagglutination-inhibition test were found relatively intact under the experimental conditions but this type of antibodies behave abnormally not only in this case, but also against the background of many other experimental influences.

Thus, we have a fundamental coincidence of the data obtained on a model of infections completely different in their pathogenesis. At the same time, these data are quite comparable: the same experimental setup was used to generate an MF, and the same species of animals was used in the experiments.

Unfortunately, studies on the third type of infection were done by a different method, and, therefore, the interpretation of the obtained data (and they were substantially different) was difficult.

This refers to the work [371], where the causative agent was Trypanasoma equiperdum, i.e., a microbe from the class of flagellates (protozoa type). The experiments were in two variants. In the first variant, the animals were exposed to an MF of 600 oersteds for seven days before infection. In this case, the experimental mice died earlier than the control ones. On the contrary, the same factor after the infection had a favorable therapeutic effect: by the fifth day of the experiment, all mice in the control group died, while more than 80 percent of the "magnetized" mice survived beyond this period. All animals which were completely free from parasites after the irradiation produced a specific immunity later.

Thus, a prolonged exposure to a strong MF, as a rule, aggravates the course of bacterial, viral, and probably, protozoal infections. This effect is, most probably, connected with the lowering of the immunobiological reactivity of the organism both in its specific and nonspecific aspects.

However, in some instances, MF was capable of causing an opposite effect. Later, we shall see that this refers not only to the infection process, but also to the phenomena of immunity which are closely connected with it. This is a complex problem because we are dealing with the interaction of two stimulants -- specific (causative agent) and nonspecific (MF). The final result depends on many conditions, including the temporal interrelations of both factors.

MF and Factors of Natural Immunity

The effects of MF on the PhAL in vitro and in vivo are treated in a number of works, but it is difficult to classify their results because of the different methods used.

M.P. and O. Ye. Savchuk [169] used a CMF of 2,000 oersteds, PMF of 5,000 oersteds (pulse length -- 10 milliseconds), and a field of ultrasonic frequency (60 megahertz). All these factors inhibited the PhAL in the test tube.

In the experiments by Tomus, et al [398], blood specimens of dogs were placed in an ultra-incubator situated between the poles of an electromagnet (MF intensity -- 700 oersteds, exposure -- 30 minutes). Under these conditions the PhAL was stimulated by 71.8 percent, and the increase was expressed more when the PhAL in the control was lower, and vice versa. The exposure of the blood to the MF for 30 minutes before the addition of the microbes did not produce this effect. The authors believe that the activation of phagocytosis by an MF has a complex mechanism because this physical factor does not influence many components necessary for the realization of the phagocytal act.

Tkachenko et al [49] experimented with the blood of white mice and rabbits immunized against anthrax in the state of radiation sickness.

Test tubes with a mixture of blood and a vaccine strain of bacilli anthracis were placed for 30 minutes in an incubator under the effect of the north and south poles of a CMF. Apart from this microbe, staphylococcus was used. In some series of experiments, a high-frequency (30 megahertz) AMF was applied. It was shown that the MF inhibited phagocytosis, particularly near the north pole of the magnet.

On the basis of these data, it is possible to make only one conclusion: MF with various characteristics produce a clear effect on phagocytosis in vitro. It is impossible to give more details on the directivity of this influence and on the conditions of its realization because of the limited factual material.

The results of observations conducted in vivo are more definite.

Sherstneva [244, 245] reports on an increase in the PhAL in rabbits exposed to MF. Similar data were obtained by M. P. and O. Ye. Savchuk [169]. The authors immunized rabbits with brucellosis vaccine three times. After each injection, the animals were exposed to a PMF of about 5,000 oersteds with a pulse length of 10 milliseconds for 5-15 minutes (length of experiment -- 4-5 days). On the 7th-8th day after each injection of the vaccine, they studied the PhAL for brucellae and staphylococci. The ultrasonic frequency field (60 megahertz) with an exposure of up to 10 minutes also caused an increase in the phagocytal index by 2-3 times. A CMF of 2,000 oersteds also stimulated the PhAL.

Stimulation of PhAL by CMF was also observed by Sapegina [180].

This problem was also studied by Tkachenko and Padalka [49, 198, 199]. The purpose of their work was to study the effects of an EMF with a frequency of 2,000 megahertz on the luminescence and phagocytosis of leukocytes in the blood of white mice immunized with an antianthrax vaccine STI [expansion unknown]. The animals (white mice) were in the field of action of an ultra-high-frequency generator of 500 watts for 7, 49, 210, or 1260 hours. It was established that the influence of ultrahigh-frequency EMF in the course of 1, 7, and 30 days increased the phagocytosis activity in the first studies after the completion of the experiment, and a longer exposure led to opposite results.

The weak point of the cited works is the absence of information regarding the completion of phagocytosis, without which it is possible to judge the MF effect only on the initial stages of the phagocytal act.

In recent years, PhAL and the completion of phagocytosis under the effect of a MF was studied by one of us [23,24]. The experiments were done on white rats which were placed in an AMF of 200 oersteds and frequency of 50 hertz

for 24, 168, and 336 hours. PhAL was determined by the generally accepted methods, and the completion of phagocytosis -- by the Berman and Slavskaya method. The object of study was a listeria culture. The obtained data are shown in Table 22.

Table 22

Effects of an AMF on the Phagocytal Activity of Leukocytes
and on   Completion of Phagocytosis

(1) Экспози-ция, сут.	(2) ФАЛ		Перенаривающая способность (5)	
	(3) опыт	(4) контроль	(3) опыт	(4) контроль
2	22,57	19,0	28,16	29,0
5	8,4	9,3	21,4	16,7
7	25,0	24,0	19,4	26,7
14	25,0	25,0	—	—

Key: 1. Exposure, days   4. Control
      2. PhAL   5. Digestive ability
      3. Experiment

It can be seen from the table that no clear difference was revealed under the experimental conditions between the indexes of the experimental and control groups.

All that has been said above characterized the effects of MF on the PhAL of the peripheral blood.

The data on the influence of this factor on the activity of the macrophagic system of the organism are contained in the works by Sokolova et al [183] and Lantsman [49].

Some of the experiments were done on white mice placed for 7 hours in an AMF (200 oersteds, 50 hertz). Twenty-four hours after this, they were given a solution of trypan blue intraperitoneally. After 48 hours, the intensity of the staining of the organs and tissues was approximately the same as in the control. Observations during later periods (4 and 8 hours) revealed that the color of tissues of the experimental mice remained the same, but became much paler in the control mice. In the experimental animals, the amount and dimensions of Kupffer cells increased noticeably after 48 hours. Most of them contained numerous large grains of stain. These phenomena were expressed much weaker in the control mice. The picture was stable for the experimental mice 4 and 8 days after the injection, but the stain content decreased in the control. The contrast was particularly great on the 8th day of the experiment.

The authors believed that this indicated an increase in the phagocytal activity of the cells of the RES (reticulo-endothelial system) of the liver. However, along with this, there developed a state of prolonged blocking of the RES.

Further studies in this area [49] indicated that the nature of the MF effects on the RES macrophages depended on the length of exposure. If mice were exposed to an AMF with the above characteristics for 32 hours (4 days, 8 hours daily), there was a deep inhibition of the phagocytal function of the RES of the liver, spleen, lungs, bone marrow, and lymphocytes. These phanomena were combined with a delay in the elimination of the stain.

On the whole, this gives an impression that moderate "doses" of MF activate the macrophagic system, and large ones inhibit it. In this respect, the MF influence resembles effects caused by any other nonspecific stimulant. The material is still insufficient to judge the state of the macrophagic system.

The problem of the effects of MF on the factors of the congenital humoral immunity has been studied even less. In a series of experiments [24-27] we attempted to follow up the influence of this factor on the titers of the complement, properdin, lysozyme, normal antibodies, as well as on the overall hemolytic activity of the blood serum. Properdin was determined by Ioffe's method modified by Yakovleva and Komleva, lysozyme -- by Yermol'yeva's method or Vasil'yev's method [37], and other indexes -- by studying a seragram [38].

Exploratory experiments were done on rabbits exposed one time for 7 hours to a CMF of 2,000 oersteds. Immunity indexes were studied for 7 days after the exposure. No substantial changes were found in them. Further experiments were done on white rats (89 animals). The animals were divided into 2 groups: the experimental group and the control group. The first group was exposed to an AMF (200 oersteds, 50 hertz) in the course of 2 weeks. The second group was under the same conditions, but was not exposed to the MF. The indexes were determined on the 7th and 14th days of the experiment

It was revealed that a one-week exposure to the AMF did not have any substantial effect on properdin titer, but caused statistically certain stimulation of the lysozyme activity and some inhibition of the complementary properties. By the end of the 2nd week of the experiment, these changes were normalized.

This material shows that the MF influence is not indifferent for the factors of natural humoral immunity. The high effectiveness of the 7-day exposure is, probably, explained by the adaptation of the animals to the MF which develops by the end of the second week. So far it is difficult to say anything definite regarding the mechanism of the shifts on the part of the factors of specific immunity. It seems probable to us that an important role here is played by the hypophyseal-epinephral system, and it is not ruled out that an MF is a stress factor in this case.

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Effects of MF on Antibody Formation and on the Immuno-Morphological Processes

There are few works on the influence of MF on the formation of specific immunity.

The above-mentioned article by M. P. and O. Ye. Savshuk [269] noted an increased titer of antibodies in rabbits immunized with a brucellosis vaccine under the effect of MF. A large series of experiments was done by a group of members of the university in Yassy under the direction of P. Zhitaryu. They established that a low-intensity MF (100 oersteds), when applied daily for 15 days, 3 minutes a day, stimulated the production of antibodies to sheep corpuscles, to proteus OX$_{19}$, and to tetanus toxoid in rabbits and guinea pigs [337-339]. However, such effects were not observed by all researchers. On the contrary, Gross [287], for example, observed a considerable inhibition of antibody formation in strain white mice immunized with sheep corpuscles and placed in a CMF of 4,000 oersteds. The effect was not revealed after immunization with some other antigens (ovalbumin, ox serum albumin). Similar data are contained in another work by Gross [320] in which Ehrlich's carcinoma cells were used as an antigen.

In our work published earlier [42], we made it our goal to study the influence of an AMF (200 oersteds, 50 hertz) after a single 6-7 hour exposure on the formation of antibodies to sheep corpuscles in mice. The experiment was set up in such a way that the moment of the field influence with respect to immunization varied in different experiments. Moreover, in some series, the exposure was long -- 7-14 days. The antibody titer was determined on the 7th and 14th day after the initial immunization. The main data of these experiments are given in Table 23.

Table 23

Dependence of the Effects of AMF and CMF on the Production of Antibodies on the Exposure Time with Reference to Immunization

(1) Характер чередования иммунизации (И), воздействия МП (М) и кровопускания (К). Цифрами отмечены сутки	(2) ПеМП		(5) ПМП БТВ %
	(3) БЭР %	(4) БТВ %	
М 7 И 7 К	95	178	98
М 3 И 7 К	—	53,6	237
М И 7 К	70	73,4	43
М 7 И 7 И 7 К	103	130	98
И 2 М 5 К	195	93,3	—
И 3 М 4 К	140	167	325
И 2 М 5 И 7 К	170	112	—
И 7 М И 7 К	95	29	72
И 7 И 3 М 4 К	90	104	128

Note:—P < 0.05; ---0.1 > P > 0.05.

Key: 1. Nature of immunization alternation (И), action of MF (M) and bloodletting (K). The numbers stand for days.
2. AMF
3. Sheep corpuscles
4. Typhoid vaccine
5. CMF -- typhoid vaccine

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It follows from the materials presented in this work that: 1) MF with various characteristics but high intensities, if applied directly before immunization, will, as a rule, hinder the formation of antibodies to a certain degree (although this tendency is not statistically certain); 2) the same factor applied in an early period of immunization (2nd-3rd day after the initial introduction) stimulates this process noticeably; 3) late stages of antibody production are relatively magnetoresistant.

Therefore, there is a certain analogy with what takes place under the effect of ionizing radiation. The difference is that radiation, being applied in the inductive phase of immunogenesis, as a rule, hinders the production of antibodies.

Let us add that a long exposure of immunized animals to an AMF stimulates the formation of antibodies. For example, mice immunized with a typhoid vaccine which were exposed to an AMF for 14 days since the moment of immunization had an antibody titer 166 percent higher than in the control group ($P < 0.001$). The CMF was a less active factor than the AMF.

We encountered another phenomenon at this stage of work. With some schemes of experiments, although the MF had an effect, the directivity of the effect differed in different series. This was a basis to assume that MF bring about effects which are difficult to class as "stimulation" or "inhibition." It seemed probable that, at least in some experimental situations, there occur some changes in the dynamics of antibody formation. In other words, the antibody production may be hindered at some stages, and may be activated at some others. If we assume that this variant is real, it will be obvious that it is difficult to study these changes in detail merely by taking blood on the 7th and 14th days.

In this connection, the experiments were continued according to the following scheme. Just as in the preceding experiments, the antigen (sheep corpuscles) was introduced intraperitoneally to white mice twice with a one week interval. But the determinations of the antibody titer, as well as of the number of the antibody-forming cells by Ierne's method and the spleen cytogram, were done daily throughout the experiment -- for 14 days.

In the first experiment, the AMF was applied 1.5 hours before the initial immunization. Here, during the entire observation period, the number of antibody-forming cells in the spleens of the experimental animals was considerably lower than in the control. For example, on the 4th day, this number in the experiment was only 9.5 percent of the control. The antibody titer of these animals was also considerably lower throughout the experiment, sometimes being only 12.5 percent of the control (Figure 23).

In the second series of observations, the exposure to the AMF was on the 3rd day after immunization. Here, the picture was more complicated. At first, the antibody titer of the experimental animals was lower than in the control. This continued up to the 10th day (3rd day after the second immunization). On the 5th day after the first stimulus, the antibody titer of

the experimental mice was 33 percent of the control, and on the 3rd day after
the second immunization it was 57 percent. But starting with 11th day, the
ratio changed substantially, and the titer of the experimental group became
higher than that of the control group. By the 7th day after the second im-
munization this increase reached 225 percent.

In the third variant, the animals were exposed to the MF 7 days before the
first injection of the antigen. Here, starting with the 4th day after the
immunization, the antigen titer started exceeding the level of the control
animals. The maximum difference was on the 4th day after the reimmunization,
when the antibody titer in the experimental group was 540 percent of the
control.
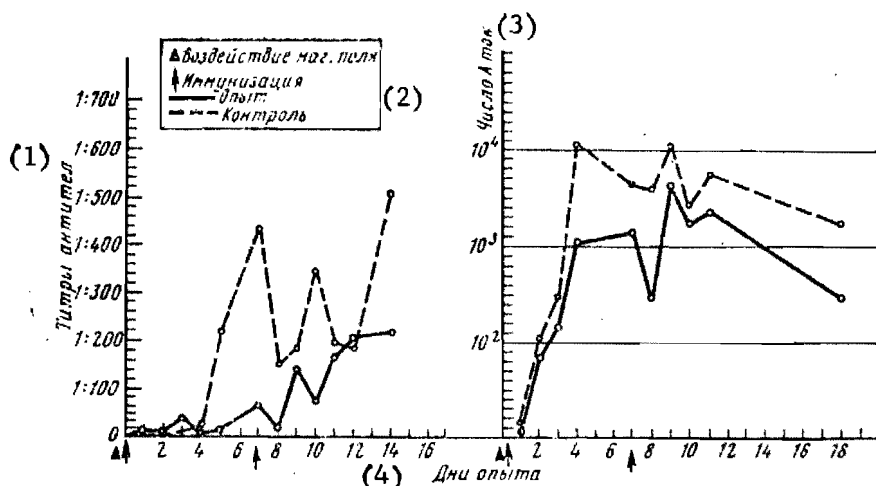
Figure 23. Influence of an AMF on the Antibody Titer and
the Number of Antibody-Forming Cells in White Mice after Two
Introductions of Sheep Corpuscles.
Key:
    1. Titers of antibodies
    2.   MF action
        Immunization
    —— Experiment
    --- Control
    3. Number of antibody forming cells
    4. Days of experiment

As we can see, these experiments revealed an important fact: the initial
assumption regarding the inadequacy of the schemes usually used in the ex-
periments for a detailed analysis of the dynamics of antibody formation
under the conditions of additional influences on the organism was fully
confirmed. In fact, the stimulation of antibody formation which is observed
under the effect of a magnetic field on the 3rd day after the initial stim=
ulus appears to have a more or less long preceding phase of expressed inhi-
bition. In the same way, the scheme of applying a MF 7 days before immuni-
zation, which is relatively ineffective under usual conditions, turned out
to be very effective at a daily pace. If we consider that the maximum of

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the phenomenon takes place approximately on the 4th day after reimmunization, it becomes evident that the test on the 7th day after it fell within the period when the phenomenon was attenuating.

In general, the dynamics of the number of antibody-forming cells corresponded to the dynamics of the antibody titer.

In these experiments, we also studied the cytological characteristics of the immune response: spleen smears-impressions were prepared both from the experimental and the control animals; they were fixed in methyl alcohol and stained with azure eosin. The dynamics of the following cellular forms was studied: reticular cells, lymphoblasts, lymphocytes, plasmoblasts, protoplasmocytes, neutrophils, eosinophils, mast cells, normoblasts, monocytes, and megakaryocytes.

In the control animals (immunization without MF exposure), the introduction of the antigen caused a substantial cytological readjustment which was characterized by the following:

the lowering of the relative percentage of the lymphocyte content during the entire experiment,

proliferation in the course of the immune response of the cells of the plasmocyte series, first of plasmoblasts and then mature plasma cells,

increased content of neutrophils and eosinophils in the spleen,

considerable proliferation of normoblasts.

In the first experiment (exposure to an AMF 1.5 hours before the first introduction of the antigen), the reading of the splenogram revealed that, in conformity with the inhibition of the immune respose, the relative percentage of the plasmoblasts in the spleens of mice in the experimental group was lower than the control during the entire experiment, and their percentage was often even lower than the background values (Figure 24). The relative percentage of plasmocytes in the experiment was, on the contrary, higher than in the control and constituted 4.8 percent. The relative percentage of neutrophils and eosinophils also reached higher values than in the control. Although the relative percentage of normoblasts increased in the course of the experiment, exceeding the background, but still it did not reach the values characteristic of the control.

It should be stressed that, in spite of the differences in the cytological shifts in the spleens of the experimental and control groups, there was much in common in them, and the basic directivity of the processes coincided. This confirms our earlier conclusion [40, 251] that MF action does not cause fundamental changes in the immunomorphological readjustment occurring against the background of influences by various corpuscular antigens.
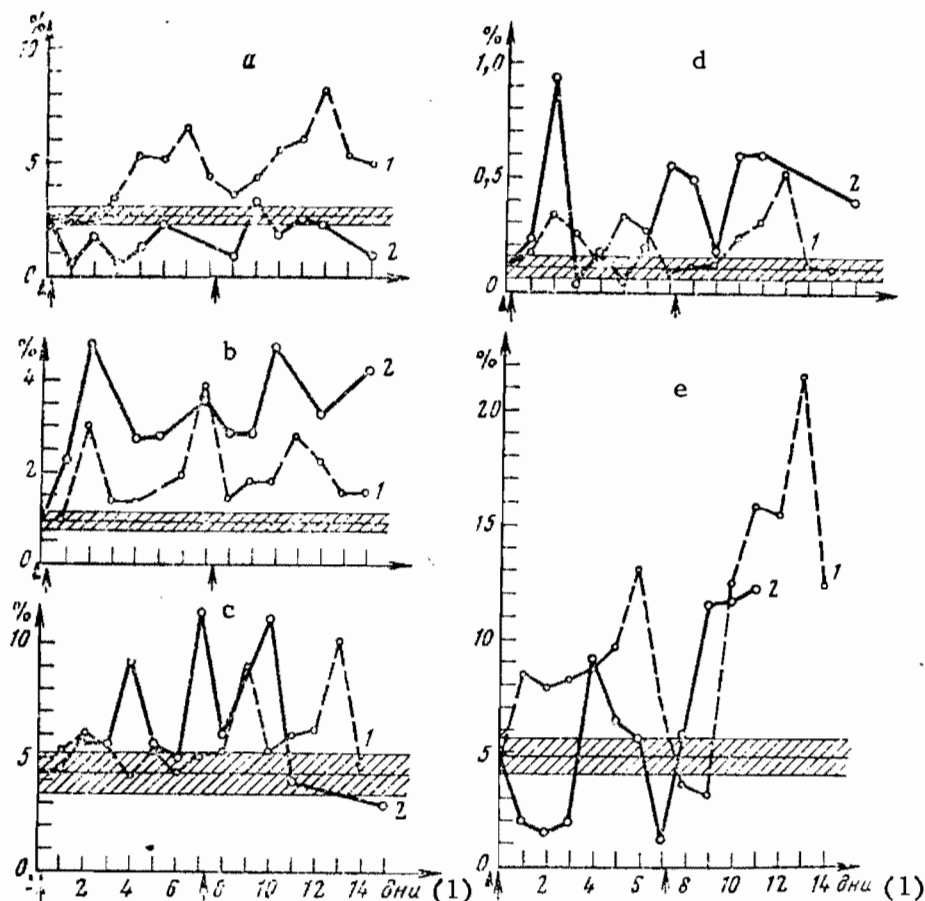
Figure 24. Splenogram of White Mice Subjected to the Action
of an AMF 1.5 Hours Before the First Introduction of the Antigen.
a -- plasmoblast; b -- plasmocytes; c -- neutrophils; d -- eosin-
ophils; e -- normoblasts; arrow -- indroduction of antigen;
triangle -- MF action; shaded area -- confidence interval;
1 -- control group; 2 -- experimental animals.
Key:
    1. Days

In the experiment when the animals were exposed to the MF action 7 days before
the first introduction of the antigen, the cellular shifts were essentially
the same in the experiment and in the control. At the same time, as has
been mentioned before, the antibody titer of these animals exceeded the
control indexes. Comparison of these results with those obtained in the
first experiment permits us to assume that the inhibition of antibody for-
mation by the AMF observed there was due to the absence of the proliferation
of plasmoblasts, the basic products of antibodies. At the same time, the
stimulation of the production of antibodies in the second series of experi-
ments was, evidently, caused not by a quantitative increase of the plasmo-
blastic reaction, but, probably, by the fact that a larger amount of plasmo-
blasts were antibody producers.

In one of our early reports [251] we showed that the influence of an AMF on immunized animals increased the number of pyroninophilic cells in the spleens. The same was observed by Odintsov [141] somewhat earlier. He studied the dynamics of the pyroninophilic cellular reaction in the spleens of animals infected with listeria and "magnetized." It is interesting that, in this case, stimulation of the plasmatic reaction progressed parallel with the inhibition of antibody formation in the experimental animals. All this made it possible to assume that the AMF could by itself influence the cellular composition of the lymphoid tissue. It appeared probable that the superposition of this effect on the process of immunomorphological readjustment could be the cause of the disturbances in antibody formation which we observed in the experiments described above. In this connection, we made a more detailed study of the changes occurring in the lymphoid tissue against the background of the MF action alone, without immunization. These experiments were conducted by us (partly, together with Z. F. Kiseleva [43]) on guinea pigs and white mice which were exposed one time for 6 hours to the action of an AMF (100 oersteds, 50 hertz). The results of these experiments showed that:

the application of the AMF resulted in the proliferation of plasmoblasts, plasmocytes, and normoblasts;

the above changes resembled, in many respects, those occurring after the immunization of animals with corpuscular antigens.

This suggests that both immunization and MF have common features in their action mechanisms, being nonspecific stimulants.

The effect of the AMF on the cytological and histological picture of the spleen makes it possible to conclude that the AMF effect on immunization shows itself to a considerable degree at the cellular level as a result of changes in the course of the immunomorphological and immunocytological processes determining the formation of antibodies.

Cytological analysis of the spleen impressions, as well as the earlier histological studies of sections stained by Brachet's method, made it possible to assume that MF could affect the nucleic acid content in lymphoid tissues of immunized animals. It is even more probable, since there are indications in literature that nucleic acids are one of the possible application points of the biological influence of MF. In this connection we conducted experiments in which we studied simultaneously the content of accumulated acids, RNA and DNA, in the lymphoid tissues, liver, and kidneys, the spleen cytogram, and the antibody titer in the peripheral blood. The experiments were done on guinea pigs divided into three groups: immunized with sheep corpuscles, exposed for 6 hours to the action of an AMF (200 oersteds, 50 hertz), and exposed to a combined effect of both factors. The animals were immunized according to the usual scheme, nucleic acids were determined 1, 3, 7, 8, 10, and 14 days after the beginning of the experiment by the methods of A. S. Spirin and R. G. Tsanev, and G. G. Markov. Some of the results are shown in Figure 25.
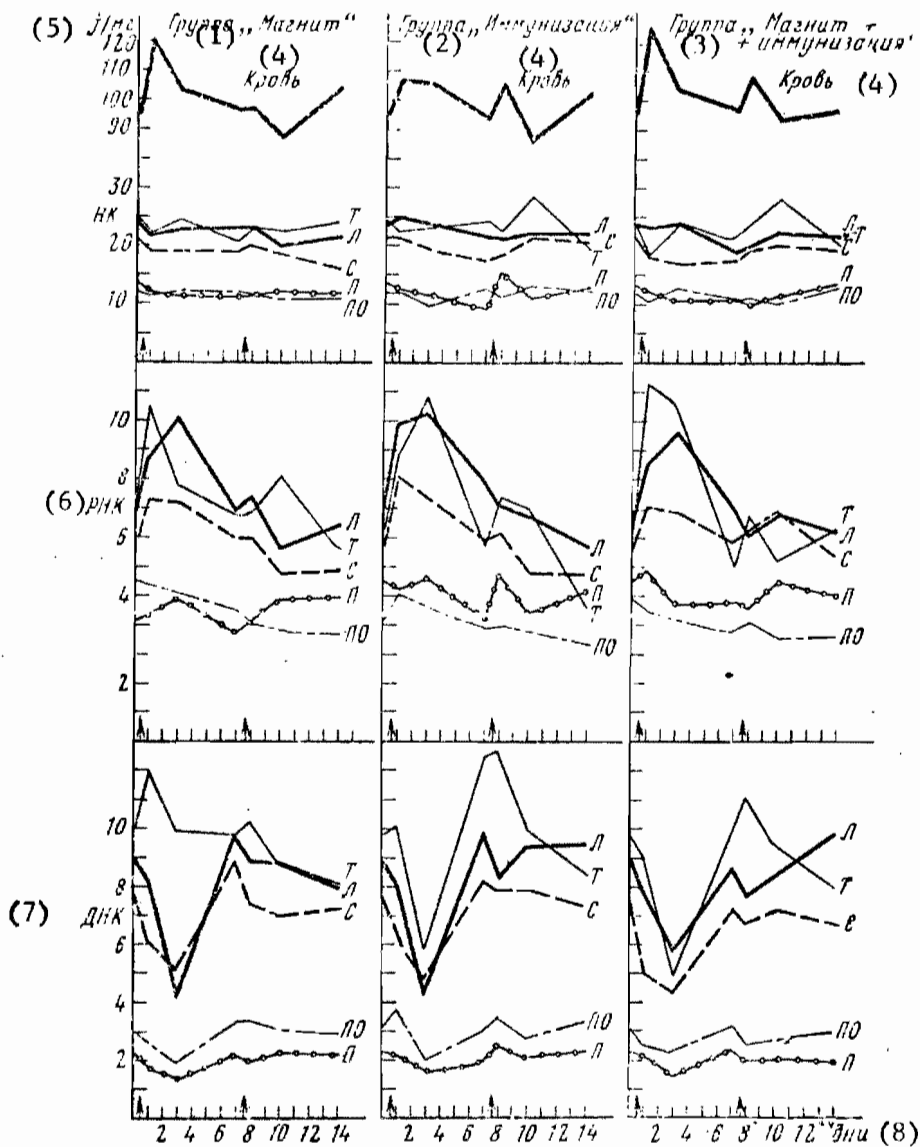
Figure 25. Dynamics of the Nucleic Acid Content in the Blood
and Viscera of Guinea Pigs Subjected to the Effects of Immuni-
zation and a Magnetic Field.
Л, T -- lymph nodes; C -- spleen; П-- liver; ПО -- kidney;
arrow -- introduction of antigen.

Key:

1. "Magnet" group
2. "Immunization" group
3. "Magnet + Immunization" group
4. Blood

5. mg
6. RNA
7. DNA
8. Days

The curves of Figure 25 are self-explanatory. There is a clear similarity in the dynamics of nucleic acids when the antigen and nonantigen stimulants were applied. It can hardly be considered a coincidence Most probably, just as the cytological data, this indicates the presence of common points in the action of the antigenic stimulation and MF. Considering the great difference in the physical nature of both factors, it is possible to assume that the common characteristic in the effects of both stimulants is the fact that both of them are stimulants. It seems very probable to us that both the MF and the antigenic stimulus are stress factors, and that the problem of MF effects on the formation of antibodies amounts to studying various kinds of stresses on immunogenesis.

Thus, it can be considered as proven that both AMF and high-intensity CMF [44, 180, 252, 253] produce a noticeable effect on the infection and immunity processes. In the majority of cases, the influence of this factor aggravates the course of infectious diseases. It also affects the factors of specific immunity, although it is too early to say anything final regarding the changes occurring in it. Finally, there occur deep shifts in the formation of antibodies -- both in the serological and the immunomorphological aspect.

The directiveness and the degree of these shifts depend on the stage of immunogenesis at which the MF is applied. In this respect, there seems to be some analogy with the effects of ionizing radiation: in both instances, the factor applied before immunization inhibits the formation of antibodies; its early -- inductive -- phase is also sensitive; its later phases are relatively resistant. Unlike ionizing radiation, the MF action in the inductive phase, as a rule, does not inhibit the production of antibodies, but stimulates it. However, it is more correct not to speak just of "stimulation" or "inhibition," but of a peculiar "phase shift" when, after the influence at some stages, the process of antibody formation develops more rapidly and intensively, and at some other stages, slower and more sluggishly than in the control animals.

Analysis of the results by means of cytological methods, makes it possible to assume that MF influence immunogenesis as a nonspecific stimulant. Thus, the problem of its influence on immunity is a special case of a broader problem of the influence of nonspecific stimulants on the processes of infection and immunity in general. This area has not yet been studied sufficiently well, and it is not ruled out that MF will prove to be a convenient instrument for its study.

It is quite probable that MF act as stress factors. In this case, the changes in the cytogram described above are connected, most probably, with the elimination of cortisone by the suprarenal glands -- at an early stage -- and with intensive production of somatotropic hormones -- at later stages. The inhibiting effect of cortisone on progress of infections is well-known, therefore, it is possible that this is one of the mechanisms of the negative influence of MF on the infectious process.

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Magnetoimmunology is still in a very early stage of its development. In our opinion, the following directions of research are the most promising: 1) studies on the mechanism of MF effects on the formation of antibodies and immunomorphological process; 2) analysis of MF effects on tolerance; 3) influence of MF on allergic processes; 4) the possibility of the appearance of autoantigens and autoantibodies in the organism against the background of MF effects.

In studying these problems, just as any other related problems, it is not necessary to use only high-power MF. It is not ruled out that even a weak MF could be active.

Finally, it is necessary to compare the effects of MF on the processes of infection and immunity with the effects of other nonspecific stimulants of chemical and physical nature.

EFFECTS OF MAGNETIC FIELDS ON THE NERVOUS SYSTEM

[Yu. A. Kholodov, Institute of Higher Nervous Activity and Neurophysiology, USSR Academy of Sciences, Moscow]

Throughout the entire history of magnetobiology, the influence of MF has been attracting the attention of researchers. In discussing the therapeutic effects of MF in the past [18], it was suggested that MF influenced only the nervous system. It was believed that MF could have a favorable effect chiefly during an intensive activity of the nervous system. The effect of MF was particularly striking in histeria patients.

We know now that the nervous system cannot claim to be a sole detector of MF in the organism, because any live cell, and not only a nerve cell, reacts to MF (this collection). However, in spite of this "equalizing" statement, we should not overlook the quantitative, and, possibly, qualitative peculiarities of the responses of various biological systems to MF. It is possible to assume that the nervous system is first among all other systms of the organism to react to MF, since it is first to encounter any environmental stimulant. We should not forget that under the conditions of a whole organism, the nervous system participates in the organization of reactions regardless the place of their origin. In other words, the nervous system can react to an MF either directly, or as a reflex.

What are the facts showing the influence of MF on the nervous system?

Subjective Perception of MF

Usually, any stimulant is perceived by man as a sensation. It is believed that CMF do not have a sensory effect. In any event, in the questionnaires sent out in our time to directors of many physics laboratories of the U.S.A., physicists replied that they experienced no sensations exposed to CMF of up to 20,000 oersteds for several minutes. However, special studies by medical researchers and biologists showed that, under certain conditions, MF could cause sensations.

Many medical men of the last century, who included such authorities as Botkin and Charcot, pointed out that in some patients magnets could: 1) cause an itching, creeping tingling, or pain sensation at the point of action; 2) restore the disturbed sensitivity of the skin and retina or "transfer" anesthesia from the sick half of the body to the healthy half; 3) eliminate or reveal paralysis, spasms, and contractures; 4) relieve pains of various origin or bring about past pains; 5) cause a general weakness, headache, and sleepiness [62].

When researchers started using quantitative methods, it was found that, among 100 healthy persons on whose arms magnets were placed, 60-70 persons experienced certain sensations. In 1-3 minutes, 2-3 persons had a tingling sensation, warmth, and creeping sensation in the arm; 8-10 persons had similar sensations after 4-5 minutes, 20-25 persons -- after 10-15 minutes, and 25-30 persons -- after 1 hour or longer. It turned out that approximately 2/3 of the studied persons, sooner or later, felt the presence of the CMF [78].

Frenchmen Bine and Fere [18] concluded that MF equally inhibited sensations, hallucinations, and memory. This conclusion coincides partly with the opinion of Andri and Ture, who stated 100 years earlier that MF had antispasmodic (inhibiting) effect on the nerves. But while these authors contrasted the MF influence with the electric current, Bine and Fere believed that MF acted upon the nervous system as a weak electric current, producing a constant peripheral stimulation.

The most reliable fact was D'Arsonval's discovery regarding the appearance of a subjective sensation of the flashing of light (phosphene) under the effect of an AMF with a frequency of 10-100 hertz upon the head of a man [64, 125, 266, 354, 396, 399, 401, and others]. The optimal stimulation frequency was 20-30 hertz. The effect was observed at 400 oersteds. When the intensity was increased to 800 oersteds, the length of sensation increased from 1 to 20 seconds. The phosphene sensation also occurred when a CMF was turned on and off. When it was turned off, the sensation was more intensive. However, magnetophosphene was often explained by the appearance of the electromotive force of the induction causing the stimulation of the receptory cells of the retina (rods and cones) and, therefore, it was often not connected with other magnetobiological effects. In later studies, the researchers did not agree with this explanation, because, by approximate calculations, the induction electromotive force is by 3-4 orders lower than the intensity causing electrophosphene [110] and the electrophospnene value depends on the length of the MF action [185]. In the light of these studies, the magnetophosphene theory cannot be considered completed. Probably, much can be yielded by experiments with the MF action upon the retina of animals.

Apart from phosphene, other changes were observed in the functions of the visual analyzers under the effect of MF. In an AMF, the stability of clear vision decreased in human beings [125]. A constant magnet brought close to the occiput of a person changed the visual images impressed in hypnosis [18, 36] and intensified visual hallucinations caused by mescaline intoxication [143].

In our time, people exposed for a long time under industrial conditions to the action of a magnetic field, 20-60 percent of their working time, showed some deviations on the part of the nervous system (Vyalov, in this collection). These deviations were characterized by headaches, pains in the area of the heart, fatigue, instability and decrease in the appetite, insomnia, increased sweating, and the appearance of an itching and burning sensation in the hands. EEG studies (electroencephalograms) revealed a tendency toward the inhibition in the brain. There were slow waves and spindles of the alpha-rhythm at rest and in the light test. Otoneurological studies indicated more frequently the central origin of the inhibition of the vestibular apparatus. It is believed that MF, most probably, caused the first stage of parabiosis, according to N. Ye. Vvedenskiy (changes in the lability), in the vegetative nervous system.

Thus, MF can bring about nonspecific sensations connected most frequently, with the activity of the skin analyzer. This is indicated by the old and new studies.

The above data show that, although MF do not cause special "magnetic" sensations in man, this stimulant gets into the sensory sphere most frequently through the visual or cutaneous analyzers. In the latter case, it can be considered as proven that MF influence the peripheral receptive formations, i.e., the afferent part of the three-membered reflex arc. When the sensation occurs in the visual analyzer, the MF could influence both the receptory and the central parts of the reflex arc.

It is reasonable to assume that MF can also affect the activity of other analyzers, althouth there are, obviously, not enough studies of this kind. The above-mentioned work on vestibular analyzers suggests that MF affect chiefly the central part of the reflex arc.

The recent data on the inhibitive effect of MF on hallucination and memory [9, 36, 80, 143, and others) lead to the same conclusion and confirm the results of studies of the last century [18].

Consequently, the afferent and the control parts of the reflex arc are affected by MF. But what can be said about the efferent part?

It should be mentioned that modern ideas of MF influence on the nervous system are based not only on the above-mentioned qualitative studies of psychological nature, but also on quantitative neurophysiological data obtained chiefly in experiments on whole animal organisms or on individual isolated organs.

Effects of MF on the Motor System

Since the middle of the last century, physiologists have been interested in the influence of MF on the neuromuscular apparatus of the frog. Some researchers (Dubois, Mackendrik [62]) observed muscular contractions when an electromagnet was turned on, but others [62, 63, 330, and others] did not

observe this effect. Hermann's work published in 1888, which was chiefly a study on a neuromuscular preparation, gave a negative reply to the question of whether or not MF had a biological effect.

In the XX century researchers returned to magnetobiological experiments on the frog neuromuscular preparations. No effect was found when a CMF of 10,000 oersteds acted upon an isolated nerve fiber [111]. Recently, a decrease of irritability in a CMF of 9,000 oersteds was discovered in experiments with a whole neuromuscular preparation [155]. On the other hand, a lower MF intensity did not have a stimulating effect; it changed the chronaxie of the neuromuscular preparation in two phases, increasing it at first, and then decreasing, and removed parabiosis [145, 261]. A CMF of 800 oersteds inhibited the onset of a myoneural block and total fatigue of a neuromuscular preparation when the nerve was exposed to electrical irritation with a frequency of 1.7 hertz, and a CMF of 2,200 oersteds increased the fluctuation of the threshold of electrical irritation of a muscle [180].

Thus, the majority of modern studies have revealed the influence of CMF on the activity of neuromuscular preparations. In further analysis of this phenomenon, it is necessary to consider the possibility of a decrease in the sensitivity of CMF if the structures of which the preparation is composed are isolated, as well as the possibility of a decrease in the effect at higher CMF intensity.

Muscular reactions of a frog to MF indicate that inclusion of the central nervous system (CNS) into the reacting system increases sensitivity fo CMF. It was shown that MF removed the existing Sechenov inhibition [175] and could by itself cause an inhibition of spinal reflexes in a hemisphereless frog with a local action on the region of the diencephalon [80, 223]. A CMF (800 oersteds) lowered the threshold of electrical irritation of an afferent nerve of a frog without lengthening the latent period of the muscular reaction [9].

The influence of CMF on the motor activity of man was studied on patients during hypnosis and in healthy people while they were awake. A magnet (400 oersteds) applied to the occipital region of a patient sometimes caused hypnotic catalepsy to weaken. The arm stretched in a cataleptic pose started lowering slowly. In healthy persons, the CMF (1,200 oersteds) lowered the average frequency of waves in the tremogram of a stretched arm [9].

The described experiments suggest again that the most MF-sensitive link in the reflex arc is the CNS. It should be added that fluctuations of GMF revealed the correlation with the number of occupied beds in psychiatric hospitals [279], that the decrease in this field to 10^{-5} oersteds causes changes in the activity of the visual analyzer [283], and that some people can perceive an MF gradient of thousands fractions of one oersted per meter [286].

It should be mentioned that a local action on the head of an animal changed the PhAL [245] increased the amount of hemoglobin in the blood [14] and resolved implanted tumors on the back (Ukolova et al, see this collection).

This conclusion became a basis for our experiments on reactions of a total organism to MF, such as the general motor activity, sensitivity to electric current and conditioned-reflex reactions. Leaving out the orienting effect of weak MF on animals, which was studied by Brown, as well as by G. Becker [395], and by other researchers, we concentrated our attention on the reactions occurring under the influence of sufficiently intensive MF. The participation of the brain in some reactions of animals to MF was determined while registering the electrical activity of the nervous tissues and in morphological studies on the CNS. Our goal was to describe, in experiments on animals, the initial nonspecific reaction of the CNS to MF in studies at the level of the total organism and at the systemic and cellular levels, as well as to explain the physiological mechanism of this reaction. The majority of modern studies on the influence of MF on the CNS were published after our studies or simultaneously with them.

Effects of MF on the Reactions of the Total Organisms of Animals

Increase in the motor activity in MF was observed in insects [180], in fish [219, 223], in birds [49, 219, 258, and others], and in mammals [59, 268, 358, and others].

This method made it possible for us to discover that birds react to artificial MF with an intensity of several tenths of an oersted with a latent period of several minutes. The recent work by Shumakov [255] showed that moving the birds from Kaliningrad to the region of the Kursk Magnetic Anomaly, where the GMF intensity reached 1 oersted, let to a considerable increase in their motor activity. Probably, changes in the motor activity could serve as a sensitive index in determining the threshold value of MF. However, it is difficult to analyze this extremely general reaction of the organism in studying the physiological mechanism of the MF action.

It was found in experiments on saltwater and freshwater fish that an MF of 50-200 oersteds more frequently lowers the sensitivity of the fish to the current passed through the aquarium. On the average, their sensitivity decreased by 30 percent. The nature of the MF influence was determined by the initial functional state of the animal: in the same fish, the MF lowered the sensitivity to the electric current if the initial sensitivity was high, and caused an opposite effect if the initial sensitivity was low.

In other words, the MF in these experiments acted as a corrective stimulant which changed the reaction to other stimulants. The latent period of this reaction to MF reached 1 minute, and the effect was maintained for several minutes after the termination of the action.

Published data indicate that MF lowered the sensitivity to a light stimulant in planarians [49] and to electrical stimulant in amphibians [9] and man [133]. Consequently, the corrective inhibiting action of MF on the reaction during a peripheral stimulation of the organism shows itself at various evolutionary levels of the development of the animal kingdom.

It is interesting that in our experiments the same MF intensity caused in
the same object (stickleback) an increase in the motor activity and a de-
crease in the sensitivity to the electric current. From this it is possible
to assume that MF causes excitation in the efferent part of the reflex arc
and inhibition in the afferent and central parts. However, to verify this
assumption, it was necessary to study a clearer reflex arc than the one pre-
sent during a general electrical stimulation of fish. Since it had been
established that MF influenced the organism, we attempted to develop a con-
ditioned reflex to them in order to characterize the properties of these
stimulants more fully.

By using an MF of 300 oersteds as a conditioned stimulus, Chizhenkova at-
tempted to develop a shaking-off conditioned reflex in three rabbits. While
the conditioned reflex appeared shortly and became established in response
to a sound, it was not possible to develop the conditioned reflex in any of
the rabbits in response to the MF in spite of the fact that about 70 combin-
ations were given. Having increased the MF intensity to 1,000 oersteds, we
[207] were able to develop an unstable delayed (spacing of 20 seconds) elec-
trodefensive conditioned reflex in four rabbits.
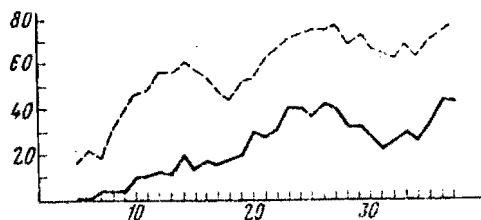
Figure 26. The Dynamics of the Stability of Conditioned
Reflexes to CMF (solid line) and to Sound (broken line)
in Rabbit No 1.
The data was processed by the sliding mean method. Or-
dinate -- stability of conditioned reflex in percent;
Abscissa -- numbers of the experiments.

It was found that the conditioned reflex to CMF developed in all studied
rabbits. It appeared on the average, after 40.1 ± 2.3 combinations, strength-
ens (showed itself five consecutive times) after 248 ± 5 combinations, and ma-
terialized with a mean latent period after 8.50 ± 0.12 seconds. The sound
reflex indexes were 26.0 ± 3.4, 131 ± 2.8 combination and 4.90 ± 0.09 second.

Figure 26 reflects the dynamics of the development of conditioned reflexes
to CMF and to sound in rabbit No 1. It can be seen that the reflex to sound
appears earlier and materializes more frequently than the reflex to CMF.

The obtained data confirm previous conclusions regarding the fact that CMF
is a weaker stimulant than such adequate stimulants as sound or light. The
definite difficulty in the development of a sound reflex is explained by a
great spacing of reinforcement. An additional series of experiments on two

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rabbits showed that when the spacing was equal to 6 seconds, both the magnetic and the sound reflexes formed somewhat earlier than when the spacing was 20 seconds. Therefore, the previous unsuccessful attempt to develop a conditioned reflex to CMF in a rabbit can be explained by the small number of combinations (only 70) and smaller intensity of the CMF (300 oersteds).

Thus, the CMF of the applied intensity can become a conditioned positive stimulant for rabbits, although the formation of this temporary bond occurs with difficulty. According to all indexes of the conditioned reflex activity, the conditioned reflex to CMF is inferior to the same reflex to sound. It is possible that the difficulty in the development of the conditioned reflex to CMF is connected with the predominance of the inhibitive process in the CNS during the CMF action.

In our experiments on four pigeons, we were able to develop positive food-finding or defensive conditioned reflexes to an MF of 200 oersteds, although we gave 400 combinations. Just as in the experiments with rabbits, the failure can be explained by the low intensity of the applied field. During the recording of the brain biopotentials of a pigeon under the action of the MF, the threshold intensity was 280 oersteds [323]. At the same time, the MF inhibited the developed conditioned light reflex in pigeons, and this inhibition showed itself not only in the presence of CMF, but also some time later after the solenoid was turned off.

The development of conditioned reflexes to MF in fish was achieved simultaneously and independently by Lissman [352] on the Nile electric fish Mormyrus and Kholodov [215] in carp.

Unlike the conditioned reflexes to adequate stimulants (light, sound), the conditioned reflexes to MF appeared later, strengthened later and were less stable. On the other hand, conditioned inhibition in response to MF developed in fish sooner and was more stable than the similar temporary bond in response to adequate stimulant.

The developed conditioned reflexes in response to light and sound were inhibited by MF in bullheads and flounders [225]. MF influenced the retraining of fish and mice in a T-shaped maze [9], and, in our experiments the preexposure of mice to a CMF of 2,000 oersteds for 30 minutes inhibited the developed maze habits.

Consequently, MF can become a conditioned stimulant and influence the developed conditioned reflexes in the representative of various classes of vertebrates. However, the conditioned reflex in fish develops in response to a lower MF intensity than, for example, in a rabbit. In other words, the higher the evolutionary level of the development of a vertebrate the more difficult is the formation of conditioned reflexes in response to MF, probably, due to the development of adaptation mechanisms. It is possible that the corrective effect of MF shows itself at lower intensities than the triggering effect. It is interesting that MF of the same intensity had a greater

influence on the retraining of young mice than on the retraining of adult mice.

There is a theory that the main role in the perception of MF in fish is played by the lateral line organ [352]. However, the denervation of the lateral line organ in three fish in our experiment did not affect the conditioned magnetic reflex.

We completely removed the eyes in seven fish and found that this operation also did not affect the development of conditioned reflexes to MF. It was found that the removal of the forebrain (8 fish), cerebellum (7 fish), or optic tegmentum (7 fish) did not reflect much on the development of the conditioned electrodefensive reflex to MF. Only the damaging of the diencephalon (6 fish) worsen it sharply. At the same time the condition reflex to light was disturbed after any interference with the completeness of the brain, particularly after a damage to the diencephalon.The reflex to sound was considerably disturbed after the removal of the cerebellum or optic tegmentum.

The results of this series of experiments suggest that the most MF-sensitive part is the central part of the reflex arc, and among the sections of the CNS in fish, the diencephalon serves as an important link in materializing the reactions to MF. Thus, MF affects many behavioral reactions of animals of various levels of organization. The lowest MF intensity was required to change the motor activity of birds. The highest intensity was required to develop a conditioned reflex to MF in mammals. Just as in the preceding sections of this survey, in the analysis of the physiological mechanism of the MF influence, its effect on the CNS appeared to be of primary importance. We decided to study the direct reaction of the brain to MF in electrophysiological experiments.

Influence of MF on CNS

In order to understand the primary physiological reactions of the CNS to EMF, we undertook a series of experiments for registering the electric activities of various parts of the CNS in rabbits. For this, 147 rabbits were subjected to 5014 1-3-minute MF exposures of the head.

In many experiments, simultaneously with EEG recordings, we registered EKG and respiration rate in the rabbits. However, we did not observe any changes in the respiration or cardiac activity under the effect of MF. On this basis, we believe that the EEG recording is a sufficiently sensitive method for registering the reactions to MF. Numerous works prove the existence of a reflex route of the MF action on the CNS, but this route was beyond the limits of our analysis not because we did not feel that it was important, but merely because the other route (direct effect) was only mentioned in most works, but not analyzed. It can be stated that, in the final analysis, the reaction of the organism to MF is determined by both the reflex and the direct influence and that in each concrete case (depending on the intensity, localization of MF, ect) one or the other route becomes more important.

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Unlike the usual for the electrophysiologist generalized reaction of desynchronization appearing with a latent period in fractions of a second in the case of the ordinary stimulants (light, sound, etc) of average intensity, the basic EEG reaction to MF was expressed in a statistically certain ($P < 0.05$) increase in the number of spindles and slow waves. Such a generalized nonspecific synchronization reaction did not develop at each MF application (approximately in 50 percent of cases), and its average latent period was 20-40 seconds.

The developed EEG reaction lasted for some time even after the electromagnet was turned off. The aftereffect was often expressed in an additional increase in the number of spindles and slow waves which was characterized by us as a reaction to the turning-off. This reaction could appear independently from the main reaction and had a shorter latent period (on the average, about 15 seconds).

Automatic frequency analysis of the EEG confirmed the results of the visual processing and showed that under the effect of MF, the EEG becomes enriched at low frequencies and at those which constitute the spindles. Moreover, we observed an increase in the amplitude of the pen of the analyzer at high frequencies (27-30 hertz), which was not observed during the visual processing of the EEG [228].

For statistical evaluation of the reaction of a rabbit to CMF (100 and 600 oersteds) we conducted a series of automated experiments in cooperation with Zhadin and Trush on a universal digital computer "Dnepr" on an EEG taken monopolarly from the sensomotor region of the right hemisphere. We evaluated the total power of EEG, dispersion and the asymmetry coefficient of the waves for a one-minute period. The selection of these indexes and the length of the analyzed interval was determined by the results of the visual study of the EEG reaction of a rabbit to CMF. Let us recall that approximately 10 seconds after the CMF is turned on, the number of spindles and slow high-amplitude oscillations increases in the EEG.

During the automated experiments, the rabbit was in a screened soundproof chamber 10 meters away from the room where the computer was. The electromagnet was turned on and off automatically depending on whether the pseudorandom number produced by the computer was odd or even. The survey of the EEG was done at a frequency of 100 hertz. The evaluation of the above parameters was done by the recurrence relations for a minute of the background, a minute of the action of the stimulants, and a minute of the aftereffect. The same scheme of the experiment was maintained for the control (with the absence of stimulants.

Four rabbits were subjected to approximately 100 exposures to CMF of 600 and 100 oersteds. About 200 control measurements were done on the same animals.

It was found that in the control recordings and under the effect of the CMF of 100 oersteds, there was no difference between the one-minute sections of the EEG with respect of all registered parameters. The asymmetry coefficient also did not change at the CMF of 600 oersteds.

Under the effect of the CMF of 600 oersteds, the total power of EEG increased, on the average, by 43 percent ($p=10^{-5}$), and the mean quadratic deviation -- by 7 percent ($p=0.05$) (Figure 27). According to the same indexes after the electromagnet was turned off, the EEG did not differ substantially from the EEG during the exposure, which indicated the presence of a long aftereffect process. The analysis of the dynamics of the calculated parameters in the course of 20 seconds after the electromagnet was turned on showed that the latent period of the reaction exceeded 10 seconds.
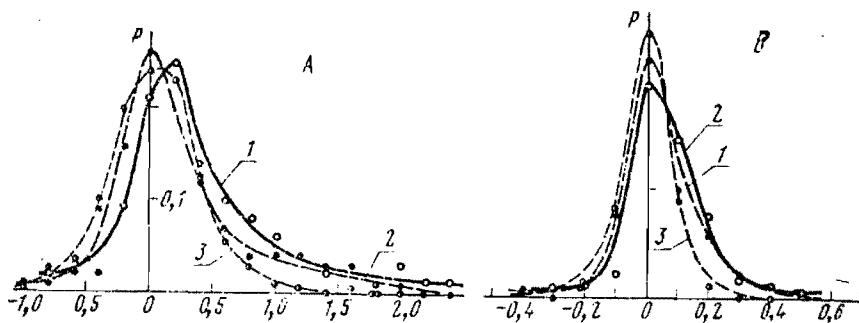
Figure 27. The distribution of the relative values between the minute recordings of the EEG of a rabbit over the integral of the square amplitude (A) and over the average quadratic deviation (B) in comparing the minutes of the background and the minutes of the action of the CMF of 600 oersteds (1, A; 2, B), the minutes of the background, and the minutes after the electromagnet was turned off (2,A; 1, B) and two background minutes in the control recordings (3).

Characterizing the changes in the EEG with respect to MF, it should be mentioned that these reactions depended on the indiviaual peculiarities of the animals and on their initial functional state. The EEG reactions improved after the introduction of caffeine or adrenalin and   decreased after the introduction of amine azine or barbiturate.

If the MF exposure did not exceed three minutes, we did not detect the summation effect or the adaptation effect when the number of exposures was increased. However, when the rabbit spent 3 hours daily in the MF, we observed the summation of the effects, which was expressed in the increase of the EEG amplitude.

When we registered the electrical activity of various parts of the rabbit's brain, we discovered that reactions in the form of increased numbers of slow

waves and spindles develop simultaneously in all recordings (at the record-
ing rate of 15 mm/sec), and the most intensive reaction was observed in the
hypothalamus, then followed the sensomotor cortex, optic cortex, specific
nuclei of the thalamus, nonspecific nuclei of the thalamus, hippocampus,
and the reticular formation of the mesencephalon. It is possible to conclude
that the most reactive formations of the CNS under the effects of MF are the
cortex and hypothalamus and that the MF can influence any section of the brain,
but the intensity of the reaction is determined by its reactivity.

For evaluating the functional state of the CNS during the MF influence, we
selected the recording of the reactivity curves [112] of the EEG of the optic
region under the effect of light of increasing brightness with a frequency
of 3.5 hertz. The criterion of the excitability of the optic analyzer was
the time of the appearance of the reaction of the assimilation of the rhythm
of the light flashes. It was found that this criterion increased under the
effect of a CMF of 200 or 460 oersteds.

It is important that we saw the changes in the reactivity criterion approxi-
mately twice as often as the changes in the spontaneous EEG under the influ-
ence of MF. In other words, in this case too, just as in the study of con-
ditioned reflexes, the corrective effect of the MF was revealed more frequently
than the triggering effect.

The influence of the MF on the slow electrical activity of the brain was ob-
served in reptiles [278], in pigeons [323], in rabbits [49, 84, 118, 217, 222,
227, 228, 234-238], in cats (our unpublished data), in monkeys [342], and in
man [52, 54, 180, 305]. Changes in the EEG consisted most frequently in an
increase in the number of slow high-amplitude oscillations and activation
of the outburst activity in the form of spindles.

Our and literature data indicated that MF chiefly involved the cynchronizing
mechanisms of the brain into the reaction. It was possible to assume that
the described reaction results from the influence of MF on nonspecific struc-
tures of the diencephalon. However, this assumption had to be checked ex-
perimentally.

We tried to establish whether all sections of the rabbit's body were sensi-
tive to the MF. For this purpose, we exposed the rabbit's legs, abdomen,
chest, and head alternately to the MF action. It is clear that the local-
ization of the MF in these experiments was relative, because the diminished
field was outside the limits of the area of interest to us. But the results
of the experiments were sufficiently definite: changes in the EEG were ob-
served by us only when the head was exposed to the MF.

One-sided destruction of the reticular formation of the mecencephalon, pos-
terior ventrolateral nucleus of the thalamus, or the posterior hypothalamus
did not prevent the appearance of the EEG reactions to MF and did not cause
any asymmetry of these reactions. It is possible to assume that one-sided
interruption of the routes of the temperature, pain, tactile, and

proprioceptive sensitivity did not affect the EEG of the reaction under the influence of the MF. If we recall that the destruction of the distance receptors in fish also did not affect the reactions under the influence of the MF, then it seems logical to assume that MF have a direct influence on the CNS. We decided to verify this assumption on isolated sections of the brain.

It was found that the preparations of an isolated brain obtained after cutting at the level of the mesencephalon reacted to MF more frequently, with a shorter latent period, and more intensively, (sometimes, spasmotic discharges occurred in response to the MF influence), than the intact brain. The EEG reaction consisted in an increase in the number of slow waves, spindles, and spasmotic discharges.

It still remained unclear whether the complete structure of prosencephalon reacted to the MF or any section of the cerebral tissue. In order to answer this question, we conducted experiments on neuronally isolated strips of the cerebral hemisphere cortex of a rabbit.

A 5 x 15 x 5 mm strip of the cortex was isolated in the sensomotor or optical region. The electrocorticogram (ECoG) recording was done by the bipolar method by means of cored electrodes. In the majority of cases, spontaneous electrical activity of the strip was registered in the form of irregular or regular slow high-voltage potentials, as well as in the form of spasmotic discharges.

The ECoG response to the MF was expressed most frequently by an increase in the electric activity. This reaction was characterized by a short latent period in comparison with the intact brain and the preparation of an isolated brain, although, in its degree of stability, the ECoG response of the strip to the MF was close to the EEG response of the intact brain. The response of the strip of the MF did not depend on the point of isolation. Within 7 hours, the stability of the main response was increasing with the length of time since the isolation. The last fact makes the strip more similar to the preparation of an isolated brain and indicates that isolation of brain structures increases their reactivity to MF.

The electrical reaction of the strip to the turning-off of the EMF did not differ in its indexes from a similar reaction of an intact brain and the preparation of an isolated brain.

This series of experiments showed that the neuronally isolated strip of the cortex reacted to the MF with a shorter latent period than an intact cortex and, consequently, under the conditions of a complete brain, the EEG reaction to MF formed with the participation of the cortex and subcortical sections. This conclusion is confirmed both by the EEG reaction of the complete brain to MF, and by the length of its latent period.

The electrical response to MF may arise in a small section of the cerebral tissue supplied with blood through the arachnoid membrane of the brain. The possible role of the humoral factor in the appearance of these responses should have been studied in experiments on nerve tissue cultures of vertebrates where there is no blood supply. However, under our conditions it was possible to study the electric activity of only the surviving isolated nervous systems of invertebrates. We shall be discussing the electric response to an MF of an isolated abdominal section of the nerve system of crayfish studied by S. N. Luk'yanova [180]. The reason for utilizing this preparation was not only the possibility of its isolation from hormonal and nervous influences, but also a transition to the study of responses to MF by the cellular elements of the nervous system.

The Influence of MF at the Cellular Level

The studied preparations consisted of six ganglions and their connectives of their abdominal nerve system. The preparation was placed in a humid chamber with Harreveld's physiological solution and spike discharges of neurons from one of the connectives were registered by means of silver electrodes. The background frequency of the discharges varied widely depending on the peculiarities of the preparation, survival time, season of the year, and so on.

Fifty preparations were exposed 103 times for 3 minutes to an MF of about 2,000 oersteds. In 36 cases (Figure 28), a statistically certain reversible decrease of the spike frequency ($P < 0.05$) was observed. The latent period of the response exceeded 3 seconds. In other instances, charges in the electric activity of the system were insignificant. It is necessary to mention that the nature of the MF effect depended on the background frequency of neuron discharges: inhibition often occurred when the initial frequency was high. In the control experiment (20 preparations, 30 recordings), it was not possible to register any spontaneous inhibition of the electric activity.

It is known that the corrective effect of MF shows itself more frequently than the triggering effect. This regularity was also observed on this preparation. Utilizing the ability of certain neurons of the abdominal nervous system of crayfish to react to light of the visible part of the spectrum [154], the experiments on the 50 preparations included 100 exposures to light (3 seconds) without the MF and the same number of exposures against the MF background 1 minute after the electromagnet was turned on. In 39 percent of the case, there was a reversible increase in the number of spikes in response to light in the presence of the MF ($P < 0.05$) in 23 percent of the cases -- its decrease ($P < 0.05$), and no effect in the remaining cases. In the control experiments (20 preparations, 6 recordings), no changes in the response to light were detected if the MF was not applied.

Thus, the experiments on a completely isolated nervous system of crayfish showed that a nervous tissue having no humoral connection with the rest of

the organism could react to MF. More frequently, the response was expressed as the inhibition of the spontaneous electric activity of neurons. Similar results were obtained by American researcher Sittler [395], who exposed an isolated subesophageal ganglion of a cockroach, and by Kogan et al ([95], see this collection), who studied impulse activity of the stretching neurons of crayfish.

Experiments on the nervous system revealed that the results of the CMF influence depended on the season: in the autumn and winter, the reaction were clearer than in the spring and summer.

However, the results of this series of experiments were obtained on the nervous system of invertebrates which may have its own peculiarities. In order to characterize the reaction of the brain neurons of vertebrates to MF, Luk'yanova [56, 116, 117] conducted experiments on five rabbits to perform an extracellular registration of the electric activity of 352 neurons of brain sections studied before with macroelectrodes. A total of about 400 one-minute exposures of the heads to a CMF of 1,000 oersteds were done.

The summarized data indicate (Figure 29) that 33 percent of neurons reversibly inhibited the spontaneous activity under the effect of the MF (P< 0.05), 25 percent increased the activity (P<0.05), and the remaining did not react to this stimulant. Many researchers, registering the extracellular electric activity of brain neurons of rabbits under the effect of various stimulants, observed that approximately 50 percent of the neurons reacted to the stimulus, and that the majority of the neurons responded by excitation. Magnetic fields differed from the ordinary stimulants (light, sound, and others) in the fact that in all registered sections of the brain, there was a predominance of neutrons which inhibited their activity. Moreover, the latent period of the response to CMF exceeded 10 seconds regardless of its directivity. It is interesting that the largest number of reacting nerons was found in the hypothalamus, i.e., in the part of the brain which was found to be the most responsive to MF according to the data with the macroelectrode recording of the electric activity of the brain.

It is important to note that the reaction of the neurons was not limited to the period of the MF action, but continued for some time after the electromagnet had been turned off. In other words, the aftereffects which had been clearly expressed in the studies at the level of the CNS and a complete organism were also found at the neuron level.

In order to study the corrective effect of MF, a series of experiments was carried out for studying the reactions of 23 neurons of the optic cortex to a flash of light in the background during the action of an MF of 200 oersteds upon a rabbit's head and after the electromagnet had been turned off [223]. It was found that the overall neuron reaction to a flash of light increased both during the MF action and immediately after the electromagnet had been turned off. In the control experiments on 36 neurons, no dependence was found between the response to a flash and the number of preceding light influences.

microvolts
seconds
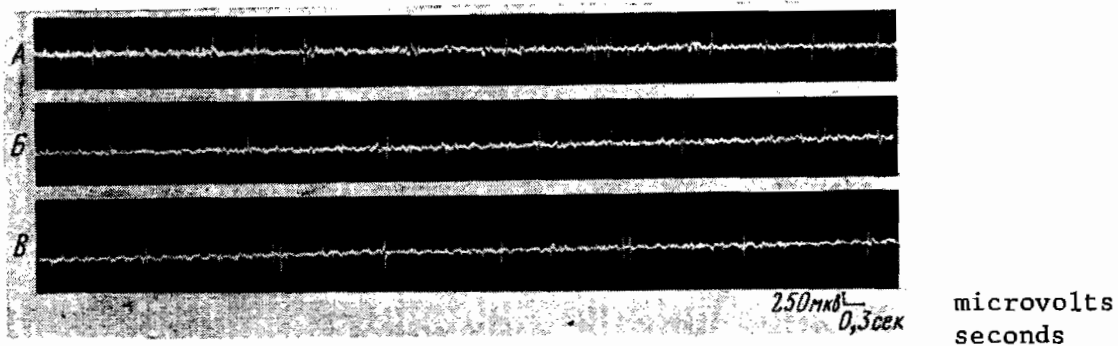
Figure 28. A Recording of the Electric Activity of Neurons
of an Isolated Abdominal Nervous System of a Cryfish.
A -- backbround; B -- action of CMF; C -- after the CMF
action.

135

a

B

C

100мкв (1)
1сек (2)

2,50мкв (1)
0,1сек (2)

2,50мкв (1)
0,1сек (2)

10 20 30 40 50   10 20 30 40 50   10 20 30 40 50 Время,сек (6)
(3)Фон   (4)Период действия ПМП   Период последействия ПМП (5)
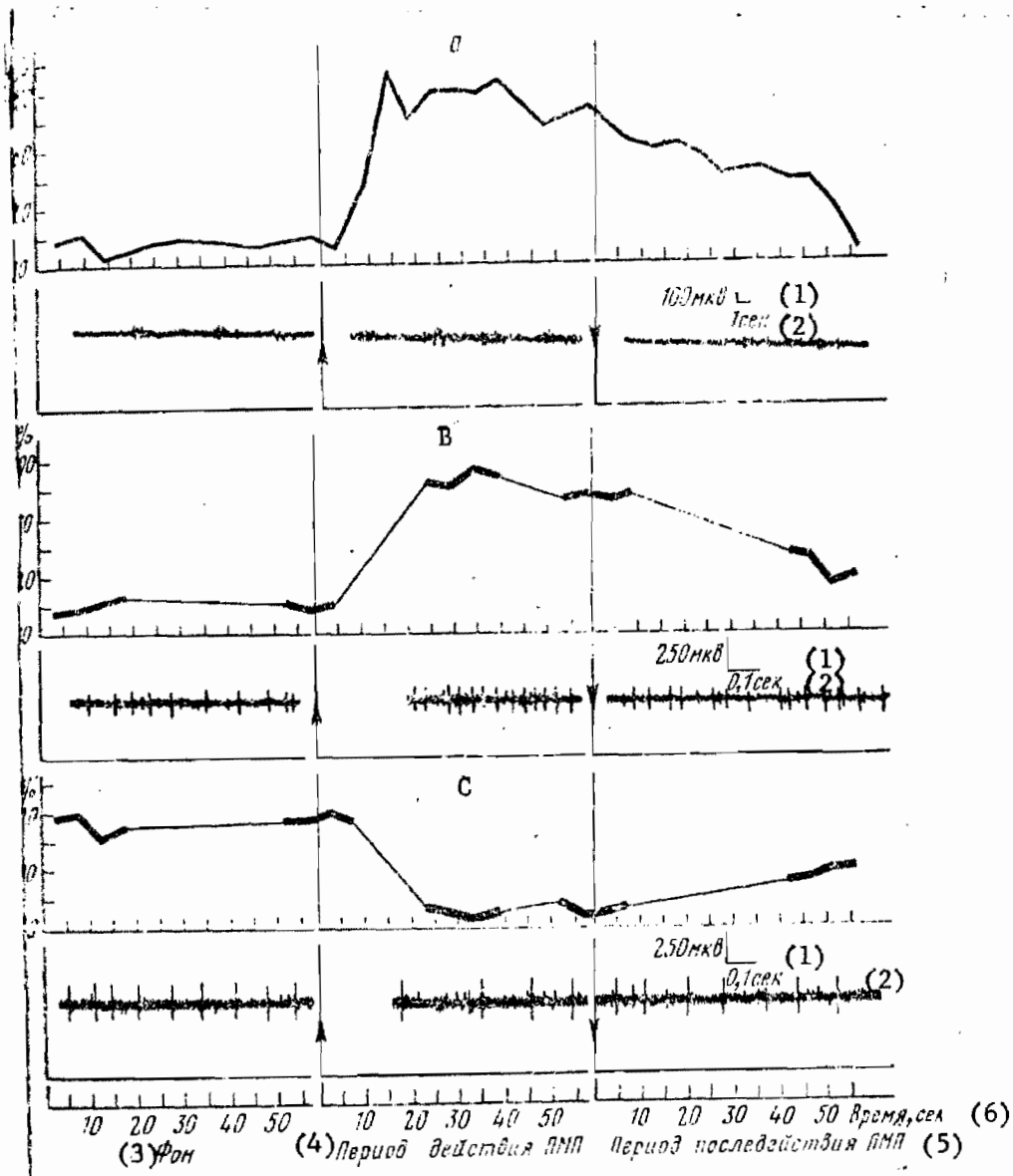
Figure 29. The Dynamics of the Number of Spindles (a) and the
Number of Neuron Discharges (b,c) in Registering the Electric
Activity of the Hypothalamus Before, During, and After the
Exposure of the Rabbit's Head to a CMF of 1,000 Oersteds.
Abscissa -- changes in the indexes, percent; Ordinate -- time,
seconds; thick lines -- recording time of the spike activity
of neurons; arrows indicate the moments when the electromag-
net was turned on and off. Separate recordings of the processes
are shown.

Key: 1. Microvolts
2. Second
3. Background
4. Period of CMF action
5. Period of CMF aftereffects
6. Time, seconds

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A more detailed analysis of another series of experiments showed that a CMF could not only intensify the reaction of the neurons to light, but also to inhibit it, influencing the latent period of the response and the length of of the inhibition pause [56]. Consequently, the corrective effect of a CMF at the neuron level shows itself in a more variety of ways than at higher levels of the organization of the reaction.

In studying the effects of CMF, light, and sound, as well as combinations of these stimuli on the same neurons of the optic cortex, it was found [56] that the influence of a CMF on the activity of the neurons caused by light was observed in 53 percent of the cases and more frequently (30 percent) was of inhibitive nature. The influence of CMF on the sound response showed itself with the same frequency (53 percent), but the intensities of the inhibitive effect were higher, leading sometimes (7 percent) to the disappearance of the reaction to sound in the presence of CMF. Inhibiting reactions also prevailed during the MF action in complex reactions of the neurons to sound + light.

Thus, MF changes reversibly both the spontaneous and the induced activity of neurons. When the background activity changes, the ratio of the excited neurons to the inhibited neurons under the effect of MF is approximately 1:1, but in the case of induced activity this ratio reaches 2:3, indicating more expressed inhibition during the corrective action of MF in comparison with the triggering action. This corrective effect on the neuron activity is of nonspecific nature which similarly affects the reactions caused by stimuli of various modality.

Recordings of the impulse activity of neurons in an isolated strip of the cortex confirmed that data obtained by means of macroelectrodes regarding the existence of electric activity of neurons in neuronally isolated structures and regarding a greater reactivity of a strip to MF in comparison with a complete brain. However, the isolated section of the cortex preserved its humoral connection with other sections of the brain which were also subjected to the CMF action. In order to study the direct reaction of the cortex, mini- ature constant magnets with an MF intensity near the surface of the poles of up to 200 oersteds were attached with styracryl for 2-40 days to the bone above the sensomotor region of five rabbits. It was found that the EEG of the section in direct proximity of the magnet differed from the EEG of other sections of the cortex by the predominance of slow high-amplitude oscilla- tions (Figure 30). Thus, local and prolonged influences of the MF caused local changes in the electric activity of the cortex.

It should be mentioned that, in registering the electric activity of the brain by means of macroelectrodes under the influence of MF there were more unambiguous changes than when microelectrodes were used. In the latter case, the reactions were expressed both as decreases and increases in the frequency of discharges. This fact made it possible to assume that, apart from neurons, other structural units of the nerve tissues were involved in the reactions of the brain to CMF. Moreover, under the effect of MF, neurons reacted with a long latent period unusual for them, which suggested that they were included

into the reaction for a second time. Since glial cells were a more inert formation of the brain tissue, it was important to study their participation in the responses of the brain to MF.
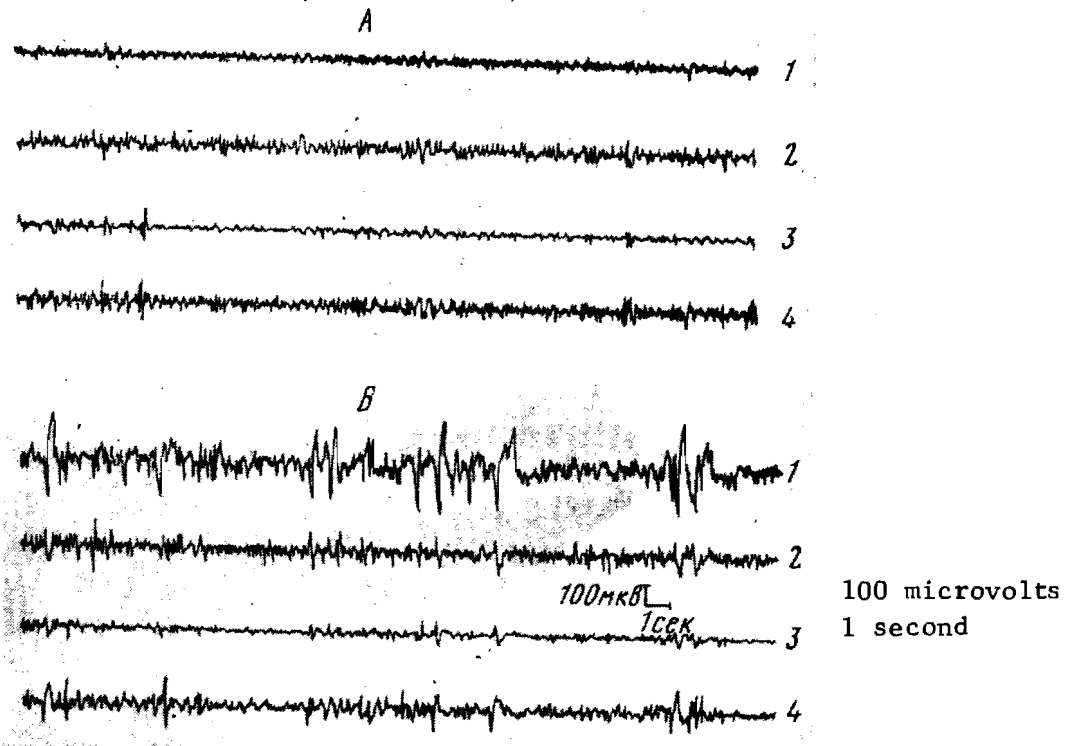
Figure 30. EEG of a Rabbit Before (A) and After (B)
Attaching the Magnet over the Left Sensomotor Region of the
Hemisphere Cortex.
1 -- left sensomotor; 2 -- left optic; 3 -- right sensomotor;
4 -- right optic region of the cortex.

It should be added that there were assumptions regarding the connection of glial elements with the generation of slow [159, 160, 181, and others) and superslow oscillations [2] in the electric activity of the brain. Recently, it has been established [322] that the appearance of spindles in EEG is accompanied by changes in the membrane potential in the glial cells. Thus, the general tendency among neurologists to consider the glioneuron complex as a single morphological structual unit of the CNS [314, and others] and the concrete changes in the EEG under the influence of CMF compelled us to study the role of glia in the CNS reactions to CMF.

In the studies conducted by us in cooperation with M. M. Aleksandrovskaya [3-7, 20, 49, 395], the reaction of neuroglia and neurons of the sensomotor region of the hemisphere cortex of animals exposed to a CMF of 200-300 oersteds was determined by morphological methods: astrocytes were stained by Cahal's and Snesarev's methods, oligodendrocytes -- by Aleksandrovskaya's method, and nerve cells -- by Nissl's method.

As early as 3 minutes after beginning of the action of the MF upon the rabbit's head, it was possible to see an increase in the number of stained astrocytes in the field of vision of the microscope from 9.0 ± 0.5 (control) to 16.7 ± 0.4 and an increase in the number of microglia from 11.5 ± 0.4 (control) to 19.7 ± 0.4. An increase in the number of oligodendroglia cells was also observed. Under the same conditions, neurons remained preserved, with a well expressed nucleus and nucleole and a clear tigroid substance.

One hour after the beginning of the CMF action, the rabbits showed a sharper increase (up to 23.0 ± 0.50) in the number of impregnated cells of astrocytal glia with hyperplasia and hypertrophy of bodies and processes. The number of calls of other types of glia increased also. Neurons remained intact.

The number of glial cells in rabbits and cats remained high in comparison with the norm 10-12 hours after the beginning of the action. There were perivascular and marginal gliofibrosis of astrocytes, and swelling of solid dendritic forms of oligodendroglia and hypertrophy of drainage glia. Neurons suffered reversible changes in the form of swelling and hyperchromatosis.

Productive-dystrophic disturbances of neuroglia with the swelling of oligodendrocytes and the appearance of drainage cells were observed in rabbits, cats, and rats 60-70 hours after the beginning of the action of the CMF. The picture of hypoxic encephalopathy with distrophic changes of both astrocytes and microglia was determined morphologically.

It is known that glia is sensitive to oxygen shortage [403]. On the other hand in analyzing the reactions of various biological objects to MF, many researchers observed changes in the processes of biological oxidation (see this collection.

Studying the changes in the frequency of contractions of an isolated heart of a frog under the effect of MF, Podshibyakin [20] observed that preparations which were in a state of some hypoxia reacted to an increase of the MF by 0.006 oersteds, i.e., to a value observed during some geomagnetic storms.

Taking into consideration that oxygen difficienty in the environment affects, first of all, the activity of the brain [144], we conducted experiments in oxygen want on 192 adult white mice in order to study the effects of CMF on oxidation processes. The animals were placed in hermetically sealed containers of various sizes and the time of their death in CMF was determined.

Table 24

Effects of a CMF of 400 Oersteds on the Time of Death of
Mice in a Sealed Container

Группы животных (1) (2) Условия опыта	(7) Контроль-ная	(8) Магнитные			
		I	II	III	IV
(3) Число мышей	30	30	30	30	12
(4) Время пребывания в ПМП (мин.) до герметизации со- суда	0	0	15	60	120
(5) Длительность жизни (мин.) в замкнутом сосуде	24,5±0,8	22,6±0,8	19,3±0,9	19,3±1,1	20,0±0,3
(6) Отличие от контроля по критерию Стьюдента (t)	—	1,7	4,3	3,7	5,6

Key: 1. Groups of animals
2. Experimental conditions
3. Number of mice
4. Time spent in CMF (minutes)
   before the sealing of container

5. Life span (minutes) in the
   sealed container
6. Difference from control by
   Student's criterion (t)
7. Control
8. Magnetized

Table 24 indicates that the stay of the mice in a CMF of 400 oersteds for 25 minutes did not produce any statistically significant effect. But when the length of the exposure was 35 minutes, statistically certain difference (P < 0.01) was observed in the life spans of the experimental and control animals. When the length of the action of the MF of 400 oersteds was increased to 80 and 140 minutes, the same effect as after the 35 minute exposure was observed.

A container of a small size (approximately one-half the size) was used in the experiments on the application of a CMF of 2,000 oersteds. This series of experiments showed that the average survival time of the control mice (30 animals) in a sealed container was 13.0+0.4 minutes, and that of the "magnetized" mice (30 animals), after they had been exposed for 15 minutes to the CMF, was 11.0+0.4 minutes (t = 3.5).

The CMF of 2,000 oersteds shortened the life span of the mice in the sealed container after 25 minutes.

It was found that MF of 400 and 2,000 oersteds acting in the course of a certain period of time shortened the life span of mice, on the average, by 15-20 percent.

Consequently, the action of MF of the selected intensities lowers the sta- bility of animals against oxygen difficiency. This reaction depends to some degree on intensity and length of the applied factor. It is possible that CMF, by causing tissue hypoxia in the brain, shortens the life span of animals under the oxygen-want conditions.

This assumption can be supported not only by the above-mentioned fact of the appearance of hypoxic encephalopathy, but also by the fact that the changes in the electric activity of the isolated strip of the hemisphere cortex and of the complete brain of the rabbit in experimental hypoxia [120] resembled the responses of the same brain structures under the effect of MF. However, in order to substantiate our conclusion in detail, it is necessary to determine the rate of oxygen consumption in the brain under the effect of CMF.

In studying trace reactions of various kinds of glia of the motor region of cerebral hemispheres of cats at various times after a 6-hour exposure to an MF of 200-300 oersteds, it was found that the increasing of the number of astrocytes had a wave-like characteristic, and particularly significant increases were detected 4 hours and 14 days after exposure. The increasing of the number of stained cells of other types of glia also had a wave-like characteristic, but had different time parameters.

An increase in the number of gliocytes around neurons was also observed in the intramural ganglia of guinea pigs several days after their exposure to a CMF of 7,000 oersteds in the course of 4-7 hours [161]. Increased affinity to silver after the exposure to MF was observed in nerve cells of the skin and the gastrointestinal tract of guinea pigs [162, 163].

It was characteristic that sometimes an expressed reaction of glia was combined with morphological intactness of neurons. This may indicate a predominant role of neuroglia in trace processes after a one-time action of weak alterative agents.

With regard to the physiological significance of the discovered trace changes in astrocytes, it is possible to assume that they are connected with the restoration process after the action of weak alterative agents and play a definite role in the responses of the CNS to the subsequent stimulation.

The ability of the structures of the nervous tissues to become impregnated with silver depends on the level of their oxidation-reduction potential. It is possible to assume that the observed changes in the amount of impregnated astrocytes do not reflect the true variations in the number of cells, but are connected with the changes in their metabolism, as a result of which a large amount of glial cells acquires the ability to become impregnated with silver. It is not ruled out that a certain increase in the number of astrocytes, particularly during later periods after the end of the MF action, may be a result of the amitotic division of these elements.

When we examine the obtained morphological data, we observe, first of all, the long duration of the changes in neuroglia. For example, 20 days after a single exposure to an MF, there still is an expressed reaction of astrocytes. The obtained results coincide with Gorshenina's observations [60], who discovered prolonged morphological changes in the CNS of guinea pigs after their 6-hour stay in a CMF of 200 oersteds.

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Increases in the number of neuroglia cells while the neurons are intact, the appearance of slow oscillations in the electric activity of the brain and the increase in the response to a light stimulus reflect, possibly, various aspects of the inhibitive process in the CNS under the effect of the MF. This hypothesis needs further experimental confirmation, but even at this stage of study it is possible to conclude that studies of the glioneuronal relations in the brain by the morphological method in combination with physiological methods may yield new interesting information regarding the intimate mechanisms of the development of basic nervous processes.

In his discussion of the biophysical mechanism of the MF influence on nerve cells, Valentinuzzi [402] came to a conclusion regarding the most probable action of MF on the alternating excitable axon zones. However, according to the calculated data, this effect is so small that it is possible to register such changes only in the case of multiplication and summation within the limits of many nerve elements. Becker [278] pointed out the semiconductor properties of the nervous tissues. It seems to us that it will be more promising to assume the presence of a general mechanism of MF action on any live cell (including nerve cells). Changes in the oxidation and nucleic metabolism become most important.

Concluding the survey of the data on the influence of MF on the nervous system, it should be mentioned that the use of the modern methods in the study of the CNS confirmed earlier conclusions regarding the fact that this system is particularly sensitive to MF. It is necessary to conduct further detailed studies on the dependence of nervous reactions on the length and intensity of MF, including very weak fields. Such studies are necessary for the practical needs of magnetohygiene, magnetotherapy and magnetoecology.

From the neurophysiological viewpoint, it was unexpected that glial cells, which are considered electrically unexcitable by many researchers, react more intensively to MF than neurons. The most trivial mechanism of MF influence, which allows for the induction electromotive force, becomes less important here. It is possible that biochemical or structural processes at a level of certain cellular or intracellular membranes are most sensitive to MF.

It is important to stress that the effect of MF on the CNS is not specific and resembles the effect of such penetrating factors as the radio-frequency EMF and ionizing radiation. On the other hand, this influence does not resemble the reaction to adequate stimuli. Consequently, MF can be rightfully used in neurophysiological laboratories as a special stimulus which will help in studying certain obscure properties of the CNS.

In connection with the above, it is appropriate to compare magnetobiological methods of studying the nervous system with the electrobiological methods. Two basic facts brought electrophysiology to the foreground of the neurophysiological studies. The first fact is connected with the possibility of locally influencing microsections of the brain with electric current by

means of implanted electrodes. The second fact is the possibility of registering bioelectric phenomena accompanying nervous processes.

Judging by the facts available today, MF have the above-mentioned properties of the electric current. The developing magnetophysiology of the CNS can utilize local effects of the MF on various sections of the nervous system for further studies on local and spreading processes. It has been shown recently that the spreading of a pulse along a nerve of a frog [317] and the cerebral activity in man [295] are accompanied by the appearance of MF. It is true, however, that the intensities of the discovered MF were not high. In the case of a magnetoencephalogram, they reach the order of 10^{-9} and require for their registration a special kind of screening from GMF and special amplifying equipment. However, the same problems were facing electroencephalography at the beginning of its development.

Thus, there are many reasons for the development of magnetobiological studies in neurophysiology but to achieve success in this field, intensive work of many researchers is required.

EFFECT OF MAGNETIC FIELDS ON EXPERIMENTAL TUMORS (DIRECT AND THROUGH THE NERVOUS SYSTEM)

[M. A. Ukolova and Ye. B. Kvakina, Rostov Scientific Research Institute of Oncology of the Ministry of Public Health RSFSR, Rostov-on-the-Don]

In the short period of time since the attention of researchers turned to the study of the effects of MF on the tumoral process [348], a sufficient amount of facts have been accumulated to consider such studies promising.

Antitumoral effects of CMF with various gradients, AMF, and PMF were discovered. By means of a CMF of 4,200 oersteds, Barnothy [267, 286] achieved disengagement of transplanted adenocarcinoma in mice. Gross [286] found that mice exposed to CMF 30 days before ⸱ transplanting a tumor survived longer. Experiments conducted in our institute with transplanted sarcomas 45,M-1 and cancer of mammary glands in rats (RMK) showed that CMF could intensify the antitumoral effect of irradiation and, at the same time, to weaken the development of the radiation syndrome [97]. It was observed that CMF inhibited the growth and reduced the yield of spontaneous tumors of mammary glands in C_3H strain mice [285, 358]. In earlier experiments [348], the action of AMF lowered the transplantability of Ehrlich's carcinoma. A high-frequency AMF of relatively low intensity (620 oersteds) in combination with an EMF caused total disappearance of a uterus tumor T-8 and lymphosarcoma [388-389]. Dem'yanko [180] reported recently on a considerably longer life span of mice with Ehrich's ascitic carcinoma in a PMF.

In all of these experiments, the entire organism of the animal was subjected to the MF action. Direct inhibitive effect of MF on a tumor was observed by us with physicist Khimich [210], when the tumor was surrounded by a magnetized wire ring. Cytostatic effects of MF were shown in a tissue culture [288, 363].

When the entire animal is placed in a MF, in addition to the direct effect of field on the tumor, the antitumoral effect may materialize through changes in the neuro-endocrinic functions of the organism. The role of these functions in the tumoral process is widely known [85, 184, 188, 196, 344]. However, no special studies have been done on the MF effects on the tumoral process through these functions.

Kholodov's experiments [216, 223, 224] on healthy animals showed that the hypothalamic region of the brain, which, as is known, unites the nervous and endocrinic regulation, was the most sensitive to MF. There have been reports that the hypophyseal-suprarenal system [180] participates in the reaction of an animal to MF. At the same time, the role of hypothalamus in the tumoral process has been defined recently. It was possible to cause the resolution of various experimental tumors by changing the functional state of this region by means of repeated electric stimulation through implanted electrodes [50, 121, 203, 209],

All this provided us with a basis for testing the possibility of MF action not only directly on tumors, but also through the central nervous apparatus capable of changing the metabolism of the entire organism.

Unlike the electric stimulation of the brain through implanted electrodes, MF has the advantage of a distant stimulant and, at the same time, of a local cytostatic factor.

We studied the action of MF separately on the tumor and on the head of an animal with a tumor, as well as the combined effect of the two factors. In the majority of our experiments we used AMF produced by a revolving permanent magnet with a frequency of two revolutions per minute.

I. Effects of a MF Applied to a Tumor

At first, the inhibition of the growth of experimental tumors was achieved by us and Khimich [210] with the use of weak ring-like steel-wire magnets magnetized in a coil through which short pulses of alternating currents from the city line were passed. The magnetized coils were attached with Mendeleeff's paste to the clipped skin of the rat around the tumor. We used rat sarcomas 45 and novocain-synestrol strains [208]. Rings left in this position for several hours caused a 60 percent resorption of small tumors (1 to 1.5 cm) in diameter . Nonmagnetized steel rings, as well as rings of copper or aluminum wire, did not affect the growth of tumors. Magnetized rings also did not have any effect on larger tumors. Therefore, we used a different method [121]. We used bar magnets with an induction of 500 gauss (the size of the bar 50 x 18 x 18 mm). The magnets were attached eccentrically on the shaft of a Warren's motor which rotated the magnet (at a rate of two revolutions per minute) above the tumor along its periphery (Figure 31, A). The animal was in a fixed position. The action of the magnet continued for 15-20 minutes daily or every other day. The magnetizing was done when the tumor reached Shrek's mean diameter of 0.7-1 cm.

In our experiments on white rats with novocain-synestrol sarcoma, the growth of the tumors was inhibited in all 11 experimental animals. This inhibition was noticeably expressed one week after the beginning of the exposure (mean diameter 1.3 ± 0.2 in comparison with 2.25 ± 0.8 in the control). Later, the tumors in 3 animals resolved completely.
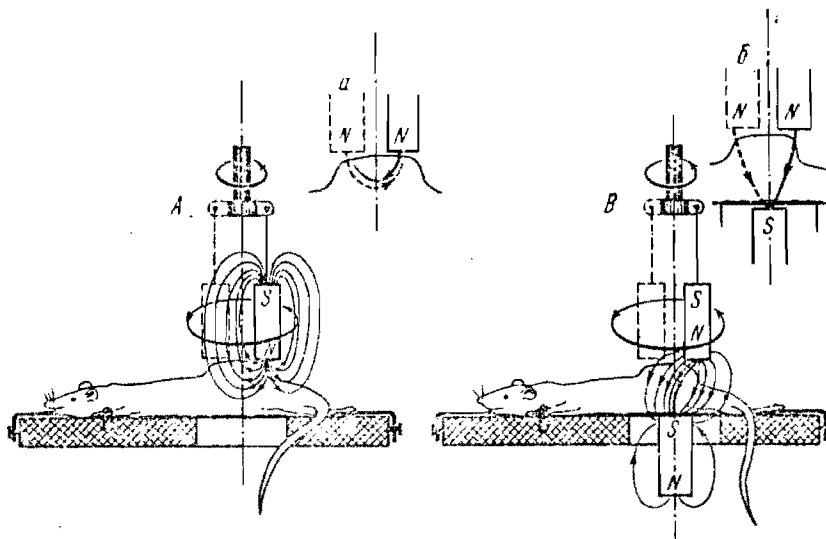
Figure 31. Variants of Tumor Magnetization.
A -- with one revolving magnet; B -- with a revolving
and a stationary magnet; a, b -- schemes of the changes
in the direction of the lines of force.

In rats with sarcoma 45, the inhibition of growth was less expressed, but
the life span of the animals was 1.5-2 times longer than that of the control
animals.

The best results of the magnitization of tumors were obtained on animals with
the first generations of sarcoma induced with 3,4-benzopyrene (sarcoma BP).
The tumors resolved in 9 out of the 13 experimental rats. In the remaining
rats, the growth of the tumors was sharply inhibited, and only one rat showed
progressive growth, just as in the 15 control animals. The results were of
the same type in all generations.

In order to intensify the antitumoral effect, we decided to concentrate the
MF around the tumor. To achieve this, in addition to the magnet revolving
over the tumor, we placed another stationary magnet under the tumor. Two
series of experiments were conducted: with sarcoma 45 and with V generation
of sarcoma BP. In both series, the same progressive growth was observed as
in the control. Some statistically uncertain inhibition of growth of sarcoma
BP was observed only when the magnetizing was started immediately after the
transplanting.

Evidently, the attempt to intensify the MF was ineffective. It can be seen
from Figure 31,A that when one revolving magnet was used there were changes
in the direction of the magnetic lines of force passing through the tumor
(every 1/2 revolution to the opposite direction). When a stationary magnet
was placed under the rotating magnet, the rotation of the upper magnet had
almost no effect on the direction of the field (Figure 31,B). In this case,
the field differed little from the permanent field.

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Since an AMF even of a low intensity and frequency has an inhibitive effect, it is possible to think of a nervous-reflex effect rather than of a direct cytotoxic effect.

II. Effects of Magnetic Field Applied to Tumors and to the Head ("General" Magnetization). Intensification of the Effect by Increasing the Magnetic Susceptibility and Reactivity of the Organism to MF

We used three types of magnetization in these experiments. One type was with the use of two permanent bar magnets with the induction of 300 and 600 gauss; the first magnet was installed in a stationary position near the head of a fixed animal, and the second rotated over the tumor. In the second type, a rotating magnet with the induction of 600 gauss was used for magnetizing the head, just as for the tumor. In this case the magnetizing was done successively: first the head, then the tumor (10 minutes each). The third type of magnetization consisted in placing the animal for 15 minutes every other day between the poles of a permanent magnet with a field intensity of 2,500 oersteds.

The experiments were done on mongrel rats and on the Vistar strain rats.

The first series of experiments -- with novocain—synestrol sarcoma and one type of magnetization -- showed a high percentage (up to 80 percent) of resolution of even large tumors consisting of conglomerates of nodes.

The first type of magnetization was also effective with respect to sarcoma BP.

However, this effect differed depending on the generation of the induced sarcomas used in the experiment. For instance, out of 13 rats of V and VI generations, the tumors resolved in 9 rats (in 4 rats, they grew as in the control), but in the VII generation, the tumors resolved only in 2 out of 7, and the growth was merely inhibited in 2 (tumors in 3 rats grew just like in the control). This relationship was even clearer when the second type of magnetization was used. No animal with sarcoma BP of VI or VIII generation showed resolution or inhibition of the tumor growth, while sarcoma of II generation resolved in 4 out of 5 rats. Thus, the antitumoral effect of the MF after "general" magnetization depended on the degree of the tumor "progression," i.e., the development of changes in the tumor leading to its relative autonomy in the organism.

Having obtained these results, we started working on increasing the magnetic susceptibility of the tissues and the reactivity of the organism.

In order to increase the magnetic susceptibility of the organism, we used reagents generating free radicals [121], which, as is known, have paramagnetic properties. It is believed that free radicals have radiomimetic effect [76, 367] connected with chromosomal rearrangement and the affection of the structure of live cells [76]. For the formation of free radicals we used
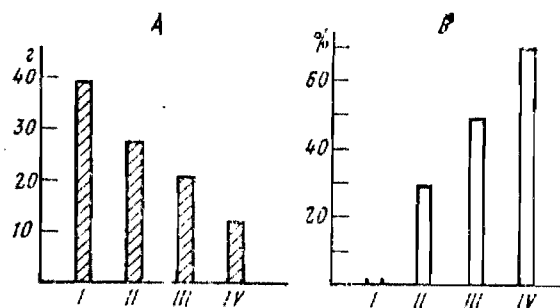
Figure 32. Growth Inhibition of Mammary Gland Cancer in
Rats Under the Effect of "General" Magnetization.
A -- average weight of tumors (grams) after 10 exposures
and introduction of a radical-forming reagent;
B -- percentage of growth inhibition of the mammary gland
cancer in rats in comparison to the control.
I -- control; II -- reagent; III -- magnetization;
IV -- magnetization against the background of the intro-
duction of reagent.

Udenfriend's reagent consisting of copper sulfate and ascorbic acid in a cer-
tain ratio. Under the effect of the reagent, hydroxyl radicals form first
from the water molecules [306, 373]. Then they react actively with organic
biomolecules, resulting in their radicalization: R:H+.OH → R.+HOH. Free
radical R. exixts longer than the primary water radicals [367]. The reagent
dissolved in 5 ml of distilled water in the amount of 0.0455 g $CuSO_4$ and
0.88 g of ascorbic acid was administered intravenously at a dose of 0.2 ml
before exposing the animal to the MF. The magnetizing was done with a re-
volving magnet over the tumor and a stationary magnet near the head. The
experiments were done on rats with transplanted cancer of the mammary gland
of rats and transplanted sarcoma BP [121]. Animals with mammary gland cancer
of rats were killed after 10 sessions of magnetization, and the tumors were
enucleated and weighed. Average weight of the tumors for each group and the
percentage of growth inhibition in tumors (T) were calculated by the formula
used for assessing the effectiveness of antitumoral preparations [108]
T = Bk-Bo/Bk · 100%, where Bk and Bo are the average weights of the tumors
in the control and the experimental group, respectively. The greatest growth
inhibition of the tumors (Figure 32) was observed in rats which had been
given the reagent and then magnetized (T=69.4%); it was less expressed in
the group which was only magnetized (T=49.7%), and still less expressed in
the group which received only the reagent (T=30%).

In the experiments with sarcoma BP, at first the tumors in rats of all groups
were growing. Then, the tumors of the experimental rats started growing
slower in comparison with the control rats (Table 25).

Table 25
Changes in the Size of Sarcoma BP-1 (by the 14th Day of Experiment)

(1) Характер воздействия	(6) Средняя разность объема опухолей (прирост за 14 дней)	(7) Ошибка средней разности, m	t	P
(2) Реактив + омагничивание	1,93	0,8	2,42	<0,05
(3) Омагничивание	4,9	1,54	3,18	<0,01
(4) Реактив	6,49	2,44	2,66	<0,05
(5) Контроль	10,58	2,34	4,53	<0,001

Key: 1. Nature of influence
     2. Reagent + magnetization
     3. Magnetization
     4. Reagent
     5. Control
     6. Mean difference in the size of tumors (increase in 14 days)
     7. Mean difference error, m

As can be seen from Table 25, on the 14th day of the experiment (which corresponded to 7 sessions of magnetization and the same number of reagent injections), the highest inhibition of tumor growth, just as in the experiments with mammary gland cancer of rats, was observed in the group of rats which had received the reagent and were magnetized; lesser inhibition was in the rats which were only magnetized, and still lesser of those which only received the reagent. At the same time, the tumors of the control animals were growing progressively.

After another 5-10 days, the tumors of rats with magnetization against the background of the reagent resolved in 100 percent of the cases, while the tumors in the rats which were only magnetized resolved in 60 percent of the cases, and in the rats which were given only the reagent -- in 35 percent of the cases.

The antitumoral activity of the radical-forming reagent which was revealed in this experiments along with the intensification of the MF effect is not unexpected and agrees with the modern concepts of the role of free radicals in the tumoral process [33, 48, 259, 260], according to which not only the inhibition but also the activation of free-radical processes could lead to the inhibition of tumor growth. It is not ruled out that free-radical reactions are also included in the mechanism of the antitumoral action of MF in the absence of artificially created excess of free radicals. This is in agreement with the existing notions regarding the influence of MF on free-radical reactions [286, 287]. In this case, one of the causes of definite sensitivity of tumor cells to MF could be the different levels of free radicals in them.

As for the increasing of the organism's reactivity to MF, we proceeded from the data [224] on the increase in the response of the hypothalamus and reticular formation to MF after the introduction of adrenaline. At the same time, adrenaline activating central nervous structures, has an antitumoral effect under certain conditions [34, 121].

The results of the experiments on the combined effects of general magnetization and adrenaline are given in Table 26. Adrenaline was administered in a 0.01 percent solution at 0.1 ml per 100 g of the rat's weight. As can be seen from the table, MF itself (without adrenaline) was most effective in the early II generation of sarcoma BP and much less effective in the VI, VII, and VIII generations, and AMF was more effective than CMF. It can also be seen that adrenaline intensified the antitumoral effect of "general" magnetization on the later sarcoma generations and did not change it almost at all with respect to the II generation.

Table 26

Influence of Adrenaline and "General" Magnetization
on the Growth of Sarcoma BP of Various Generations

(1) Вид воздействия	(8) Генерация опухоли	(9) Число животных в группе	(10) Количество рассосавшихся опухолей	(11) Количество тормозящихся опухолей	(12) Количество растущих опухолей
(2) ПМП напряженностью 2500 э	II	5	2	1	3
	VII	4	—	—	3
(3) ПМП напряженностью 2500 э + адреналин	II	4	2	—	2
	VII	7	6	1	—
(4) Омагничивание головы и опухоли вращающимися магнитами	II	5	4	—	1
	VI и VIII	6	—	—	6
(5) Такое же омагничивание + адреналин		7	4	1	2
		8	5	—	3
(6) Адреналин	II	5	2	—	3
	VI и VIII	9	—	—	9
(7) Контроль	II	4	—	—	4
	VII	5	—	—	5

Key:
1. Kind of influence
2. CMF of 2,500 oersteds
3. CMF of 2,500 oersteds + adrenaline
4. Magnetization of the head and tumor with revolving magnets
5. Same magnetization + adrenaline
6. Adrenaline
7. Control
8. Tumor generation
9. Number of animals in the group
10. Number of resolved tumors
11. Number of inhibited tumors
12. Number of growing tumors

Thus, adrenaline improved the antitumoral effect of MF with "general" magnetization in those cases when this effect itself was weak.

Special experiments on the influence of adrenaline on the effect of the magnetization of tumors showed that adrenaline did not change the MF effect in those cases. At the same time, as will be shown in the next section, adrenaline improves considerably the antitumoral effect of MF applied to the head. Just as in the experiments with "general" magnetization, the intensification of the effect of head magnetization by adrenaline occurs also when the MF effect itself is weak. This interesting phenomenon connected with the nature of the influence of adrenaline and MF on CNS needs further studies.

The experiments on "general" magnetization alone and in combination with adrenaline and with chemical generators of free radicals were also done on tumors induced in Vister strain rats with 3,4-benzopyrene. For a radical-forming reagent, we used Fenton's reagent consisting of $FeSO_4$ and H_2O_2 in centinormal solutions. The experiments were done on 15 rats with well-formed tumors which had been given 4 months before two injections (with a 1-month interval) of 3,4-benzopyrene in peach oil, 2 mg of cancerogen per injection. The rats were divided into four groups: I -- AMF, II -- AMF + adrenaline, III -- AMF + Fenton's reagent, IV -- control. The exposure to the AMF was done every other day for 10 minutes consecutively, first the head, and then the tumor. One month after the beginning of the magnetization, the average size of the tumors in the control rats was 33.7 ± 9.2, in rats of group I -- 2.47 ± 1.11 ($p < 0.02$), in rats of group II -- 8.9 ± 7.6 ($0.1 > p > 0.05$), and in rats of group III -- 3.59 ± 2.6 ($p < 0.05$) (Figure 33). Thus, during the first month of the experiment, there was a sharp inhibition of the growth of the induced tumors in the rats of all experimental groups. However, then all tumors, except one, started growing intensively just as the control tumors did earlier.

The results of the experiments described in this section showed that an AMF of relatively low intensity and frequency applied to the tumor and to the head of the animal ("general" magnetization) caused a considerably greater inhibition of the growth of experimental tumors than a high-intensity CMF. It was possible to intensify the antitumoral effect of "general" magnetization with reagents generating free radicals, as well as by the application of adrenaline. Inhibition of the growth of tumors induced with 3,4-benzopyrene was achieved, which showed that, in principle, MF could influence not only transplanted but also induced tumors.
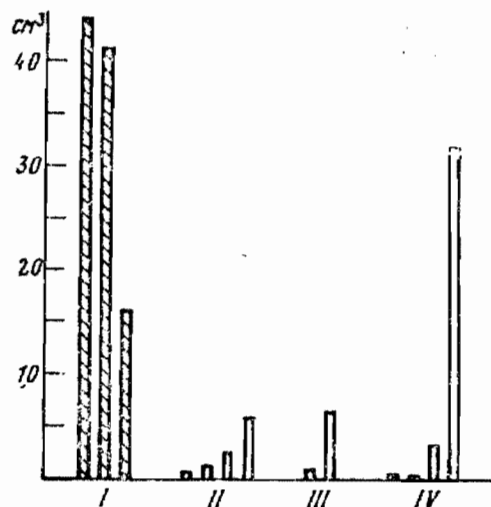
Fig. 33. Growth Inhibition in Induced Tumors by the End
of the First Month of Influences (tumor size in cm^3
according to Shrek)
I -- control; II AMF on the head and tumor; III -- AMF
on the head and tumor + Fenton's reagent; IV -- AMF on
the head and tumor + adrenaline.

III. Effects of MF Applied to the Head

The experiments were conducted on mongrel rats and the Vistar strain rats.
When magnetizing the heads of the animals, the possibility of the spreading
of the MF influence on the tumor was practically nil, because the distance
to the tumor from the magnet over the head exceeded several cross sections
of the magnet. Nevertheless, in some of the experiments the body of the rat
was screened with a strip of steel. Brass bars were used for the control
rats instead of bar magnets.

In a number of experiments, the exposure to MF was started 1-2 weeks before
the transplanting of tumors. As can be seen from Table 27, the MF effect,
regardless of the beginning of exposure, was similar (experiments with sar-
coma before the IX generation). Just as in the case of general magnetization,
the results of the MF influence depended on the generation of the tumor.

Up to the IX sarcoma generation, the effect was the same: the tumors re-
solved in almost half of the cases (in 13 out of 28). No resolution was ob-
served in the rats of the IX generation, but only inhibition was noted in a
smaller number of animals. The use of adrenaline was highly effective when
the MF effect was weak (IX generation of sarcoma). The MF without adrenaline
did not resolve tumors of the IX generation in any of the cases, while the
combination of MF and adrenaline resolved them in 6 cases out of 10 (Table
27).

Analogous data (intensification of the magnetization effect by adrenaline)
were obtained with a transplanted tumor of rat ovaries (a strain derived
from an intrasplenic tumor of the ovary by the Biskind method). Inhibition

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of these tumors was observed chiefly when the AMF action on the head was com-
bined with adrenaline. The latter, however, did not improve the effect of
the magnetization of the head and the tumor.

Table 27
Effects of MF Applied to the Head on the Growth of Sarcoma BP

(1) Вид воздействия	(7) Генерация опухоли	(9) Число животных в группе	Кол-во рассосавшихся опухолей (10)	Кол-во тормозившихся опухолей (11)	Кол-во растущих опухолей (12)
(2) Омагничивание головы до перевивки	VI	18	8	5	5
(3) Омагничивание при развившейся опухоли	До IX гене-рации (II, VI,VII,VIII) (8)	28	13	5	10
	IX	9	--	2	7
(4) Омагничивание головы + адреналин	До IX гене-рации (8)	16	7	3	6
	IX	10	6	1	3
(5) Адреналин	II и VI	6	2	1	3
(6) Контроль	—	14	—	—	14

Key: 1. Kind of influence
2. Magnetization of the head before the transplantation
3. Magnetization during the development of tumors
4. Magnetization of the head + adrenaline
5. Adrenaline
6. Control
7. Tumor generation
8. Before the IX generation
9. Number of animals in the group
10. Number of resolved tumors
11. Number of inhibited tumors
12. Number of growing tumors

The attempt to intensify the effectiveness of the magnetic action by concen-
trating the MF failed, just as in the case when the tumor was magnetized
(see Section I). The growth of sarcoma BP in these experiments did not dif-
fer from the growth of sarcoma in the control rats. Evidently, the fact that
the magnet revolved was also important for the action applied to the head.

Thus, it was possible to influence the growth rate of tumors by means of MF
applied only to the head of the animal. The data on the role of the hypo-
thalamic region of the brain in the tumoral process and on the high reacti-
vity of the hypothalamus to MF given above make it possible to assume that
the facts obtained by us regarding the inhibition of the growth rates of tu-
mors after magnetizing the head can be connected with the MF effect on the
hypothalamus. The intensification of the antitumoral effect of the

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magnetization of the animal's head also indicates the participation of the reticular formation of the brain in this process.

IV. On the Mechanism of the MF Effect on a Tumor under the Conditions of a Complete Organism

The fact of the inhibition and resolution of tumors under the action of AMF on the head of an animal indicates the role of the nervous system in the mechanism of the antitumoral influence of the "general" exposure to MF.

In order to establish the role of hypothalamus in this influence, we studied various aspects of the functional state of the hypothalamic region under the effect of MF.

In experiments with G. Ya. Chernyavskaya, we studied tissue respiration, oxidative phosphorylation, anaerobic and aerobic glycolysis of the hypothalamus and the adjacent sections of the thalamus in rats of various experimental groups. The results of the experiments are shown in tables 28 and 29.

<div align="center">

Table 28

Tissue Respiration and Oxidative Phosphorylation in the Hypothalamic Section of the Brain under the Effects of AMF

</div>

$t = +28°$ C	(5) Интактные (без опухоли)	(6) Интактные после воздействия МП	(7) Рассасывание после воздей- ствия МП	(8) Рост после воздействия МП
(1) QO₂ за 1 час, мкM на 1 г сырого веса ткани	50,6±1,9	63,4±2,6	64,0±2,16	54,2±3,44
		$P < 0,001$		$P < 0,05$
(2) Число животных	31	11	11	5
(3) АТФ + КФ через 30 мин. инкубации, мг%	6,0±0,3	7,1±0,5	9,8±0,4	4,4±0,3
		$0,05 < P < 0,1$		$P < 0,001$
(2) Число животных	19	9	8	3
(4) Эстерификация НФ за 30 мин., мг%	9,5±0,45	9,8±0,63	10,4±0,4	7,5±0,42
		$P > 0,5$		$P < 0,001$
(2) Число животных	19	11	10	5

Key:
1. QO₂ in 1 hour, μM per 1 gram of raw tissue weight
2. Number of animals
3. ATPh (adenosine triphosphate) + CPh (creatine phosphate) after 30 minutes of incubation, mg percent
4. Esterification of NPh in 30 minutes, mg percent
5. Intact (without tumors)
6. Intact after exposure to MF
7. Resolution after exposure to MF
8. Growth after exposure to MF

Table 29

Anaerobic Glycolysis (in 1 hour in μM of Lactic Acid per 1 g of Fresh weight) in the Hypothalamic Region of the Brain in White Mongrel Male Rats Under the Effect of AMF

$t = +28°$ C	(4) Питательные (без опухоли)	(5) Питательные после воздействия МП	Рассасывание саркомы БП после воздействия МП (6)
(1) Анаэробный гликолиз	45,8±1,47	50,0±1,82	47,8±1,8
		$0,05 < P < 0,1$	
(2) Число животных	20	9	6
(3) Аэробный гликолиз	14,8±0,66	40,1±2,86	42,5±1,7
		$P < 0,001$	
(2) Число животных	21	11	7

Key: 1. Anaerobic glycolysis
2. Number of animals
3. Aerobic glycolysis
4. Intact (without tumors)
5. Intact after MF action
6. Resolution of sarcoma BP after MF action

It follows from Table 29 that AMF increase the glycolysis in the brain, particularly aerobic glycolysis. The same stimulation of the carbohydrate-phosphorus exchange occurs during the resolution of tumors under the effect of MF with the difference that phosphorylation increases more than in the intact rats. But when MF did not cause any inhibition of the tumor growth, both the respiration and the phosphorylation were sharply lowered (Table 28). A growing tumor inhibits brain metabolism, including the energy metabolism. When an MF is capable not only of removing this inhibition, but also to cause the activation of these processes in the hypothalamus, then a higher functioning level of higher vegetative and endocrinal centers is ensured.

Together with Ye. S. Kotlyarevskaya we studied the susceptibility of nerve structures of the hypothalamus to electric stimulation through implanted electrodes. The irritibility was determined by the irritability threshold causing the motor reaction in the animals [135]. The threshold irritability value was measured in units of current intensity. It was found that even a single application of AMF to the heads of intact rats caused a considerable decrease in the threshold (Table 30).

Consequently, AMF applied to the head increases the irritability of the hypothalamus. The influence of MF on the functional state of hypothalamus was mentioned by Kholadov [223, 224] on the basis of electroencephalographic data.

Since the regulation of the metabolic functions of the organism on the part of the hypothalamus is accomplished by two routes -- through the vegetative

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Table 30
Changes in the Irritation Thresholds of the Hypothalamus in Rats under the Effect of Single AMF Application to the Head

(1) № крысы	Локализация электродов (2)	Величина порога до воздействия, мкА (7)	Величина порога после воздействия, мкА (8)	Уменьшение порога (9)		M средняя разность величины порогов, % (11)	m	t	P
				абсолютное, мкА (10)	%				
1	Аркуатное ядро гипоталамуса (3)	40	10	30	75				
2	Супрамаммиллярное ядро (4)	16	5	11	68,8				
3	Латеральная гипоталамическая область (5)	30	16	14	46,7	61,5	4,4	11,7	<0,001
6	Латеральная гипоталамическая область (5)	30	13	17	56,7				
8	Дорзальное гипоталамическое ядро (6)	31	10	21	67,7				
11	Латеральная гипоталамическая область (5)	35	16	19	45,7				

Key: 1. Number of the rat
2. Localization of electrodes
3. Arcuate nucleus of the hypothalamus
4. Supramammillary nucleus
5. Lateral hypothalamic region
6. Dorsal hypothalamic nucleus
7. Threshold value before exposure, μA
8. Threshold value after exposure, μA
9. Threshold decrease
10. Absolute, μA
11. M average difference of threshold values, percent

part of the nervous system and endocrine glands -- it is possible to expect that MF action on the hypothalamus will change the state of both links. This is supported by the data of our experiments with adrenaline which were cited earlier. In order to have some idea of the role of the cholinergic link in the mechanism of the MF influence on the hypothalamus, we conducted studies together with L. M. Aref'yeva on the cholinesterase content (by Khestrin's method) in the blood of intact rats subjected to the AMF action on the head. It was found that directly after this the cholinesterase level in the flood rose to 32 percent, and after 6 hours the cholinesterase content returned to the initial level. In order to reveal the routes of the spreading of MF effects from the hypothalamus to the organs and tissues of the organism, we selected the SH-groups, which, on the one hand, are the functional groups of the cellular reactive systems, including the cholinoreceptory system [204],

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and, on the other hand, are the points of application of the action of many hormones [50, 58]. The most expressed changes in the total number of SH-group (in amperometric titration) were found in the thyroid gland when the heads of intact rats were exposed to AMF (increase from 1.75 to 3.0 μM SH per 100 mg of fresh weight, and sufficiently clear changes were present in the suprarenal glands (decrease from 4.85 to 3.25 μM).

It was interesting to make a direct study of the state of endocrine glands in animals after the resolution of tumors under the MF influence. For this purpose, we conducted histochemical studies in cooperation with Yu. N. Bordyushkov and G. Ya. Mar'yanovskaya on the anterior lobe of the hypophysis controlling the functions of the peripheral glands. The staining of the hypophyses by the Purvis-Grisbakh method and with aldehyde-fuchsin by Mayorova's method revealed a large number of thyreotropic cells in the hypophyses of rats with tumors which resolved after the AMF action on their heads (Table 31). Similar changes in the hypophysis structure were observed by Yu. N. Bordyushkov when tumors resolved under the effect of electrical stimulation of the hypothalamus [121].

Table 31
Changes in the Cellular Composition of the Hypophysis under the Influence of AMF (per 200 cells)

№ препа-рата (1)	Воздействие и результаты (2)	Переход-ные клетки (7)	Фоллику-лостиму-лирующие гонадот-рофы (8)	Лютео-трофы (9)	Тирео-трофы (10)
802	ПеМП на голову, интакт-ная (без опухоли) (3)	134	39	22	5
845	ПеМП на голову, расса-сывание опухоли (4)	61	51	64	24
859	ПеМП на голову, рост опу-холи (5)	124	53	22	4
853	Контрольная крыса с рас-тущей опухолью (без МП) (6)	127	37	33	3

Key: 1. Number of preparation
2. Action and results
3. AMF on the head, intact (without tumor)
4. AMF one the head, resolution of tumor
5. AMF on the head, growth of tumor
6. Control rat with growing tumor (without MF)
7. Transitional cells
8. Follicle-stimulating gonadotropic cells
9. Luteotropic cells
10. Thyreotropic cells

Since the determination of the SH-group and the study of the cellular composition of the hypophysis advanced the thyroid gland to a special place in the process of the antitumoral influence of AMF through the brain, we considered it necessary to study the thyroid gland histologically. The results of this study revealed that, when MF caused the resolution of the tumors, the thyroid gland showed the signs of hypersecretion (Figure 34). However, if the tumor grew in spite of the MF action, then the histological picture showed secretion stasis (Figure 35). It is known from published reports that tumor growth is accompanied by inhibition of the function of the thyroid gland, and this gland is classed with systems having antiblastic effect [12].
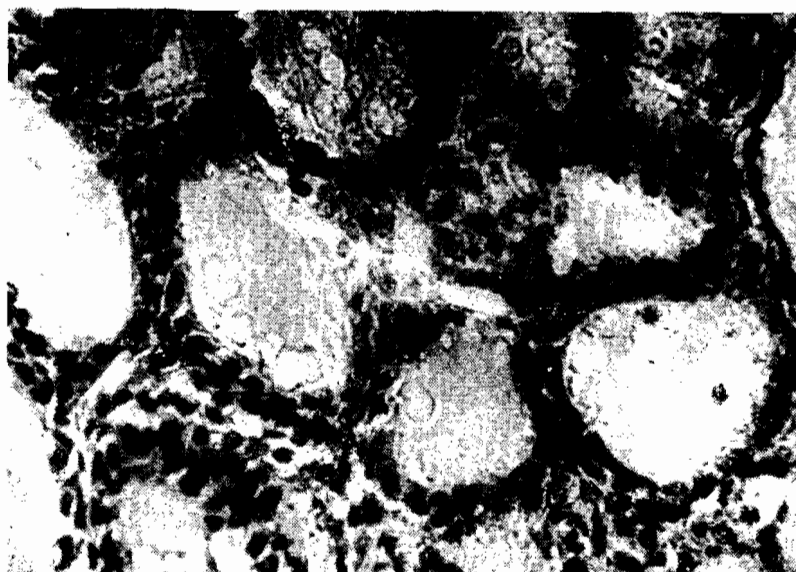
Figure 34. Thyroid gland of a rat with a tumor resolving under the AMF action on the head. Rounded nuclei are the nuclei of the follicular epithelium; considerable vacuolization of the colloid. Hematoxylin-eosin, 40 x 7.

The participation of the thyroid gland in the antitumoral influence of MF is, evidently, accomplished not only through the manifold changes in the organism's metabolism. The hormones of the thyroid gland directly influence the lymphatic system [307], as well as through the thymus, causing its hyperplasia [311]. It follows from this that the increased secretion of the thyroid gland under the effect of the MF must also raise the function of the thymus, which plays an exceptionally important role in immunity [122]. We observed the state of the thymus in animals with tumors exposed to MF. In fact, during the inhibition of tumor growth, the thymus weighed more; but if the growth of the tumor progressed, the thymus weighed less (Figure 36).

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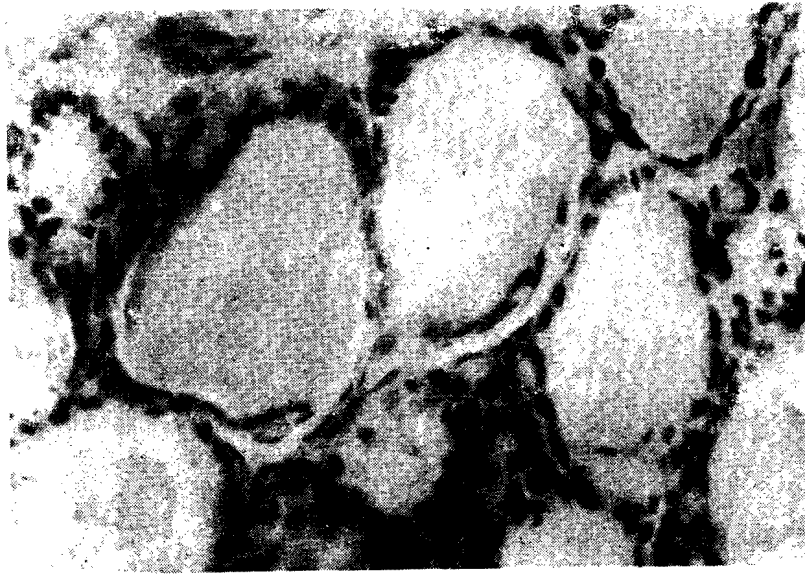
Figure 35. Thyroid gland of a rat with a growing tumor in
the absence of the MF influence. Epithelial nuclei are flat,
follicle are stretched by the colloid. Hematoxylin-eosin,
20 x 7.

Thus, through the hormones of the thyroid gland, the thymus is included in
the mechanism of the antitumoral influence of MF. An increase in the size
of the thymus was observed in out laboratory during the resolution of tumors
under the effect of electric stimulation of the hypothalamus [121]. It is
possible that the thyroid gland played a role in this case too.
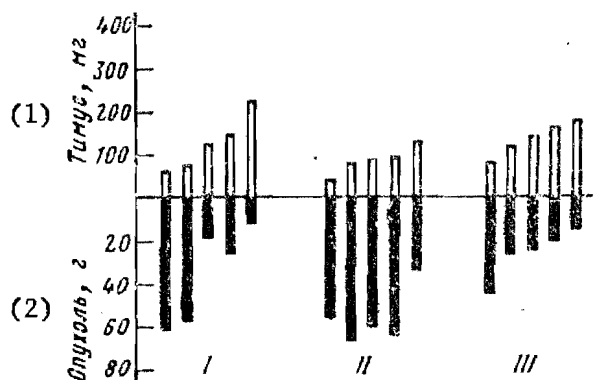
Figure 36. Relation between the size of the tumor and the
thymus during the inhibition of tumor growth by AMF and AMF
with adrenaline.

I -- AMF on the head and tumor; II -- AMF on the head and
tumor + adrenalin; III -- AMF on the head + adrenaline.
Key:
1. Thymus, mg
2. Tumor, g

The problem of how hyperplasia of the thymus under the MF effect reflects
on the apparatus of immunogenesis requires special study, particularly be-
cause the data on the MF influence on immune responses are contradictory
([180, 287], see this collection).

Barnothy [286], who obtained the rejection of transplanted tumors of mammary
glands in mice, treats this process (by analogy with the rejection of hetero-
transplants by tissues) as a result of transplantation immunity.

In our experiments with MF, we have never encountered "rejection" of tumors.
If the MF action was effective, the tumors began to diminish in size, first
slowly, then faster and faster. When the tumor was approaching the initial
size, then, after 1-2 days, it was impossible to measure it, or sometimes
to feel it. Only in studying the subdermal cellular tissue, we found a small
solid tissue formation. Histological studies showed the growth of connective
tissue in place of the former tumor (Figures 37 and 38). Moreover, in all
instances it was possible to see an elevated rim of lymphocytes along the
periphery, and sometimes infiltration in the center of the preparation
(Figure 38).

Figure 37. Sarcoma BP (II generation). Well growing
round-celled sarcoma with mitosis patterns. Hematoxylin-
eosin, 40 x 7.

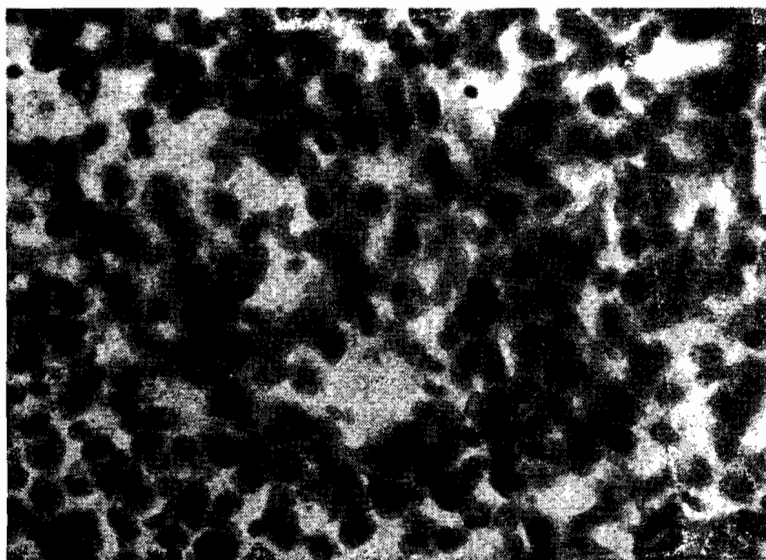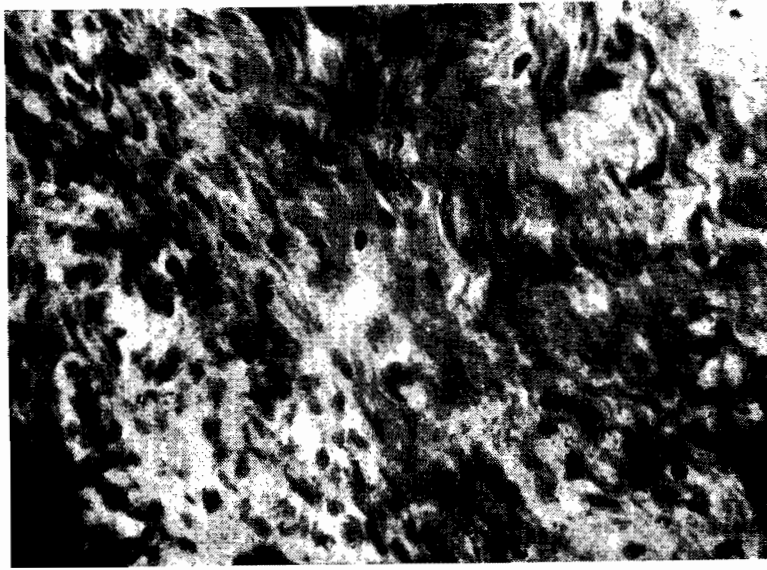Figure 38. Sarcoma BP on the 14th Day after Exposure to AMF. Between the cords of the tumor cells with degenerative changes -- growth of connective tissue and lymphocyte infiltration. Hematoxylin-eosin, 40 x 7.

Although in our experiments we used not only mongrel rats, but also Vistar strain rats, on which we obtained and transplanted tumors induced with a cancerogen, we connot rule out the role of transplantation immunity intensified by MF in the resolution mechanism of these tumors. However, the obtained growth inhibition of the initially induced tumors by MF suggests another mechanism of antitumoral resistance*.

In essence, studies on the MF effects on the tumoral process have just started. This particularly refers to the mechanism of this influence.

The mechanism is, evidently, similar to the mechanism of antitumoral stimulation of the hypothalamus of "average force (dose)"causing the development of general nonspecific adaptation "reaction of activation" described in our laboratory by L. Kh. Garkavi [121]. Unlike the adaptation "stress" reaction, this reaction is characterized not by a decrease in the size of the thymus, but by an increase, and not by a lowering, but by an increase in the mineralocorticoid function of the suprarenal gland, and in the functions of the thyroid gland and the gonads. Moreover, according to Yu. N. Bordyushkov's

*Recently, we have completed a series of experiments with sarcomas induced with 3,4-benzopyrene, where we used the same AMF (2 rpm), but with a longer exposure. As a result, the tumors of 5 out of 12 experimental rats resolved completely:four rats received MF on the head, and one on the tumors.

data, during the "activation" reaction, there is not only increased production of the adrenocorticotrophic hormone as during the "stress" reaction, but also of all tropic hormones of the hypophysis.

From this viewpoint, antitumoral effect can be obtained by means of the action of various magnetic fields which by themselves or in combination with other effects are capable of producing the development of the "activation reaction." When, in spite of all these effects, the "activation reaction" did not develop, tumors continued to grow. Therefore, the different reactivity of the organism to the same MF should be kept in mind.

On the basis of our experiments on combined effects of MF with radical-forming reagents and with adrenaline, we believe that, apart from searching for the optimal MF parameters, it is possible to test the means intensifying the magnetic susceptibility of living organisms.

In conclusion, it is possible to say that the understanding of the mechanism of the antitumoral effect of MF, which is one of the manifestations of its biological influence, will be facilitated by studies in the MF influence at various levels -- submolecular, molecular, cellular, organic, and at the level of the organism. Our studies at the level of the organism revealed an increase in the functional state of the CNS, particularly hypothalamus, which caused activation of its vegetative and endocrinal links and resulted in the inhibition of the tumoral growth.

CLINICO-HYGIENIC AND EXPERIMENTAL DATA ON THE EFFECTS OF MAGNETIC FIELDS
UNDER INDISTRIAL CONDITIONS

[A. M. Vyalov, Moscow Scientific Research Institute imeni F. F. Erisman,
Moscow]

In the last 20 or 30 years, the sphere of application of magnetic materials
and magnetic units in the national economy and research has broadened notice-
ably. In this connection, the intensity and the area of the spreading of
magnetic fields are growing considerably.

There are reports that there are magnetic units in the Soviet Union which
are used on the principle of superconductivity and make it possible to ex-
cite fields of 100,000 and more oersteds in the gap of the electromagnet,
and some units can excite a PMF of even 25 million oersteds. All this re-
sults in the fact that there are more and more workers who, by nature of their
industrial and scientific activities, can be subjected to the effects of MF
of average or even high intensity. The data of numerous experimental pro-
jects on the biological effects of MF show convincingly that MF (in a broad
sense) have harmful effects on the whole organism, single physiological sys-
tems, organs and tissues, as well as on plants and bacteria ([19, 103, 104,
106, 168, 201, 223, 261, 280, 286, 329], this collection, and others). It
should be considered that the significance of MF as a factor of the indus-
trial environment has increased noticeably in recent years. At the same time,
the broad circles of hygienists, occupational pathologists, public health
physicians and also plant and factory physicians still do not have any liter-
ature available to them on this problem and normative materials on labor hy-
giene and prevention of harmful MF effects on people working in industry and
research institutions.

Publications on magnetobiology contain some contradictory viewpoints. For
example, some authors [63, 330, and others] state that CMF does not have any
biological effect, while some others, which have been mentioned above, dis-
agree with them. Evidently, there are many reasons for this. The most im-
portant among them are the following: 1) better technical equipment and me-
thods available to modern researchers; 2) the works of the last century and

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beginning of this century chiefly described the effects of low intensity MF, while the latest studies are done more frequently with stronger MF; 3) finally, the results of numerous experimental studies of recent years sometimes do not make it possible to compare and generalize the results because of great differences in the biological objects used and the physical parameters of MF. Consequently, this does not facilitate the understanding of the mechanism of MF action, which, evidently, is not of the same type in different ranges of their intensities.

Clinico-hygienic studies of MF have been conducted in the Moscow Scientific Research Institute imeni Erisman since 1961 [49, 52-54]. Studies have been done on the labor conditions and state of health of workers who in the process of their productive activity come in contact with magnetic materials or are subjected to the action of MF excited by magnetic devices. Studies were done in the industry of permanent magnets and in the machine-building industry. In the permanent magnet industry, studies were done on the working conditions and state of health of laboratory controllers and heat treatment workers, and in the machine-building industry -- on controllers engaged in magnetic flaw detection and grinders. The work was done at enterprises in a number of cities.

Various metal products are magnetized and unmagnetized by means of CMF, AMF (50 hertz), and PMF. The values of MF intensity at various distances away from magnetic devices and permanent magnets in the magnet industry and the machine-building industry are given in Table 32.

As can be seen from the table, the highest intensity near the electromagnets was observed in the case of laboratory controllers when they test and check magnetic materials; somewhat lower intensity was found in the case of controllers engaged in magnetic flaw detection; a still lower level was near grinding machines, and the lowest MF effects were found for thermal treatment workers. Periodically (up to 10-15 percent of the working time), when safety precautions are not observed, these MF levels may rise 10-50 times. Usually, the intensity gradient was 5-20 oersteds/cm. At a distance of 0.5-1.5 m from the machines and permanent magnets, the MF intensity reached background values. Workers' hands are exposed to the most intensive MF action.

The maximum intensity of AMF (50 hertz) used in these industries does not exceed 1,000 oersteds. According to calculations, the PMF intensity is not high: at the hand level, it is from 20 to 50 oersteds, and at the head and chest level -- 3-5 oersteds.

We have shown that, regardless of the physical characteristics of MF in industry, in magnet control, and in research, the workers are always exposed to low-frequency MF from 0.1 to 50 hertz. In this connection, an electromotive force of up to 0.4 mw (millivolt) may develop in the aorta and up to 0.045-0.075 mv in the vessels of the hand [52].

Table 32
Magnetic Field Intensity (oersteds) at Work Places

	(7) Максимальная напряженность на уровне			(11) Наиболее часто (в 80%) встречающаяся напряженность на уровне		
	(8) зазора электромагнита	(9) рук	(10) туловища	(8) зазора электромагнита	(9) рук	(10) туловища
I. Производство постоянных магнитов (12)						
(1) 1. Контролеры-лаборанты						
(2) А. Электромагниты	1500—1200	1000—5000	300—750	260—1000	50—900	15—250
(3) Б. Пост. магниты	1000—5000	1000—5000	30—150	150—760	100—550	13—70
(4) 2. Термисты						
(2) А. Электромагниты	1200—5000	150—360	60—80	120—250	24—150	16—150
(3) Б. Пост. магниты	1000—5000	1000—5000	30—150	150—760	100—560	10—50
II. Машиностроительная промышленность (13)						
(5) 1. Контролеры-дефектоскописты						
(2) А. Электромагниты	400—1000	300—900	50—150	100—550	120—460	18—110
(3) Б. Пост. магниты	350—800	270—850	30—150	150—160	50—160	12—60
(6) 2. Шлифовщики						
(2) А. Электромагниты	600—1000	400—700	75—100	100—200	50—100	10—50
(3) Б. Пост. магниты	300—750	250—700	30—150	150—160	50—160	15—70

Key: 1. Laboratory controllers
2. A. Electromagnets
3. B. Permanent magnets
4. Heat treatment workers
5. Controllers-magnetic flaw detectors
6. Grinders
7. Maximum intensity at the level of:
8. Electromagnet gap
9. Hands
10. Trunk
11. The most frequent (80 percent) intensity at the level of:

Changes in the coloration of the skin appeared first. At first, the skin on the palmar surfaces turned pink during the work. This coloration disappeared 1-3 hours after the end of the work. Later, the skin of the hand turned bluish-pink and did not change this color during rest. After 3-5 years, as a rule, the skin on the hands became bluish. During the last period, cyanosis was particularly acute in the distal sections of the hands and increased noticeably when the hands were lowered. Normally, according to Bogolepov, when the hands are lowered and then raised, their paleness develops after 30 seconds, but in our observations this phenomenon occurred after 5-15 seconds. At the same time, we observed rapid development of a white spot after 1 second. According to Rusetskiy, normally it appears after 2-3 seconds. Capillaroscopic studies revealed convoluted and lengthened capillaries, widening of venous loops, and cyanotic shade of the background in the majority of the workers who had worked from 3 to 5 years (46 in group I, 28 in group II, 49 in group III, 54 in group IV, and 16 percent in the control group).

Together with passive, conjested, intensified blood-filling of the vessels of the hand, the studied persons showed some increase in the temperature in the distal sections of the hands, due to which there were disturbances in the normal proximal-distal temperature ratios. As is known, the normal temperature at the shoulder is higher than that of the forearm, and it is higher at the forearm than at the hand. The people working in MF had the same temperature of the hand as of the forearm, or the former was higher by 1.0-1.5 percent. The temperature between the forearms and the shoulders also could be the same or lower at the forearm by 1.0-1.5 percent. These disturbances were observed more frequently in groups I and IV (75 and 50 percent, respectively), less frequently in groups II (22 percent), III (11 percent), and the control (9 percent). As a rule, these changes were more expressed at the end of the working day than at the beginning, particularly in the workers who had not worked long (up to 3 years) in contact with MF. Along with the disturbances in the proximal-distal ratios, there were temperature asymmetries ($\pm$ 0.4 degree C) at the hands (in the groups, 20, 16, 14, 12 percent, respectively, and 8 percent in the control.

Along with the relative rise of the temperature of the hands, abundant sweating was also observed. Quite often, particularly in the palms of the hands, sweat flowed freely. A small number of workers had dry skin on the hands during the entire shift, but in the majority of the workers (81-87 percent), the dryness of the skin developed when they were not working. This usually took place 3-4 hours after their shift and was observed up to the beginning of work on the following day. As a rule, the appearance of dryness of the skin on the hands was accompanied by decrease in its elasticity due to nodular or massive infiltration, particularly on the fingers and the palm. Because of this, active movements in the interphalangeal joints became somewhat limited, and passive movements became springy.

Simultaneously with the changes in the secretion of sweat, there were also some changes in the electrocutaneous resistance, which usually decreased.

Studies by means of intracutaneous adrenaline-histamine tests in the region of the lower third of the forearm showed decrease and instability of the reactions to adrenaline and intensification of the reactions to histamine.

Because of the relative rise in the temperature of the hands and abundant sweating, an impression was often created as if the hands had just been removed from hot water. Very early, 1-3 months after the beginning of work, there developed a slight hyperesthesia in the hands, and 1-2 years later there developed hypesthesia.

After 3-5 years of work, trophic disturbances were added to the above-mentioned disorders in the hands. The skin and the subcutaneous fat cellular tissue on the hands often became edematic, pastose, and solid. In these cases, the difference between the morning and evening measurements of the transverse perimeter of the hands of some workers increased by 1-2.5 cm. The palms of some workers (12-76 percent) developed hyperkeratosis, or the thinning of the skin with almost total disappearance of its pattern. The skin became shiny, and quite often tightness of movement was observed, particularly in the interphalangeal joints, which was, evidently, connected with the hydration of the hand tissues. Along with this, there appeared other trophic changes: longitudinal lines, brittleness, and deformation of the finger nails.

Studies on pain sensitivity carried out by the algesimetric method revealed a noticeable increase in the threshold pain sensitivity in the workers (44-67 percent) up to 80-50 microns (normally, 30-50 microns) connected with the length of their work and MF intensity. At the same time, we established that the pilomotor reaction on hands of these persons decreased or disappeared completely.

As for the motor sphere, there were isolated cases of a slight decrease in the muscular strength, chiefly in the flexors of the fingers, and a lowering of the muscular tonus. This was observed more frequently in the muscles innervated by the median nerve. Sometimes there were isolated cases of light atrophy in several muscular groups. In these cases, a slight flattening of the palms of the hands was revealed in some observations.

Along with the changed localized in the hands, MF under industrial conditions also caused general disturbances which could be treated as asthenovegetative syndrome. First of all, this syndrome was characterized by general functional disturbances among which the vegetative innervation of the cardiovascular system and cerebrospinal apparatus were not prominent. Along with this, there were disturbances in the regulation of biochemical and hematological processes.

There were complaints from 16-50 percent of the studied persons regarding headaches, periodic nonsystemic dizziness, noise in the ears and unclear vision. Sometimes they were irritable, hot tempered, impatient, worried, and alarmed. The following symptoms were quite important in the clinical picture: various unpleasant and painful sensations in the area of the heart, the changes

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in the sonorousness of the heart sounds (11-43 percent). As for the EKG, all
of the professional groups showed a relative decrease in the QRS complex,
lengthening of the electrosystole and intraventricular conductivity (up to
0.1 sec and higher), as well as a slight lowering or increasing of the "T"-wave,
but no organic changes were observed in the cardiac muscle. Bradycardia
occurred in 5-43 percent of cases, tachycardia -- in 22-37 percent, tendency
to arterial hypotension -- in 34-43 percent, asthenic vascular reactions with
functional loads were observed in 52-64 percent of cases, and in 33 percent
of the cases in the control group. In some workers, the indexes of the or-
thostatic and clinostatic tests and the Ashner phenomenon differed notice-
ably from the normal values.

Studies on the arterial pressure revealed a statistically certain lowering
of the maximum pressure by 10-18 mm Hg and the minimum pressure by 4-8 mm Hg
toward the end of the 2nd-3rd year of work under the influence of MF, increas-
ing to normal values in subsequent years. The frequency of the hypertonic
disease in the studied groups was in the inverse proportion to the MF inten-
sity levels.

In studying the fine vessels of the skin in the area of the chest by the me-
thod of mechanical stimulations of various strengths,we found, as a rule, a
diffuse and persistent red dermographism (in 60-80 percent) which often be-
came petechial. In the majority of our observations, sweating was intensi-
fied (58-82 percent), particularly in the face and in the armpits, and in
women -- on the chest and in the interinguinal regions. As was mentioned
before, the sweating of the hands also increased considerably. However, in
some cases there was a decrease or even the absence of general and local
sweating.

As for the digestive system, the subjects complained of unstable (4-25 percent)
or poor (10-15 percent) appetite, periodic pains in the epigastrium and in
various sections of the abdomen, and women -- particularly in the region of
the gallbladder projection on the abdominal wall. Quite a few persons had a
tendency toward constipation or expressed constipation (21-37 percent).

As the neurological state was studied, some persons showed more frequent
(than in the control) changes in the oculovestibular reactions (up to 30
percent) in the rotational and color tests, both in the direction of increase
and decrease; positive sensitized Romberg's symptom; slight tremor of the
hands, tongue, and less frequently, eyelids. Tendon and periosteal reflexes
(18-60 percent) of the workers in the above-mentioned industries were lively
or functionally elevated, polykinetic with widened reflex zones.

In addition to the above, they showed general physical weakness and consider-
able fatigue during the   second half of the working days or after work.
Some persons complained of periodic pains in the muscles, joints, long bones,
and the spine, as well as paresthesia (crawling sensation) chiefly in the
interscapulum and on the hands.

The itching sensation was localized only on the hands. In some cases the sensations of paresthesia and itching were more frequently expressed at the beginning of the work period, and in some through their shift or toward the end of the work period, and finally, after work.

In the psychic sphere, there were disturbances with regard to attention, making it difficult or impossible for the workers to concentrate on the necessary material or problem, or to memorize new material. Some workers had periodical depressions. Some developed a peculiar "matnetophobi," inclination toward hypochondriac reprocessing of viseral sensations, and other pathological experiences.

Clinicophysiological studies carried out by P. I. Shpilberg by the electroencephalographic method made it possible to establish that bioelectric activity of the cerebral cortex in the workers exposed to a chronic influence of MF suffer changes which progress in three stages. During the first stage, they had short-term intensification of desynchronization, then, during the second stage, there was an increase in the number of alpha-waves with a frequency characteristic close to the lower boundary of the norm and changes in the response to photostimulation. During the third period, there was an increase in the slow waves and the presence of alpha-wave spindles, as well as a lower excitability and reactivity to discontinuous photostimulation in comparison with the control tests. The first stage was observed chiefly in the controllers-magnetic flaw detectors, the first and second stages -- in the controllers in the industry of permanent magnets, and the second and third -- in the thermal treatment workers.

Biochemical and morphological studies of the peripheral blood in workers exposed to MF made it possible to detect deviations of some indexes. A relative increase in gamma-globulins was revealed. It was more frequent during the first 3 years than in the following years. It was established that the content of sialic and nucleic acids, as well as of oxidase, in the blood was low. As for the morphological composition of the peripheral blood, there were regular instances of moderate leukopenia (less than 5,000). When the leukocyte content was normal, the subjects showed relative lymphocytosis and monocytosis, as well as a lower erythrocyte sedimentation test (less than 6 mm in 1 hour).

The above-mentioned changes, as compared with the control studies, were more frequent in controllers and thermal treatment workers in the industry of permanent magnets, somewhat less frequently in the controllers-magnetic flaw detectors, and sometimes among grinders.

These data indicated that most of these changes were functional in nature and only some of them indicated stable pathological disturbances. These disturbances developed under industrial conditions where the MF influence was supplemented by other unfavorable factors. Therefore, in order to understand the significance of MF effects on the human organism, we conducted special laboratory studies. The effects of CMF were studied on a group of practically healthy men 21-23 years of age.

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Magnetic fields in these studies were registered both in the electromagnet gap and within a radius of 0.8 m from it. The CMF was created by direct electric current passing through the coils of an electromagnet.

We studied the skin temperature, sweating and pain sensitivity of the hands, as well as the EKG, blood pressure, morphological composition of the blood, the content of sodium, chlorine and calcium, and fractional composition of the blood albumin.

The observations were conducted for 9 days. During the first 3 days, we studied the skin temperature, sweating, and pain sensitivity of the right hand before and after the CMF action. In the next 3 days, we took blood pressures, EKG, and studied the latent period of the visuomotor reaction. And, finally, during the last 3 days, the above-mentioned biochemical and hematological studies were carried out.

Daily, before the exposure to CMF, the subjects rested in the reclining position for 30 minutes. During the entire rest period and the subsequent experiment, the right hand was in the gap of the electromagnet. Direct current was fed to the electromagnet after their rest, when the background physiological, biochemical, or hematological indexes were registered. Each series of studies was done with a definite exposure time and CMF intensity. Physiological indexes were registered directly after the end of the exposure, then after 1, 5, 15, and 30 minutes, and blood from a finger and a vein for hematological and biochemical tests was taken before the exposure and 15 minutes after it.

In this article, we shall limit ourselves to presenting the factual material which confirms the presence of the CMF effects after a short exposure (15 minutes) and an intensity of 1,000 oersteds.

Some results of the above mentioned laboratory observations are given in Table 34.

Comparison of the indexes before and after the exposure to CMF indicates the presence of substantial shifts which developed under the MF influence. The content level of light ions (sodium, chlorine) decreased, and the amount of the total calcium increased. This fact is in full agreement with the modern physical notions of MF properties. Polarization develops under the influence of CMF, and a high velocity of movement is imparted to light ions, due to which they leave the blood channel faster, and the heavy molecules of calcium move at a considerably slower rate. Evidently, these circumstances again influence the functional state of the cellular membranes and, first of all, the value of the biopotentials, i.e., in the final analysis, they change the excitability of various organs and physiological systems of the entire organism. This is indicated by the changes in the rhythm of cardiac contractions, the lengthening of the time of repolarization of cardiac muscles, and the lowering of the tone of the peripheral vessels, which is seen particularly clearly by the blood pressure level. Finally, the threshold of pain

sensitivity of the hands increases (Table 34). All these changes reached their maximum at the 1st-15th minute after the exposure, and 30 minutes after the end of the CMF exposure the indexes returned to the background values.

Table 34
Changes of Some Clinicophysiological and Biochemical Indexes Under the Influence of CMF (intensity 1,000 oersteds) Exposure 15 Minutes

(1) Показатели	(12) Количество испытуемых	(13) Исходный уровень, M±m	(14) Уровень после воздействия M±m	(15) Достоверность различий, P
(2) Общий кальций, мг%	11	10,60±0,02	10,85±0,07	0,999
(3) Ионизир. кальций, мг %	11	4,15±0,15	4,67±0,05	0,98
(4) Натрий, мг %	11	196,0±3,5	180,0±3,5	0,95
(5) Хлор, мг %	11	301,4±5,3	279,5±4,0	0,98
(6) Пульс, к-во уд. в 1 мин.	11	69,0±2,0	62,3±2,2	0,95
(7) Макс. А/Д, мм. рт. ст.	12	109,2±4,4	103,2±1,9	0,95
(8) Мин. А/Д, мм. рт. ст.	12	67,7±1,4	64,9±1,3	0,90
(9) Шир. зубца, «Т», сек.	11	0,16±0,01	0,19±0,01	0,95
(10) Темп. кисти, °C	12	31,9±0,1	33,8±0,1	0,98
(11) Болев. чувствит. на кистях рук, м. в	12	52,5±5,4	54,3±6,0	0,90

Key:
1. Indexes
2. Total calcium, mg %
3. Ionized calcium, mg %
4. Sodium, mg %
5. Chlorine, mg %
6. Pulse, number of beats per minute
7. Maximum arterial pressure, mm Hg
8. Minimum arterial pressure, mm Hg
9. "T" tooth width, sec
10. Hand temperature, degrees C
11. Pain sensitivity of hands
12. Number of studied persons
13. Initial level, M±m
14. Level after exposure, M±m
15. Certain degree of difference, P

Thus, both clinical and experimental laboratory data indicate the same directivity of the process under the MF influence. As a rule, physiological reactions to MF are based on the intensification of the vagotonic effect, which, according to our observations, is more frequently connected with the dropping of the tone of sympathetic innervation. On the basis of the data obtained in clinical and experimental studies, it should be considered that the influence of magnetic fields above certain levels of intensity can have unfavorable effects on the human organism. At the present time, the maximum permissible levels are being refined. On the basis of available clinicohygienic and experimental-laboratory studies, recommendations have been developed for therapeutic and preventive measures. Persons who are being hired to work with magnetic devices or magnetic materials should be examined by medical commissions.

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On the basis of our studies, medical contraindications have been developed. They include the following diseases and functional disturbances: organic diseases of the heart and vessels, angina pectorus, arterial hypotonia and hypertonia, endocrine diseases, organic disturbances in the central and peripheral nervous systems, particularly vasovegetative polyneuritis, neurosis, and neurosis-like states, and the vegetative vascular dysfunction. Moreover, when working in the sphere of MF influences, it is also necessary to consider the presence of other unfavorable factors of the industrial environment. Consequently, the list of contraindications must be expanded in each concrete case.

It is possible to treat general disturbances (asthenovegetative syndrome) quite successfully in out-patient polyclinics. If there is a marked peripheral vasovegetative syndrome, the workers should be removed temporarily from working with magnetic devices or magnetic materials. Physiotherapeutic and symptomatic drug therapy has been developed for such disturbances to noramlize the neurohumoral regulation of the organism. On the basis of our experience, it is expedient to prescribe local vibratory massage of the hands, ionogalvanotherapy with calcium, water baths (at first, indifferent temperature, and then lowering it every 2-3 days by 1 degree and concluding the therapy at 16-18 degrees). In order to reduce the edema and pastiness of the hands, remedies for consolidating the vessel walls have been suggested (calcium vicasol, citrin, and rutin). It is desirable to combine local treatment with general, for which it is recommended to prescribe vitamins B and C, sedatives, and other general restorative drugs (injections of duplex, mezaton, etc). Usually, these measures are sufficient to control local and general pathological manifestations.

In our opinion, the most rational measures are those of improving the working conditions of persons exposed to the MF influence. For this purpose, it is necessary to carry out engineering and technical improvements which would permit the personnel not to be exposed to MF of higher intensities than those which are now considered to be permissible: for the hands -- 700 oersteds, for other parts of the body -- 300 oersteds.

PECULIARITIES OF METHODS AND METHODOLOGY OF MAGNETOBIOLOGICAL EXPERIMENTS

[A. A. Shul'pekov, Scientific Research Institute of Instrument Building, Moscow]

At this stage of its development, magnetobiology is an experimental science, and its progress is closely connected with correct organization of magneto-biological experiments. One of the initial points of such experiments is the method of creating a magnetic field and its correct quantitative evaluation as a factor affecting a biological object.

In practice, we very rarely deal with "truly constant" magnetic fields. In most cases they are MF changing with time or from one or several spatial co-ordinates. Table 35 attempts to systematize MF by the characteristics of their changes with time and space.

The most popular AMF are those produced by supplying magnetizing coils with an alternating current of 50 hertz. The same MF are often referred to as fields of industrial frequency. These fields are produced by load-lifting electromagnets, power transformers, and other electric power equipment. It is evident that fields of higher frequencies may be covered by the term MF of industrial frequency. For example, they are MF in units for high-frequency heating of metals in which electric current frequency reaches tens and hun-dreds of kilohertz. It is possible to encounter MF of even higher frequen-cies in modern engineering, however, their biological effects are the subject of thermobiology rather than magnetobiology. Therefore, although it is dif-ficult to evaluate quantitatively where the thermal effect starts and where the magnetic effect ends, but, within the limits of the obvious, it is ex-pedient to limit the area of the scientific interest of magnetobiology with respect to the frequency range of MF to 50 hertz.

The sources of CMF are usually permanent magnets and electromagnets. Since MF exactly follow the changes in the electric current flowing in the winding of the electromagnet, it is expedient to use storage batteries as sources of supply, because even the most perfect rectifier has pulsations of a certain level which may affect the results of the experiment.

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Table 35

Table 35
Characteristics of Magnetic Fields

Постоянное маг- (1) нитное поле		(5) Переменное магнитное поле			
(2) постоянное магнитное поле (ПМП)	(3) магнитостатическое поле (СмП)	(6) синусоидально изменяющееся магнитное поле (ПеМП)	(8) импульсное магнитное поле (ИМП)	(10) пульсирующее магнитное поле (ПуМП)	(12) геомагнитное поле (ГМП)
(4) Намагничивание постоянного магнита; питание катушки электромагнита током одного направления от аккумулятора	(7) Питание катушек электромагнита током частотой 50 гц или другой частотой	(9) Питание катушек электромагнита импульсами тока; периодическое приближение на биологический объект одиночного магнита	(11) Питание катушек электромагнита током от выпрямителя	(13) Магнитное поле Земли и его магнитное поле ионосферы

Key:
1. Constant magnetic field
2. Constant magnetic field (CMF)
3. Magnetostatic field (MSF)
4. Magnetization of a permanent magnet; electromagnet coils supplied with unidirectional current from a storage battery
5. Alternating magnetic field
6. Sinusoidally changing magnetic field (AMF)
7. Electromagnet coils supplied with a current of 50 hertz or other frequencies
8. Pulsed magnetic field (PMF)
9. Electromagnet coils supplied with current pulses; periodic application of a single magnet to a biological object
10. Pulsating magnetic field (PuMF)
11. Electromagnet coils supplied with current from a rectifier
12. Geomagnetic field (GMF)
13. Magnetic field of the Earth plus the magnetic field of the ionosphere

Both in the case of permanent magnets and in the case of electromagnets, MF is one of the aspects of a single electromagnetic process called EMF [45]

Electromagnets and permanent magnets are fundamentally different from the viewpoint of the place of application of the electric field, which is another aspect of EMF. In the case of an electromagnet, the electric field is applied to the terminals of the magnetizing coils, ensures the flow of the magnetizing electric current, and is concentrated spatially in the material of the coils. In the case of a permanent magnet, the electric field exists at the molecular level and is the source of the hypothetical Ampere currents creating the magnetic flux of the magnet.

Thus, both in the case of an electromagnet and in the case of a permanent magnet, the electric field is "packed" in material of the magnetizing coils and in the mass of the material from which the permanent magnetic is made. In both cases, the electric field does not reach the experimental space.

However, this does not mean that the biological object is insured against the influence of electric fields. If the entire biological object or a part of it moves in the MF, there will be induced electric fields. In order to avoid induced electric fields, which, in turn, could cause electric currents, it is necessary to eliminate the relative motion of the CMF and the studied object, and also to ensure the permanency of the magnetic field in time. Such an MF will be magnetostatic in nature. Is is evident that experiments with magnetic fields will not be general in nature, because it is often difficult or impossible to ensure the immobility of the studied object.

The use of a magnetic circuit with a permanent magnet whose poles can be implanted over the parts of the CNS of interest to us is an example of the utilization of a magnetostatic field in an experiment. Figure 39 shows a sketch of such magnetic system. With the diameters of the poles of two millimeters and the distance of one millimeter between them, the value of magnetic induction in the gap is 1,000 oersteds. Such a magnetic system, when implanted, will ensure a time-constant influence of MF and a relative immobility of the MF and the biological object.
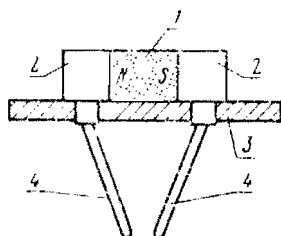
Figure 39. A Sketch of a Magnetic Circuit
1 -- permanent magnet; 2 -- pole shoes;
3 -- arbor; 4 -- pole pieces (magnetoids)

Magnetic circuits of electromagnets, as a rule, are made of a magnetically soft material with the lowest remanent magnetization. However, there are no ideal materials in which the remament intensity of magnetization is zero after the magnetizing current is turned off. Therefore, there is always a remanent MF which may be tens and hundreds of times higher than the GMF. A remanent MF can be reduced by compensating with an electric current of the opposite direction.

Permanent magnets are made of hard magnetic materials according to GOST [All-Union State Standard] 9575-60 and are bar-shaped, horseshoe-shaped, or U-shaped.

The experimental space is usually the air gap in the magnetic circuit of an electromagnet or a permanent magnet. The experimental space is limited on two sides by the poles of the magnetic system and the surface of the magnetic tube of force through the air gap. As is known, an MF tube is the MF region limited by a continuous surface whose generatrices are the magnetic induction lines. In order to obtain comparable results in magnetobiological experiments,

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it is necessary to measure the MF value correctly and to know the law of MF distribution in the experimental space.

Magnet field measurements are done with special instruments. They include galvanometers, webermeters, meters with Hall's data units (teslameters), and others. All these instruments are produced by industry.

The term magnetic poles which we still use appeared during the period when the existence of MF was connected with the notion of positive and negative magnetic masses which, supposedly, are capable of concentrating in definite point of space or a physical body and creating an effect of mutual attraction or repulsion of other physical objects whose magnetic inductivity is different from the magnetic inductivity of a vacuum. It has been established by later studies that MF cannot be concentrated in any large or small space in separate negative or positive "packages" and that magnetic fields consist of closed lines of magnetic induction which have neither a beginning nor an end.

However, the modern methods of MF studies are connected to a certain degree with the original notions of positive and negative magnetic masses. If it would be really possible to obtain a unit of positive magnetic mass, which is conventionally considered as nothern, and to place it along the route of the magnetic induction, then, for the observer looking in the direction of the current flow, the unit of the positive magnetic mass would start its rotation clockwise. In other words, the property of the lines of magnetic induction to be closed at all times and under any circumstances presupposes dialectical unity of the northern and southern magnetic poles at any point of the line of magnetic induction.

When the magnetizing electric current increases from zero to some established maximum value, the magnetic induction lines originate from a point lying on the axis of the conductor with the magnetizing current and develop in space in the form of concentric circles. When the magnetic induction lines move in space, they cross physical bodies along their route exciting an electromotive force in them which causes eddy currents. When the electric current decreases from the established value to zero, the process of the spatial translocation of the magnetic induction lines progresses in reverse order. The magnetic induction lines reduce their radius and, drawing to the center of the conductor, induce an electromotive force of the opposite direction in the physical bodies which they cross.

In practice we become convinced constantly that a number of objects, including magnetic needles in MF, experience attraction or repulsion. But behind all this lies the interaction of the lines of magnetic induction, the manifestation of the properties of real magnetic fluxes. Therefore, the method of presenting the northern and southern magnetic poles as the points of hypothetical concentration of magnetic masses is strictly formal in nature, does not reveal any special characteristic of northern and southern magnetism, serves only as a teaching method facilitating to understand the complex phenomena of electromagnetic processes, and has no scientific relation to magnetobiological experiments.

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However, the criticism of the differentiated influence of the northern and southern magnetic poles and the assertion of their biological identity are valid for an experimental space with a uniform MF in which successive contacts of a biological object with the southern and northern magnetic poles can be materialized by linear translocation of the object along the lines of magnetic induction without changing the spatial orientation. But when an experiment is done with a bar magnet by successive applications of the northern and southern magnetic poles to the object, then, due to the vector characteristics of the MF, we are dealing with fundamentally different fields which are quantitatively identical, but opposite in their directions.

This should be supplemented by considerations regarding the influence of the MF gradient. In most cases, the experimenter has to deal with MF whose non-uniformity increases in the pole regions. Considering that it is difficult to expose the object successively to the southern and northern magnetic poles, and sometimes almost impossible, we can assume that the different effects of the northern and southern poles are caused by the stay of the biological object in directionally identical MF with different gradients.

In designating magnetic poles, some researchers limit themselves to the term magnetode by analogy with electrodes, thus stressing their structural inseparability from the magnetic circuit and their purpose as conductors of the magnetic flux when it is brought to the experimental space.

By analogy with electric charges, Coulomb's law was written in the XVII century for magnetic masses and became a basis of qualitative analysis of MF. There is no doubt that this method is fruitful. Its scientific longevity predetermined the similarity of the mechanical manifestations (attraction and repulsion forces) of MF with mechanical manifestations of electric and gravitational fields. The CGS (centimeter-gram-second) system was based on this method and units for measuring MF were derived. The unit of magnetic flux was the maxwell, the unit of magnetic induction was the gauss, and the unit of magnetic intensity was the oersted. The unit of magnetic induction, gauss, expresses the intensity of spatial distribution of the magnetic flux, and the unit of MF intensity, oersted, gives an indirect idea of the magnetizing force which must be applied in order to obtain a given field. In the CGS system, these units coincide quantitatively, since the magnetic inductivity of the "vacuum" is taken to be equal to one.

In practice, it is often possible to encounter the quantitative evaluation of MF expressed in oersteds. This is due to various reasons. Sometimes, no importance is attached to this because there is a quantitative equality between gauss and oersted, and sometimes it is done because of the desire to accentuate the significance of the magnetizing force which created a given MF.

At the present time, the country is preparing to switch to the new International System of Units (IS). The basic units of this system are the meter, kilogram, second, ampere, Kelvin degree, and the candle. The IS of magnetic flux is the weber, the unit of magnetic induction is the tesla, and the unit

of the MF intensity is one ampere per meter [232]. The peculiarity of this
system with respect to the formation of electromagnetic units and their prac-
tical application is the fact that the IS magnetic value constant -- magnetic
inductivity of a "vacuum" -- is substantially different from one and, con-
sequently, there is no quantitative equality between the units of MF magnetic
induction and intensity [87].

Biological experiments study and causal relationship between the factor chang-
ing the ecological zone and the functions of the biological object. There-
fore, when characterizing an MF, the biologist may have the problem of what
to use as a basis for quantitative evaluations. It is evident that the char-
acteristic of MF intensity gives an idea of the energy aspect of the experi-
ment, indicating indirectly what electric current should be passed through
the magnetizing coils of the electromagnet in order to obtain the necessary
magnetic flux in the experimental space. The role of the acting factor and
stimulant will be played by the magnetic flux. Therefore, the basic quanti-
tative characteristic of an MF should be the values of the magnetic flux and
magnetic induction which give an idea of the density of the magnetic flux.

Table 36 can be used for converting the units from one system to the other.
It gives the dimensions, notations, and ratios of principal electromagnetic
units.

Apart from this purely metrological aspect of the problem, there is also the
natural science aspect, which is of great philosophical significance for ex-
perimental confirmation of our notions of EMF as special forms of matter.
The development of magnetobiology, its latest achievements in the investiga-
tion of MF effects on the CNS, the entire organism, tissues, and live cells
again raised the question: "What are electric and magnetic fields?" [61]

Here are some formulations explaining the MF phenomenon which are given in
the most popular textbooks and handbooks.

"If a certain area has forces acting on a compass needle which they force to
turn in a certain direction, then we say that there is a magnetic field in
that area. The direction of the field is indicated by the direction of the
compass needle which can freely assume the position in that direction" [214],
or "The magnetic field is an inseparable companion of the electric current."

The magnetic field, just as the electric field, can exist in a vacuum. The
presence of air molecules is of secondary importance. We can familiarize
ourselves with the magnetic field only through experience. In the magnetic
field, we observe different processes than in an ordinary space. This is of
decisive importance here. So far, the most important of these processes was
the arrangement of iron filings in the form of chains giving the picture of
the magnetic field" [150]. Other authors make more definite statements, al-
though they mention that treating MF as a force is not the only possible
explanation.

Table 36
Principal Electromagnetic Units

(1) Основные электромагнитные величины	(16) Обозначение	(17) Наименование	(18) Единицы в системе СИ		(20) Единицы в системе СГС		(21) Соотношение единиц систем СИ и СГС
			(19) размерность	(16) значение	(17) наименование	(16) обозначение	
(2) Механическая сила	F	(22) ньютон	м кг сек⁻² (30)	н	(49) дина	дин	ньютон = 10⁵ дин (55)
(3) Электрический ток	I	ампер (23) а	(31)	а	ед. СГС	ед. СГС	ампер = c10⁻¹ ед. СГС (56)
(4) Количество электричества	q	кулон (24) а сек	(33)	к	ед. СГС	ед. СГС	кулон = c10⁻¹ ед. СГС (57)
(5) Электродвижущая сила, напряжение	e, V	вольт (25) м² кг сек⁻³ а⁻¹ (39)	в	ед. СГС	ед. СГС	вольт = c⁻¹10⁸ ед. СГС (58)
(6) Напряженность электрического поля	E	вольт на метр (26) м кг сек⁻³ а⁻¹ (40)	в/м	ед. СГС	ед. СГС	вольт на метр = c⁻¹10⁶ ед. СГС (59)
(7) Электрическая емкость	C	фарада (27) м⁻² кг⁻¹ сек⁴ а² (41)	ф	ед. СГС	ед. СГС	фарада = c²10⁻⁹ ед. СГС (60)
(8) Электрическое сопротивление	R	ом (28) м² кг сек⁻³ а⁻² (42)	ом	ед. СГС	ед. СГС	ом = c⁻²10⁹ ед. СГС (61)
(9) Индуктивность	L	генри (29) м² кг сек⁻² а⁻² (43)	гн	ед. СГС	ед. СГС	генри = c⁻²10⁹ ед. СГС (62)
(10) Электрическая постоянная	ε_0	фарада на метр (30) м⁻³ кг⁻¹ сек⁴ а² (44)	ф/м	—	—	—
(11) Магнитная постоянная	μ_0	генри на метр (31) м кг сек⁻² а⁻² (45)	гн/м	—	—	—
(12) Напряженность магнитного поля	H	ампер на метр (32) м⁻¹ а (46)	а/м	эрстед (51)	э	ампер на метр = 4π10⁻³ эрстед (63)
(13) Магнитная индукция	B	тесла (33) кг сек⁻² а⁻¹ (47)	тл	гаусс (52)	гс	тесла = 10⁴ гаусс (64)
(14) Магнитный поток	Φ	вебер (34) м² кг сек⁻² а⁻¹ (48)	вб	максвелл (53)	мкс	вебер = 10⁸ максвелл (65)
(15) Магнитодвижущая сила	F	ампер (35) а (37)	а	гильберт (54)	гб	ампер = 4π10⁻¹ гильберт (66)

Note: $C = 3\cdot10^{10}$ is the numerical value of the velocity of light in a vacuum expressed in centimeters per second.

Key:

1. Principal electromagnetic units
2. Mechanical force
3. Electric current
4. Quantity of electricity
5. Electromotive force, voltage
6. Electric field intensity
7. Electric capacitance
8. Electrical resistance
9. Inductance
10. Electrical constant
11. Magnetic constant
12. Magnetic field intensity
13. Magnetic induction
14. Magnetic flux
15. Magnetomotive force
16. Notation
17. Name
18. IS units

(Key of Table 36 cont'd)

19.	Dimensions	42.	m^2 kg sec^{-3} a-2
20.	CGS units	43.	m^2 kg sec^{-2} a-2
21.	IS-CGS Ratio	44.	m^{-3} kg^{-1} sec^4 a2
22.	Newton	45.	m kg sec^{-2} a-2
23.	Ampere	46.	m^{-1} a
24.	Coulomb	47.	kg sec^{-2} a-1
25.	Volt	48.	m^2 kg sec^{-2} a-1
26.	Volt per meter	49.	dyne
27.	Farad	50.	CGS units
28.	Ohm	51.	Oersted
29.	Henry	52.	Gauss
30.	Farad per meter	53.	Maxwell
31.	Henry per meter	54.	Gilbert
32.	Ampere per meter	55.	Newton = 10^5 dynes
33.	Tesla	56.	Ampere = c 10^{-1} CGS units
34.	Weber	57.	Coulomb = c 10-1 CGS units
35.	Ampere	58.	Volt = c^{-1} 10^8 CGS units
36.	m kg sec^{-2}	59.	Volt per meter = $c^{-1}10^6$ CGS units
37.	a	60.	Farad = c^2 10^{-9} CGS units
38.	a sec	61.	Ohm = c-2 10^9 CGS units
39.	m^2 kg sec^{-3} a^{-1}	62.	Henry = c-2 10^9 CGS units
40.	m kg sec^{-3} a^{-1}	63.	Amperes per meter = 4π 10^{-3} oersteds
41.	m^{-2} kg^{-1} sec^4 a2	64.	Tesla = 10^4 gauss
		65.	Weber = 10^8 maxwells
		66.	Ampere = 4π 10^{-1} gilberts

"The space in the vicinity of a magnet or a conductor with a current is in a special state which we call 'magnetic field.' The name expresses the idea that there are mechanical forces in this space which act upon other magnets or conductors with currents. However, this is not the only manifestation of the magnetic field. It is possible to name a large number of other physical phenomena which show the effects of the field. For example, magnetic fields change the electric resistance of various metals; some bodies placed in a magnetic field change their dimensions, etc [257].

This "etc" includes the widest manifestations of MF, such as the galvanomagnetic effect, opticomagnetic effect, photomagnetic effect, water magnetization effect, paramagnetic absorption, and Hall effect.

This list can be expanded, however, it is clear that the presence of each of these phenomena alone could become a basis for a formulation of the answer to the question: "What is a magnetic field? On the basis of the above examples, we could define the magnetic field as an area where the photomagnetic effect shows itself, or as an area where water loses its ability to dissolve salts, etc. Such definitions impoverish the phenomenon of the magnetic field and make the approach to the definition of this physical phenomenon one-sided without really explaining it.

It should be noted that such misinterpretations occur in some works on magnetobiology. The following appeared in a recently published monograph [153]:

"Any change in an electric field is always accompanied by the appearance of a magnetic field and, vice versa, any change in a magnetic field results in the appearance of an electric field. Such fields which are interconnected and interconvertible are called electromagnetic fields. Their principal parameters are: oscillation frequency f (or the period $T = 1/f$), amplitude E (or H), and phase φ determining the state of the oscillation process at any moment of time."

Here, the criterion of EMF is the interconnection and interconvertibility of electric and magnetic fields. However, there are other values in physics whose parameters are also interconnected and interconvertible, but they cannot be classed with electromagnetic phenomena. Moreover, as has been mentioned before, EMF can assume peculiar forms (electromagnets, constant magnets) where the magnetic aspect is obvious, but the electric aspect is hidden and there are no oscillation processes.

Some authors go even farther, viewing the problem from relativistic positions and attempting to prove that the MF, even in its schematic and nonmaterialistic interpretation, is capable of appearing and disappearing, depending on the method of observation. Here are some statements by the authors of this direction [213].

"Let us assume that we finally succeeded in drawing a picture of a magnetic field by means of some lines or some cog wheels rolling through space. Then you will attempt to explain what happens to two charges moving in space parallel to one another at the same rates of speed. Since they are moving, they are behaving like two currents and possess a magnetic field connected with them. But an observer moving abreast with these two charges will consider them immobile and will say that there is no magnetic field there. The "cog wheels" and the "lines" disappear when you are moving next to an object! All you have achieved is that you invented a new problem. Where could these cog wheels disappear?! If you drew the lines of force, you will have the same problem. It is not only impossible to determine whether or not these lines move together with the charges, but they can even disappear completely in some system of coordinates."

Thus, in attempting to explain MF from the point of the manifestation of some of its properties (force, photomagnetic, opticomagnetic, magnetoionic, etc) or from the viewpoint of relativistic concepts, the main property of EMF -- its materiality -- escapes notice, after which it ceases to resemble a stimulant.

Academician V. F. Mitkevich contributed greatly to our understanding of magnetic fields. In his classic work MAGNITNYI POTOK I YEGO PREOBRAZOVANIYA (Magnetic Flux and Its Transformations) [124] he wrote:

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"... The magnetic field is a space filled by a magnetic flux ...

Firstly, the magnetic flux is a physical reality which has properties of the magnetic field. Secondly, the magnetic flux is a form of moving matter."

Analagous definitions of the MF in which it is represented as a material medium can be encountered in works of some other authors. For example, the following is the clearest definition in this respect:

"As a result of thorough investigations of this phenomenon, scientists concluded that conductors with a current interact at a distance through a material medium which is inseparably linked with the current and is called magnetic field. The magnetic field is not a substance, but is a type of matter continuously present in space, unlike the matter concentrated in individual particles. Being a matter, the magnetic field has energy. The magnetic field energy is continuously distributed in space" [35].

The quantitative aspect of MF influence on biological objects in magnetobiology is at present extremely problematic. At the present time, magnetobiologists are using the classification of MF values borrowed from engineering. According to this classification, which, in turn is conventional and rather historical than technical, weak and superweak MF are fields up to 100 gauss (0.01 tesla), average -- from 100 to 10,000 gauss (0.01 ÷ 1.0 tesla), strong -- from 10,000 to 100,000 gauss (1 ÷ 10 tesla), and superstrong -- over 100,000 gauss.

Of course, it would be wrong to transfer this classification to magnetobiology automatically and expect a proper quantitative effect.

In this connection, we should mention the attempts of some researchers to study stronger MF in the hope of obtaining a clear, convincing, and indisputable effect. But the experimental material obtained here is often negative and it only deepens the gulf between the physicists and biologists. Demanding immediate satisfaction for their unsuccessful or incorrectly conducted magnetobiological experiments, some physicists, in turn, intrude tactlessly into an area which has not yet been insufficiently studied and therefore, requires maximum patience and minimum haste in judgements.

At the present time, it is becoming more and more obvious that the nature of the interaction of gigantic organic molecules, physiologic solutions, and nervous and muscular tissues with MF is much more "delicate" than it is represented by the supporters of strong interactions at the electron-nuclear level.

What is a weak MF and what is a strong MF? Magnetobiologists have to answer this question. What is considered weak in engineering may prove to be strong in magnetobiology. Magnetobiologists must give their quantitative evaluation of MF and their classification which may not coincide with that in engineering. It is logical to assume that magnetobiological experiments will have

their own paradoxes, their own anomalies, and their own regularities which will have to be understood in order to strengthen the close union of biologists with physicists and chemists. The works of Soviet physicist Ya. G. Dorfman are examples of such fruitful union of physics with magnetobiology.

Works of Soviet magnetobiologists have provided an experimental confirmation of the materiality of EMF and, particularly, of CMF. In their works, MF appears as an all-penetrating aggressive factor, perceived as a stimulus directly by the CNS responsible for morphological changes in the tissues of the organism, accelerating or slowing down biochemical reactions in the cells, and changing the ecological zone of the entire biological object.

It is possible that studies on the MF effects on biological objects and the work on the creation of a theory of the primary mechanism of MF action will lead to a new understanding of the processes occurring in living organisms and will enrich our knowledge of the nature of EMF.

On the basis of the above, it is possible to make the following conclusions:

1   Both in the case of the electromagnet and in the case of the permanent magnet, the experimenter deals with EMF. In the case of the electromagnet, the magnetic component in the form of a magnetic flux is concentrated in a closed magnetic circuit passing through the experimental space, and the electric component is concentrated in the conducting mass of the coils, providing the magnetizing current. In the case of permanent magnets, the magnetic flux closes in the magnetic circuit, and the electric component at the molecular level produces hypothetical Ampere currents.

2.   Since the principal characteristic of the magnetic flux is its closed condition in space, since the lines of magnetic induction have neither a beginning nor an end and have identical properties over all their length, and since magnetic poles are merely structural formations directing the magnetic flux to the experimental space, in principle, it does not matter which coordinates link the biological object with the magnetic flux if its direction and intensity are constant.

Therefore, it is methodologically unsound to stress differences in the biological effects of the northern and southern magnetic poles. If there are such differences and they are statistically certain, then it is more appropriate to speak of different quantitative levels of influence due to considerable MF gradients near the poles and inaccuracy in the rendering of the coordinates.

3.   It is expedient to interpret the expression "MF influence" as "magnetic flux influence," since a physical reality in the form of a magnetic flux is used as a stimulant in magnetobiological experiments.

4.   For qualitative expression of CMF used in magnetobiological experiments, it is expedient to use units describing the value of the magnetic flux (Weber) and its intensity (tesla), because these units have been accepted for measuring

magnetic fluxes as a physical reality in the International System of Units (IS) which is now being introduced.

5.   The works of Soviet magnetobiologists provide an experimental confirmation of the materiality of MF.   Studies on the biological effects of EMF on live organisms and works on the primary mechanism of their action broaden our knowledge of living matter and strengthen our materialistic understanding of the nature of EMF.

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The limited scope of this collection does not permit us to give a complete bibliography of magnetobiological studies, but we attempted to include the most important works of recent years. Yu. I. Novitskiy contributed much effort to the compilation of this list.

Works which are not on the subject of magnetobiology are marked with an asterisk. To save on space, publications which include several magnetobiological studies are mentioned only once. We used the data published in Russian and foreign journals of abstracts, as well as card files in the library of the Biology Department of the USSR Academy of Sciences and in the State Central Medical Library.

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List of Abbreviations

ADPh	--	adnosinediphosphate
ATPh	--	adenosinetriphosphate
GMF	--	geomagnetic field
RQ	--	respiration quotient
DNA	--	desoxyribonucleic acid
PMF	--	pulsed magnetic field
MF	--	magnetic field
CMF	--	constant magnetic field
AMF	--	alternating magnetic field
RNA	--	Ribonucleic acid
PhAL	--	phagocytal activity of leukocytes
CNS	--	central nervous system
EMF	--	electromotive force
EKG	--	electrocardiogram
EMF	--	electromagnetic field
EEG	--	electroencephalogram
PuMF	--	pulsating magnetic field
CGS	--	centimeter-gram-second (system)
IS	--	international system
MSF	--	magnetostatic field

ABSTRACTS OF ARTICLES

UDC 577.3

Kholodov, Yu. A. "Introduction." THE INFLUENCE OF MAGNETIC FIELDS ON BIO-
LOGICAL OBJECTS. 1971, 1-14.

The article gives a brief historical survey of magnetobiological works on the
effects of artificial magnetic fields, fluctuations in the intensity of the
geomagnetic field, and the weakened field of the earth on biological objects.
It is pointed out that the influence of magnetic fields has been discovered
at all levels of biological organization: from the molecule to the popula-
tion. A hypothesis on the ecological significance of the geomagnetic field
is stated. 1 figure.

UDC 577.3

"Physical Phenomena Occurring in Live Objects Under the Effect of Constant
Magnetic Fields." Dorfman, Ya. G. THE INFLUENCE OF MAGNETIC FIELDS ON
BIOLOGICAL OBJECTS, 1971, 15-23.

The article describes three principal physical effects occurring under the
influence of artificial CMF on biological objects. They include: 1) magneto-
hydrodynamic inhibition of the movement of the blood and other biological
fluids; 2) elastic oscillations of nervous, muscular and plant fibers during
the propagation of bioelectric pulses in them (these oscillations may cause
distortion and inhibition of the pulses), 3) orientational and concentration-
al changes in biologically active macromolecules in solutions which reflect
on the kinetics of biochemical reactions and other physicochemical processes.

UDC 577.3

"Influence of Magnetic Fields on Enzymes, Tissue Respiration, and Some Aspects
of Metabolism in an Intact Organism." Shishlo, M. A. THE INFLUENCE OF MAG-
NETIC FIELDS ON BIOLOGICAL OBJECTS, 1971. 24-40.

The author discusses the published and his own data on the influence of mag-
netic fields on the metabolic processes of various biological objects and ex-
presses his opinion regarding the nonspecific nature of this phenomenon.
Emphasis is placed on the changes in the aging rate of enzymes in vitro,
changes in the ratio of free and phosphorylation oxidation, intensification
of glycolysis, stress reaction of the entire organism, etc. It is probable
that magnetic fields, by changing the energy of weak interactions, influence
the supramolecular organization of live structures, which can again result
in quantitative changes in chemically specific reactions. It is not ruled
out that magnetic fields may influence biological objects through the changes
in the properties of water. 1 table, 3 figures.

UDC 577.3

"The Influence of Magnetic Fields on Microorganisms." Pavlovich, S. A.
THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 41-55.

It is shown that magnetic fields can influence the processes of vital activity in microorganisms. The effect depends on the nature of the magnetic field, its intensity, and biological peculiarities of the test objects. The latter is particularly clear in short exposures to magnetic fields. The differences in the nature of the obtained data are sometimes due to the differences in the experimental conditions. Prolonged exposure to a magnetic field results in a clear manifestation of the biological effects. Specific influence of various fields levels out and the observed changes have the same directivity. These studies indicate that the changeability of microorganisms is, probably, the result of the influence of magnetic fields on the enzymal systems and RNA. This may account for the influence of magnetic feilds on the nature and rate of growth of microorganisms and increased thermotolerance of "magnetic" cultures. However, magnetic fields also cause other changes in the metabolism of microorganisms, which is exemplified by the phenomenon of phage induction.

UDC 577.3

"The Mechanism of Biological Effects of a Constant Magnetic Field." Kogan, A. B., Sachava, T. S., Dorozhkina, L. I., Pavelko, V. M., and Gol'tseva, I. N. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 56-68.

The authors studied the influence of constant magnetic fields on the organisms of various evolutionary levels. In their experiments on infusoria, they observed changes in the movements, redistribution and decrease of RNA (protoplasmic), and increase in aerobic glycolysis under the effect of a constant magnetic field. In the cells of Nitella, they discovered a decrease in the rest potential during the action of the magnetic field by using the method of intracellular registration of the biopotentials. The effect depended on the intensity of the field and on the seasonal conditions of the experiments. It was established by the study of an individual cell of the stretching receptor of a crayfish that a magnetic field of 500 oersteds, after exposure of 30 minutes, caused an inhibitory reaction of neurons whose intensity depended on the season of the year. Structural changes in neurons were characterized by disintegration of RNA lumps and its accumulation in the perinuclear region. The physiological activity of adrenalin changed after the magnetic treatment when it was checked on an isolated heart of a frog by Straube's method. 8 tables, 3 figures.

UDC 577.3

"The Influence of Magnetic Fields on Radiation-Induced Chromosomal Aberrations in Plants." Pozolotin, A. A. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 69-97.

Studies on the influence of pulsed and constant magnetic fields on radiation-induced chromosomal aberrations in the meristematic tissue of the pea revealed changes in the yield of aberrations caused by gamma-irradiation of the ends of roots. The effect was observed only since the stage when the soaking of the irradiated seeds had ended and depended on the dose of the preliminary irradiation. The effect was not well-defined during the first mitosis, which meant that the magnetic field influenced the restoration rate of the initial potential injuries of the chromosomes. The obtained results confirm the conclusion that the magnetic field is a weak biological stimulus. 7 tables, 1 figure.

UDC 577.3

"Pathologoanatomic Characteristics of Changes in Experimental Animals Under the Influence of Magnetic Fields." Toroptsev, I. V., Garganeyev, G. P., Gorshenina, T. I., and Teplyakova, N. L. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971. 98-107.

Comparison of all studied morphological changes in the organs and tissues of laboratory animals revealed that male gonads were the most sensitive to magnetic fields. This physical factor disturbed mitosis, which resulted in the appearance of giant multinuclear cells in a number of organs (testes, liver, kidneys, suprarenal glands, epithelium of the crystalline lens). The aggregate of the morphological changes caused by a magnetic field in the entire organism makes it possible to speak of the specificity of the pathologoanatomic picture. A study of the dynamics of morphological changes revealed a marked tendency toward normalization of the disturbed structures in the organs and tissues after the termination of the action of magnetic fields. The biological effectiveness of pulsed and alternating magnetic fields was higher than that of constant magnetic fields. Pathological changes in a number of organs and systems occurring under the conditions of the tested magnetic fields were not catastrophic in their nature. 6 figures.

UDC 577.3

"Magnetic Fields, Infection, and Immunity." Vasil'yev, N. V., Shternberg, I. B., and Boginich, L. F. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 108-123.

The article gives the results of studies carried out in various laboratories, primarily by the authors, on the influence of magnetic fields on the immuno-biological reactivity of the organism. It is shown that the magnetic field

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is a physical factor which is undoubtedly active with respect to the mechanism of immunobiological reactivity, both in its nonspecific and specific aspects. The influence of magnetic fields on the formation of antibodies has similarities with the effects of ionizing radiation. It was established that the magnetic field itself, without immunization, was capable of causing changes in the lymphoid tissues which were similar to immunomorphological changes. It is not ruled out that this is connected with the stress effect of both the immunization and the magnetic field. Basic directions of research in this area are suggested. 3 tables, 3 figures.

UDC 577.3

"Effects of Magnetic Fields on the Nervous System." Kholadov, Yu. A. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 124-146.

It is shown that constant magnetic fields increase the motor activity of vertebrates, inhibit conditioned reflexes developed by them to other stimuli, and can themselves serve as conditioned stimuli for carps and rabbits. Electrophysiological studies revealed that magnetic fields caused a synchronization reaction in the EEG of the rabbit which developed with a latent period of 10-20 seconds. The electrographic reaction to the magnetic field in a preparation of an isolated brain and in neuronally isolated strip of the cortex of the cerebral hemispheres of a rabbit occurred more intensively and with a shorted latent period than a similar reaction of an intact brain. The author concludes that magnetic fields have direct influence on the brain tissues. This is confirmed by microelectrode studies on the spike activity of neurons and by morphological studies on the glioneural complex. The lowering of the stability of mice against oxygen want after exposure to a magnetic field compels the author to assume that magnetic fields influence the oxidizing metabolism of the brain. He stresses the nonspecific nature of reaction of the CNS to the magnetic field, because this reaction is detected after the exposure to radio-frequency electromagnetic fields and ionizing radiation. 1 table, 5 figures.

UDC 577.3

"Effects of Magnetic Fields on Experimental Tumors (Direct and Through the Nervous System)." Ukolova, M. A. and Kvakina, Ye. B. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 147-164.

The effects of constant and alternating (low-frequency) magnetic fields on the development of transplanted and induced tumors were studied in experiments on rats. The authors exposed either the tumor directly, or the head of the animal to a magnetic field, or combined these two methods. The application of the magnetic field often caused the experimental tumor to resolve. The effect was stronger with additional administration of Undenfriend's reagent or adrenalin. The action of a magnetic field on the head intensified tissue respiration, aerobic glycolysis, phosphorylation, and

excitability of the hypothalamus. Moreover, the cholinesterase level in the blood rose, the total amount of the SH-groups decreased in the suprarenal glands and increased in the thyroid gland. Histological studies also revealed hypersecretion in the thyroid gland caused by the magnetic field. Thus, the activation of the vegetative and endocrinic sections of regulation performed by the hypothalamus is one of the mechanisms of the influence of magnetic fields on the development of tumors. 7 tables, 8 figures.

UDC 577.3

"Clinico-Hygienic and Experimental Data on the Effects of Magnetic Fields Under Industrial Conditions." Vyalov, A. M. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 165-177.

Analysis of the clinicophysiological data obtained in studying workers subjected to the effects of magnetic fields made it possible to isolate two principal syndromes: peripheral vasovegetative and asthenovegetative. The central place in both syndromes usually belonged to the functional vascular or cardiovascular changes. Vasovegetative changes occurred more frequently and were expressed more clearly in the distal parts of hands than in other parts of the body. Experimental laboratory data indicate the same directivity of the process under the influence of magnetic fields. Physiological reactions to this factor are based on the intensification of the vagotonic effect, which is most frequently connected with the decrease in the tonus of sympathetic innervation. It should be considered that the action of magnetic fields above certain levels of intensity can have unfavorable effects on human organisms. At the present time, the maximum permissible levels are being determined more precisely. Recommendations for therapeutic and preventive measures have been developed. 3 tables.

UDC 577.3

"Peculiarities of Methods and Methodology of Magnetobiological Experiments." Shul'pekov, A. A. THE INFLUENCE OF MAGNETIC FIELDS ON BIOLOGICAL OBJECTS, 1971, 178-189.

In magnetobiological experiments, a physical reality in the form of a magnetic flux is actually used as a stimulant. Therefore, it is expedient to use units characterizing the value of the magnetic flux -- weber and its intensity -- tesla, since these units have been accepted in the International System of Units (IS) for measuring magnetic fluxes. It is methodologically wrong to stress the difference in the biological effects of the north and south magnetic poles. If there is such a difference, then it is possible to speak of different quantitative levels of the effect resulting from the considerable magnetic field gradients near the poles and inaccurate reproduction of the coordinates. The works of the magnetobiologists confirm the materiality of magnetic fields and broaden our knowledge not only regarding biological processes, but also regarding the nature of electromagnetic fields. 2 tables, 1 figure.

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