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# THE EFFECT OF ELECTROMAGNETIC AND MAGNETIC FIELDS ON THE CENTRAL NERVOUS SYSTEM

by Yu. A. Kholodov, Academy of Sciences USSR

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THE EFFECT OF ELECTROMAGNETIC AND MAGNETIC FIELDS  
ON THE CENTRAL NERVOUS SYSTEM

By Yu. A. Kholodov

Translation of "Vliyaniye elektromagnitnykh i magnitnykh  
poley na tsentral'nuyu nervnuyu sistemу."

Academy of Sciences, USSR, Institute of Higher  
Nervous Activity and Neurophysiology.  
Izdatel'stvo "Nauka." Moscow, 1966.

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T A B L E   O F   C O N T E N T S

FROM THE AUTHOR . . . . .	1
INTRODUCTION . . . . .	4
<u>PART I. THE ELECTROGRAPHIC METHOD OF STUDYING THE EFFECT OF ELECTROMAGNETIC FIELDS ON THE CENTRAL NERVOUS SYSTEM</u> . . . . .	8
EXPERIMENTAL METHODOLOGY AND TREATMENT OF THE RESULTS . . . . .	9
<u>Methods Used Under Different EMF</u> . . . . .	9
<u>Methods of Recording the Electrical Activity</u> . . . . .	11
<u>Surgical Methodology</u> . . . . .	12
<u>Methods of Treating the Experimental Data</u> . . . . .	15
CHAPTER 1. THE EFFECT OF A UHF FIELD ON THE ELECTRICAL ACTIVITY OF THE RABBIT BRAIN . . . . .	19
<u>The Effect of a UHF Field on the Central Nervous System</u> . . . . .	19
<u>Changes in the EEG of Rabbits Following the Influence of a UHF Field of Thermal Intensity</u> . . . . .	22
<u>Changes in the EEG of Rabbits During the Influence of a UHF Field of Weakly Thermal Intensity</u> . . . . .	25
<u>The Effect of a UHF Field on the Assimilation Reaction to a Rhythm of Light Flashes</u> . . . . .	31
<u>Physiological Analysis of the Mechanism of Effect of a UHF Field on the Electrical Activity of Rabbit Brain</u> . . . . .	32
<u>Role of the Distance Receptors in the EEG Reactions of Rabbits to a UHF Field</u> . . . . .	33
<u>The EEG Reaction to a UHF Field After Removal of the Cervical Sympathetic Ganglia</u> . . . . .	37
<u>The EEG Reaction to a UHF Field Following Damage to the Hypothalamus, Thalamus and Reticular Formation of the Midbrain</u> . .	40
<u>The Effect of a UHF Field on the EEG Reaction of an Isolated Rabbit Brain Preparation</u> . . . . .	43
<u>The Effect of a UHF Field on the Electrical Activity of a Neuronally-Isolated Strip of Cerebral Cortex</u> . . . . .	47
<u>Discussion</u> . . . . .	56
<u>Conclusions</u> . . . . .	59
CHAPTER 2. THE EFFECT OF AN SHF FIELD ON THE ELECTRICAL ACTIVITY OF RABBIT BRAIN . . . . .	61
<u>The Effect of an SHF Field on the CNS</u> . . . . .	61
<u>The Effect of a Constant SHF Field of Thermal Intensity on the Rabbit EEG</u> . . . . .	65
<u>The Effect of an SHF Field on the Reactance Curve</u> . . . . .	66

<u>The Effect of an SHF Field on the Electrical Activity of a Neuronally-Isolated Cortical Strip . . . . .</u>	67
<u>The Effect of a Modulated SHF Field on the Rabbit EEG . . . . .</u>	70
<u>The Effect of Caffeine on the EEG Reaction of Rabbits During the Influence of a Constant SHF Field . . . . .</u>	71
<u>The Effect of Pulsed SHF Fields of Thermal and Nonthermal Intensity on the Rabbit EEG . . . . .</u>	72
<u>The Effect of an SHF Field on the Rabbit EEG After Sectioning at the Level of the Midbrain . . . . .</u>	76
<u>The Dependence of the EEG Reaction of an Intact and an Isolated Brain on the Intensity of an SHF Field . . . . .</u>	77
<u>The Effect of Caffeine on the EEG Reaction of an Intact and an Isolated Rabbit Brain During the Influence of an SHF Field . . . . .</u>	78
<u>Discussion . . . . .</u>	82
<u>Conclusions . . . . .</u>	84
<b>CHAPTER 3. THE EFFECT OF A CONSTANT MAGNETIC FIELD ON THE ELECTRICAL ACTIVITY OF THE RABBIT BRAIN . . . . .</b>	<b>86</b>
<u>The Biological Effect of Magnetic Fields . . . . .</u>	87
<u>The Effect of a Constant Magnetic Field on the Rabbit EEG . . . . .</u>	94
<u>The Effect of a CMF on the EEG of an Isolated Brain . . . . .</u>	100
<u>The Effect of a CMF on the Electrical Activity of a Neuronally-Isolated Strip of the Cerebral Cortex . . . . .</u>	103
<u>The Electrical Reaction of Different Sections of the Rabbit Brain to a CMF . . . . .</u>	104
<u>The Effect of a CMF on the Pulsed Electrical Activity of Cerebral Neurons . . . . .</u>	107
<u>Discussion . . . . .</u>	112
<u>Conclusions . . . . .</u>	115
<b>CHAPTER 4. THE EFFECT OF AN ELECTROSTATIC FIELD ON THE RABBIT EEG . . . . .</b>	<b>117</b>
<u>Conclusions . . . . .</u>	119
<u>Synopsis . . . . .</u>	119
<u>The Form of the EEG Reactions . . . . .</u>	120
<u>The Reaction to Turn-Off . . . . .</u>	122
<u>Reactions at the Moments Electromagnetic Fields are Turned On and Off . . . . .</u>	123
<u>The Basic Reaction . . . . .</u>	125
<u>The Direct Effect on the Brain . . . . .</u>	127
<b>PART II. THE CONDITIONED REFLEX METHOD OF STUDYING THE EFFECT OF ELECTROMAGNETIC FIELDS ON THE CENTRAL NERVOUS SYSTEM . . . . .</b>	<b>130</b>
<b>EXPERIMENTAL METHODOLOGY AND TREATMENT OF RESULTS . . . . .</b>	<b>131</b>
<u>Procedure for Development of Conditioned Reflexes . . . . .</u>	131
<u>Surgical Methodology . . . . .</u>	134
<u>Methods of Treating the Results . . . . .</u>	136

CHAPTER 5. THE DEVELOPMENT OF CONDITIONED REFLEXES TO ELECTROMAGNETIC FIELDS IN RABBITS, PIGEONS AND FISH . . . . . 138

<u>The Development of Conditioned Reflexes to a Constant Magnetic Field in Rabbits</u> . . . . .	138
<u>The Development of Conditioned Reflexes to a Constant Magnetic Field in Pigeons</u> . . . . .	139
The Development of a Positive Reflex to a Constant Magnetic Field . . . . .	139
The Development of Conditioned Inhibition to a CMF + Light Stimulus . . . . .	141
<u>The Development of Conditioned Reflexes to Electromagnetic Fields in Fish</u> . . . . .	147
The Development of a Positive Conditioned Reflex . . . . .	147
Development of Conditioned Inhibition to the CMF + Light Stimulus . . . . .	151
Development of Conditioned Reflexes to a UHF Field in Fish . . . . .	162
Development of Conditioned Reflexes to Ionizing Radiation in Fish . . . . .	162
<u>Discussion</u> . . . . .	166
<u>Conclusions</u> . . . . .	169

CHAPTER 6. ANALYSIS OF THE MECHANISM OF THE FORMATION OF CONDITIONED REFLEXES TO A MAGNETIC FIELD IN FISH . . . . . 171

<u>The Effect of Denervation of the Lateral Line Organ on the Conditioned Magnetic Reflex in Fish</u> . . . . .	171
<u>Similarity in the Effects of Light and a Magnetic Field on Fish</u> . . . . .	172
<u>Retention of the Conditioned Magnetic Reflex in Fish After Enucleation</u> . . . . .	174
<u>The Role of Different Sections of the Fish Brain in the Realization of a Conditioned Electrodefensive Reflex to a Magnetic Field</u> . . . . .	178
Development of Conditioned Reflexes After Damage to the Visual Tegmenta . . . . .	178
Development of Conditioned Reflexes After Removal of the Cerebellum . . . . .	180
Development of Conditioned Reflexes After Removal of the Forebrain . . . . .	182
Development of Conditioned Reflexes After Damage to the Diencephalon . . . . .	183
<u>Discussion</u> . . . . .	185
<u>Conclusions</u> . . . . .	190
<u>Synopsis</u> . . . . .	190

<u>PART III. OTHER METHODS FOR STUDYING THE EFFECT OF ELECTROMAGNETIC FIELDS ON THE CENTRAL NERVOUS SYSTEM . . . . .</u>	193
<u>CHAPTER 7. THE CHANGE IN THE SENSITIVITY OF FISH AND AMPHIBIANS TO A MAGNETIC FIELD OR LIGHT . . . . .</u>	194
<u>Investigation of Sechenov Inhibition During the Influence of Light or a Magnetic Field on the Diencephalon of Frogs with Their Hemispheres Removed . . . . .</u>	194
<u>The Effect of Light or a Magnetic Field on the Sensitivity of Fish and Axolotl to an Electric Current . . . . .</u>	199
<u>Discussion . . . . .</u>	204
<u>Conclusions . . . . .</u>	204
<u>CHAPTER 8. THE CHANGE IN THE MOTOR ACTIVITY OF FISH AND BIRDS DURING THE INFLUENCE OF A CONSTANT MAGNETIC FIELD . . . . .</u>	205
<u>The Change in the Motor Activity of Stickleback During the Influence of a CMF . . . . .</u>	205
<u>The Change in the Motor Activity of Birds During the Influence of a CMF . . . . .</u>	206
<u>Discussion . . . . .</u>	211
<u>Conclusions . . . . .</u>	212
<u>CHAPTER 9. CHANGES IN THE HISTOLOGICAL PICTURE OF THE BRAIN DURING THE INFLUENCE OF ELECTROMAGNETIC FIELDS . . . . .</u>	213
<u>Conclusions . . . . .</u>	216
<u>Synopsis . . . . .</u>	216
<u>GENERAL CONCLUSIONS . . . . .</u>	217
<u>REFERENCES . . . . .</u>	223

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## THE EFFECT OF ELECTROMAGNETIC AND MAGNETIC FIELDS ON THE CENTRAL NERVOUS SYSTEM

Yu. A. Kholodov

**ABSTRACT.** The basic approach of this volume is to clarify the physiological mechanism of the effect of EMF on the functions of the brain through the use of the electrophysiological and conditioned-reflex methods. In addition, various methods of recording motor activity, determining the sensitivity to electrical and chemical stimuli, and certain morphological methods were used. The experimental objects were different classes of vertebrates, beginning with fish and ending with mammals.

### FROM THE AUTHOR

The vigorous development of the physical sciences in the XIX and XX centuries is associated with the application of new physical factors in technology, among which electromagnetic fields occupy an important place. The "century of electricity", the "century of radio", the "century of atomic energy", all these concepts of our epoch involve electromagnetic fields of different frequencies. There is no doubt that the harnessing of new types of energy will sharply improve human working and living conditions; on the other hand, however, the creation of an even greater number of power, radio and atomic stations will change, if we can express it this way, the electromagnetic background of the earth. How will this affect the health of man, his work capacity and his progeny?

At present, the biological effect of ionizing radiation has been studied to the extent that its danger has become known to every inhabitant of our planet. The effect of ionizing radiation now has become not only a biological factor, but also a political factor in limiting the nuclear arms race. However, prior to the Second World War not as much was known about the effect of ionizing radiations on an organism. The fact that these radiations did not produce any sensations in man during their effect made it possible to consider them to be harmless.

Approximately the same position is now observed with respect to the study of the biological effect of radio-frequency electromagnetic fields although, of course, their effect on the organism is manifested to a much weaker degree than that of ionizing radiation.

It should be emphasized that the problem is not limited to a hygienic evaluation of any new physical factor. Electromagnetic fields (EMF) have long been used for therapeutic and diagnostic purposes. The problem facing the investigator is not to prove the harmfulness of these factors; they can also be useful.

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\*Numbers in the margin indicate pagination in the foreign text.

However, to determine their meaning for man we must know the biological mechanisms of the effect of EMF. This knowledge will enable us to further develop the concepts on the functions of the organism, in particular, the functions of the central nervous system (CNS).

It should also be noted that man encounters EMF not only in industry or in the doctor's office. EMF are an ecological factor to a certain degree. Life originated and has developed in the earth's EMF, which change periodically and, possibly, affect certain physiological functions.

Finally, EMF are not only passively absorbed, but they are actively emitted by certain living structures. Thus, they are a factor of the functional organization of separate parts of the organism, and, as certain investigators [Granovskaya, 1961; Kazhinskiy, 1962; Turlygin, 1942; Presman, 1964a; Mancharskiy, 1964] assume, they are a factor of communication between organisms.

Among the wide range of EMF we have selected fields of ultrahigh frequency /4 (UHF) with wavelengths from 1 to 100 m, superhigh frequency (SHF) with wavelengths from 1 cm to 1 m, and a constant magnetic field (CMF). The UHF field attracted us because its biological effect was already well known in the 30's, and our problem consisted of conducting an electrophysical analysis of this effect on the organism. The biological effect of an SHF field is being studied more intensively at the present. Therefore, we compared our data with the results of other investigators who use modern physiological methods. The biological effect of a CMF cannot now be considered proven. We wanted to validate the hypothesis concerning the effect of a magnetic field on an organism by methods that would make it possible to observe the effect of weak EMF. The use of CMF removed certain methodological difficulties connected with the possible thermal effect of EMF and the focusing of the electrodes with which electroencephalograms (EEG) were recorded.

Thus, significant sections of the spectrum of electromagnetic oscillations entered the sphere of our experimental investigations, which, considering the reference data, allowed us to characterize certain general aspects of the physiological effect of EMF.

In the course of these works we used not only different ranges of EMF, but also employed different physiological methods and different methods of treating the data. From the characteristics of just the qualitative properties of the biological effect of EMF we went to a strict quantitative evaluation of the changes, using the methods of variational statistics. From this viewpoint, not all the chapters of this book are equivalent. We wanted to show not only what was obtained, but also how it was done.

Questions regarding dosimetry, primary mechanisms of the biological effect of EMF, biochemical changes, etc., remained outside the limits of our investigation. We conducted only a physiological analysis of the effect of EMF on the central nervous system of vertebrates. We were interested in the initial physiological changes which occur during the first minutes of exposure, i.e., the properties of EMF as stimuli. This explains the insufficient development of many important questions related to the problem of the effect of EMF on the CNS.

The author hopes that this book will promote increased interest in this problem, which requires further investigation.

I would like to express my gratitude to my instructors, Corresponding Member of the USSR Academy of Sciences, Professor M. N. Livanov, and Corresponding Member of the RSFSR Academy of Pedagogical Sciences, Professor L. G. Voronin; I would like to thank Professor M. M. Aleksandrovskaya and Assistant Professor Z. V. Gordon for their advice and practical aid in this work, and also wish to express my gratefulness to my colleagues.

## INTRODUCTION

Although interest in the biological effect of different physical fields /5 developed long ago, this problem has become particularly urgent in our time. The question of the biological effect of EMF has been brought up many times, particularly when physicists discovered a new type of EMF. We shall discuss the effect of EMF on the CNS in more detail later, but shall now give a brief historical survey.

Even the ancients distinguished magnets from other minerals, not only because they could attract iron, but also because various healing properties were ascribed to them. True, each doctor used them in his own manner. Galen used a magnet as a purgative. Avicenna treated diseases of the liver with a magnet. Paracelsus used a magnet to treat hernia, dropsy, jaundice and many other diseases. Mesmer began by treating certain nervous disorders with a magnet, and ended up acknowledging the existence of an "animal magnetism" that affects the patient just as magnetism affects a mineral. This "animal magnetism", however, was less useful than the "animal electricity" discovered at approximately the same time by Galvani. A commission of the French Academy of Sciences judged "animal magnetism" to be unscientific and Mesmer passed into history as a great charlatan. At the same time, the commission acknowledged the biological effect of a magnetic field, having written in its report that the "healing effect of a magnet is caused by the direct effect of a magnetic force on the nerves".

The problem of the biological effect of EMF was formulated by V. J. Danilewsky (1900), who spoke of the effect of "electricity at a distance". [Translator's note: i.e., "long-range" effect.] This term was put in quotation marks by the author himself since, for convenience, all forms of induction were unified into the concept of "electricity". In the general problem, V. J. Danilewsky included "the effect of a magnetic flux, electrical and electromagnetic fields, the effect of electrical beams in their different forms and combinations, including the effect (long-range) of high-voltage and high-frequency currents, etc. As objects we must consider not only sectioned nerves and muscles, but also entire organisms, beginning with the lower organisms, i.e., microbes".\* /6 The formulated problem was of great interest for general biology, hygiene and electrotherapy.

The first description of the long-range effect of electricity was provided by Galvani in 1791. He suspended a neuromuscular preparation from a frog on a wire and placed it in a glass vessel. Upon a spark discharge from an electrical machine or a "flash of lightning", the muscle contracted. However, although these experiments were the first of their kind, Galvani's classical investigations further developed only the electrical contact method of stimulating a neuromuscular preparation.

Remote electrical stimulation of a frog neuromuscular preparation was also

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\*V. J. Danilewsky: Issledovaniya nad fiziologicheskim deystviem elektrichestva na rasstoyanii. (Investigation of the Long-Range Physiological Effect of Electricity.) Volume 1, Kharkov, 1900, pp. 6-7.

produced by Zahn (1868) in the Helmholtz Laboratory by means of the monopolar effect of a magneto. The contractions were explained by the effect of an oscillatory electrical field. In 1876, Tiegel and Gerens independently reported similar tests. Schiff (1879) repeated Charcot's experiments on the restoration of skin sensitivity in hysterical females by placing their hands in the field of a solenoid. Magini (1885) noted that the observed effect depends on the orientation of the biological object with respect to the windings of the magneto coil. In 1888, Hermann published the results of his investigations on the effect of a magnetic field on a frog neuromuscular preparation. He did not observe muscle contractions in a magnetic field. The excitability and conductivity of the neuromuscular preparation also did not change. We should also note that under similar experimental conditions McKendrick (1879) observed contraction of a neuromuscular preparation when an electromagnet was turned on.

In 1891, D'Arsonval and Tesla independently observed the biological effect of high-frequency fields on an entire organism for the first time. D'Arsonval placed his object inside a solenoid that had a high-frequency current flowing in its windings, and he observed increases in respiration and perspiration, weight loss, and a reduction in blood pressure in vertebrates. N. Ushinskiy (1897) noted a weight increase in guinea pigs under the same conditions.

In 1896, I. R. Tarkhanov first reported on the effect of x-rays on the CNS.

Thus, when V. J. Danilewsky wrote his two-volume monograph (1900-1901), the literature contained a certain number of disconnected works devoted to the effect of EMF of different frequencies on a biological object. Although the basic object of his investigations was a frog neuromuscular preparation, Danilewsky <sup>17</sup> proposed that EMF must cause not only muscle contraction. "We cannot ignore the other side of the matter, i.e., the possibility of the effect of electrokinetics in one form or another on the nutritional processes of nerve fibers and cells, including all the physical chemistry of this side of life. The nutritional interaction between the axon and the medullated sheath, between the nerve fiber, the cell and the external plasma of the tissue, the blood, the lymph, and other physical and chemical conditions of the life of a neuron can no doubt be modified under the effect of electricity. This in turn can be reflected on the functions of the nerve apparatus."\*

Danilewsky states the purpose of his investigations as the study of electrokinetic stimulation of the frog motor nerve by means of open and closed secondary magneto circuits.

From this simple problem he went on to study such problems as the electrical properties of the motor nerve, the effects on excitability, sensory nerves, nerve centers, etc. Then he studied the physiological effect of "electrical beams", a magnetic flux, and combinations of various electrical effects.

Electrokinetic stimulation did not differ from contact stimulation except that the first method did not suppress muscle contractions as the frequency

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\*V. J. Danilewsky. Issledovaniya nad fiziologicheskim deystviem elektrichestva na rasstoyanii. (Investigation of the Long-Range Physiological Effect of Electricity.) Volume 2, Kharkov, 1901, p. 103.

of oscillations is increased above 200 Hz, and the reaction was accomplished with a shorter latent period. Human sensory nerves were also stimulated by EMF. The sensations were diverse: labored breathing, warmth, tingling, pain. Sometimes, when the head was placed in the field, light flashes were sensed. When the entire subject was placed in the field, animated nervousness sometimes resulted.

After the work of V. J. Danilewsky, it would seem that the problem of the effect of EMF on an organism would have developed rapidly. However, we observe the expected interest in this problem only in the 30's; after the extensive introduction of electric lights it became possible to produce powerful UHF fields. Dozens of monographs and thousands of articles devoted to the biological effect of UHF fields were published during these years. The Second World War abruptly cut off the development of this problem.

The atomic explosions over Hiroshima and Nagasaki gave preeminence to the problem of the biological effect of ionizing radiations on the organism in general and on the nervous system in particular. There are numerous works on this question, and their number is growing steadily. Several monographs devoted to /8 the effect of ionizing radiations on the nervous system have been published recently [Lebedinskiy, Nakhil'nitskaya, 1960; Livanov, 1962; Minayev, 1962; Livshits, 1961]. These publications contain the general propositions regarding the mechanisms of the effect of penetrating physical factors on the functions of the nervous system. Knowledge of these propositions must be considered in a study of the effect of electromagnetic oscillations of any range on the nervous system.

The post-war appearance of radar stations has pointed out the problem of the biological effect of EMF of the SHF range. There are already thousands of reports on this question. Finally, the conquest of outer space, where significant changes in the intensity of magnetic fields are possible, and the magnetic shielding of a spacecraft from ionizing radiations, have again increased interest in the biological effect of a magnetic field.

Of course, we cannot consider these reasons the only motives for scientific development of the questions on the biological effect of one or another range of electromagnetic oscillations. The effect of ionizing radiations on an organism was studied even before the invention of the atomic bomb, SHF fields were used in biological experiments before the discovery of radar, and the effect of a magnetic field on man was investigated when space flights were only dreams. However, after considering the mentioned changes in human existence, the discussed problems take on even greater importance.

Thus, the urgency of the problem regarding the effect of EMF on an organism is prompted by the intensive development of many fields of science and technology.

The CNS plays a leading role in the reaction of an organism to various factors of the environment. The method of conditioned reflexes and the electro-physiological method have played a significant role in the study of reception of various stimuli from the environment and from within the organism. These

methods, however, have not been used extensively in the investigation of the biological effect of EMF.

Therefore, the main purpose of this work is to clarify the physiological mechanism of the effect of EMF on the functions of the brain by means of electrophysiological and conditioned-reflex methods. Besides these methods, we have used the methods of recording motor activity, determining the sensitivity to electrical and chemical stimuli, and also certain morphological methods. The experimental objects were representatives from various classes of vertebrates, beginning with fish and ending with mammals.

One of the leading ideas used in presenting the material is the concept concerning the similar effect of SHF, UHF and constant magnetic fields on the brain. We realize that it is difficult to compare the biological effect of various physical factors whose intensities, in themselves, are difficult to compare. It is probable, therefore, that we will be most frequently limited to describing the initial period of general nonspecific reactions which occur during exposure to various types of EMF of different intensities; in analyzing the results, the noted similarity of the biological reactions comes to the fore. The existing distinctions in the biophysical effect mechanism of the studied EMF, which are explained by their different degrees of penetration through the surface tissue, the presence of the thermal effect of variable fields, the presence of an induced electromotive force when a CMF is varied, etc., were brought out to a lesser degree in our analysis. /9

The main questions of this investigation, such as the form of the EEG reaction, the direct effect of EMF on the isolated brain, and the presence of a reaction when the fields were turned off, were answered in experiments in which the effect of each field was investigated separately.

Based on the hypothesis regarding the similar effect of SHF, UHF and constant magnetic fields, in certain cases we applied the results obtained in experiments with one of the fields to other fields. Thus, we clarified the role of the distance receptors and the effect of partial sympathectomy only in experiments with a UHF field, and we studied the dynamics of the pulsed activity of cortical neurons and the reaction of brain neuromia only under the effect of a CMF.

Throughout the work we tried to compare the physiological effect of EMF of the studied ranges not only with one another, but also with the effect of such stimuli as light, sound, heat, ionizing radiation, and an electrostatic field (ESF).

P A R T    1.    T H E    E L E C T R O G R A P H I C    M E T H O D  
O F    S T U D Y I N G    T H E    E F F E C T    O F    E L E C T R O-  
M A G N E T I C    F I E L D S    O N    T H E    C E N T R A L  
N E R V O U S    S Y S T E M

/10

Electrographic methods that can record the direct reaction of the CNS have been insufficiently used in studying the biological effect of EMF. This can be explained by two reasons.

First, the wave of interest in the biological effect of EMF observed in the 30's historically belongs to the period in which the electrographic method of investigating the CNS had just been developed. Second, there were difficulties in the methodology; these were connected with the possible effect of EMF on the electrodes used to record the bioelectric reactions.

We know of only six works published prior to 1960 in which the effect of EMF on the electrical activity of the brain was studied. These were reports on the effect of a UHF field on the EEG of rabbits [Pardzhanadze, 1954], the effect of an SHF field on the EEG of rabbits and cats [Bychkov, 1957 and 1959], of monkeys [Baldwin et al., 1960] and of man [Sinisi, 1954], and also the effect of EMF of an undetermined frequency characteristic on the EEG of rabbits [Livanov et al., 1960]. In recent years we have noted an increase in this type of investigation, in which great attention has been devoted to the mechanism of the effect of EMF on the CNS [Bavro, Kholodov, 1962; Bychkov, 1962; Khvoles et al., 1962; Gvozdikova et al., 1964a, b; Vyalov et al., 1964; Zenina, 1964; Nikonova, 1963; Kholodov, 1962a, b, c; 1963a, b, c; 1964a; Kholodov, Yanson, 1962a, b; Kholodov, Luk'yanova, 1964; Fleming et al., 1961; Dinculescu et al., 1963; Becker, 1963 and others]. Thus, with each year electrographic methods are applied more widely to investigate the biological effect of EMF, and it is now time to introduce certain results of these investigations.

We should note that the electrographic analysis of the effect of ionizing /11 radiation on the nervous system is based on the recent monograph of M. N. Livanov (1962). Knowledge of the material in this book is necessary to study the effect of penetrating factors on the CNS, and we will often turn to it in the future.

All our tests were conducted on unanesthetized rabbits.

In studying the effect of different EMF on the electrical activity of the brain, we used the same methodology and methods of treating the data, a description of which will be given later.

## EXPERIMENTAL METHODOLOGY AND TREATMENT OF THE RESULTS

### Methods Used Under Different EMF

In all tests the rabbits were placed on a wooden stand with their spine upwards: the four extremities and head were secured with bandages.

In most tests we placed the field on the head region. We used total-body exposure only under a pulsed SHF field. In certain tests we separately focused the field on the head, chest, intestines, pelvis and hind legs.

Sources of the UHF field (wavelength, 6.6 m) were a UVCh-300 (UHF-300) generator giving a field strength of about 5,000 v/m (thermal dose) and a UVCh-2m-40 generator giving a field strength of about 1,000 v/m (oligothermal dose).\* The latter generator was designed for dc feeding, which allowed recording the electrical activity of the brain during the influence of the field. The plate electrodes of the UHF generator were placed bitemporally 12 cm apart so that the entire head of the rabbit was placed between the electrodes (Figure 1).

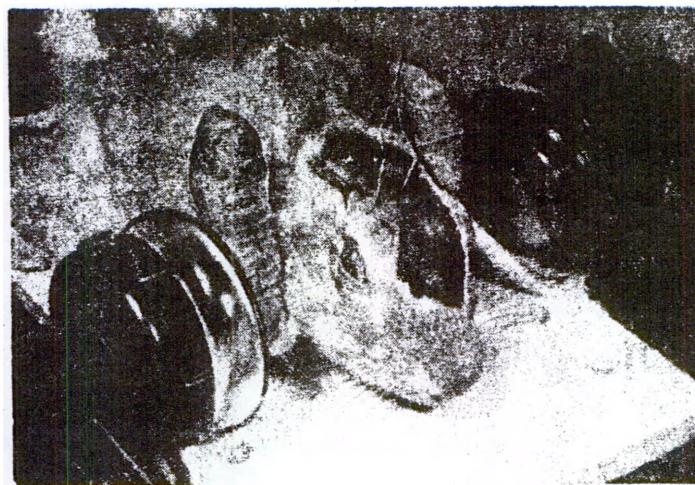


Figure 1. Position of the Electrodes for Recording the Influence of a UHF Field on the Head of a Rabbit.

modulation index was about 100%.

A pulsed SHF field (wavelength, 52 cm) was used in both thermal (power flux/14

\*The dosimetric investigations of the UHF and SHF fields were conducted with the help of B. I. Stepanov and Ye. I. Kurakin, colleagues of the Z. V. Gordon Physical Hygiene Laboratory of the Institute of Labor Hygiene and Occupational Diseases; the author expresses his sincere gratitude to them.

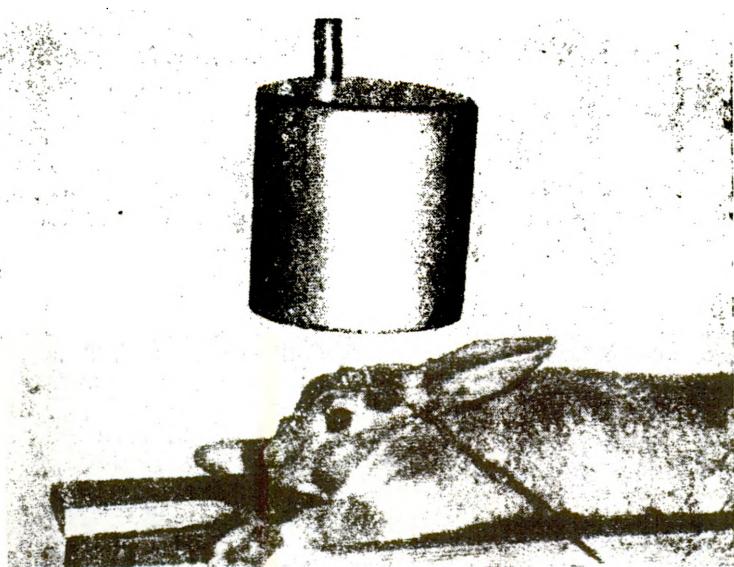


Figure 2. The Position of the Emitter for an SHF Field on the Head of a Rabbit.

gap between the poles, where the head of the secured rabbit was placed (Figure 3), could be changed by moving one coil. Most frequently, we used CMF with strengths of 200, 400, 800 and 1,000 Oe. The field strength was varied by a "Norma" fluxmeter. When the electromagnet switch was turned on, the time for reaching limiting strength was 1 sec; when it was turned off, the CMF disappeared in 0.2 sec.

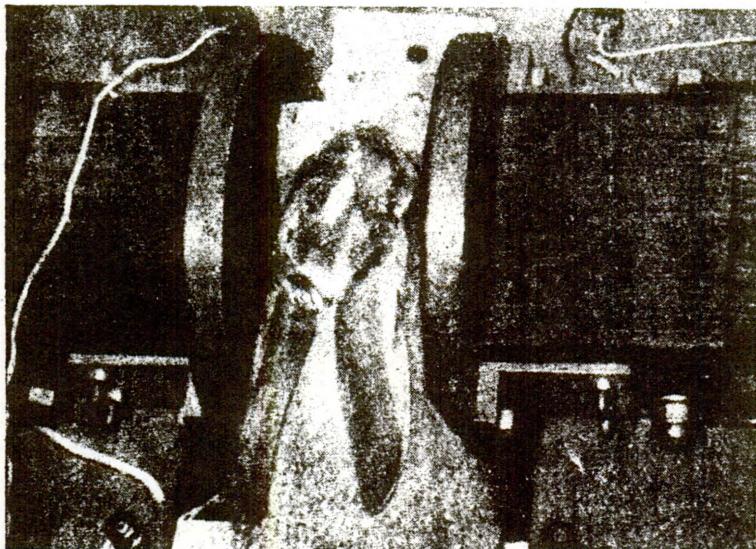


Figure 3. Position of the Electromagnet for a Constant Magnetic Field on the Head of a Rabbit.

density of  $50 \text{ mw/cm}^2$ ) and nonthermal (10 and  $2 \text{ mw/cm}^2$ ) intensities for total body irradiation of the animal.

A constant magnetic field was created with one of our two battery-fed dc electromagnets. Sometimes a selenium rectifier was switched in parallel with the batteries. With a rheostat switched into the circuit according to the divider principle we could regulate the current power and thereby change the strength of the CMF.

The electromagnets differed in size. The pole diameter of one was 90 mm, of the other, 220 mm. The secured rabbit was placed (Figure 3), could be changed by moving one coil. Most frequently, we used CMF with strengths of 200, 400, 800 and 1,000 Oe. The field strength was varied by a "Norma" fluxmeter. When the electromagnet switch was turned on, the time for reaching limiting strength was 1 sec; when it was turned off, the CMF disappeared in 0.2 sec.

An electrostatic field (ESF) was created with a AF-3 generator. The electrodes were  $4 \times 6 \text{ cm}$  copper plates. For insulation each electrode was sandwiched between two 5-mm thick plexiglass plates, whose edges were glued. These electrodes were placed bitemporally around the head of a rabbit in such a way that the brain was between them (Figure 4). The rabbit's head was reliably secured in a head harness. We used field strengths of 1.25, 2.50 and 5.00 kv/cm.

The duration of the influence of each field was most frequently limited to 1

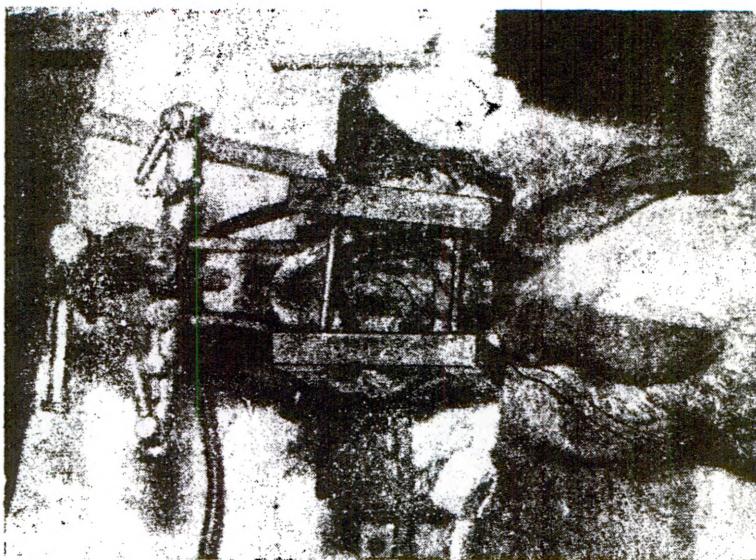


Figure 4. Position of the Electrodes for an Electrostatic Field on the Head of a Rabbit.

or 3 minutes with an interval of 10-20 minutes. In separate experiments with a CMF the duration of the exposures varied from several seconds to several hours. Depending on the purpose of the investigation, the duration of the experiment with each animal varied from several hours to several months.

#### Methods of Recording the Electrical Activity

Electroencephalograms (EEG) were recorded with the aid of needle electrodes driven through the bone. The fastening of leads was always monopolar: an inert electrode was fastened to the nasal bones. Before the test, the upper surface of the animal's skull was usually scalped.

Electroencephalograms were recorded from the sensorimotor, parietal and visual regions of the cerebral cortex with the aid of recording electroencephalographs developed by the VNIIMI or the Edisvan (Translator's note: Edison?) and Alvar Companies, and also with the aid of a UNCh-6 amplifier of the AMN (Academy of Medical Sciences) Experimental Plant based on a nine-loop oscillograph of the Siemens Company. On the same instruments we recorded electrocorticograms and the electrical activity of a neuronally-isolated strip of the cerebral cortex. In the last case, the recording was performed by the bipolar method with cotton-wick electrodes. The distance between electrodes was 3-6 mm.

To record the electrical activity of different subcortical formations of the brain we used nichrome electrodes (diameter, 100 microns), which were insulated with resin and resistant to biological effects.

According to the Sawyer coordinates [Sawyer et al., 1954] with the

Meshcherskiy correction [R. M. Meshcherskiy et al., 1960] and using stereotaxic apparatus, electrodes were imbedded in the sensorimotor and parietal regions of the cortex, the hypothalamus, hippocampus, thalamus proper, reticular nucleus of the thalamus and reticular formation of the midbrain. The hypothalamus is considered to be the formation most sensitive to different ionizing radiations [Aladzhalova, 1962], including magnetic fields [Kholodov, 1959]. The hippocampus most clearly changed its electrical activity under the influence of ionizing radiation [Monnier, Krupp, 1962]. After unilateral damage to the reticular formation of the midbrain the electrical activity of the cortex did not change on the side of the damage in response to x-rays [Izosimov, 1961a, b; Lebedev, 1963].

The reaction of nonspecific nuclei of the thalamus was investigated because electrical stimulation of this section of the brain causes spindle-shaped oscillations on the EEG, i.e., the characteristic form of the EEG reaction to SHF and UHF fields. Furthermore, electrodes were embedded in specific nuclei of the thalamus.

To record the pulsed extracellular activity of neurons, we used a micro-electrode holder such as that designed by A. M. Melekhova (1961). The micro-electrode was a glass capillary with a tip diameter of 1-2 microns. It was filled with 2.5 M KCl. The inert electrode was fastened to one ear.

The activity of the neurons was amplified by a UBP-01 amplifier with a cathode follower. The activity was recorded from the screen of a two-beam cathode oscilloscope operating on film.

To record the neuron activity the rabbits were preliminarily scalped, then a 2-mm hole was drilled in the skull, the dura mater was opened, and the pia mater was punctured with a microelectrode. A micromanipulator was fastened to the skull bone with dental cement. Rotating the screw of the micromanipulator slowly embedded the microelectrode into the brain. When we observed a spontaneously stimulated neuron, we recorded its activity. Recordings were taken before and during the effect of the CMF on the animal's head. /16

Besides recording such spontaneous electrical activity of the brain, to elicit the presence of a reaction to the EMF we also used test stimuli methods. For purposes of testing, we used the reactance curve method (after M. N. Livanov) and the reaction of the visual cortex neurons to a single light flash. In both cases the parameters of the electrical reaction to the light stimulus were determined before, during and several minutes after the influence of the field.

In several series of experiments we investigated the electrical reaction of the brain to EMF after certain pharmacologic preparations had been injected.

#### Surgical Methodology

To determine the physiological mechanism of EMF perception, we destroyed the remote receptors and different sections of the brain, performed partial desympathization, and made an isolated brain preparation (*cerveau isolé*, in certain cases *encephale isolé*) and a neuronally-isolated strip of the cerebral

cortex. The electrical reaction to EMF was investigated both before and after such surgical intervention.

To exclude vision, we performed a bilateral section of the optic nerves. In an unanesthetized animal that was secured in a head harness, we cut a section of the skin under the orbit and cut out a small section of bone immediately in back of the eyeball with a spatula; trying not to interfere with the blood vessels, we moved the muscle tissue in order to observe the optic nerve. It was sectioned with a scalpel during visual contact. After the nerve was sectioned, we sutured the skin and performed a similar operation on the other side.

The auditory analyzor was destroyed according to the method described by A. B. Tsypin and Yu. G. Grigor'yev (1961). With a syringe needle bent at a right angle, we injected 1-3 cc of 96% ethyl alcohol into the middle ear. This destroyed not only the auditory, but also the vestibular analyzor, although in the future we shall call these animals "deafened".

Macroscopic investigation of the outer, middle, and inner ears of both rabbits showed that the region of the middle ear sustained deep destruction on both sides during the operation. The tympanic membrane was completely absent. The ossicles of the middle ear (the malleus, incus and stapes) could not be observed.

Very noticeable destruction was observed in the region of the inner ear (the cochlea). With relative retention of the scala tympani and the receptor formations of the inner ear, we noted mechanical lesions of the auditory nerve at the base of the cochlea. These lesions varied in severity, but, as a rule, the auditory nerve was completely destroyed. In the sections of bone adjacent to the cochlea, we noted sharply expressed hyperemia. Together with bone residue, we observed certain traces of osteogenesis. The test rabbits were unable to perceive sound with such destruction of their auditory analyzor.\*

The olfactory analyzor was destroyed by vertical section of the olfactory bulb. We scalped the animal, trepaned a transverse slot over the olfactory brain and then, through this slot, sectioned the olfactory bulb with a scalpel.

Destruction of the different brain sections was performed with a DT4-3 diathermy apparatus. We secured the rabbit in a stereotaxic apparatus and embedded a live electrode, which consisted of a No. 2 sewing needle insulated with bakelite over its entire length except for the tip. The inert electrode, which was a lead plate wrapped in moist gauze, was placed on the animal's side. The place where the inert electrode was applied was preliminarily shorn. A 0.2-amp current was passed from 20 to 60 seconds. After the tests the animals were killed and the results of the lesions were checked histologically.

To remove the upper cervical sympathetic ganglia from a rabbit held with its back downwards on a stand with the aid of a head harness, we sectioned the larynx under ether. Moving the muscle tissue aside with a spatula, we found a

\*The morphological analysis of the auditory analyzor structure in the two deafened rabbits was conducted by Candidate of Biological Science, I. I. Glezer, to whom the author expresses his gratitude.

sympathetic ganglion and, grasping it with forceps, we cut the nerve fibers emerging from it. Then, we sutured the skin on the neck and after a day we subjected the animal to experiments on the influence of EMF.

To obtain an isolated brain preparation (*cerveau isolé*), we used the following method for sectioning the midbrain. An unanesthetized rabbit was securely fastened in a stand with the aid of a head harness. Its skull was scalped and, parallel to the transverse suture but remaining 3-5 mm in back of it, we made a slot for the scalpel with the aid of a dental drill and manicure scissors. Then, we sectioned the midbrain with a scalpel and partially damaged the occipital region of the cerebral hemispheres located over it. During this operation /18/ the spinal arteries were not damaged, so that blood supply was retained to a significant degree to the isolated brain preparation; the remainder of the animal served only as a heart-lung system for the preparation. Two out of 10 rabbits died immediately after the operation. Just as with normal rabbits, we recorded the EEG from the isolated brain preparation with needle electrodes embedded in the bone.

After the tests the animals were killed, and the brain was removed and fixed in formalin. A morphologic analysis showed that sectioning of the midbrain was most frequently complete, occurring at the level of the lamina quadrigemina.

In determining the size of the neuronally-isolated strip of cerebral cortex, we considered the fact that the most convenient and bloodless isolation was possible in the sensorimotor region of the cortex. Proceeding from the dimensions of this region, we always isolated a  $5 \times 15$  mm strip 5-8 mm deep with the aid of a U-shaped loop of steel wire 0.4 mm in diameter. A wire that served as the handle was secured to one of the ends of the loop and perpendicular to its plane.

Isolation was performed in the following manner. The rabbit's head was secured in the head harness. The upper part of the skull was scalped using no anesthetic. We then performed trepanation, revealing the interior part of the hemispheres. With a scalpel we made a transverse incision in the dura mater in the region of the olfactory brain of one hemisphere, and deepened it to 3-5 mm. We vertically inserted the forward edge of the loop into this incision and, gradually bringing it to the horizontal, we moved it all the way to the posterior section of the brain. We then moved the loop, located under the cortex and parallel to the surface of the brain, vertically upwards and pressed the dura mater against the whole perimeter of the loop with a finger. Through the dura mater we could see that the loop had completely isolated a strip of the cortex below it. We then performed the same operation in reverse in order to free the loop. Thus, the loop passed over the same path twice, effectively isolating the strip. A histologic check showed that isolation was complete (Figure 5).

We should note, as did other authors [Aladzhalova, Koshtoyants, 1960], that in the initial experiments we operated on and recorded the activity of strips from animals that had been injected with Diplacin. However, it was observed that injecting this substance reduced the electrical activity of the strip, so we conducted the remaining series of experiments on unanesthetized animals.

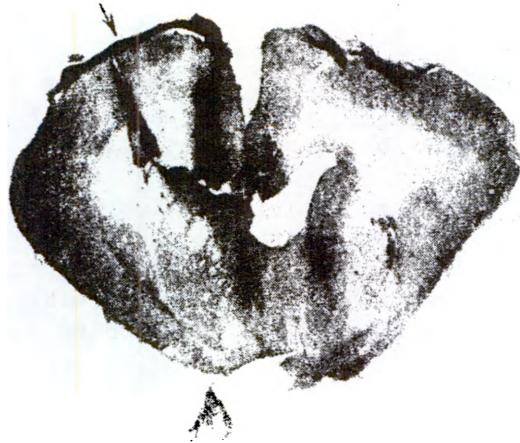


Figure 5. A Transverse Section of the Brain of a Rabbit. The Arrow Shows the Neuronally-Isolated Strip of Cortex.

cord in the following manner. We sheared the fur from the neck, both below (for subsequent tracheotomy) and above. Under ether, with a scalpel we made a longitudinal section of the skin along the spine immediately behind the occiput. We separated the muscle tissue with a spatula and removed certain sections with scissors in order to observe the first cervical vertebrae. Then, the upper part of the two cervical vertebrae was broken off with forceps, thereby revealing the spinal cord. The rabbit was injected with Dipalatin, tracheotomy was performed and the animal was put on artificial respiration. Electroencephalograms and the effects of a UHF field in these rabbits were recorded by the same method as in normal animals. After several sessions, we sectioned the spinal cord with a scalpel and resumed the treatment with a UHF field on an isolated brain preparation (*encephale isolé*).

In the initial experiments /19 we also resected the dura mater, but subsequently we became convinced that retaining the dura mater did not introduce significant changes in the electrical activity of the strips, while it also protected the brain surface from drying out and from reduced blood flow. Furthermore, retention of the dura mater allowed conducting repeated experiments with a strip over several days.

In some experiments we isolated the strip after preliminary sectioning down to the level of the midbrain or the spinal cord.

We sectioned the spinal

cord in the following manner. We sheared the fur from the neck, both below (for subsequent tracheotomy) and above. Under ether, with a scalpel we made a longitudinal section of the skin along the spine immediately behind the occiput. We separated the muscle tissue with a spatula and removed certain sections with scissors in order to observe the first cervical vertebrae. Then, the upper part of the two cervical vertebrae was broken off with forceps, thereby revealing the spinal cord. The rabbit was injected with Dipalatin, tracheotomy was performed and the animal was put on artificial respiration. Electroencephalograms and the effects of a UHF field in these rabbits were recorded by the same method as in normal animals. After several sessions, we sectioned the spinal cord with a scalpel and resumed the treatment with a UHF field on an isolated brain preparation (*encephale isolé*).

#### Methods of Treating the Experimental Data

/20

During each application of any stimulus, there were three portions of the tracing of electrical brain activity: the background, the period of exposure and the period of the aftereffect. Frequently, each portion was 1 minute long and we evaluated the change in electrical activity under the influence of the stimulus as a result of analyzing a three-minute tracing of the brain electrical activity. Sometimes the recordings of the background and the period of exposure were not equal, but the analytical principle remained the same.

Besides the background recording, before each application of the stimulus we conducted control experiments with a "false" influence; the recording of electrical activity was conditionally divided into background, exposure and after-effect periods. The control experiments were conducted by exactly the same method as the tests involving application of stimuli.

A visual analysis of the tracings revealed that changes in the electrical

activity (in comparison with the background recording) did not occur during each application of the stimulus.

In a number of cases, when a reaction was observed in the EEG of an intact brain during the period of exposure to different EMF, at the moments the generator was turned on and off a brief desynchronization of biopotentials occurred.

The characteristic changes in electrical brain activity, which we shall call the "basic" reaction to the stimulus, appeared several seconds after the generator was turned on, and frequently continued until it was turned off. Finally, several seconds after the generator was turned off there were brief changes in the electrical activity; these we shall call the reaction to switching off or the "off effect".

Thus, we analyzed 4 types of reactions to the influence of stimuli: 1) desynchronization at turn-on; 2) the "basic" reaction; 3) desynchronization at turn-off; 4) the off-effect. Each of these reactions was characterized by a stability or a recurrence, i.e., the percentage ratio of the number of reactions to the number of stimulus applications.

The latent period of the desynchronization reactions could not be determined from the recordings made on the ink-writing electroencephalograph since this period was a fraction of a second; we evaluated these reactions in terms of the degree of stability, and sometimes from the duration.

We calculated the average latent period of the basic reaction and the reaction to turn-off, plotted the curve of the distribution of latent periods and /21 determined the stability of the reactions. These data were compared with similar results from the control experiments.

Sometimes we calculated the average, most characteristic frequency and amplitude of cerebral cortex biopotentials for each minute of the EEG, taking the average indices in the background recordings as 100%. The curve of the dynamics of change in these indices characterized the intensity of the reaction.

Since the basic and turn-off reactions under EMF were most frequently expressed by an increase in the number of spindle bursts and slow waves, we used a more detailed method of treatment, calculating the number of these changes in each 5-second portion of the EEG. Each such portion was characterized by the alternate presence and absence of these indices. The results of a series of experiments, which included several tens of exposure periods on several rabbits, were treated statistically according to the Student criterion for alternative variability. The following formulas were used:

$$Pb = \frac{K_1 + K_2}{N_1 + N_2}, \quad (1)$$

$$\sigma = \sqrt{(N_1 + N_2) Pb(1 - Pb)}, \quad (2)$$

$$t = \left| \frac{N_2 Pb - K_2}{\sigma} \right|, \quad (3)$$

where  $K_1$  is the number of spindles or other EEG indices in the background recordings;  
 $K_2$  is the number of EEG indices during the influence period of the stimulus;  
 $N_1$  is the number of 5-second portions in the background recordings;  
 $N_2$  is the number of 5-second portions during the influence period of the stimulus;  
 $P_b$  is the probability of a spindle being in the background and test recordings;  
 $\sigma$  is the mean square deviation; and  
 $t$  is the Student criterion.

When the background recording and the influence period are equal, the formula is simplified, taking on the form:

$$t = \left| \frac{\frac{K_1 + K_2}{2} - K_2}{\sqrt{\frac{K_1 + K_2 - (K_1 + K_2)^2}{2N}}} \right|, \quad (4)$$

where  $N$  is the number of 5-second portions in the background recordings, and the remaining designations are the same as in formulas 1-3.

In our experiments these results were considered reliable when the Student criterion was not less than 1.98, which corresponded to a level of significance of  $p \leq 0.05$ .

The dynamics of the number of spindles and slow waves in the background, /22 during and after the influence period are usually presented in graphic form.

When using the reactance curve method, we calculated the time for the appearance of the assimilation reaction to light flashes. Using the Student criterion, we also evaluated the statistical reliability of the difference in the index in the background and during the influence period of the field, using the known formula [Rokitskiy, 1961; Beyli, 1964; and others]:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{\bar{m}_1^2 + \bar{m}_2^2}{2}}}, \quad (5)$$

where  $\bar{x}_1$  is the average time for the appearance of assimilation in the background;  
 $\bar{x}_2$  is the average time for the appearance of assimilation during the influence period;  
 $\bar{m}_1$  is the average error for the background; and

$m_2$  is the average error during the influence period.

During extracellular recording of the electrical activity of separate neurons, the basic index was the frequency of spikes per unit time, which we determined in the background, under the EMF and in the aftereffect period. This index was determined from the total data for all neurons without exception, and also from the total data separately for neurons of group I (which increased their activity during the influence period), group II (which decreased their activity during the influence period) and group III (which did not change their activity during the influence period). A neuron was classified in group I or II only when the frequency of its spikes changed by approximately 2 times during the influence period.

## CHAPTER 1. THE EFFECT OF A UHF FIELD ON THE ELECTRICAL ACTIVITY OF THE RABBIT BRAIN

The biological effect of a UHF field (wavelength, 1-100 m) was observed by D'Arsonval and Tesla 3 years after this field was discovered by Hertz in 1888. In the next 70 years the question concerning the effect of a UHF field on a living organism was investigated in many publications [Libezni, 1936; Shlifake, 1936; Likhterman et al., 1936; Slavskiy, 1937; Frenkel', 1939-1940; Popov, 1940; Livshits, 1954; Abrikosov, 1958; and others]. The reader who is interested in general questions concerning the biological effect of a UHF field will find a /23 sufficiently full description of the achievements in this region in these works. However, our purpose is to discuss the effect of a UHF field on the nervous system. This subject has been considered in many survey works devoted to the biological effect of UHF fields, but basically it is discussed in two recent articles by N. N. Livshits (1957, 1958).

### The Effect of a UHF Field on the Central Nervous System

The effect of a UHF field on the functions of the nervous system was noted even in the first works on the biological effect of such a field. "There is no doubt that the nervous system, both cerebral and autonomic, is very sensitive to the influence of UHF waves".\*

People subjected to the systematic influence of a UHF field complained of somnolence, headaches, fatigability and irascibility [Likhterman et al., 1936]. These same authors note that the reactions to a UHF field are distinguished by their phase nature and reversibility, and they depend on the individual characteristics of the organism and upon the initial functional state. They examined, both directly and through the reflexes, the UHF field as the unique stimulus that affects not only the skin receptors, but also the receptor formations located more deeply in the organism.

The autonomic nervous system is distinguished by its special sensitivity to a UHF field.

It should be mentioned that many authors distinguish between the thermal effect of a UHF field, when an increase in body temperature is observed, and a nonthermal (specific) effect, when no change in temperature is recorded. Under a strong UHF field the following stages of behavior have been noted in animals: an increase in motor activity, depression, spasms and death.

Because there is no accurate dosimetry for the UHF field it is difficult to compare the results of different investigators. However, in most cases non-thermal or weakly thermal doses were used to study the function of the nervous system. In this survey we will speak only about the qualitative changes that occur in the activity of the nervous system under a UHF field.

\*V. A. Militsin: Ul'travysokaya chastota v klinike nervnykh bolezney. (UHF in Clinical Studies of Nervous Disorders.) Nevropatologiya i Psichiatriya 7:18, 1938.

The effect of a UHF field on the higher centers of the CNS has been studied experimentally by the method of conditioned reflexes. It has been shown that a 3-5-minute exposure of a UHF field on the head of a pigeon increases the latent period of alimentary reflexes by approximately 2 times. Multiple exposures lead to a disappearance of positive reflexes, which are slowly restored after the exposures are stopped [Kharchenko, 1939].

Tests on dogs have shown that the effect of a UHF field on the head increases the conditioned and unconditioned alimentary reflexes. A weakening of the processes of inhibition has been observed under repeated exposures [Glezer, 1940a]. In normal dogs, in the first phase of the effect, a UHF field increases the alimentary secretory conditioned reflexes, but in the second phase under repeated application it reduces the positive conditioned reflexes and disinhibits differentiation. Dogs with higher nervous activity disturbances exhibit a deepening of the pathological state during the first phase, and a normalization of activity during the second phase [Promtova, 1956].

During local exposure of the UHF field on the temporal and frontal region of the cortex of dogs, changes in the conditioned-reflex activity were recorded in some tests, while in others they were not. The character of the reaction also depended on the type of higher nervous activity of the animal. In dogs with a strong type of higher nervous activity, the effect of the UHF field on the auditory region was a reversible lowering of the conditioned reflexes, or disinhibition of differentiation only within limits of the auditory analyser. In dogs with the weak type of higher nervous activity the same exposure reduced the conditioned reflexes from different analysors [Livshits, 1957].

After multiply exposing rats to an HF field (500 kHz), a shortening of the latent period of the alimentary motor reflex was noted [Nikonova, 1964].

Thus, an analysis of the experiments conducted according to the conditioned reflex method shows that a UHF field has a phase-reversible effect on the functions of the cerebral cortex, that this has a cumulative effect, and that it depends on the type of higher nervous activity of the animal and upon the initial functional state.

After the head of a chicken was placed in a powerful UHF field, the bird did not drink, eat or even change its position autonomously. An autopsy revealed hyperemia and reduction of the cerebral hemispheres [Heller, 1932].

Therapeutic doses on the human head produced deflection of extended arms [Hoff, Weissenberg, 1932], changes in the auditory thresholds [Sheyvekhman, 1949], a change in the spatial perception of sound [Alekseyenko, 1949], a change in the flow of sequential visual images [Zagorul'ko, 1948] and an increase in the area of light sensitivity with a simultaneous reduction in the area of color sensitivity [Bludova et al., 1953]. These reactions did not appear during each exposure; this is possibly explained by the direct effect of the UHF field on the brain, and not on the receptors.

When the head of an animal was placed in a UHF field, a change in body temperature [Slavskiy, 1937], an increase in basal metabolism [Tonkikh, 1941], re-

tention of sugar in the blood [Popov and Morkovnikova, 1938], changes in the cardiac rhythm [Popov, 1940] and blood pressure [Glezer, 1940b], and also inhibition of the spinal reflexes in frogs [Sych, 1940; Bekauri, 1941] were noted.

Since the effect of a UHF field on the head of a rabbit produced changes in the activity of the smooth muscles of the intestine, pancreas and salivary glands, and since a change in respiration was noted in a rabbit under similar experimental conditions, it was suggested that a UHF field can locally affect the autonomic centers of the brain [Popov et al., 1940].

A change in the latent period and the excitability threshold of cerebrospinal reflexes was noted during total-body and local exposure of a UHF field on the region of the spinal cord [Piontkovskiy, 1936; Kocherga, 1940; Rozanova, 1939; Moskalyuk, 1949; Grishko, 1959]. A low-strength UHF field reduced the latent period of cerebrospinal reflexes in frogs; when the strength was increased this period lengthened.

Under UHF fields of various intensities, the latent period of the flexor reflex in rabbits was reduced after 1 minute and increased after 2-15 minutes. In man, the latent period of the reflex was reduced after 2 minutes and increased after 20 minutes. This index is considered a sensitive indicator of the effect of a UHF field [Moskalyuk, 1949].

It is considered that a UHF field affects the central part of the reflex arc more strongly than the peripheral part, and the afferent more strongly than the efferent parts. It is possible that a UHF field loosens the protoplasmic membranes of the intercalary neurons, as a result of which their permeability increases and the membrane potential decreases [Grishko, 1959].

Morphological investigations of the CNS of animals subjected to the influence of UHF fields of different intensities frequently reveal hemorrhage [Slavskiy, Burnaz, 1935; Tolgskaya, Nikonova, 1964], proliferation, and migration of microglia to the midbrain and the gray matter of the spinal cord [Nikolau et al., 1934], changes in the neuronal nucleus and in the distribution of Nissl bodies, tigrolysis in the neurons [Shvarts, 1945], and changes in the axosomatic synapses of separate nerve cells of the brain, which are manifested as overimpregnation and thickening of the end plates and their exfoliation from the nerve cell body [Tolgskaya, Nikonova, 1964].

Chronic exposure of dogs to a UHF field produced a reduction of the morphological changes in the CNS in comparison with the data from an acute test [Zhukhin, 1937], which testifies to the reversible character of the reactions of /26 the CNS to a UHF field [Shvarts, 1945]. During chronic exposure, the greatest histological changes were observed in the autonomic centers of the hypothalamus [Shvarts, 1945].

Almost all investigators have noted the inconsistency of the CNS reaction to a UHF field. This can be explained by the fact that the reaction depends on the individual characteristics of the human and animal CNS, its initial functional state, the phase nature, and localization and intensity [Popov, 1940]. Furthermore, the possible participation of the processes of adaptation or summation should be considered.

Thus, the participation of the CNS in the reactions of an organism to a UHF field can be considered proven. Many authors attribute the leading role to the reflex mechanism, noting that either the reflex is realized directly by a stimulated region on one or another organ, or it is realized secondarily on all systems of the organism through an essential change in endocrine activity.

The direct effect of the UHF field on different sections of the CNS has been noted by many investigators, but a comparative evaluation of the role of the reflex and the direct effects has been difficult because the reactions have usually been evaluated from a change in the activity of the peripheral organs and systems. We know of only one work [Sh. K. Pardzhanadze, 1954, submitted as a thesis] devoted to the effect of a UHF field on electrical brain activity. The author noted an acceleration of biopotentials and an increase in their amplitude in the cerebral cortex of the rabbit. The respiration rate was also reduced from 72 to 60 cycles a minute; the EKG and the skin temperature did not change.

Simultaneously with our publications on the change in the rabbit EEG under a UHF field [Kholodov, 1962b, c, 1936b, c, 1964a, b; Kholodov, Yanson, 1962a, b], reports appeared concerning a change in the rabbit EEG during the influence of a pulsed low-frequency (2-350 Hz) field [Khvoles et al., 1962] and of a high-frequency (500 kHz) field [Nikonova, 1963, 1964]. Under the influence of low- and high-frequency fields, the authors noted the appearance of slow, high-amplitude oscillations in the bioelectric potentials of the cortex.

We have assumed that electrographic methods of investigating the CNS, in combination with surgery, would allow us to evaluate the importance of direct reactions of the brain to a UHF field and to qualitatively characterize them.

#### Changes in the EEG of Rabbits Following the Influence of a UHF Field of Thermal Intensity

/27

We assumed that the higher the UHF field strength, the greater the probability of a reaction appearing in the EEG. In the first series of experiments, we recorded the EEG of the visual regions of 4 rabbits for one minute before, and after 30-60-second exposures to a UHF field with a strength of about 5000 v/m. This duration of the influence period was selected because we noted acute motor reactions of the animal when it was increased. The interval between exposures was 10-20 minutes because the initial EEG picture was restored in exactly this time. There were 83 exposures in all. In 18% of the cases we did not see changes on the EEG, in 32% we observed an increase in the amplitude of the biopotentials, and in 50% we observed a decrease in the amplitude (Figure 6). Since we observed an increase in the amplitude of the biopotentials only in one /28 out of four rabbits, we assumed that the most characteristic EEG reaction following the influence of a UHF field of this intensity is a reduction of the bio-potential amplitude. However, there are still questions concerning the origin of the changes in the electrical brain activity. Were they caused by a specific effect of the UHF field on the CNS and other systems of the organism, or were they caused only by the thermal effect? Are the processes which occur in living tissues under a UHF field the cause of the changes in the EEG, or are these changes connected with stimulation (thermal or electrical) of the brain through the embedded electrodes? An analysis of the reactions is complicated by the

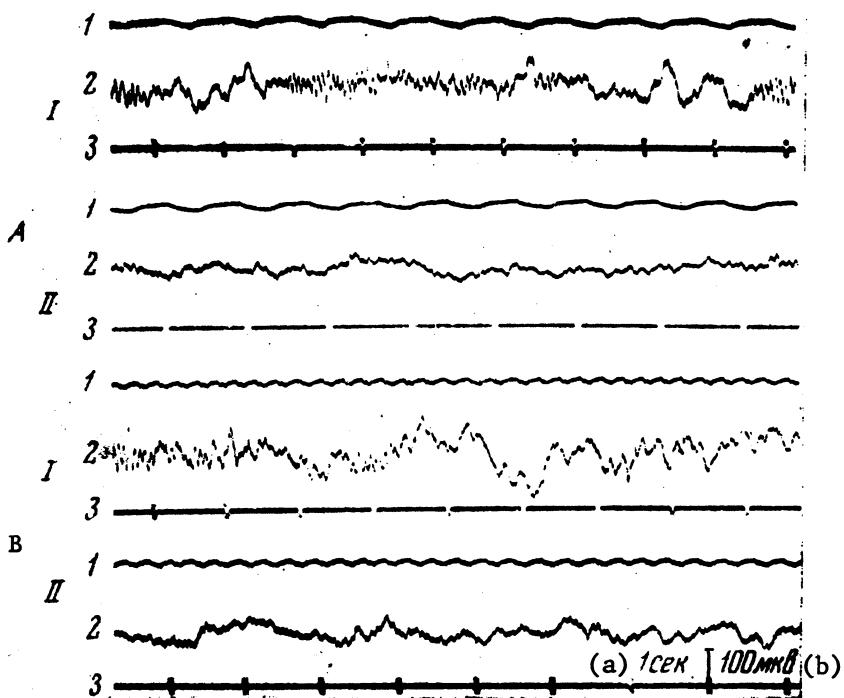
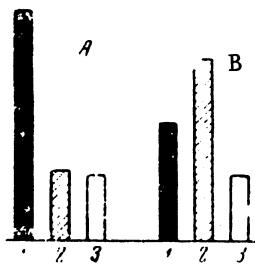


Figure 6. Changes in the EEG of Rabbit No. 1 (A) and Rabbit No. 2 (B) Before (I) and After (II) the Influence of a UHF Field of Thermal Intensity. 1 = Respiration; 2 = EEG of the Visual Cortex; 3 = Time Markings (1 Sec). Key: (a) 1 Sec; (b) 100  $\mu$ V.

fact that the rabbits sometimes began to twitch and cry out under the field, which testified to the painful nature of the effect.

After several tests, we noted that ulcers appeared on the forelegs of the animals. On certain rabbits the ulcers developed to such a degree that the pads dried out and fell off. Continuing these tests, we noted that the ears of the animals began to swell. Because of their small dimensions, and because they were closer to the electrodes, the UHF field could be concentrated on these sections of the head and legs. To check this assumption we used another method of harnessing the rabbit on the stand in which the animal's legs were tied to its back and its ears were held along the midline of the spine. Thus, the ears and legs of the animal were removed from the surface of the generator electrodes. The results appeared just as rapidly.

Figure 7 shows a comparative evaluation of the results of EEG tests using different methods of fixing the animals. Here we have the previously described results of 83 exposures on 4 rabbits that had their forelegs tied along their head, and the results of 100 exposures on 15 rabbits that had their forelegs tied along their back. The duration of the influence period was 30-60 seconds.



**Figure 7. Forms of the EEG Reaction Under UHF Fields of Weakly Thermal (A) and Thermal (B) Intensities on the Rabbit Head.** 1 = Increase in the Amplitude of Cortical Biopotentials; 2 = Decrease in the Amplitude; 3 = Absence of Changes.

the effect of the UHF field, then the assumption concerning the painful nature of its effect becomes more probable in the case of reduced biopotential amplitude. We should also add that exposure of just the hind legs caused only a reduction in the biopotential amplitude.

Thus, we can speak of two forms of the EEG reaction following the influence of a UHF field: an increase and a decrease in the biopotential amplitude (the first case was most frequently accompanied by a decrease in biopotential frequency, and the second, by an increase; but since there was rarely no change in frequency, for now, we shall be limited only to an analysis of the biopotential amplitude).

Decreases in amplitude (the desynchronization reaction) were observed most frequently during a painful effect. The animal usually exhibited motor reactions. The reaction had a sharply expressed reflex character since its source was localized on the periphery: on the extremities or the ears of the animal, where the field was concentrated. The cause of this type of EEG reaction probably was due to heat, as during external heating with the aid of two reflectors we observed a similar reaction. Briefly, the analyzed reaction was a nonspecific EEG reaction that occurred during the influence of different stimuli and was ably elicited by painful stimuli.

The second form of the reaction, manifested as an increase of the biopotential amplitude, occurred during the influence of a UHF field on the head. This form of the reaction did not change when we removed the electrodes from the skull during the influence period, then refastened them after this period was over.

As is evident from the diagram, there was an identical number of nonreactive cases (18%) with the different methods of harnessing. When the legs were held along the head, i.e., next to the electrodes of the generator, the decrease in biopotential amplitude predominated (50% versus 32%), but when the forelegs were held along the back,<sup>/29</sup> the increase in biopotentials predominated (63% versus 19%).

It can be assumed that, as for other stimuli [Mnukhina, 1963], phase changes of the EEG occur under a UHF field; in some rabbits we recorded a desynchronization phase, and in others, because of their individual characteristics, a synchronization phase starting at the same time. Postponing the discussion of the phase characteristics of this reaction until the end of this section, we now want to introduce certain facts testifying to the reflex character of the desynchronization reaction. With the forelegs held along the back, of the 18 cases involving reduced biopotentials following the influence of a UHF field, 12 were accompanied by a motor reaction. It is probable that in these cases the UHF field caused a pain reaction, concentrating its effect on the ears of the rabbit. If we also add that after removal of the ears from 3 rabbits, with their forelegs fixed along their back, we only noted an increase in the biopotential amplitudes on the EEG after

the effect of the UHF field, then the assumption concerning the painful nature of its effect becomes more probable in the case of reduced biopotential amplitude.

Consequently, this type of EEG change was connected with the influence of the UHF field on the tissue of the head of the rabbit, and not with possible stimulation of the brain through the electrodes.

It was possible to assume that high-frequency heating of the head region had a different effect on the EEG than the same heating of a different section /30 of the rabbit body. We noted the solution to this problem by using less intense UHF fields in which a thermal effect was less probable. We also set ourselves the problem of studying the rabbit EEG during the influence of the field in order to find out the latent period and the initial character of the bioelectric reaction. Therefore, in later investigations we used a weaker UHF field.

#### Changes in the EEG of Rabbits During the Influence of a UHF Field of Weakly Thermal Intensity

When we began using a weaker UHF generator, holding to the previous methodology, we decided to find out if the less intense UHF field caused heating.

We measured the skin and rectal temperature with a TSM-1 (058) electric thermometer before and after the influence of the UHF field. It turned out that a prolonged influence period (several tens of minutes) not only did not increase the temperature of the skin on the head, but sometimes it even lowered it. For example, in one rabbit the temperature of the ear before the influence was 35.9°, after 13 minutes of the influence, 35.6°, after 27 minutes, 34.1°, after 60 minutes, 25.2°, after 148 minutes, 25.0°, and after 200 minutes, 25.2°C. Control experiments in which a rabbit was only fastened to the stand and not subjected to the field showed that just fastening the rabbit caused an increase in its temperature, which then dropped slowly. Similar results are described in the literature [Kondrat'yeva, 1958]. We later determined the temperature of the ear, head and rectum for several rabbits during the influence of the UHF field. Table 1 gives the results of measuring the skin temperature of the parietal section of the head and ear, and also the rectal temperature in 7 rabbits before and after a 3-minute exposure to a UHF field. The UHF field was not shut off when the temperature was measured.

TABLE 1. TEMPERATURE OF THE SKIN OF THE HEAD AND EAR AND THE RECTAL TEMPERATURE OF RABBITS BEFORE AND AFTER A 3-MINUTE EXPOSURE TO A UHF FIELD WITH A STRENGTH OF 1,000 V/M ON THE HEAD.

Rabbit No.	Temperature of the skin of the head, °C			Temperature of the ear, °C			Rectal temperature, °C		
	initial	final	difference	initial	final	difference	initial	final	difference
1	31.4	30.8	- 0.6	36.9	36.6	- 0.3	38.0	38.2	+ 0.2
2	31.5	31.8	+ 0.3	37.2	36.8	- 0.4	38.2	38.1	- 0.1
3	32.2	32.6	+ 0.4	28.8	28.6	- 0.2	39.8	39.6	- 0.2
4	32.0	31.8	- 0.2	37.4	37.1	- 0.3	39.5	39.4	- 0.1

TABLE 1. (CONTINUED)

Rabbit No.	Temperature of the skin of the head, °C			Temperature of the ear, °C			Rectal temperature, °C		
	initial	final	difference	initial	final	difference	initial	final	difference
5	31.9	31.8	-0.1	36.8	37.2	+0.4	39.2	39.2	0
6	31.8	31.6	-0.2	35.2	34.8	-0.4	37.2	37.3	+0.1
7	35.0	35.2	+0.2	32.8	34.0	+1.2	37.3	37.4	+0.1
Average	32.3	32.2	-0.1	35.0	35.0	0	38.5	38.5	0

As the average results of our measurements show, the field did not affect the temperature (at least in the cases when we measured it).

In contrast to the influence of a UHF field of thermal intensity, during this series of tests, under the influence of a less intense UHF field, we did not once observe vocal or motor reaction by the rabbits, salivation did not occur once, nor did trophic lesions appear. Heartbeat and respiration rate did not change. The rabbits did not deteriorate, and not one of them died, although the experiments were conducted for several months (up to six months).

Table 2 gives the qualitative characteristics of the influence of UHF fields of different intensities and of the thermal effect (bilateral heating with the aid of two reflectors up to a temperature of 50–60°C) on the head of the animal according to the reactions recorded in our experiments.

TABLE 2. COMPARATIVE CHARACTERISTICS OF THE INFLUENCE OF UHF FIELDS WITH STRENGTHS OF 1,000 AND 5,000 V/M AND OF A THERMAL EFFECT (50–60°C) ON THE HEAD REGION OF A RABBIT.

Reaction	UHF field, v/m		Heating
	1,000	5,000	
EEG	present	present	present
temperature	absent	"	"
motor	"	"	"
vocal	"	"	"
respiratory	"	"	"
cardiac	"	"	"
salivation	"	"	"
trophic lesions	"	"	"

The table clearly shows that heating and the influence of a strong UHF field caused rather similar physiological reactions in rabbits. It is possible that this similarity is explained by the nonspecific effect of any strong stimulus, but this assumption does not explain the different character of the EEG change /32 in rabbits under the influence of a heat or a UHF field. The EEG index turned out to be the most interesting of all the indices of physiological reactions we recorded.

First, during the influence of a 1,000 v/m UHF field for 3 minutes, of all the recorded reactions, we only saw changes on the EEG, which testifies to the greater sensitivity of the bioelectric processes of the brain to this factor. Second, a common effect of a UHF field of different intensities in our experimental conditions was the similar character of the changes on the EEG (an increase in the amplitude). During later investigations, to characterize the EEG reaction to this physical factor more completely, we used only UHF fields with a strength of 1,000 v/m.

If we disregard the artifact that appeared at the moment of turn-on and the brief (several seconds) reaction of desynchronization, we did not note any abrupt changes on the EEG immediately after the generator was turned on.

According to visual evaluation, changes either did not occur on the EEG, or they appeared several seconds (as a rule, more than 10) after the generator was turned on and had a very diverse character in both form and duration. To decide which EEG changes should be considered as reactions to our activities, we conducted a number of control experiments (30 recordings on 7 rabbits) in which the same procedure of recording the EEG was retained, but the influence of the field was absent. It turned out that the majority of EEG changes occurring under the influence of the field could also occur under "false" influences. Although only a qualitative comparison of the EEG under the real and "false" influences could not testify to the absence of a reaction, we soon decided to consider only the changes that were not encountered in either the background recording or the control experiments as reactions.

Proceeding from this assumption, we called the change in the EEG that was expressed in the appearance of high-amplitude slow potentials, a bioelectric reaction; these potentials occurred during UHF treatment, gradually increased in amplitude and continued for some time after the treatment ceased. The EEG shown in Figure 8 can serve as an illustration of this definition of the reaction.

It must be acknowledged that our definition of the reaction has a somewhat formal character, since only the definite qualitative character of the EEG changes and only prolonged changes are considered. These changes had to last at least 30 seconds and be preserved in the aftereffect. It is reasonable to assume that the reaction to the UHF field could depend on the initial functional state of /33 the CNS and could be manifested not only as an increase in the amplitude of cortical biopotentials, but also as a decrease. The duration of the EEG changes could be less than 30 seconds, could have a phase character, and these changes may not be preserved in the aftereffect period.

In the most characteristic cases the EEG changes began with the appearance of single high-amplitude slow waves, which initially alternated with background

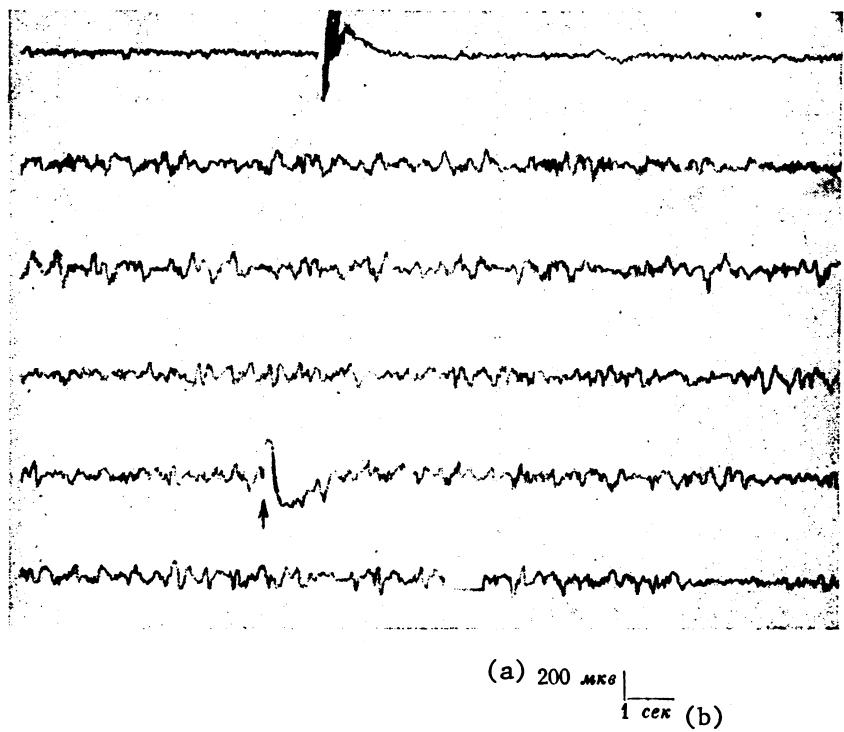


Figure 8. Changes in the EEG of a Rabbit During the Influence of a UHF Field of Weakly Thermal Intensity. A Continuous Recording of the EEG of the Visual Cortex. The Arrows Indicate the Moments the Generator was Turned On and Off. Key: (a) 200  $\mu$ v; (b) 1 Sec.

activity, but then occupied ever-increasing sections of the EEG and, finally, began to dominate all other types of activity. After the generator was turned off, we noted reverse changes in the EEG. Reversibility of the EEG changes following the influence of the UHF field is an essential index of the presence of a reaction.

In the initial experiments, we recorded the EEG from the sensorimotor, parietal and occipital regions of both hemispheres. In the sensorimotor region, 1/34 the reaction was manifested as an increase in the number of spindle bursts. However, we received the sharpest changes of electrical activity from the occipital region in the form of an increase of the slow waves during the influence. Therefore, in later experiments we frequently recorded the EEG from only this section of the cortex. Most frequently, changes in the EEG occurred simultaneously in all leads, which indicated the diffuse character of the reactions to a UHF field.

Being certain of the existence of an EEG reaction to a UHF field, we decided to characterize it quantitatively. The essential fact is that the reaction does not appear for each influence period of a UHF field of the same intensity. We introduced the concept of "reaction stability" and determined it quantitatively

by the percentage ratio of the number of reactions to the number of exposures.

Depending on their individual characteristics, in 34 rabbits the reaction stability varied from 25 to 76%, averaging  $47 \pm 2\%$ . The fact that in one rabbit the reaction stability varied from test to test, indicated its dependence on the initial functional state.

Thus, the EEG reaction to a UHF field actually exists. But why does it have such a low stability? We can assume that this is explained by the weak nature of the stimulus. It is appropriate to recall that under the influence of a stronger UHF field, the reaction stability attained 82%. However, the sufficiently intense and prolonged EEG reaction occurring in half of the cases testifies that the reaction stability is also determined by the level of excitability of the structures on which the UHF field acts. In connection with this, it is interesting to follow the dynamics of the stability of the EEG reaction to a UHF field in one rabbit, and the average dynamics of the stability for several rabbits. / 35

Table 3 gives the results of 20 influence periods on each of 10 rabbits. The "+" indicates the presence of the reaction, and the "-", its absence. One can see that the test results on rabbit no. 1 demonstrate the summation phenomenon, i.e., the number of reactions increases as the number of exposures increases. There were 6 reactions for the first 10 exposures, and 8 for the second 10. The test results on rabbit no. 8 demonstrate the adaptation phenomenon since there were 6 reactions for the first 10 exposures and only one for the second 10. In rabbit no. 3, the number of reactions for the first and second 10 exposures was identical (3).

TABLE 3. STABILITY OF THE EEG REACTION TO  
A UHF FIELD IN 10 RABBITS FOR 20 EXPOSURES.

(a) Номер кролика	(b) Номер воздействия																				(c) $B_{сero}$
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
1	-	-	-	+	+	+	-	+	+	+	+	-	+	+	+	+	+	+	-	+	14
2	-	-	-	+	+	+	-	-	-	+	+	+	-	-	-	-	-	-	+	-	7
3	-	+	-	+	-	+	-	-	-	-	+	-	-	-	-	-	+	+	-	-	6
4	+	+	+	-	-	+	-	-	-	+	-	+	-	-	-	-	-	-	+	+	8
5	-	+	-	-	+	+	-	-	-	+	-	-	-	-	-	-	+	-	-	-	5
6	+	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	5
7	+	+	+	-	+	-	+	-	+	-	-	-	-	-	-	-	-	-	+	+	8
8	+	+	-	-	+	+	-	+	+	-	-	-	-	-	-	-	-	-	+	-	7
9	-	-	+	-	+	-	+	-	+	+	-	-	+	+	-	-	-	-	+	+	10
10	-	+	-	-	-	+	-	-	-	+	+	-	+	+	-	-	-	-	-	+	9
(c) $B_{сero}$	4	5	4	5	3	7	4	3	3	6	6	3	2	3	4	2	2	3	5	5	79

Key: (a) Rabbit Number; (b) Exposure Number; (c) Total.

The dynamics of the reaction stability are given on the bottom line. One can see that the reaction stability varied around an average (40%) and did not have a significant tendency to increase or decrease. Consequently, the experimentally observed EEG reaction does not obey the laws of adaptation or summation within the limits of 20 exposures. The appearance of the reaction has a probability character, and in each specific case it cannot be predicted, but the stability is characterized with sufficient definitiveness for a large number of exposures.

Going to a quantitative characteristic of the reaction itself, we investigated 66 reactions in 23 rabbits. We visually determined the predominant frequency and amplitude of the cortical biopotentials for a 1-minute interval for each 3-minute influence period (exposure) that caused a reaction. Furthermore, we determined the same indices for 3 minutes before the generator was turned on /36 and for 1, 3, 5, 7, 10 and 15 minutes after it was turned off. Then we calculated the average indices for 66 reactions. The dynamics of the changes in the biopotential amplitude and frequency during the influence of the UHF field are given in Figure 9. The change in the amplitude is expressed in percent. The average amplitude of the biopotentials before the generator was turned on was taken as 100%. On the graph, one can see that in the first minute of the influence period the amplitude increased by 35%, in the second minute, by 25%, and in the third minute, by 10%. In 3 minutes, the amplitude increased an average of 70%. Over this same time the biopotential frequency was reduced by a factor of 2. However, we encountered the increase in amplitude more frequently than the reduction in frequency. When slow waves predominated in the background, the reaction was manifested only as an increase of the biopotential amplitude. The correlation coefficient between these indices during exposure was  $0.56 \pm 0.08$ .

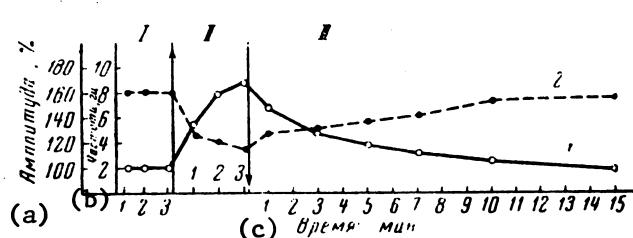


Figure 9. Graph of the Change of the Average Amplitude (1) and the Average Frequency (2) of Rabbit Cortical Potentials During Exposure to a UHF Field on the Animal's Head. I = Background; II = Influence Period (Exposure); III = Aftereffect. The Arrows Indicate the Beginning and the End of the Influence Period (Exposure). Key: (a) Amplitude, %; (b) Frequency, Hz; (c) Time, Min.

ficant (from 15 to 115 seconds).

Figure 10 shows the distribution curve of the latent periods of 100 reac-

Thus, the average intensity of the reaction is manifested as a 70% increase of the biopotential amplitude and as a reduction of the biopotential frequency. The changes in the EEG caused by 3-minute exposure to a UHF field are retained after the generator is turned off. The aftereffect lasts 10-15 minutes.

Due to the smoothness of the increase in the biopotential amplitude, we did not always manage to precisely determine the time of onset of the reaction. However, a possible error of 1-3 sec /37 in determining the length of the latent period could not introduce large distortions, since the spread of the indices was signi-

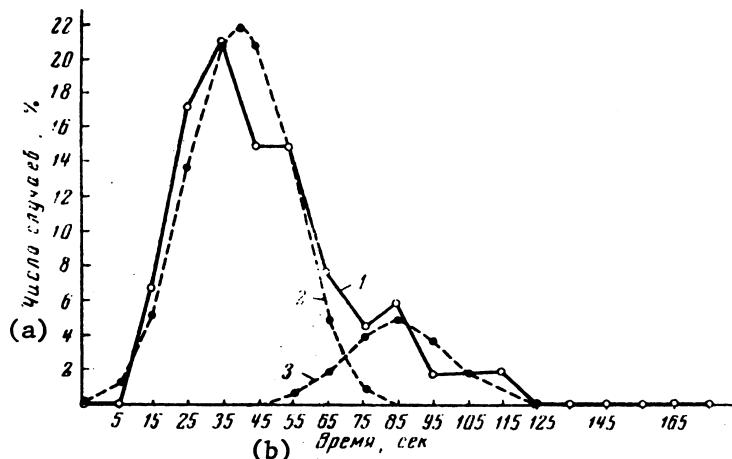


Figure 10. Empirical Distribution Curve (1) of the Latent Period of the Bioelectric Reaction of the Rabbit Cerebral Cortex During the Influence of a UHF Field. 2,3 = Theoretical Curves of Normal Distribution Into Which the Empirical Curve Can Be Decomposed. Key: (a) = Number of Cases, %; (b) = Time, Sec.

Since the reaction occurred maximally in 2 minutes, or did not occur at all, we established the duration of the exposure at 3 minutes, and considering the length of the aftereffect, we established the interval between exposures as 20-30 minutes.

#### The Effect of a UHF Field on the Assimilation Reaction to a Rhythm of Light Flashes

As an index of the functional state of the CNS, we selected reactance curves of the visual cortex EEG for the influence of light on the eyes in increasing brightness with a frequency of 3.5 pulses/sec (the reactance curve according to M. N. Livanov, 1944). The criterion of cortical excitability was the time for the appearance of the assimilation to a rhythm of light flashes. We determined this index before, during and 1 minute after exposure to the UHF field.

From 5 rabbits we recorded 40 reactance curves before, during and after the exposure.

The average time for the appearance of assimilation before the exposure was  $20.3 \pm 0.4$  seconds, during the exposure,  $17.5 \pm 0.3$  seconds, and after the exposure,  $18.7 \pm 0.3$  seconds. Statistical treatment showed that the excitability of the visual cortex during and 1 minute after a UHF field on the animal's head reliably increased ( $p < 0.05$ ).

Thus, the results of tests with the light stimulus supported our conclusions,

tions to a UHF field obtained from 37 rabbits. As can be seen from the figure, the majority of the reactions have a latent period of 35 seconds. The curve has an asymmetric form with a shift to the right, and it can be described as the sum of two theoretical curves of normal distribution with the following parameters:  $n_1 = 82$ ,  $\bar{x}_1 = 42 \pm 1.6$ ,  $\sigma_1 = 14.5$  and  $n_2 = 18$ ,  $\bar{x}_2 = 87 \pm 4$ ,  $\sigma_2 = 15$ .

Thus, the EEG reaction to a UHF field is characterized by a long latent period. The lengths of the latent period and the time of aftereffect allowed us to determine the methodology of future experiments.

reached during an analysis of spontaneous EEG, concerning the change in the functional state of the CNS under the influence of a UHF field on an animal's head. The application of reactance curves also showed the presence of an aftereffect. The stability of the reaction to a UHF field determined from the change in the reactance curve exceeds the stability of the reaction to the same stimulus determined from the change in the spontaneous EEG by almost 2 times. The number of decreases in the time for the appearance of assimilation to a rhythm of light flashes during the influence of the UHF field was 88%, and 1 minute after the generator was turned off, it was 62% (versus 47% of the changes in the spontaneous EEG under the influence of the field). Consequently, the spontaneous EEG recordings do not always indicate the reaction of the CNS to a UHF field, and the reaction stability is determined to some degree by the peculiarities of the recorded physiological reaction. To determine the threshold intensity of the UHF field and to elicit the functional state of the CNS under the influence of this factor, it is reasonable to apply the more sensitive method of test stimuli.

Because the activity of isolated sections of the brain is difficult to characterize through test stimuli, to clarify the physiological mechanism of the effect of a UHF field, in later experiments we basically used the method of recording the spontaneous electrical activity of both an intact brain and its separately isolated sections.

#### Physiological Analysis of the Mechanism of Effect of a UHF Field on the Electrical Activity of Rabbit Brain

After establishing the existence of an EEG reaction to a UHF field, our basic problem was the clarification of the mechanism of effect of this field on the organism.

In the first series of experiments, we tried to find out whether all sections of the rabbit body are sensitive to a 3-minute exposure to a 1,000 v/m UHF field. For this purpose we placed the animal's hind legs, stomach, chest and head transversely in the interelectrode space. It is understandable that localization of the UHF field was relative in these experiments, since the reduced field exceeded the limits of the interelectrode space. But the test results were sufficiently definitive: we observed EEG changes only when the influence of the field was on the head (Figure 11). As was said earlier, the influence of a strong UHF field on any section of the rabbit body causes a change in the EEG in the form of a desynchronization reaction. It is possible that a field of this intensity would cause a change in the EEG if the influence period was increased. It is also possible that certain physiological reactions not recorded by our methodology occur in the exposed section of the body during the 3-minute exposure. However, this series of tests definitely showed that the greatest sensitivity to a UHF field is observed in the head region.

The changes that occur in the organism depend not only on the direct effect of an electromagnetic field on the tissues and organs, but they can also be explained by stimulation of the receptors of different reflexogenic zones, which has been shown in morphological investigations [Tolgskaya, Gordon, 1960].

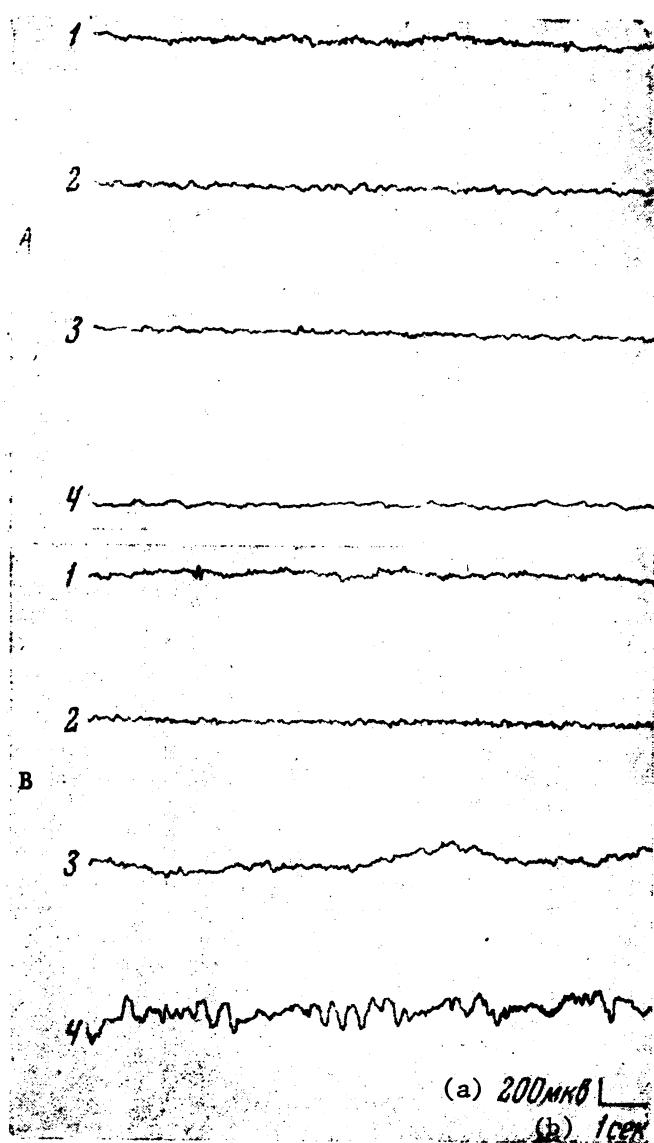


Figure 11. Changes in the Rabbit EEG During the Influence of a UHF Field of Weakly Thermal Intensity on the Hind Legs (1), Pelvis (2), Stomach (3) and Head (4). A = Before the Influence; B = After the Influence. Key: (a) 200  $\mu$ v; (b) 1 Sec.

that the a, b and d waves of the electroretinograms were suppressed and the latent period of the reaction to light was reduced after the influence of a UHF field on an isolated frog eye. The effect was clearest in experiments with light-adapted retinas. The author proposed that a UHF field acts on the nerve endings of the ANS located in the retina or on the molecular structure of rhodopsin.

#### Role of the Distance Receptors in the EEG Reactions of Rabbits to a UHF Field

We decided first to elicit the role of the known distance receptors (visual, auditory and olfactory) in the perception of a UHF field. The reference data on the effect of EMF on the functions of these distance analyzers served as the basis for our decision.

Even D'Arsonval (1893) had shown that accommodation phosphene is sensed by man during exposure to a variable magnetic field. This phenomenon was later supported by many authors [Danilewsky, 1905; Thompson, 1910; Magnisson, Steven, 1911; Barlow et al., 1946; Mogendovich, Skachedub, 1957]. Phosphene sensation occurs most easily under the influence of a variable magnetic field with a frequency from 10 to 30 Hz.

Changes in dark adaptation of the retina were noted during the influence of a UHF field on the human head [Livshits, 1947]. These changes appeared with a large latent period (3-4 minutes) and were distinguished by a long aftereffect (from 15-20 minutes to 2-3 days). These peculiarities of the reaction allowed the author to state an assumption regarding the formation of the reaction to a UHF field through the autonomic nervous system (ANS). The same assumption was expressed by L. T. Zagorul'ko (1948), who had studied the effect of a UHF field on sequential visual images, K. Kh. Kekcheyev et al., (1941) and S. Ya. Turlygin (1937), who measured the thresholds of achromatic vision in man.

G. Demirchoglyan (1953) showed

that the a, b and d waves of the electroretinograms were suppressed and the latent period of the reaction to light was reduced after the influence of a UHF field on an isolated frog eye. The effect was clearest in experiments with light-adapted retinas. The author proposed that a UHF field acts on the nerve endings of the ANS located in the retina or on the molecular structure of rhodopsin.

Thus, by primary or secondary means, a UHF field can affect the activity of the visual analysor and thereby cause changes in the rabbit EEG.

Our problem also included a determination of the role of the peripheral sections of the distance analysors, which was accomplished with the aid of denervation or destruction of the corresponding formations.

We acknowledged that surgery, with which the basic results described in this 41 chapter were obtained, is an extremely coarse method of influencing the activity of the whole organism. The reactions of an animal to a UHF field following different types of transections or lesions resemble the reactions of an intact organism only to a certain degree. Particular care must be used with respect to negative results obtained after surgery.

But, on the other hand, this method is successfully used by physiologists in solving various neurophysiological problems, and it allows determination of the receptor structures and clarification of the role of different sections of the CNS in various reactions. Therefore, decisive use of the results obtained in short and prolonged series of tests involving destruction or denervation of separate structures is a necessary stage in our investigation.

Transection of the optic nerves was previously described. The experiment involving the influence of a UHF field began either on the day of surgery or the next day. In all, 3 rabbits were blinded. Two of them were given 20 3-minute exposures to the UHF field, and the other was given 18. Each day they were given 2 exposures with 15-20 minute intervals. Immediately after blinding, we observed changes in the EEG. They were most frequently expressed in a reduction of the biopotential amplitude. Other investigators [Sarkisov, 1934; Novikova, 1960, 1962; and others] also noted similar changes.

The EEG reaction of blinded rabbits to a UHF field did not differ in form from the corresponding reactions of intact animals (Figure 12, A). The qualitative characteristics of the reaction to a UHF field by intact rabbits was obtained on the basis of initial experiments on each of the 10 rabbits in which one of the distance analysors was subsequently destroyed, and from a prolonged series of tests on 2 normal rabbits. The tests on the intact animals were conducted on the same days as the tests on the subjects.

Thus, the possible effect of individual peculiarities of the animals and the uncontrollable environmental factors were eliminated to some degree.

The previously described reaction of 34 normal rabbits was characterized by an average stability of 47% and an average latent period of 48 sec, and the corresponding indices for another 12 normal rabbits were 45% and 53 sec. As is evident, the differences are so insignificant that we can confidently use the data obtained on the 12 animals for normal characteristics.

In the 3 blinded animals, we observed a reaction stability of 40, 50 and 25%, and an average latent period of 51, 64 and 69 sec, which gave 38% and 61 42 sec as averages for the stability and latent period. The reduction in stability and the increase in latent period of the reaction to a UHF field by the blinded animals is hardly worth discussing since experiments on 3 animals are clearly

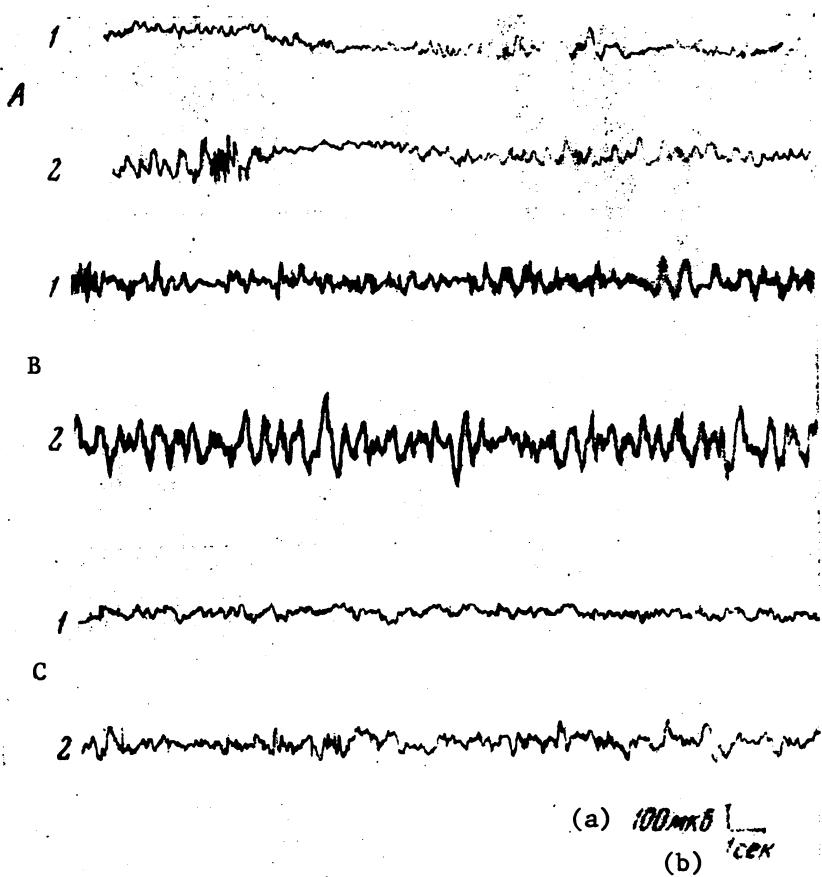


Figure 12. EEG of the Visual Cortex of a Rabbit Before (1) and During (2) the Influence of a UHF Field of Weakly Thermal Intensity Following Destruction of the Visual (A), Auditory (B) or Olfactory (C) Analyzers. Key: (a) 100  $\mu$ v; (b) 1 Sec.

insufficient for a quantitative evaluation of the difference in the reactions between normal and blinded rabbits. However, these experiments allow us to form a definite conclusion regarding perception of the EEG reaction to a UHF field in blinded rabbits. Consequently, in the perception of a UHF field by an animal, the retina either does not participate, or its role in the formation of the reaction is insignificant.

Can the auditory analyser react to a UHF field? According to the data of N. Yu. Alekseyenko (1949), a 7-minute exposure to a UHF field on the head of a 1/43 subject destroyed the spatial perception of sound. In similar experimental conditions, B. Ye. Sheyvekhman (1949) observed changes in the threshold of perception of auditory stimuli. The latest works of Frey (1962, 1963) show that man can sense, on his head, the influence of EMF with a frequency of 300-3,000 MHz and an average power flux density of 0.4-7.0  $\text{mw/cm}^2$  as sound stimulation. High-frequency (the 3- and 10-cm range) EMF changed the sensitivity of rats to

sound stimulation [Kitsovskaya, 1960]. Investigations were conducted by the methods of L. V. Krushinskiy (1954) on a genetic strain of rats that react to the sound of an electric bell with a specific motor reaction or convulsive spasms. EMF (power flux density of 1 or 10 mw/cm<sup>2</sup>) most frequently reduced the sensitivity of these rats to sound stimulation, which was manifested as an increase in the latent period of the reaction and a transition of a single-wave reaction into a double-wave reaction. These effects were reversible. Thus, the reference data allow us to assume the participation of the auditory analyzor in the reaction to a UHF field.

Immediately following surgery, the deafened rabbits remained immobile for several hours. For several days following surgery the EEG was distinguished by a reduced amplitude and lowered the biopotential frequencies, although the changes were expressed less sharply than after blinding. Other investigators [Novikova, 1962; and others] have reported a similar change in the EEG of deafened animals.

The tests involving the influence of a UHF field on deafened rabbits began approximately a week after surgery and were conducted just as those on the blinded animals. The form of the EEG reaction did not change (Figure 12, B). In the 3 deafened animals, the reaction stability was 50, 30 and 35%, and the average stability was 45, 68 and 110 sec respectively; the average stability was 38% and the average latent period, 74 sec. As is evident, the introduced indices of the EEG reaction to a UHF field differed little in 2 rabbits from the corresponding reaction of normal rabbits. In the third rabbit we noted a significant increase in the latent period.

Consequently, the EEG reaction to a UHF field can also exist after destruction of the auditory analyzor.

Among the distance analyzers, we have yet to analyze the role of the olfactory receptor in the perception of a UHF field. Ye. A. Lobanova and Z. V. Gordon (1960) observed a reduction in olfactory sensitivity in people who worked under the influence of SHF electromagnetic fields. Kolin and others (1959) showed that under the influence of an EMF with a frequency of 1,000 Hz, the subjects /44 reported a sensation similar to a stuffed-up nasal cavity.

G. Ya. Khvole and others (1962) reported that removal of the olfactory bulbs or painting the nasal mucosa of a rabbit with a 10% cocaine solution stopped the EEG reaction of the animal to a pulsed low-frequency field (frequency, 2-350 Hz; pulsed strength on the order of 100  $\mu$ V). Thus, reference data testify to the participation of the olfactory analyzor in the reaction of the CNS to EMF. Experiments involving the influence of a UHF field began one day after surgery.

After the olfactory bulbs were removed, changes in the EEG consisting of a reduction in the potential amplitude were observed [Novikova, 1962]. However, the form of the EEG reaction to a UHF field remained as before (Figure 12, C). For each rabbit, its stability was 30, 15, 20 and 20%, the latent period was 62, 50, 57 and 56 sec; the average figures for the operated rabbits were 21% and 57 sec. Thus, after destruction of the analyzor the stability of the reaction to a UHF field was reduced significantly (almost twice), although the average latent

period did not change. Consequently, the EEG reaction to a UHF field can also exist after destruction of the olfactory analyisor.

As a result of a later, larger series of experiments on operated rabbits, we have become convinced that the EEG reaction to a UHF field is also observed after simultaneous destruction of the visual and olfactory (2 rabbits), visual and auditory (1 rabbit), and all three distance analysors (2 rabbits).

The comparative characteristics of the EEG reactions to a UHF field of normal and operated animals are given in Table 4.

TABLE 4. STABILITY AND LATENT PERIOD OF THE EEG REACTIONS TO THE INFLUENCE OF A UHF FIELD IN NORMAL AND DEAFFERENTATED RABBITS.

Test conditions	Number of rabbits	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
normal rabbits	12	67	30	45	53
destruction of the visual analyisor	3	58	22	38	61
destruction of the auditory analyisor	3	48	17	35	74
destruction of the olfactory analyisor	4	76	16	21	57

The table shows that destruction of any distance analyisor reduces the stability of the reaction to a UHF field and increases its latent period to some degree. However, only the reduction (by 2 times in each rabbit) of the reaction stability after destruction of the olfactory analyisor is significant. The remaining operations caused insignificant changes, which sometimes were determined by the individual characteristics of the animals. It should be noted that separate analysors were destroyed by different methods. During destruction of the visual analyisor we sectioned only the optic nerve, during destruction of the auditory analyisor, we mechanically and chemically destroyed the peripheral and possibly the central part of this and neighboring analysors, and during destruction of the olfactory analysors, we touched only its central part. Thus, a certain difference in the results obtained on rabbits after destruction of different analysors can be explained by the differences in the methods of destruction. However, the noted differences do not affect the basic conclusion regarding the presence of an EEG reaction to a UHF field in rabbits following destruction of the distance analysors. /45

The EEG Reaction to a UHF Field After Removal of the Cervical Sympathetic Ganglia

Many physiotherapists [Shcherbak, 1936; Markelov, 1948] and physiologists [Orbeli, 1934; Tonkikh, 1940; Livshits, 1958; and others] have noted the importance of the role of the autonomic (especially the sympathetic) nervous system in the perception of different physical factors, in particular a UHF field.

Therefore, we set ourselves the task of investigating how the bioelectric reaction of the rabbit cortex to a UHF field changes following unilateral or bilateral resection of the ganglia cervicale superius.

The literature contains contradictory reports regarding the changes in electrical brain activity following removal of the superior sympathetic ganglia. Some authors have found no changes in the EEG after unilateral removal of this ganglion [Shvyrkov and Pukhal'skaya, 1960], others have found suppression [Sollertinskaya, 1958, 1960; Karamyan, 1959; Wang T'ai-an, 1960], and still others have found an increase [Aleksanyan and Arutyunyan, 1959] of slow oscillations of potential in cortical activity after removal of the sympathetic ganglia. In the pigeon-rabbit-cat evolutionary class, it is said that the reduction effect in the amplitude of brain biopotentials following removal of this sympathetic ganglion is reduced [Sollertinskaya, 1962].

In our experiments, following unilateral or bilateral resection of the cervical sympathetic ganglia, there was usually a reduction in the biopotential amplitude. From 4 rabbits, we unilaterally resected the superior sympathetic ganglion, but from 2 rabbits, we removed it from both sides. We recorded the EEG of the occipital regions of both hemispheres before, during and after 3-minute exposure to a UHF field on the animal's head.

The testing was conducted 1-2 times a day for several weeks. In all, the 6 rabbits were given 64 exposures.

The general results of the experiments are given in Table 5.

TABLE 5. STABILITY AND LATENT PERIOD OF THE EEG REACTION TO A UHF FIELD IN PARTIALLY DESYMPATHIZED RABBITS.

Rabbit number	Type of sympathectomy	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
1	unilateral	10	4	40	33
2	"	5	1	20	30
3	"	16	7	44	28
4	"	14	8	57	35
5	bilateral	4	3	75	16
6	"	15	9	60	40
	total	64	32	50	30

As the table shows, only the rabbits that were given the least number of exposures (rabbits number 2 and 5) differed from the average level, which was characterized by a reaction stability of 49% and an average latent period of 30 sec. These data indicate a certain improvement in the EEG reaction of sympathectomized rabbits to a UHF field in comparison with normal animals, for which the average stability was 45%, and the average latent period, 53 sec (see Table 4). In contrast to normal rabbits, in operated animals the EEG reaction was not always manifested as an increase in the amplitude and a decrease in the frequency of biopotentials, although this form of the reaction predominated. Sometimes during the influence, we noted a prolonged decrease in biopotential amplitude (Figure 13). This type of change in the potentials occurred only during the influence and with the same latent period as the increase in amplitude; and it continued for some time in the aftereffect period. These circumstances allowed us to consider these changes on the EEG of sympathectomized rabbits as a reaction to the UHF field.

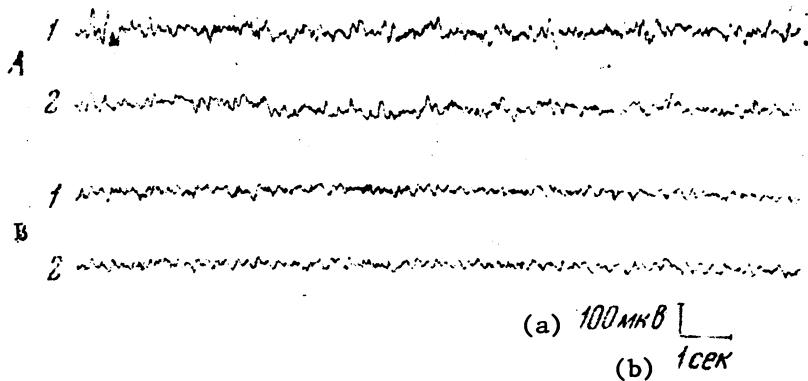


Figure 13. EEG of the Sensorimotor (1) and Visual (2) Cortex of a Rabbit Before, (A) and During (B) the Influence of a UHF Field of Weakly Thermal Intensity After Partial Sympathectomy. Key: (a) 100  $\mu$ V; (b) 1 Sec.

It should be noted that a certain aggravation of the reaction in sympathec-/47 tomized rabbits was manifested not only as changes in the form of the EEG reaction, reduction of its average latent period, and an increase in stability, but also as an increase of the aftereffect of up to 30 minutes (normal, 10-15 minutes). Based on the data of Table 5, we can assume that after bilateral sympathectomy, the stability of the reaction to a UHF field becomes greater than after unilateral sympathectomy. However, the small volume of experimental data does not allow us to insist upon this conclusion at this time.

Thus, the EEG reaction of rabbits to a UHF field is maintained following resection of the superior cervical sympathetic ganglia.

On rabbits and cats, K. P. Golyshova (1942) showed that removal of the cervical sympathetic ganglia lessens the rise in rectal temperature during the in-

fluence of a UHF field on the head. In tests on cats, A. V. Tonkikh (1941) noted that after bilateral removal of the stellate and inferior cervical sympathetic ganglia an increase in the basal metabolism was not observed in a UHF field. After removal of the cervical sympathetic ganglia from cats, D. Ya. Glezer (1940b) noted that the quickening of the cardiac rhythm lagged behind the rise in temperature under a UHF field, while in control animals a correspondence of the chronotropic and temperature effects was noted. After sectioning of the sympathetic pathways from frog extremities, in contrast to local exposure, total body exposure to a UHF field did not cause contraction of the vessels. N. Koiwa (1939) showed that after sectioning the sympathetic nerves, the effect of a reduction in diuresis during the influence of a UHF field was weakened. I. V. Bekauri (1941) observed that the Sechenow inhibition in frogs caused by a UHF /48 field was reduced by sectioning the sympathetic nerves.

As this brief listing of reference data reveals, these authors usually recorded some peripheral effect caused by a UHF field. Numerous results agree that the sympathetic nerves frequently serve as effectors for the realization of the effect of a UHF field on the periphery. However, in our experiments with recording of the EEG, the sympathetic nerves could fulfill only an afferent function. As the results show, the sympathetic nerves did not maintain this afferent function and after removal of the superior cervical sympathetic ganglia the sensitivity of the animal to a UHF field increased somewhat. In the preceding cases, when we performed certain surgery (destruction of the distance analyzers), the reaction to the UHF field deteriorated. It is possible that removal of the sympathetic ganglia increases the sensitivity of the CNS to a UHF field, primarily the sensitivity of the hypothalamic region, where the higher autonomic centers are located. Therefore, in the following series of experiments, we decided to investigate how the EEG reaction of rabbits to a UHF field changes following damage to the hypothalamic region.

#### The EEG Reaction to a UHF Field Following Damage to the Hypothalamus, Thalamus and Reticular Formation of the Midbrain

These tests were conducted jointly with Z. A. Yanson. In 8 rabbits, we unilaterally destroyed the hypothalamus and, as a control, in 5 rabbits we destroyed the thalamus, and in 4, the reticular formation of the midbrain. The tests were begun either on the day of the operation or on the day after. A 3-minute exposure to a 1,000 v/m field was conducted 1-2 times a day. The changes in the EEG after destruction of any section of the brain were manifested as the appearance of slow high-amplitude oscillations immediately following the operation. This type of change was revealed particularly sharply on the side of the destruction. The asymmetry of the EEG disappeared 3-7 days after the operation and we recorded electrical brain activity that differed little from the corresponding activity of normal rabbits. /49

The general results of the tests on the influence of a UHF field on operated rabbits are given in Table 6.

If we recall that in normal rabbits the stability of the reaction to a UHF field was  $47 \pm 2\%$ , then it becomes clear that after destruction of these sections of the brain the reaction stability increases, and this increase was particularly

TABLE 6. STABILITY OF THE EEG REACTION TO A UHF FIELD AFTER DESTRUCTION OF DIFFERENT SECTIONS OF THE RABBIT BRAIN.

Characteristics of the operation	Number of rabbits	Number of exposures	Number of reactions	Stability %
destruction of the hypothalamus	8	35	29	83
destruction of the midbrain	5	40	21	52
destruction of the reticular formation of the midbrain	4	25	16	64

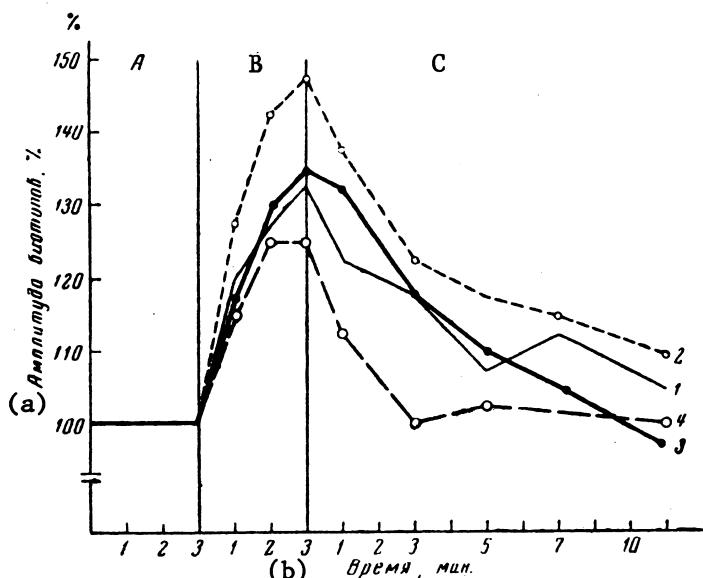


Figure 14. Dynamics of the Change in the Average Amplitude of Cerebral Cortex Biopotentials During the Influence of a UHF Field in Normal Rabbits (1), After Unilateral Destruction of the Hypothalamus (2), After Destruction of the Nonspecific Nuclei of the Thalamus (3) and After Destruction of the Reticular Formation of the Midbrain (4). A = Background; B = Influence Period; C = Period After the Influence. Key: (a) Biopotential Amplitudes, %; (b) Time, Min.

significant after destruction of the hypothalamus. If, however, we characterize the obtained results by the intensity of the reaction (Figure 14), then it is evident that after destruction of the hypothalamus the intensity of the reaction increased significantly in comparison with the normal (data obtained from the same 17 rabbits before the operation). After damage to the nonspecific nuclei of the thalamus, the intensity of the reaction of operated rabbits to a UHF field differed little from the reaction of normal rabbits, and after destruction of the reticular formation of the midbrain, the difference from the norm towards a reduction in the intensity of the reaction appeared essentially during the aftereffect period. /50

Thus, an analysis of the stability and intensity of the EEG reaction to a UHF field consistently testifies to an enhancement of this reaction after unilateral damage to the hypothalamus.

The average latent period of the reactions after damage to the hypothalamus turned out to be the same as in normal rabbits (56 versus 53 sec).

In form, the reactions to a UHF field in rabbits after destruction of the hypothalamus were most frequently the same as the reactions of normal rabbits, i.e., the amplitude of the biopotentials increased and the frequency decreased or the number of spindles increased. However, sometimes in the operated rabbits, oscillations appeared in the cardiac rhythm during the influence (Figure 15), which we never recorded in our other animals. Just as the increase in the stability and intensity of the reaction, the appearance of "autonomic" rhythms testifies to an increase in the reactance of rabbits to a UHF field following destruction of the hypothalamus.

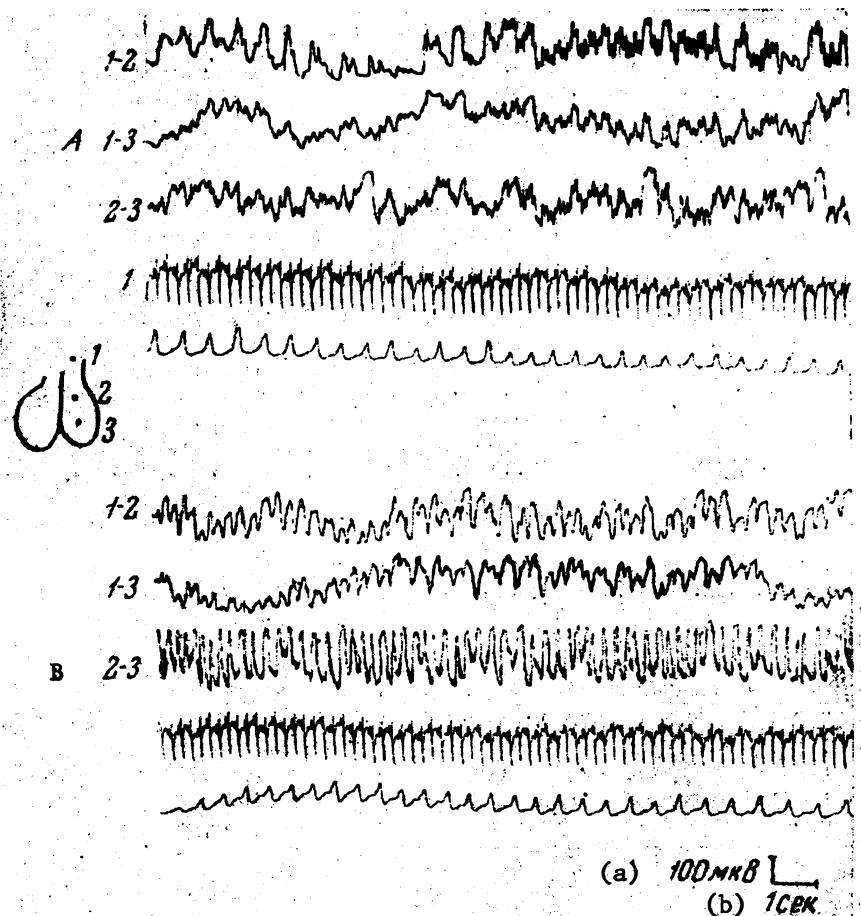


Figure 15. EEG of a Rabbit Before (A) and During (B) the Influence of a UHF Field of Weakly Thermal Intensity After Unilateral Destruction of the Hypothalamus. The Numbers Designate the EEG Leads (See the Diagram). The Bottom Two Recordings Are an EKG and a Pneumogram. Key: (a) 100  $\mu$ V; (b) 1 Sec.

Consequently, damage to the central (unilateral destruction of the hypothalamus) or peripheral (removal of the cervical sympathetic ganglia) sections

of the autonomic nervous system increases the reactance of rabbits to a UHF field. It should be noted that the increase in the reaction is observed mainly during the first several days after the operation.

The experiments that served as a control to the destruction of the hypothalamus showed that damage to the thalamus or the reticular formation of the midbrain weakly affects the EEG reaction during the influence of a UHF field.

Graduate Student R. A. Chizhenkova conducted special investigations to clarify the role of the reticular formation of the midbrain, the thalamus and the hypothalamus in the EEG reaction of rabbits to UHF, SHF and constant magnetic fields. Her results show that the integrity of these sections of the brain is not a necessary condition for the existence of an EEG reaction to these physical factors.

On the other hand, G. V. Izosimov (1961a) observed that exclusion of the reticular formation of the midbrain involves a disappearance of the changes in bioelectric activity during the early periods after total-body irradiation of rabbits with  $\text{Co}^{60}$ , 700 R, using an EGO-2 stand; destruction of the hypothalamus aggravates the electrical reaction of the brain to irradiation.

Similar results were obtained by I. N. Kondrat'yev (1962) and A. N. Lebedev (1963). Thus, besides the specific systems, the nonspecific systems of the hypothalamus and the reticular formation of the midbrain also participate in the formation of the early radiation reaction of the cerebral cortex. M. N. Livanov /51/ (1962) noted that during exposure to ionizing radiation, afferent impulses also increased significantly, which affects the initial disturbance of cortical electrical activity following exposure. Destruction of the reticular formation of the brain stem somewhat reduced the flow of pathological afferent impulsation. This circumstance also led to changes in the cortical biocurrents appearing to a lesser degree in the first hours after the irradiation.

Since the EEG reaction of rabbits during exposure to EMF did not change /52/ significantly after destruction of the nonspecific formations of the midbrain, thalamus and hypothalamus, it was assumed that this reaction does not depend on afferent impulsation and is realized as a result of the direct effect of the field on the brain. However, peripheral impulses can also reach the cortex along specific pathways. Therefore, to check this assumption we conducted experiments on isolated rabbit brain preparations.

Starting from the first tests of Bremer (1936), physiologists have widely used the classic isolated brain preparations, encephale isolé and cerveau isolé, to clarify the role of afferentation in the formation of electrical brain activity, to study the functions of separate sections of the brain, and to derive the mechanism of the effect of different chemical substances on the CNS. However, we have not encountered works which used these preparations to clarify the mechanism of the effect of physical agents on the CNS.

#### The Effect of a UHF Field on the EEG Reaction of an Isolated Rabbit Brain Preparation

This series of tests was conducted under acute experimental conditions. These conditions required a new methodological approach. We have already considered different surgical methods from the standpoint of the activity of the total organism. Since we could not preserve the life of the animals for more than one day after the sectioning, it became necessary to apply the influence of the UHF field more frequently. While previously we were limited to 1-2 exposures per day, fearing that an increase in the number of exposures would some-/53 how change the functional state of the CNS, now the number of exposures per test was from 2 to 20. Did this intensification of the experiment affect the obtained results? It turned out that it did not. Some 15-20 minutes after a 3-minute exposure to a 1,000 v/m UHF field on the head of a rabbit, the effect of the preceding reaction was not experienced. In this period of time, repair (adaptational) processes probably fully eliminate the consequences of such a brief stimulus.

The fact that we recorded the EEG of the parietal region from the isolated brain preparation, and the occipital region from normal rabbits, did not have decisive importance since the EEG reaction to the UHF field had a diffuse character. Finally, additional damage to the occipital lobes of the hemispheres during sectioning of the midbrain did not have a noticeable effect on the EEG reaction of the brain. After sectioning, the experiments lasted 1-6 hours. The method of exposure to the UHF field was the same as in the experiments with normal rabbits.

The EEG changed abruptly immediately after sectioning. Slow, high-amplitude oscillations appeared in the biopotentials in all cases. Spindles sometimes arose in the background of separate oscillations. However, in spite of the fact that the sectioning itself caused the same kind of change in the EEG as the influence of the UHF field, the reaction of the isolated brain preparation (like the reaction of an intact brain) was manifested as an increase in the amplitude and a decrease in the frequency of the biopotentials (Figure 16).



Figure 16. EEG from an Isolated Brain Preparation Before (A) and During (B) the Influence of a UHF Field.  
Key: (a) 200  $\mu$ V; (b) 1 Sec.

Table 7 shows the results of the influence of a UHF field on isolated brain preparations from 10 rabbits.

TABLE 7. STABILITY AND LATENT PERIOD OF THE REACTIONS  
TO A UHF FIELD IN AN ISOLATED BRAIN PREPARATION.

Rabbit number	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
1	5	5	100	31
2	4	2	50	47
3	7	4	57	53
4	6	5	83	25
5	3	3	100	30
6	3	3	100	30
7	4	4	100	43
8	2	2	100	20
9	5	4	80	18
10	3	2	67	33
total	42	34	81	33 ·

The table shows that we observed a reaction to each application of the UHF/54 field in half of the animals after sectioning the midbrain. The lowest stability was 50%. In other words, an analysis of the reaction stability in each rabbit shows that the isolated brain preparation reacted more frequently to a UHF field than a normal brain.

Contradistinct to the tests involving destruction of the hypothalamus, in which the reaction stability also increased significantly, with the isolated brain preparation the reaction was observed not only more frequently, but also with a smaller latent period. This fact is demonstrated by both the averages of the latent periods (33 sec in the isolated brain preparation in comparison with 53 sec in normal animals) and the graph of the distribution of the latent periods of the reactions in normal rabbits and in rabbits after sectioning of the midbrain (see Figure 20). Most of the reactions after sectioning of the midbrain took place after a latent period of 25 sec, while in normal rabbits the mode of the latent period distribution curve occurs at 35 sec. The graph also indicates that the spread of the results is reduced after sectioning. In short, after sectioning of the midbrain, the EEG reactions to a UHF field were more frequent and had a shorter latent period than in normal animals. The obtained results were unexpected. We had assumed that such a severe interference as sectioning at the level of the midbrain must sharply reduce the reaction to a UHF field, which is a weak stimulus. However, the operation reinforced this reaction.

Structures of the diencephalon and telencephalon that were neuronally connected with only the optic and olfactory nerves were included in the isolated brain preparation.

When we additionally sectioned the optic nerves on 2 sides in 4 rabbits,

the reaction of the isolated brain to a UHF field did not change either in the degree of stability, or in the length of the latent period. Consequently, the structures of the diencephalon and telencephalon, which had retained nervous connection with only the olfactory analyisor, reacted just as after sectioning of the midbrain.

In other words, if we exclude the humoral mechanism, the structures that perceive the influence of a UHF field are in the brain itself or in the olfactory analyisor system. In discussing this material now, as well as later on, we have not considered the possibility of the effect of EMF on the sections of the CNS located below the level of the sectioning.

But how will an isolated brain react to a UHF field after damage to the olfactory analyisor? To answer this question we conducted a series of experiments on 8 rabbits which involved the influence of a UHF field on the head after sectioning of the midbrain and additional sectioning of the olfactory brain and the optic nerves.

The changes in the EEG under the influence of a UHF field on totally deaf-/55 deafferentated structures of the diencephalon and the forebrain were the same as during this influence on the cerveau isolé preparations. The test results are given in Table 8.

TABLE 8. STABILITY AND LATENT PERIOD OF THE REACTIONS TO A UHF FIELD IN A TOTALLY DEAFFERENTATED ISOLATED BRAIN PREPARATION.

Rabbit number	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
1	5	1	20	22
2	6	1	17	30
3	9	7	78	29
4	9	6	67	43
5	4	1	25	70
6	9	4	44	27
7	5	1	20	20
8	10	5	50	33
total	57	26	46	34

The table shows that half of the animals (nos. 1, 2, 5, 7) reacted to the UHF field only once for 4-6 exposures. The most sensitive rabbit (no. 3) did not change its sensitivity to the UHF field after additional sectioning of the olfactory brain and the optic nerves. However, on the average, the reaction stability after additional sectioning was reduced by a factor of two, although the latent period did not change.

If we compare the results given in Table 8 with the results of Tables 4 and 7, we can conclude that in some animals the integrity of the olfactory brain plays an important role in the reaction to the UHF field (the stability is reduced down to 20% regardless of whether sectioning of the olfactory brain was conducted in an intact or an isolated brain), and in other animals the reaction occurs very well even after sectioning of the olfactory brain.

In any case, on the average, the stability of the reaction to the UHF field of totally deafferentated structures of the diencephalon and telencephalon is almost equal to the stability of the corresponding reaction of an intact brain (46 versus 47%), but the latent period of the reaction of the deafferentated brain is shorter (34 versus 53 sec).

Thus, we can conclude that the fully deafferentated structures of the diencephalon and the telencephalon react better to a UHF field than an intact brain. Consequently, a UHF field has a direct effect on these structures. The increase in stability and the decrease in latent period of the reaction to the UHF field after sectioning of the midbrain can be explained as the removal of the inhibiting effect of afferent impulsion and by an increase in the excitability of the structures of the diencephalon and telencephalon. Both mechanisms seem probable, but can just the cerebral cortex react to a UHF field? To answer this question we conducted a series of experiments, recording the electrical activity of a neuronally-isolated strip of the cortex.

#### The Effect of a UHF Field on the Electrical Activity of a Neuronally-Isolated Strip of Cerebral Cortex

In recent years, the method involving a neuronally-isolated strip of the cerebral cortex has become widespread for answering questions concerning the origin of spontaneous cortical activity [Kristiansen, Courtois, 1949; Burns, 1951; Ingvar, 1955; and others] and concerning the direct effect of certain chemical [Preston, 1955; Rech, Domino, 1960; Maiti, Domino, 1961; and others] or physical factors [Aladzhalova, 1962; Gidlöf, Söderberg, 1964] on the electrical activity of the cortex.

We began recording electrocorticograms 10-20 minutes after the operation and continued for 4-6 hours on the day of the operation, and in some cases, on the day after. Immediately following the operation, we usually recorded indeterminate low-amplitude electrical activity. In comparison with the activity of the surrounding cerebral sections, the strip was "silent." However, 10-100 minutes after isolation, we began to record high-amplitude potentials from the strip. We recorded this electrical activity in 61 rabbits. The distribution of the time of appearance of high-amplitude activity from the strip after isolation is given in Figure 17. We should note that later on, we usually observed the appearance of electrical activity in the strip (after 1-1.5 hours) after injection of Diplacin or after sectioning at the level of the midbrain. In a strip isolated in the parietal-occipital region of the cortex, the activity usually appeared later than in a strip isolated in the sensorimotor region.

Thus, in an unanesthetized animal, high-amplitude activity occurred in the strip 30-40 minutes, on the average, after isolation (the mode was 25 minutes).

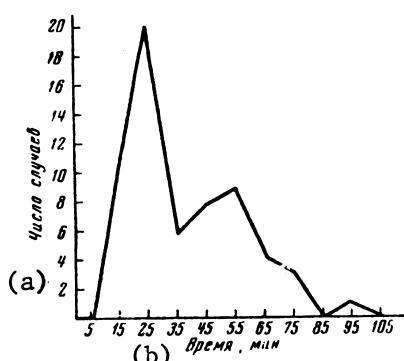


Figure 17. Distribution Curve for the Time of Appearance of Electrical Activity from a Neuronally-Isolated Strip of the Cortex in 61 Rabbits. Key: (a) Number of Cases; (b) Time, Min.

The obtained results contradict the conclusions of Burns (1958) concerning the absence of spontaneous electrical activity in a neuronally-isolated strip of cat cerebral cortex. According to his data, certain bursts of spontaneous activity can be observed for an hour or two after the operation, but they usually disappear if the strip is left in a state of total rest. In certain preparations, comprising 10% of the cases, these spontaneous bursts did not cease, but Burns considered them to be random and excluded them from further analysis. /57

In our experiments, more than 50% of the preparations retained their activity for 2 hours after isolation even if no influence was exerted on the brain. Appearing approximately 1 hour after the operation, the high-amplitude oscillations of potential were repeated only rarely at first (approximately every 20 sec), but then they gradually began to appear more frequently (every 2 sec).

As an example, we offer the dynamics of the increase in the frequency of single high-amplitude oscillations in an isolated strip of the sensorimotor region of an unanesthetized rabbit (Figure 18). The activity of the strip was recorded every 5 minutes for 2 hours and 10 minutes. One can see that the activity, which appeared 25 minutes after isolation, had reached 12 waves/min at 40 minutes, 24 waves/min at 85 minutes, and 36 waves/min at 2 hours.

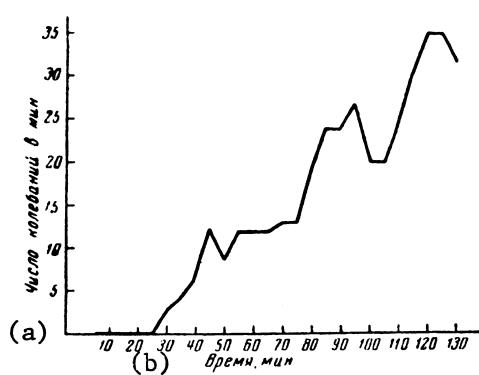


Figure 18. Dynamics of the Frequency of Single High-Amplitude Oscillations of Biopotentials in a Neuronally-Isolated Strip of Cerebral Cortex of an Unanesthetized Rabbit. Key: (a) Number of Oscillations Per Minute; (b) Time, Min.

Thus, the electrical activity of the cortical section, destroyed as a result of isolation, is initially depressed, but then it gradually increases, taking on a form that differs from the form of the electrical activity of neighboring cortical sections.

Some 3-6 hours after the operation, the electrical activity of the strip either is depressed again, or (more frequently) becomes similar to the electrical activity of the intact cortical sections. On the day after the operation, the electrical activity of the strip differs little from the electrocorticograms of adjacent sections. However, during an influence from any stimuli on the CNS, the electrocorticograms of the strip change differently than the electrocorticograms of the intact cortex.

In the literature, we encountered

several works that investigated the electrical activity of an isolated strip of rabbit cortex [Aladzhalova and Koshtoyants, 1960; Aladzhalova, 1962; Monakhov, /58 1963; Repin, 1963]. N. A. Aladzhalova (1962) isolated 6 mm x 4 mm strips, along the surface and 3 mm deep, in the parietal region of the cortex. The rabbit was given a 0.5 g/kg dose of urethan intraperitoneally or it was immobilized with Diplacrin. Spontaneous electrical activity in the strip was observed in 33 of 52 cases (65%) during periods up to 50 min after the isolation. In our experimental conditions, spontaneous activity of the strip was observed in 61 of 67 cases (91%), and they lasted for hours, frequently not stopping. The dynamics of the appearance of "spontaneous" activity of the infrequent spindle type coincides in principle with the dynamics of the corresponding activity we described above. N. A. Aladzhalova (1962) gives an example in which the electrical activity of the strip was reduced sharply 5 minutes after isolation; spindles of high-amplitude oscillations that were initially repeated with an interval of 80 sec occurred 17 min after isolation; these spindles occurred with an interval of 7 sec by the 25th minute after isolation. The spindles disappeared from the 45th minute on after isolation.

K. K. Monakhov (1963) recorded the electrical activity of an isolated strip under conditions of drugged sleep (sodium amyta, 0.1 mg/kg). High-amplitude discharges were observed in the strip after it was electrically stimulated. I. S. Repin (1963) reported that the spontaneous electrical activity of the strip consists of high-amplitude discharges that occur on a generally reduced level of electrical activity. Moderate hypercapnia suppressed these discharges.

Thus, the electrical activity of the strip we recorded is qualitatively similar to the electrical activity recorded in the same species of animals by other authors. We are inclined to explain the certain quantitative differences (we observed spontaneous activity in the strip more frequently and for a longer period of time) by the fact that we did not give Diplacrin or an anesthetic to the rabbits and we most frequently recorded the electrical activity of a strip from the sensorimotor region.

The fact that anesthesia affects the electrical activity of a strip has /59 been noted by many authors, but the dependence of electrical activity on the region of isolation has not been noted. By the way, in our experiments, the electrical activity of the sensorimotor and parietal-occipital strips differed somewhat. The activity of a strip from the posterior sections of the cortex was less than that from the anterior, which is probably connected with the peculiarities in histological structure of different regions of the cortex.

An analysis of our data and the reference data shows that a cortical strip from an unanesthetized animal has spontaneous electrical activity at least during the first hours after isolation. All authors who have studied the electrical activity of a strip consistently testify that it can react to electrical or chemical stimuli. Certain data indicate an increased excitability of the strip, the inhibiting influence from the subcortex disappears in accordance with the general principle of an increase in the sensitivity of denervated structures [Henry, Scoville, 1952]. Consequently, we can assume that a UHF field can affect the electrical activity of an isolated strip.

The influence of the UHF field was applied by the same method as in the

preceding series of investigations, i.e., the head of the rabbit was placed between the generator electrodes. The influence began 10-20 min after isolation regardless of the character of spontaneous activity in the strip. Each exposure lasted 2-3 min and was repeated every 20-40 min.

As before, prolonged reversible changes in electrical activity occurring during the influence of the field were considered to be a reaction to the UHF field. The electrical reactions of the strip differed in form from the reactions observed in an intact brain and in isolated brain preparations. The basic series of experiments conducted on 16 rabbits involving strip isolation in the sensorimotor region showed that there were 51 reactions for 98 exposures (an average stability of 52%). The average latent period was 27 sec.

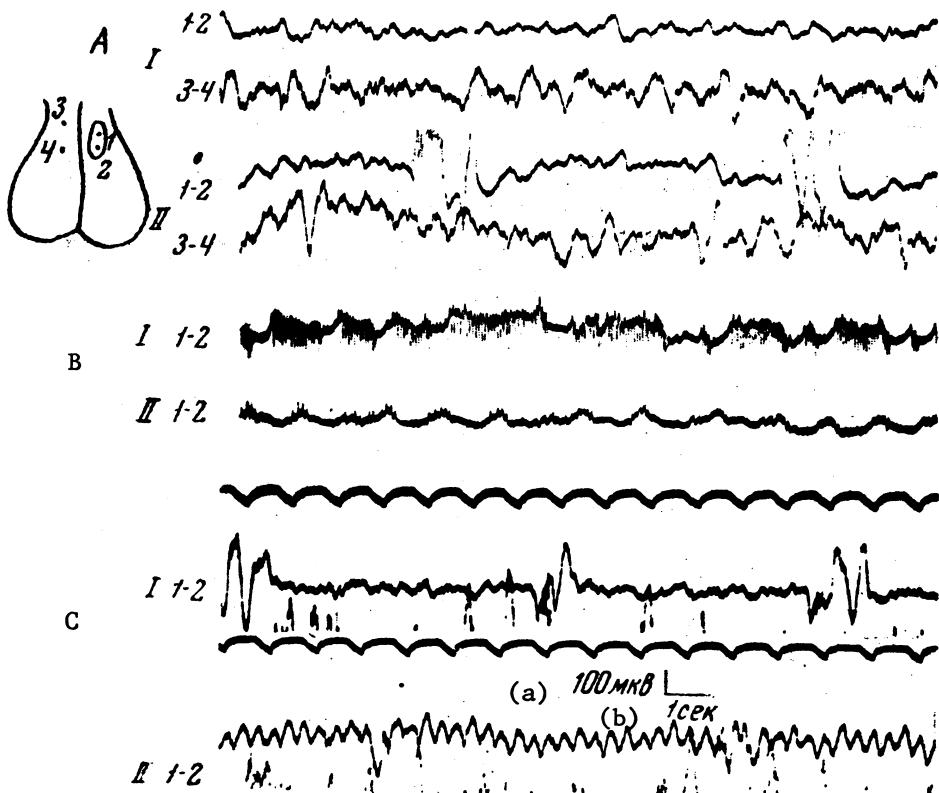


Figure 19. Electrical Activity in a Neuronally-Isolated Strip of Rabbit Cerebral Cortex (I-II) Before (I) and During (II) the Influence of a UHF Field of Weakly Thermal Intensity. Depending on the Initial Level During the Influence, the Electrical Activity of the Strip Increased (A), Although the Electrocorticogram of an Intact Hemisphere Either Did Not Change (3-4), Decreased (B) or Acquired a Rhythmic Character (C), Regardless of Respiration (See the Curves Without Numbers). The Numbers Designate the Leads for the Electrocortiogram (See the Diagram). Key: (a) 100  $\mu$ v; (b) 1 Sec.

Of the 51 reactions, 32 were manifested as an increase in activity (Figure 19,A), 12 as a reduction in electrical activity of the strip (Figure 19,B). 7 as the appearance of a regular rhythm of biopotentials with a frequency of 1-3 Hz (Figure 19,C).

During the influence on the electrical activity of the strip, we observed either the appearance of high-amplitude discharges of different frequencies on a background of suppressed electrical activity, or an increase in the frequency of the high-amplitude discharges already present in the background. Sometimes during the influence, the amplitudes of these discharges abruptly increased. This reaction can be compared, to some degree, with the reaction of an intact and isolated brain to a UHF field, and we can consider that during the influence on any section of the brain, the UHF field brings about the generation of higher/61 amplitude potentials.

With the decrease in electrical activity of the strip, we saw either a significant suppression of the potentials or their rarefaction. A similar reaction was also encountered under the influence of a UHF field on sympathectomized rabbits. To a lesser degree, suppression of the electrical activity characterizes the influence of a UHF field, and it occurs, as a rule, on the altered level of excitability of the CNS. This altered level is caused, in particular, by the surgery.

The appearance of regular rhythms of electrical activity in the strip under the influence of a UHF field sharply demonstrates the presence of the field's effect. This type of reaction did not occur in experiments involving an intact brain or with isolated brain preparations. Only after damage to the hypothalamus in certain rabbits did we note the occurrence of "autonomic" rhythms in the EEG that resembled the described rhythms of the strip in regularity. However, the regular rhythms of the strip did not coincide with the respiration rate or the frequency of cardiac contractions. It turned out that the appearance of regular rhythms is not a specific reaction of the strip to a UHF field. In certain cases, M. A. Aladzhalova (1962) recorded a rhythm of 3 Hz in a rabbit cortical strip during an interval from 15 to 25 min after isolation. A rhythm of 1 Hz, which was equal to the respiratory rhythm, but did not coincide with it in phase, sometimes occurred 25 min after isolation. Such rhythms can be caused by electrical or chemical stimulation of the strip.

Thus, although the forms of the change in electrical activity of an isolated cortical strip to a UHF field differ from those of an intact cortex, in both cases we have a nonspecific change in electrical activity, which can also occur under the influence of other stimuli.

More definite changes in the electrical activity of the isolated cortical strip, of a qualitative character in comparison with the gradual quantitative changes of the EEG under the influence of a UHF field on an intact brain, allow us to more precisely determine the latent period of the reaction and the duration of the aftereffect, and also to reveal a new type of reaction that appeared after the generator was turned off. The fact that the latter reaction sometimes appeared in the absence of the usually observed reaction during the influence of a UHF field (the basic reaction), and that it occurred following a definite latent period, led us to the assumption that its cause is the switching off of the

field. The fact that the latent periods of the basic reaction to a UHF field did not exceed 90 sec, and that the exposure usually lasted another 90 sec, during which time the reactions did not occur, repudiates the assumption concerning the possibility of a delayed basic reaction that occurs after the generator is turned off. Therefore, we assumed that, besides the basic reaction, in an /62 isolated strip there is another electrographic reaction to the turning off of the field. In its form, the reaction to turn-off was similar to the basic reaction; it occurred after approximately the same latent period after turn-off as the basic reaction did after turn-on of the generator, but the stability of the reaction to turn-off was approximately 5 times less than the stability of the basic reaction.

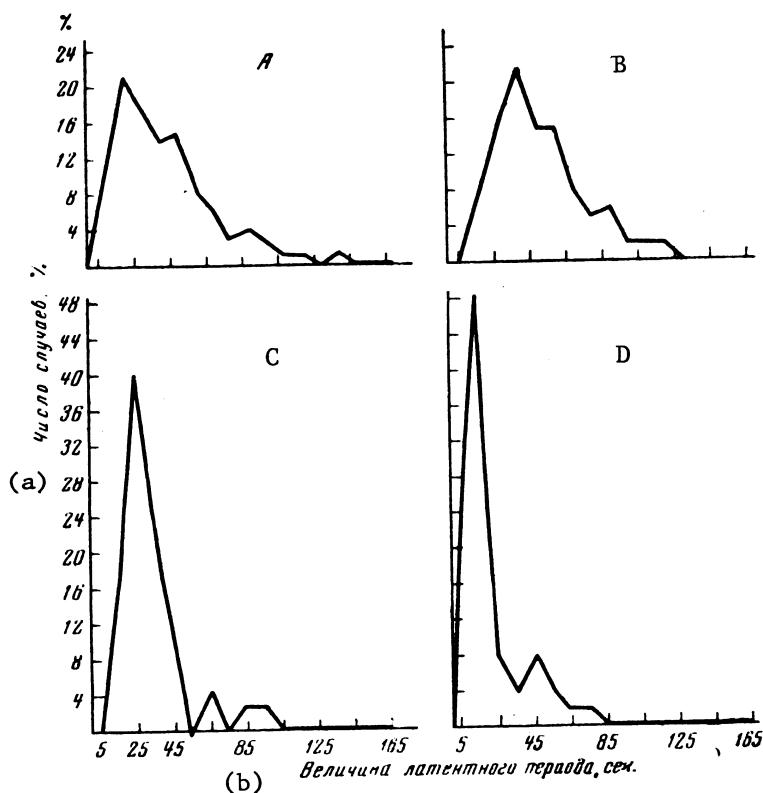


Figure 20. Latent Period Distribution Curves for Electrical Reactions to a UHF Field in Normal Rabbits (B), an Isolated Brain Preparation (C), a Neuronally-Isolated Cortical Strip (D), and the Average Curve for All the Experimental Material (A). Key: (a) Number of Cases, %; (b) Length of the Latent Period, Sec.

We saw the analog of these facts in the electrographic reactions observed during the influence of light. In our terminology, the on-effect is the basic reaction, and the off-effect, the reaction to turn-off, is especially clearly elicited in tests with an isolated cortical strip, /63 but it can also be observed under the influence of an electromagnetic field on an intact cortex. A more detailed analysis of the reaction to turn-off will be given sometime later.

The distribution of the latent periods in the reactions of an isolated cortical strip (see Figure 20, D), show that half of the reactions occur 15 sec after the beginning of the exposure to the UHF field, and one fourth occur after 5 sec. It turned out that during the average latent period (27 sec), the isolated strip is the most sensitive formation to the influence of a UHF field, leaving the intact brain far behind and far exceeding the isolated brain preparation.

Also, in the degree of stability of the reaction, the strip significantly differs from an intact brain (52% versus 45%). The aftereffect period for the strip (1-5 min) was less prolonged than the aftereffect for an intact brain (10-15 min).

It should be noted that these figures characterize the reaction of a cortical strip isolated in the sensorimotor region, and we recorded the EEG reactions to a UHF field in an intact and isolated brain from the occipital and parietal regions. On the other hand, we have previously noted that spontaneous activity in a strip isolated in the sensorimotor region predominates over spontaneous electrical activity in a strip in the parietal-occipital region. It is possible that the different cortical regions react differently to a UHF field. We have previously shown that in an intact cortex, the reaction to a UHF field occurs most clearly in the occipital region. Is this correspondence preserved after isolation of a cortical strip? To answer this question we isolated a strip in 7 rabbits in just the sensorimotor region (47 exposures), and in 6 rabbits in just the parietal-occipital region (44 exposures). The strips were identical in size.

Since the certain tendency towards an increase in reaction stability (55% versus 50%) and a reduction in the latent period (24 sec versus 26 sec) observed in strips isolated from the sensorimotor region is unreliable, the reactions to a UHF field of cortical strips isolated in different regions can be considered identical.

The reaction stability of an isolated strip in the sensorimotor region to a UHF field varied in different rabbits from 25 to 90% (in normal rabbits from 25 to 75%). Consequently, isolation of the strip did not exclude the individual characteristics of the animals during the reaction to the UHF field. Therefore, a comparison of the reactions of the cortical strips isolated in different regions should be conducted on one animal. In connection with complications involved in recording the electrical activity, which was expressed in the fact that the recording was conducted simultaneously from two strips isolated in one hemisphere, we immobilized the animals by injecting Diplacrin, and put them on artificial respiration, although we knew that such a procedure somewhat reduced the sensitivity of these isolated cortical strips.

This series of experiments was conducted on 9 rabbits (63 exposures). It /64 should be noted that in only 9% of the cases did we observe an electrical reaction in both strips under the same influence, and this reaction began, as a rule, after different latent periods. At the same time, however, the average characteristics of the reactions of strips isolated in different regions coincided. The coincidence of the average reaction stability is complete (30 and 30%), but in the average latent period the strips in the parietal-occipital region somewhat lead the strips in the sensorimotor region (34 sec versus 39 sec).

Thus, the experiments in which we recorded the electrical activity of two strips isolated in one hemisphere under different conditions, support the conclusion that the electrical reaction to a UHF field is identical in cortical strips isolated in the sensorimotor and parietal-occipital regions.

Consequently, in the future, with justification, we will compare the electrical reaction to a UHF field of an isolated strip in the sensorimotor region to the reaction of an intact and isolated brain from which we recorded the EEG of the parietal or occipital regions.

In discussing the results of this series of experiments, we must call your

attention to the fact that isolation of the strips (or one strip in two experiments) does not occur without any effect on the intact hemisphere. After isolation of a strip, the spontaneous electrocorticograms in the adjacent hemisphere change towards a predominance of slow, high-amplitude oscillations; and the EEG reaction to a UHF field, although it preserves its qualitative characteristics, i.e., is manifested as an increase in amplitude and a decrease in the frequency of biopotentials, does occur with a smaller latent period (39 versus 53 sec). In this case, the average reaction stability is reduced insignificantly (40% versus 45%). Thus, the operation of isolating a cortical strip increases the sensitivity to a UHF field not only in the strip itself, but also in the adjacent intact hemisphere. However, we intend to give a more detailed characterization of the excitability of a brain, sensitized by isolation of a strip, somewhat later.

It should be noted that, in contrast to the preceding tests, in recording the electrical activity of the strip the electrodes directly contact the meninges. Consequently, if the current fed to the electrodes has a stimulating effect, then the EEG reaction must be more marked than in the case of fastening the electrodes to the bone, which offers greater resistance. However, in several control experiments it was shown that trepanation and recording of the electrocorticograms did not change the electrical reaction of an intact brain to a UHF field either in stability, or in the latent period.

Let us return to the reaction of an isolated strip to a UHF field. If it depends little upon the place of isolation, how can it change over the time that passes from the moment of isolation? As material to investigate this question, /65 we offer a series of experiments on 16 rabbits in which a strip has been isolated in the sensorimotor region. Table 9 gives the data on the reaction stability of a strip to a UHF field for each hour that passed from the moment of isolation.

TABLE 9. DEPENDENCE OF THE STABILITY OF THE REACTION TO A UHF FIELD ON THE TIME THAT PASSED FROM THE MOMENT OF ISOLATION OF THE CORTICAL STRIP.

Index	Time of existence of the isolated cortical strip, hours							Total
	1	2	3	4	5	6	7	
number of exposures	24	34	17	7	5	6	3	98
number of reactions	11	16	8	5	3	5	3	51
stability, %	46	47	47	71	60	63	100	52

The tabular results show that during the first three hours after isolation, the reaction stability held stably at 46–47%. During subsequent hours, the stability increased to 60–100%. The conclusion regarding the increase in sensitivity as the time of existence of the strip increases is retained when we con-

sider the smaller number of exposures during each hour in the later hours. If we total the results for the 4th, 5th and 6th hours, for 20 exposures we will obtain 13 reactions (a stability of 65%), while for the 3rd hour we observed 8 reactions for 17 exposures (a stability of 47%). However, during chronic tests (2-10 days after isolation), the strip reacted to a UHF field less well than during the first hours after the operation.

Thus, on the day of the operation, the reaction of a cortical strip to a UHF field depends on the time of existence of the strip, but it does not depend on the isolation site (within experimental limits). How can we explain this last circumstance? Let us recall that in an intact brain, the occipital region reacted to a UHF field better than the sensorimotor region. Consequently, the reaction of an intact cortex to a UHF field is determined not only by the properties of the cortex itself (otherwise, the reaction would have been identical in all regions), but also by its connections with the lower-lying levels of the CNS. In other words, a comparison between the reactions of an intact and an isolated cortex shows that under the conditions involving an entire brain, a UHF field acts not only on the cortex.

Does an isolated cortical strip react to a UHF field absolutely independently, or does its behavior depend on the integrity of the lower-lying structures? To answer this question, we investigated the reaction of a strip to a <sup>/66</sup> UHF field after sectioning at the level of the spinal cord or the midbrain. We should note that spontaneous activity in the strip was reduced after sectioning at the stated levels. Working with an isolated cat brain preparation, Burns (1958) concluded the absence of spontaneous electrical activity in an isolated cortical strip. At the same time, acute changes did not occur in the reactions of a strip to a UHF field. Table 10 gives the results of experiments on the electrical activity of an isolated cortical strip in the sensorimotor region of an intact brain, and also after sectioning at the level of the spinal cord or the midbrain.

TABLE 10. STABILITY AND LATENT PERIOD OF THE REACTIONS TO A UHF FIELD OF A NEURONALLY-ISOLATED CORTICAL STRIP IN AN INTACT BRAIN, AFTER SECTIONING OF THE SPINAL CORD AND AFTER SECTIONING OF THE MIDBRAIN.

Subject of the investigation	Number of animals	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
isolated cortical strip in an intact brain	16	98	51	52	27
isolated cortical strip after sectioning of the spinal cord	6	47	26	55	24
isolated cortical strip after sectioning of the midbrain	4	19	10	53	52

The tabular data show that the reaction stability in an isolated cortical strip did not change after sectioning at the level of the spinal cord or the midbrain. These facts indirectly testify that we observed an independent reaction of the cortex to a UHF field. However, the increase in the average latent period of the reaction of the strip after sectioning at the level of the mid-brain indicates a certain effect of the subcortical structures on the excitability of the isolated strip. N. A. Aladzhalova (1962) also noted a similar reduction in the excitability of a neuronally-isolated cortical strip after intracollicular sectioning of the brain stem. She pointed out the possible role of the humoral mechanism in the realization of the influence of certain subcortical formations on the excitability of the cerebral cortex. The general conclusion is that an isolated cortical strip reacts identically (in the degree of stability) regardless of the localization of the strip or of certain additional destruction to the integrity of the brain.

### Discussion

/67

Summing up the results of experiments on the influence of a UHF field on animals, we must note that the electrographic method has become a sufficiently convenient approach to characterize the direct effect of an electromagnetic field on the central nervous system. Numerous works show the existence of a reflex path of the influence of a UHF field on the CNS, but this path has remained outside the limits of our analysis, not because we ascribe small importance to it, but only because a different path (the direct effect) has only been noted, but not analyzed in most works. It can be affirmed that, in the long run, the reaction of an organism to a UHF field is determined by both the reflex and the direct influences, and that in each specific case (depending on the intensity, localization, etc.), one or the other path predominates.

Certain differences in our results from the results of other authors can be explained by the fact that our influence lasted no more than 3 min and was repeated no more often than 20 min, when, as we have assumed, the organism has finished reacting to the preceding influence.

What are the properties of the reaction we have investigated?

First, its appearance carries a statistical character. It is impossible to predict the appearance of the reaction, but we can expect that of 100 exposures on the head of an intact animal, 50 will elicit a reaction.

Second, the reaction depends on the individual characteristics of the animal, and on its initial functional state.

Third, the reaction depends on the intensity of the influence: the more intense the field, the more stable the reaction.

Fourth, the reaction is most frequently manifested as an increase in electrical brain activity.

Fifth, the reaction has an aftereffect and an off-effect.

Sixth, the reaction has a definite latent period.

With sufficient persuasiveness, these points indicate the presence of an EEG reaction to a UHF field.

If we summarize the results of the basic series of experiments with respect to the average stability and the average latent period of the reactions (Table 11), one can clearly see that the response will depend on the type of surgery.

TABLE 11. STABILITY AND LATENT PERIOD OF THE REACTION TO A UHF FIELD IN RABBITS, BOTH CONTROL AND AFTER VARIOUS SURGERY.

Test conditions	Number of animals	Number of exposures	Number of reactions	Stability, %	Average latent period, sec
normal rabbits (control)	46	280	130	46	53
destruction of the visual analyzor	3	58	22	38	61
destruction of the auditory analyzor	3	48	17	35	74
destruction of the olfactory analyzor	4	76	16	21	57
partial desympathizat-	6	64	32	50	30
destruction of the hypothalamus	8	35	29	83	56
sectioning of the midbrain	10	42	34	81	33
sectioning of the midbrain and the olfactory brain	8	57	26	46	34
strip of the sensimo-tor cortex	23	145	77	50	25
strip of the parietal-occipital cortex	6	44	22	50	26
cortical strip isolated after sectioning of the spinal cord	6	47	26	55	24
cortical strip isolated after sectioning of the midbrain	4	19	10	53	52
total	127	915	441	48	44

As the tabular data show, 127 rabbits were given almost 1,000 exposures (915); in half of the cases (48%), we observed a change in electrical brain activity. The spread of the average reaction stability was within the interval from 21% (after destruction of the olfactory analyser) to 83% (after destruction of the hypothalamus). However, most of the experimental groups showed a reaction stability of about 50%. /68

We have tried to formally analyze the reaction mechanism in discussing the latent period distribution curve. The general averaging of the distribution curve is given in Figure 20,A. It is the result of an analysis of 391 reactions in 95 rabbits, of which 37 rabbits were control, 10 were deafferentated, 6 had their sympathetic ganglia destroyed, 8 had their hypothalamus destroyed, 10 had their midbrain sectioned, 8 had their midbrain and olfactory brain sectioned, and 16 had a neuronally-isolated cortical strip in their sensorimotor region.

We should remember that the changes in the stability of the EEG reaction to a UHF field, and in its latent period, do not always correlate with each other. Thus, after sectioning the olfactory brain in normal rabbits, and in a cereau isolé preparation, the reaction stability decreased almost twice, but the latent period did not change. After damage to the hypothalamus, the stability increased almost twice, but the latent period did not change. On the other hand, after isolation of a cortical strip, the stability remained practically unchanged in comparison with the norm, but the latent period decreased by a factor of two. It is possible that the latent period characterizes excitability, while the reaction stability characterizes the reactance of those structures that react to a UHF field. /69

The obtained average empirical curve of the distribution of latent periods of the reactions can be formally described by 3 theoretical curves of normal distribution with a mode at 15 sec, 40 sec and 85 sec, wherein the 1st group contains 27% of the reactions, the 2nd, 61% and the 3rd, 11% (Figure 20,A).

If we compare the total average curve with the distribution curve of the latent periods for normal rabbits (Figure 20,B), we will observe a similarity in the 2nd and 3rd groups of reactions.

These two groups of reactions are observed in one and the same rabbit, but sometimes the change in biopotentials occurs at the 40th and at the 90th seconds even under identical application of a UHF field. Consequently, the two possible reaction mechanisms can develop independently of each other.

Analyzing the latent period distribution curve only for reactions of normal rabbits, we cannot say anything about their hypothetical mechanism except to indicate its existence. But when we have examined the latent period distribution curves for reactions of rabbits after different types of damage, certain suppositions arise regarding the possibility of the origin for different groups of reactions. The following discussion proceeds from the assumption that the connections between different sections of the CNS during the formation of the EEG reaction to a UHF field are accomplished only along nerve pathways.

Since the reactions of the 3rd group (an average latent period of about 90

sec) were absent after sectioning at the level of the midbrain (Figure 20,C), we can assume that this group of reactions is induced by certain structures located below this level. It is known that the basic mass of afferent pathways pass into the brain below the level of sectioning. Consequently, if the reflex pathways play some role in the formation of these reactions, their share is not great (18% for normal rabbits and 11% for all the experimental material). It is also not necessary to reject the possibility of a direct influence of the UHF field on the lower-lying sections of the CNS.

The first group of reactions (an average latent period of 15 sec) are particularly clearly delineated in the reactions of an isolated cortical strip (Figure 20,D). We can assume that the cortex reacts directly to a UHF field /70 with a short latent period. However, this conclusion pertains only to isolated cortex, the excitability of which is increased. In normal rabbits, we did not observe reactions with this short latent period. Does this mean that a normal cortex does not react to a UHF field? We assume that the reaction of a normal cortex takes place with a longer latent period than the reaction of isolated cortex, and that the telencephalon and diencephalon, reacting simultaneously as one total system, give the reactions (with an average latent period of about 40 sec) that make up the majority in both normal rabbits (82%) and in the average distribution curve of the latent period of the reactions of most experimental animals (61%).

We shall return to the discussion of the question regarding the participation of different sections of the brain in the reaction to electromagnetic fields when we discuss the results of tests with electrodes embedded in certain sections of the brain.

### Conclusions

1. The character of the EEG reaction of rabbits after a 30-60-sec exposure to the influence of a 5,000 v/m UHF field on the head, depended on the method of securing the animal. If the forelegs and ears were placed between the electrodes, we noted a decrease in the biopotential amplitude on the EEG. If the legs were secured along the spine, and the ears tightly bound to the head or cut off, we noted an increase in the amplitude on the EEG. In the first method of securing the rabbit, the UHF field caused motor reactions and cries from the animal. The influence of a strong UHF field on the head sometimes caused autonomic reactions: a quickening of respiration and abundant salivation. The motor and autonomic reactions, and also the EEG reactions consisting of a decrease in the biopotential amplitude, can be explained by the thermal effect of the UHF field on the extremities and ears, since such reactions also occurred during bilateral external heating of the head region with the aid of two reflectors. The EEG reactions manifested as increases in biopotential amplitude were caused by the influence of the UHF field on the head region, and not by external heating. The stability of the EEG reaction was 82%, and the aftereffect lasted about 20 min.

2. During a 3-minute exposure to a 1,000 v/m UHF field on the head of a rabbit, we managed to record only EEG changes. Motor, vocal and salivary reactions were not observed. The pulse and respiration rates did not change. The

EEG reaction to a UHF field occurred only during the influence on the head, and it was most frequently manifested as an increase in biopotential amplitude and /71 a decrease in biopotential frequency, and also as an increase in the number of spindle-shaped oscillations. The reaction had a diffuse character, but it was most clearly observed in the occipital region. The reaction stability varied around 45%, and the aftereffect lasted 10-15 min. The latent period of the reaction varied from 15 to 115 sec, but in most cases it was equal to 40 sec. After the generator was turned off, we observed changes in the EEG similar to the off-effect. In our experimental conditions, we did not manage to observe either adaptation or summation as a result of repeated exposure to the UHF field. The excitability of the cortical end of the visual analyser, determined by the method of the reactance curve, was increased (in comparison with the normal) during and one minute after the influence of the UHF field. The reaction stability in this case attained 88%.

3. The EEG reaction to a 1,000 v/m UHF field was retained after destruction of the visual, auditory or olfactory analysors, after removal of the superior sympathetic ganglia, and after destruction of the hypothalamus, thalamus or the reticular formation of the midbrain. The electrical reaction to a UHF field in an isolated brain preparation, elicited as a result of sectioning at the level of the midbrain, and in a neuronally-isolated cortical strip, was more clearly noted than in an intact brain.

4. The change in electrical brain activity during the influence of a UHF field can occur as a result of the direct effect of the field on the brain tissue.

## CHAPTER 2. THE EFFECT OF AN SHF FIELD ON THE ELECTRICAL ACTIVITY OF RABBIT BRAIN

The dm, cm, and mm ranges of radio waves or microwaves, or superhigh frequencies (SHF), are next to the UHF range on the scale of electromagnetic oscillations. Therefore, it is not surprising that many investigators have indicated the significant similarity in the biological effect of UHF and SHF. We should note, however, the higher thermal effect and the increased possibilities of an acute local effect from an SHF field. At the present time, the biological effect of an SHF field has been studied more intensively than the biological effect of a UHF field.

A detailed survey of the questions connected with the biological effect of a UHF field is given in recent works [Presman et al., 1961; Presman, 1964b, c; 72 Gordon, 1960, 1964; and others] and in the collections "Concerning the Biological Effect of a Superhigh Frequency Field" (1957), "Concerning the Biological Influence of Superhigh Frequencies" (1960), "Biological Effects of Microwave Radiation" (1961), "Concerning the Biological Effect of Radio-Frequency Electromagnetic Fields" (1964) and "The Biological Effect of Ultrasonics and Superhigh Frequency Electromagnetic Oscillations" (1964).

### The Effect of an SHF Field on the CNS

People who work under the influence of an SHF field usually complain about increased fatigability, periodic or constant headaches, extreme irritability and somnolence [Brogichina, 1960; Sadchikova, 1960; Gembitskiy, 1962, Osipov et al., 1962; Tyagin, 1962; and others]. Prolonged exposure to an SHF field causes a number of nonspecific reactions in man, among which the CNS reactions that occur as asthenic states occupy the prime position. Autonomic nervous system changes are manifested as a predominance of vagotonic reactions, hypotonia, bradycardia and a change in the conductivity of the heart. Furthermore, there is a reduced sensitivity of the olfactory analyzor [Lobanova, Gordon, 1960] and the appearance of irregular slow waves in the tracing of the cortical electrical activity [Sinisi, 1954; Drogichina et al., 1962; Klimkova-Deycheva and Rot, 1963; Ginzburg, 1964; and others].

Investigations on the effect of microwaves on the nervous system were conducted on rabbits during exposure of the head to SHF fields of high intensity [Olendorf, 1949]. A 3-minute exposure caused the animals to refuse food. Morphologic changes in the gray and white matter of the brain were observed. Total-body exposure led to death.

Exposure of the rat occiput to an SHF field led to convulsions [Austin, Horwath, 1949, 1954]. The onset of convulsions was preceded by an increase in brain temperature up to approximately 40°C.

Using the conditioned reflex method, it was shown that, during single and repeated exposure of dogs to centimeter waves of different intensities, stimulation of the higher nervous activity was observed following small doses, and

suppression was observed after large doses [Subbota, 1957, 1958]. The character of the changes was determined by the initial functional state of the CNS and by the characteristics of the individual animals.

Investigation of conditioned and unconditioned salivary reflexes in dogs after single and repeated exposures to low-intensity decimeter waves revealed wave-like shifts in the conditioned reflex activity, and disturbance of the power ratios after repeated exposure [Svetlova, 1962]. Immediately after a single /73 unilateral exposure, there was suppression of positive conditioned reflexes on that side and insignificant reinforcement on the other side. On the next day, suppression was noted on the opposite side. Compensating and paradoxical phases frequently occurred. Differentiation was sometimes disinhibited. The unconditioned reflexes changed to a lesser degree and in a different direction. After repeated exposure, a typical neurotic state developed in certain dogs. Following a break in the exposure, normalization usually occurred in the functioning of the cerebral hemispheres. Prolonged exposure caused adaptation in some animals and summation in others.

Following chronic exposure to low-intensity microwaves, conditioned motor reflexes in rats underwent phase changes [Lobanova, Tolgskaya, 1960; Lobanova, 1964]. Following the initial exposures, there was an increase in the excitability of the cerebral cortex and a weakening of the inhibition process. A lessening of excitability and a decrease in efficiency of the cortical cells was observed as the number of exposure sessions was increased. After cessation of the exposures, the changes in the conditioned reflex activity exhibited a wave-like character, and full normalization was observed towards the end of the second month.

On the day following exposure to high-intensity centimeter waves, mice exhibited a decrease in the magnitude of their conditioned reflexes, partial disinhibition of differentiation, and disturbances of the power ratios found in the cerebral cortex [Gorodetskaya, 1960].

It has been noted [Fleming et al., 1961] that when rats are exposed to an SHF field, their thermal regulation system and previously developed conditioned reflexes are destroyed. The same authors noted that an SHF field increases the motor activity and causes insomnia in simians.

Thus, the data obtained by the conditioned reflex method testifies to the presence of an effect of an SHF field on the higher-level functions of the brain. The changes in brain activity during exposure to microwaves resemble the biological effect of a UHF field. A phase effect of an SHF field on the functions of the cerebral cortex, as well as a dependence of the reaction on the type of higher nervous activity of the animal and on the initial functional state are also observed. It is possible that the described changes in conditioned reflex activity are a nonspecific reaction of the brain to any injurious factor. In any case, ionizing radiation causes similar changes in conditioned reflex activity [Livanov, 1962].

When the head of an anthropoid was placed in a cylindrical resonator fed by a 100-w generator operating in the 225-339 mHz range, a phase reaction was /74 noted in the animal [Baldwin, et al., 1960]. If the animal's chin was elevated,

exposure for 1 min sequentially caused excitation, somnolence and destruction of sensitivity. A 3-minute exposure frequently led to convulsions, terminating in death. With the chin lowered, a 3-minute exposure led only to excitation and somnolence, and when the head was unsecured, these changes were not noted, but the animals did position their heads upwards. A definite orientation in the field was also noted in rats and dogs. The latter turned their heads toward the microwave source. Exposure of the entire body except for the head did not cause the noted reactions.

A slowing down of the frequency and an increase in amplitude was observed in the electrical activity of the cortex of anthropoids when only the head was exposed. The body temperature did not change substantially. All the changes noted disappeared 24 hours after the test. The authors consider the described reactions as phenomena of nonthermal origin occurring as a result of disturbance in the normal functions of the diencephalon and the midbrain; due to intracellular molecular changes.

Studying the reactions of the peripheral system to microwave exposure during an increase in body temperature induced by a metallic heater or infrared lights, certain investigators [McAfee, 1961, 1962; McAfee et al., 1961; Seth, Michaelson, 1964] concluded that an SHF field only causes a thermal effect. Regardless of the method of heating, in cats they noted an increase in the respiration rate, pupillary dilatation, an increase in blood pressure, tachycardia, etc., when the temperature of the peripheral nerves (radial, trigeminal or sciatic) reached 46°C.

On the other hand, in studies on the effect of an SHF field on the functions of the CNS, or on the entire organism, a concept regarding the nonthermal character of the effect of an SHF field has been expressed [Bychkov, 1962; Gordon et al., 1962; Presman, 1962; and others].

By eliminating the cathode-electrotonic syndrome of functional changes or the syndrome of cathode depression involving sharply expressed inhibition at a low level of lability, anodizing the brain had a normalizing effect on animals exposed to thermal intensities. The nonthermal influence of microwaves was characterized by anode-electrotonic changes involving suppression at a high level of lability. Under these conditions, a dc cathode had a normalizing effect [Bychkov, 1962].

An SHF field of thermal intensity reduced the resistance of mice to strychnine poisoning, but a field of nonthermal intensity increased it [Bychkov, 1961].

Under the local influence of an SHF field, anesthetization practically /75 eliminated the negative chronotropic effect on the cardiac rhythm. It is assumed that this effect has a regular nature, and that a positive chronotropic effect is induced by the direct influence of the field on the brain cells [Livitina, 1964].

During the influence of an SHF field, a disturbance was noted in the behavior of anteaters, who lost their ability to "inform" other anteaters about a food source. During the influence, the anteaters oriented their snouts along the force lines of the field [Jaski, 1960].

A. N. Frey [1962, 1963] described the auditory sensations of certain people under the influence of an SHF field as a buzzing, clicking or a whistle. Antinoise plugs increased the sensitivity to the field. According to this index, the sensitivity to a pulsed SHF field was  $3 \mu\text{w}/\text{cm}^2$ . The sound disappeared only during screening of the temporal region of the head. Frey proposed that the SHF field acts directly on the auditory nerve or on the brain cells by means of interaction with the electrical and magnetic fields formed around the nerve cells.

There is also the assumption that the nonthermal effect of an SHF field depresses the synaptic transfers of impulses [Bychkov, 1962], due to the effect on the activity of acetylcholine. It has been observed [Nikogosyan, 1960, 1964; Bychkov, Syngayevskaya, 1962] that the activity of cholinesterase in the brain is reduced under the influence of an SHF field.

A change has been noted in the epileptoid reaction of rats, which are sensitive to sound stimulation, during the influence of microwaves of different ranges [Kitovskaya, 1960, 1964]. A decrease in the severity of convulsions, an increase in the latent period and a change in the duration of the inhibition period between the first and second excitation waves have also been observed. In brief, an SHF field reduces the excitability and weakens the inhibition process.

An increase in the potassium chloride content and a decrease in the glucose requirement have been established in rats during the chronic influence of centimeter waves with an intensity of  $10 \text{ mw}/\text{cm}^2$ . An increase in the calcium requirement (appetite) was observed in rats that were subjected to the influence of centimeter and decimeter waves with an intensity of  $40 \text{ mw}/\text{cm}^2$  [Kulakova, 1964].

During exposure to strong SHF fields ( $40-100 \text{ mw}/\text{cm}^2$ ), changes were noted in the interneuronal junctions (synapses) of the cerebral cortex; these changes included disappearance of the junctions at the dendrite tips of pyramidal cells. During chronic exposure to SHF fields of different intensities, dystrophic changes were noted in the neurons, especially in the cortex and in the thalamus-hypothalamus region [Tolgskaya, Gordon, 1960, 1964]. Sometimes a productive reaction of the glia, especially the microglia, was observed [Dolina, 1961; Tolgskaya, Gordon, 1964].

In studies on the effect of an SHF field on an organism, the electrical /76 brain activity has more frequently been recorded than in studies on the biological effect of a UHF field. Apart from the already cited works of Baldwin et al. (1960), Fleming et al. (1961) and clinical EEG investigations, we should mention the works of M. S. Bychkov (1957, 1962), which especially investigated the effect of an SHF field on rabbit and cat EEGs. The EEGs were recorded before and after exposure of the animals to microwaves of different intensities. Differently directed changes in the amplitude and frequency of cortical biopotentials were noted. For brief exposure (10 min), excitation was noted, but with a prolonged exposure, an inhibition effect was noted. The most expressive EEG changes appeared on the treated side, which testifies to the direct effect of a UHF field on brain tissue. On the other hand, neurodynamic changes also occurred during local exposure on the extremities. This fact indicates the presence of

a reflex path for the effect of an SHF field on the CNS. Following the injection of novocain, the effect of local exposure on the extremities disappeared.

Simultaneously with our reports concerning the effect of an SHF field on electrical brain activity [Bavro, Kholodov, 1962; Kholodov, 1962a, Kholodov, Zenina, 1964], several investigations devoted to this question [Gvozdikova et al., 1964a, b; Zenina, 1964] appeared, which testifies to the development of electrographic methods for analyzing the biological effect of an SHF field.

We considered our problem to be a comparison of the electrical reactions of an intact and an isolated brain, and a cortical strip, to the influence of constant and pulsed SHF fields of thermal and nonthermal intensities. Furthermore, we proposed to compare the electrical reaction of the brain to SHF and UHF fields.

#### The Effect of a Constant SHF Field of Thermal Intensity on the Rabbit EEG

As an analysis of the works of Bychkov (1957) and the experiments of Baldwin et al. (1960) show, the EEG reactions of different species of animals to the influence of a UHF field were sufficiently polymorphous. It remains unclear whether this polymorphism is explained by the species peculiarities of the experimental animals or by the applied field strength. Furthermore, these investigators did not quantitatively characterize the index of the reaction that we call stability. Proceeding from these statements, we considered it necessary to investigate the EEG reaction to an SHF field in one species of animal, using one method and one treatment of the results, as was done in the study on the influence of a UHF field. Thus, the purpose of our work is a comparison of the results of the local influence of UHF and SHF fields on the head of a rabbit. /77

As in the experiments involving a UHF field, we began with exposure to a sufficiently strong SHF field, the calculated power flux density of which was close to  $1 \text{ w/cm}^2$ . The field was created by a "Luch-58" generator, whose oscillation frequency was 2,400 MHz. The duration of the exposure varied from 1 to 5 min, but most frequently it was 3 min. Twenty rabbits were exposed 92 times. Furthermore, an SHF field with a power flux density of  $100-300 \text{ mw/cm}^2$  acted on the rabbit's head for the same duration. These 12 rabbits were exposed 120 times.

The EEG changes consisted of the appearance of spindles in the sensorimotor region and slow high-amplitude oscillations in the visual region (Figure 21). Let us recall that the same type of EEG changes appeared under a UHF field, although the appearance of spindle-shaped oscillations was noted less frequently. The stability of the reaction to an SHF field of the applied intensities was 90%. The stability was identical for power flux densities of 200 and  $1,000 \text{ mw/cm}^2$ , although the latent period of the reactions depended on the intensity of the exposure.

As is evident from Figure 22, the application of stronger fields did not

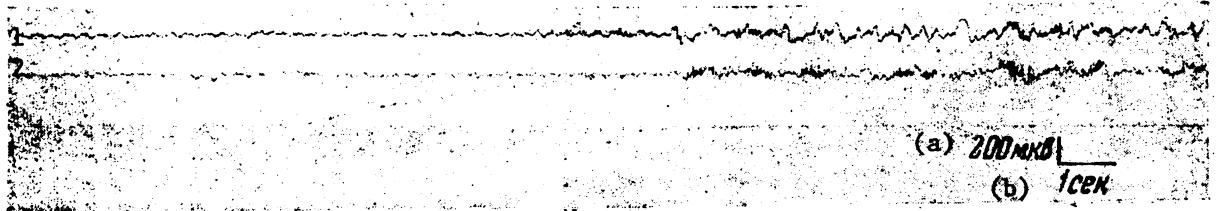


Figure 21. EEG Changes During the Influence of an SHF Field of Thermal Intensity on the Rabbit Head. 1 = EEG of the Visual Cortex; 2 = EEG of the Sensorimotor Cortex. Key: (a) 200  $\mu$ v; (b) 1 Sec.

cause reactions with a latent period that exceeded 1 min. Attention should be called to the fact that a strong field caused a reduction in the average latent period of the reactions only due to a decrease in the number of reactions with a long latent period. The mode of the latent period distribution to strong and weaker SHF fields occurred in the same interval, 25-35 sec. This fact indicates that the observed EEG reaction is triggered by such a slow mechanism that it does not change its qualitative characteristics even when a stronger SHF field is applied. /78

#### The Effect of an SHF Field on the Reactance Curve

A difference in the effect of a strong and a weak SHF field also occurred when we determined the time for the appearance of assimilation to a rhythm of light flashes of increasing brightness (the reactance curve). In 4 rabbits, we determined 30 EEG reactions to interrupted light before, 1 minute after the start of, and 1 minute after the end of an exposure to a field with a power flux density of  $100-300 \text{ mw/cm}^2$ . In 3 cases, the time for the appearance of assimilation to a light rhythm under the influence of the field did not change, in one case it increased, and in 26 cases it decreased. On the average, before exposure, this time was  $19.6 \pm 0.3$  sec; during exposure,  $17.8 \pm 0.3$  sec; and /79 after exposure,  $19.5 \pm 0.3$  sec. Thus, an SHF field with the stated power flux density increased the sensitivity of the cortical and visual analyzers with statistical significance ( $p < 0.01$ ). However, this effect was observed only during exposure to the field: It disappeared 1 minute after the generator was turned off. In this case the reaction stability was 87%, i.e., as both a triggering (one that caused its reaction) and a correcting (one that changes the reaction to stimuli of different modality) stimulus, the SHF field induced effects with identical frequency.

However, under the influence of an SHF field with a power flux density of about  $1,000 \text{ mw/cm}^2$  on the rabbit head, the excitability of the cortical terminations of the visual analyzer was reduced. The following picture emerged from the results of 25 exposures on 4 rabbits. The time for the appearance of assimilation to light flashes remained unchanged only once during the influence of the field and once after the generator was turned off. In all other cases,

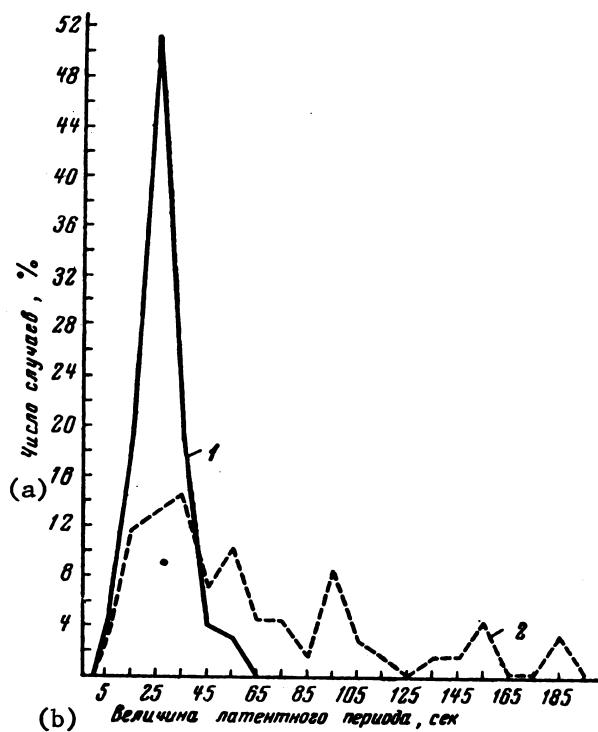


Figure 22. Latent Period Distribution Curves of the EEG Reactions to an SHF Field with a Power Flux Density of  $1,000 \text{ mw/cm}^2$  (1) and  $200 \text{ mw/cm}^2$  (2). Key: (a) Number of Cases, %; (b) Length of the Latent Period, Sec.

the time increased. Before the application of the field, it was  $18.4 \pm 0.3$  sec, during the influence of the field,  $22.2 \pm 0.4$  sec, and after the field was turned off,  $21.3 \pm 0.4$  sec. These data show that during the influence of an SHF field and 1 minute after the generator is turned off, the excitability of the cortical terminations of the rabbit visual analyzer decreased with statistical significance ( $p < 0.01$ ). Thus, like any other stimulus, an SHF field has a phase effect on the excitability of the CNS. A weaker field heightens the excitability, and a stronger field lowers it.

In this connection, we should recall that fields with different power flux densities did not differ from each other in the type of the spontaneous EEG changes they induced; in both cases an increase in the number of spindles and slow high-amplitude oscillations of potential were noted in the cerebral cortex. Consequently, just one tracing of a spontaneous EEG cannot give reliable evidence regarding the predominance of one or another basic nervous process in the rabbit CNS. The application of test stimuli is necessary.

#### The Effect of an SHF Field on the Electrical Activity of a Neuronally-Isolated Cortical Strip

In discussing the mechanism of the effect of an SHF field on the CNS, certain investigators have made statements concerning the direct effect of the field on the cerebral cortex [Bychkov, 1957; Presman, Levitina, 1962; and others]. To check this hypothesis, we conducted a series of tests on 14 rabbits bearing a neuronally-isolated strip in the sensorimotor region of the cortex on the left hemisphere. The number of exposures was 119, the power flux density was  $200 \text{ mw/cm}^2$ . The experimental methodology was the same as in the study on the effect of a UHF field on the electrical activity of a strip. /80

It was shown that a strip can react to an SHF field with an increase in electrical activity (Figure 23). This type of strip reaction also predominated during the influence of a UHF field. We should note that in this case, the

reaction of the strip was less frequent than the reaction of an intact brain. The reaction stability of a strip was 50%, and of an intact brain, 90%.

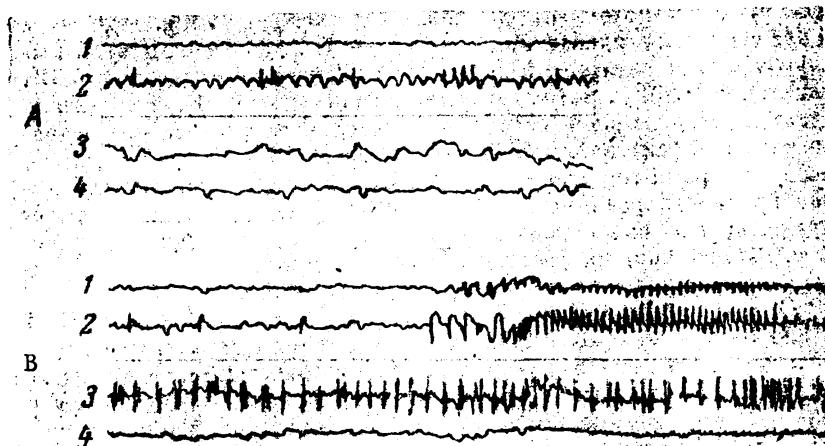


Figure 23. The Electrical Reaction of a Neuronally-Isolated Cortical Strip and Adjacent Sections of an Intact Brain to an SHF Field. A = Before Exposure; B = During Exposure; the Numbers Indicate the Electrocorticogram Leads. 1 = Isolated Cortical Strip; 2 = Visual Region of the Damaged Hemisphere; 3 = Sensorimotor Region of the Intact Hemisphere; 4 = Visual Region of the Intact Hemisphere.

The average latent period of the strip reaction was less than that of the intact brain ( $20 \pm 2$  versus  $63 \pm 4$  sec.). In the latent period distribution curve of the strip reactions, the mode was at 15 sec, while for the intact brain it was at 35 sec (Figure 24). Consequently, although the reaction is observed less often, an isolated cortical strip reacts to an SHF field more quickly than an intact brain.

Apart from spindles and slow waves, the change in the functional state of the rabbit brain following mechanical damage to the cortex of one hemisphere in order to isolate a strip sometimes led to the appearance of convulsive discharges on the EEG during the influence of an SHF field (Figure 23). We should note that the high temperature of the air (the tests were conducted in the summer) led to the appearance of convulsive discharges, which could also be elicited by any uncontrolled stimulus, and were provoked by the next stimuli we administered: light, sound, a constant magnetic field, and also an SHF field. A detailed comparative characterization of the EEG reaction to these stimuli will be given later. Here, however, we want to note that the SHF field caused convulsive discharges on the EEG more often than light or sound, and these discharges were sometimes accompanied by convulsive twitching of the animal. /81

The latent period of convulsive EEG reactions did not differ from the latent periods of other types of EEG reactions, although on the whole the damaged

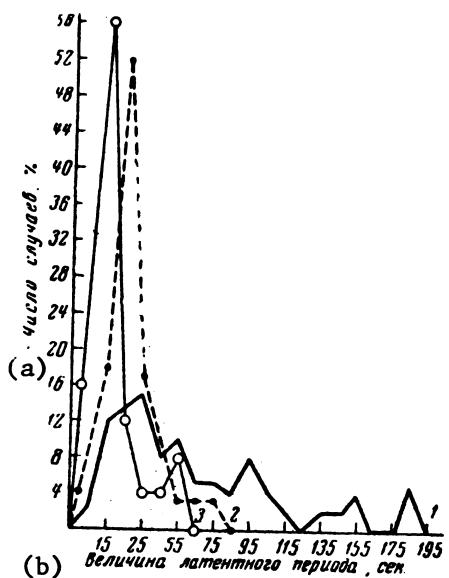


Figure 24. Distribution Curves of the Latent Period of Electrical Reactions to an SHF Field in an Intact Brain (1), an Undamaged Hemisphere (2) and an Isolated Contralateral Cortical Strip (3). Key: (a) Number of Cases, %; (b) Length of the Latent Period, Sec.

an increase in the number of spindles or slow high-amplitude oscillations on the EEG, since the latent period of the different reaction forms is identical. Second, the reaction to an SHF field can be optimized by two methods: increasing the power flux density of the field or increasing the sensitivity of the CNS. In both cases, the ceiling for optimization of the reaction was identical. The stability was 90%, and the average latent period was 25 sec.

The occurrence of a convulsive reaction to an SHF field after isolation of a cortical strip allows us to separate the reaction to generator turn-off, which can occur in the strip, the damaged hemisphere, the intact hemisphere, or in all leads simultaneously. /82

In the damaged hemisphere, the reaction to turn-off was characterized by a stability of 20% and an average latent period of  $21 \pm 2$  sec; the latent period distribution curve of the reactions to turn-off had a mode at 15 sec (Figure 25), and it resembled the latent period distribution curve of the strip reaction to turn-on of the SHF field.

The reaction to turn-off was also observed in the intact brain, only there it was encountered less often and was less distinct. The turn-off reaction coincided with the turn-on reaction (the basic reaction) in the form of the EEG changes. Several seconds after the SHF generator was turned off, we noted an increase in the number of spindles or slow high-amplitude oscillations. In

brain reacted to the SHF field more quickly than the intact brain. As is evident from Figure 24, the mode for the distribution of latent periods of the damaged hemisphere reactions falls at 25 sec.

It is interesting to compare the latent period distribution curve of damaged brain reactions to a 200 mw/cm<sup>2</sup> SHF field with the latent period distribution curve of the reactions of an intact brain to a 1,000 mw/cm<sup>2</sup> SHF field (Figure 22). These curves coincide almost completely.

Two important conclusions follow from this fact.

First, depending on the initial functional state, the form of the EEG reaction to an SHF field can change, i.e., it can be expressed in convulsive discharges following mechanical damage to the cortex. However, we can assume that this reaction is accomplished by the same mechanism as the reaction that is manifested as

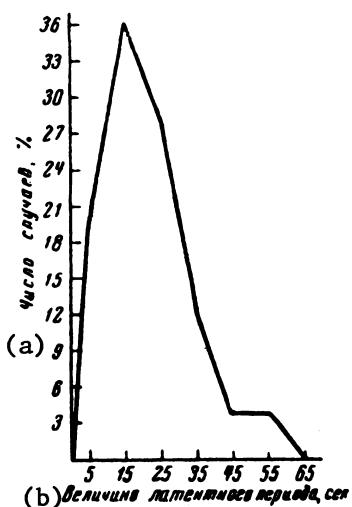


Figure 25. Latent Period Distribution Curve of the EEG Reaction to Turn-Off of the SHF Field.

Key: (a) Number of Cases, %; (b) Length of the Latent Period, Sec.

acterized by 50 exposures. The obtained results were compared with the reaction to a constant field influence.

We noted that a modulated SHF field causes EEG reactions that are the same in form and stability as those caused by a constant field. A certain difference was observed only in the latent periods.

/83

Figure 26 gives the latent period distribution curves of the EEG reaction to a constant SHF field and to the same field modulated at a frequency of 10 Hz. As is evident from the figure, the EEG reactions to a modulated field occur earlier than those to a constant field.

Figure 27 gives the curve of the dependence of the average latent period of the EEG reaction to an SHF field on the modulation frequency. As the modulation frequency increases, we observe a tendency towards shortening the average latent period of the reaction. This dependence is not proportional. The largest difference is observed upon passing from a constant field to one modulated at a frequency of 10 Hz. During transition from 10 to 50 Hz, the averages of the latent period do not change, and upon transition from a constant field to one that is modulated at a frequency of 2 Hz, the changes in the average latent period of the reactions are insignificant.

Experiments involving a modulated field force us to assume that a discontinuous field has a somewhat more expressive physiological effect on the rabbit

contrast to the basic reaction, the turn-off reaction was observed less often (in 20% of the cases versus 90%). Sometimes the basic reaction was absent, but the turn-off reaction appeared distinctly, which forces us to assume a certain independence of these reactions.

#### The Effect of a Modulated SHF Field on the Rabbit EEG

It became clear that the rabbit CNS reacts not only to the presence of fields, but also to their change. In this case, one would expect that a modulated field would have a more expressed effect than a constant field. To check this assumption, we conducted experiments in which we compared the biological reaction of rabbit cerebral cortex to an SHF field with a power flux density of  $200 \text{ mw/cm}^2$  that was constant or modulated at a frequency of 2, 5, 10 or 50 Hz. Ten rabbits were each given five 3-minute exposures to an SHF field modulated at each of these frequencies. Each range of modulation was characterized by 50 exposures. The obtained results were compared with the reaction to a constant field influence.

EEG than a constant field. The effectiveness of low frequencies (up to 10 Hz) leads to the thought that the possible coincidence of the modulation frequency of the SHF field with the frequency characteristics of the electrical activity in rabbit brains plays an important role here.

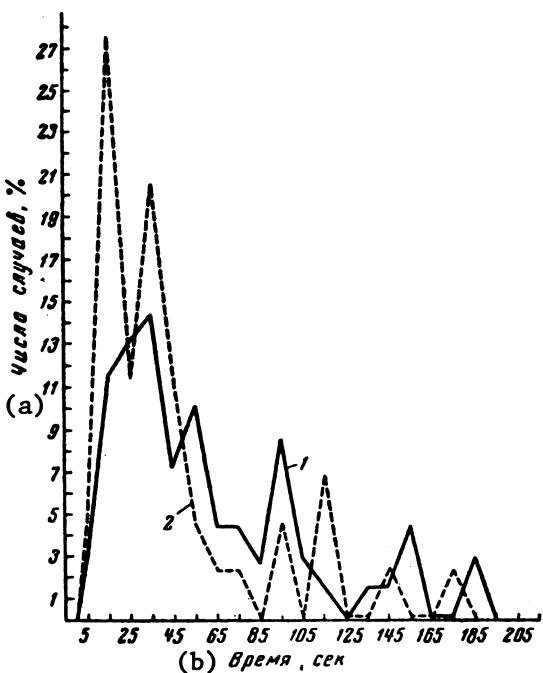


Figure 26. Latent Period Distribution Curves of the EEG Reactions of Rabbits to a Constant SHF Field (1) and to an SHF Field Modulated at a Frequency of 10 Hz (2). Key: (a) Number of Cases, %; (b) Time, Sec.

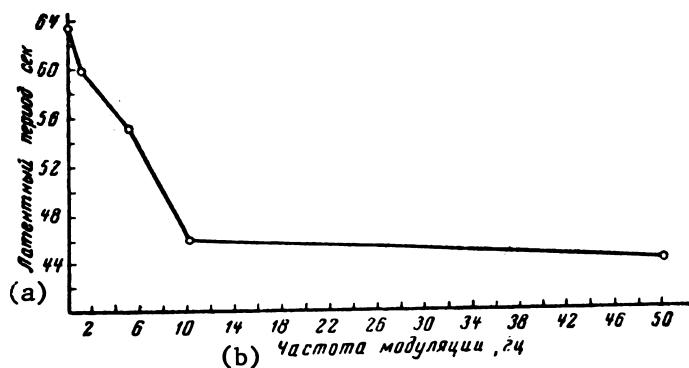


Figure 27. The Dependence of the Average Latent Period of the EEG Reactions to an SHF Field on the Modulation Frequency. Key: (a) Latent Period, Sec; (b) Modulation Frequency, Hz.

#### The Effect of Caffeine on the EEG Reaction of Rabbits During the Influence of a Constant SHF Field

As tests involving isolated cortical strips have shown, the electrical reaction of the rabbit brain to an SHF field depends on the initial functional state. For additional confirmation of this conclusion we decided to conduct tests involving the influence of a field on the head of a rabbit after preliminarily increasing the excitatory process. For this purpose, we subcutaneously (in the thigh) injected 18 rabbits with 1 mg/kg of caffeine. We began the experiments on the effect of an SHF field 30 minutes after the injection. In 13 rabbits, we observed the appearance of convulsive discharges in the EEG, and sometimes convulsive twitching 1-2 min after the start of the exposure to an SHF field with a power flux density of 1,000 mw/cm<sup>2</sup> (Figure 28).

Ninety-two 5-minute exposures of the same strength on 20 rabbits that were not injected with caffeine, did not induce one instance of convulsive discharges in the cerebral cortex. Injection, alone, of the same dose of caffeine into rabbits did not cause the appearance of convulsive discharges in the EEG. Consequently, only the summation of the physiological effects of an SHF field and of caffeine could cause these changes in the rabbit EEG.

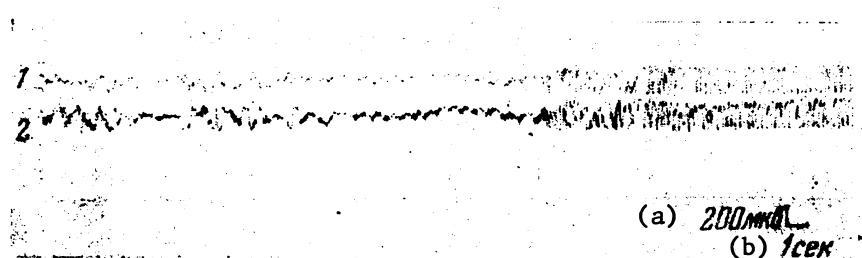


Figure 28. The Appearance of Convulsive Discharges in the Rabbit Cerebral Cortex During the Influence of an SHF Field, After Preliminary Injection of Caffeine. 1 = EEG of the Visual Cortex; 2 = EEG of the Sensorimotor Cortex. Key: (a) 200  $\mu$ v; (b) 1 Sec.

Thus, during the influence of relatively powerful SHF fields on the head of a rabbit, we observed the appearance of slow high-amplitude oscillations, <sup>/85</sup> spindles or convulsive discharges on the EEG, i.e., just the changes that characterized the effect of a UHF field. The similarity of these effects also included a long latent period of the reactions, a reaction to turn-off, and an effect on the electrical activity of a neuronally-isolated cortical strip. We also observed that a weaker SHF field increases the excitability of the cortical terminations of the visual analyser (as determined from the reactance curve), and a strong SHF field reduces it.

The similarity in the physiological effect of UHF and SHF fields, which has been noted by many authors, was revealed in our experiments very distinctly. However, in explaining the causes of this similarity, we must first assume the possible thermal effect of these fields, since in our experiments we used thermal and scarcely thermal field strengths. It was necessary to conduct similar experiments with nonthermal SHF field doses.

#### The Effect of Pulsed SHF Fields of Thermal and Nonthermal Intensity on the Rabbit EEG

We were given the opportunity of studying the biological effect of an SHF field of nonthermal strength in the Laboratory of Electromagnetic Radio-Frequency Waves (directed by Z. V. Gordon) of the Institute of Labor Hygiene and Occupational Diseases of the USSR Academy of Medical Sciences (directed by Professor A. A. Letavet). This allowed us to compare our data with the results obtained

by the coworkers of this laboratory using different methods for investigating the effect of an SHF field on the CNS of an animal. In contrast to our previous method of exposure, a pulsed SHF field ( $\lambda = 52$  cm) acted not only on the head, but also on the entire body surface of the animal from one side. Therefore, at the very start of the investigation, we asked about the possibilities /86 of a mechanism of effect that was different from the one we considered in our study on the effect of UHF and SHF fields on the head of a rabbit. Proceeding from this premise, we decided to investigate the effect of pulsed SHF fields of nonthermal (2 and 10  $\text{mw/cm}^2$ ) and thermal (50  $\text{mw/cm}^2$ ) power flux densities on the bioelectric activity of an intact and on an isolated rabbit brain. Isolation was performed by sectioning at the level of the midbrain.

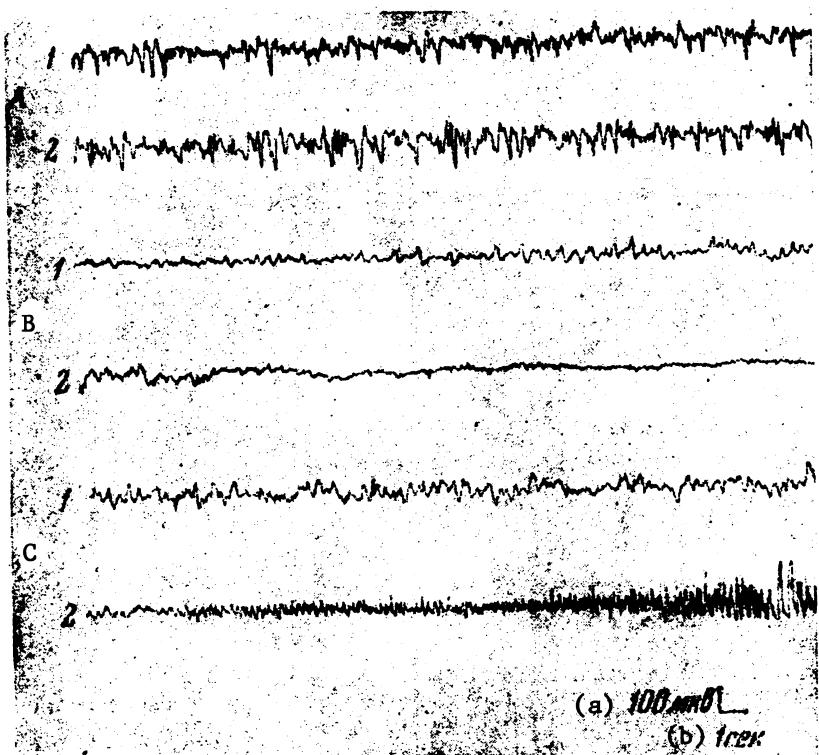
Total-body exposure was always conducted from the left side. Electroencephalograms of the parietal regions of the cortex of both hemispheres were recorded with needle electrodes by the monopolar method. The EEGs were recorded on a four-channel ink-writing VNIIMIIo electroencephalograph located in a room next to the one used for exposure. Usually, we recorded a background EEG for 1 min and, without interrupting the recording, applied a 3-minute dose, then recorded another 1 min of cortical electrical activity after the exposure ended. The exposure was repeated every 10-15 min. The tests were conducted on 14 rabbits, who received a total of 300 exposures. SHF fields of each power flux density (2, 10 and 50  $\text{mw/cm}^2$ ) were applied 100 times; an intact brain was exposed 50 times, and an isolated brain preparation, 50 times.

Most frequently (76% of the total number of reactions), in response to any power flux density on the EEG of the intact brain, we noted an increase in bio-potential amplitude, which was sometimes accompanied by a decrease in biopotential frequency (Figure 29, A). Sometimes (20% of the cases), in response to the exposure, we observed a prolonged desynchronization reaction (Figure 29, B). And, finally, convulsive discharges appeared on the EEG during the exposure (Figure 29, C), but only very rarely (4% of the cases). The EEG changes occurring during an influence (especially the slow high-amplitude oscillations) lasted for several minutes after the influence ceased.

Thus, the form of the EEG reaction to a pulsed SHF field was basically similar to the form of the EEG reaction of rabbits to a constant UHF or SHF field.

We observed convulsive discharges in the intact brain during exposure only two times in the same rabbit, and we explain this fact by the individual heightened excitability of this animal's CNS. We could obtain this type of reaction to a constant SHF field by artificially increasing the excitability by an injection of caffeine, or by mechanical damage to the cortex. It is possible that this rabbit would also react with convulsive discharges to the application of a constant SHF field. In brief, we do not note any specifics of the effect of a pulsed SHF field in this form of reaction.

The prolonged desynchronization during exposure is another matter. We /87 frequently saw this type of reaction during the influence of a powerful UHF field on the extremities of a rabbit. It is possible that the method of total-body exposure is the cause of the occurrence of this form of EEG reaction. Since this form was encountered relatively rarely (4 times less often than the



**Figure 29.** Forms of the EEG Changes During the Influence of a Pulsed SHF Field on an Intact Rabbit Brain. A = Increase in Potential Amplitude; B = Decrease in Potential Amplitude; C = Appearance of Convulsive Discharges; 1 = EEG Before Exposure; 2 = EEG During Exposure. Key: (a) 100  $\mu$ v; (b) 1 Sec.

increase in biopotential amplitude), we did not conduct a detailed analysis of the paths of its origin.

The general conclusion is that constant UHF and SHF fields and pulsed SHF fields of different intensities cause similar changes in the rabbit EEG.

This similarity appeared not only in the form of the basic reaction, but also in the appearance of the desynchronization reaction at the moments the generator was turned on and off (Figure 30, A, B). These desynchronization reactions frequently occurred with a latent period measured in fractions of a second, and they lasted for 2-6 sec. They sometimes occurred during the exposure that caused the basic reaction, but they could not appear independently of the basic reaction. The turn-on reaction could also be observed independently of the turn-off reaction. The average of the first was 31%, of the second, 12%. The certain independence of the described reactions made it possible to look for another source for them, for example, the appearance and disappearance of sound when the generator was turned on and off. However, the presence of similar reactions

during investigations of other EMF in which a sound stimulus was excluded, allow us to assume that, like any other stimulus, an SHF field causes a nonspecific EEG reaction (of the orienting type) at turn-on and turn-off.

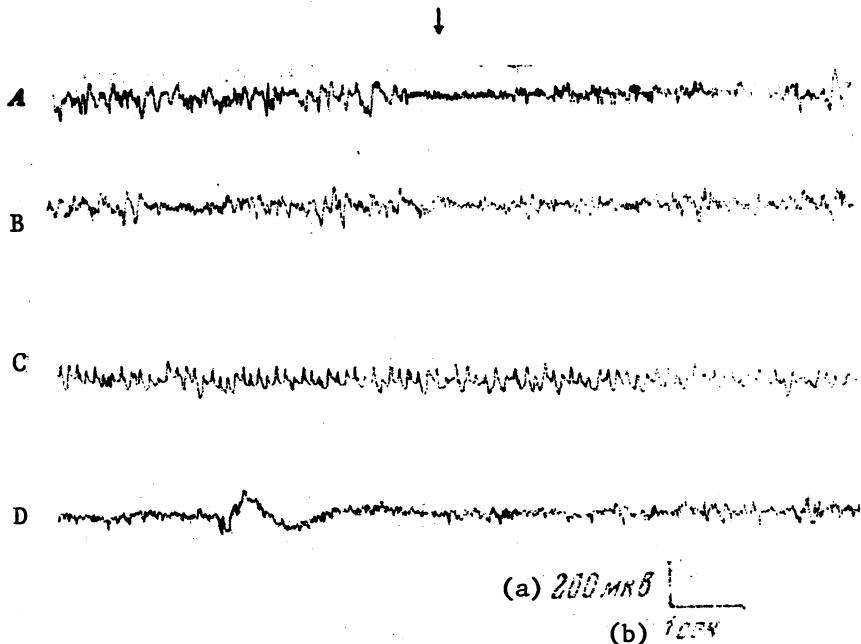


Figure 30. EEG Reactions Occurring When the SHF Generator is Turned on (A) and off (B), and the Off-Effect, the Reaction to Turn-Off (C, D). The Arrows Designate the Moments the Generator is Turned on and off. Key: (a) 200  $\mu$ v; (b) 1 Sec.

Concluding our description of the form of the EEG reactions during the influence of a pulsed SHF field, we must mention that a reaction resembling the /89 basic reaction in form (Figure 30, C, D) sometimes occurs after the field is turned off. In other words, slow high-amplitude waves and spindles appeared on the EEG 5-25 sec after the field was turned off. This reaction frequently occurred when the basic reaction was absent. The turn-off effect probably appears to a lesser degree in the background of the aftereffect from the basic reaction and, therefore, the stability of the reaction to turn-off was 13%.

Thus, we noted the following general scheme of the EEG reaction of rabbits to any UHF or SHF field. This includes changes in the EEG that occur when the field is turned on and off (these are usually an insignificant decrease in the biopotential amplitude and an increase in the biopotential frequency), and changes observed during the influence of the field and several seconds after it is turned off (usually the appearance of slow high-amplitude oscillations of potential and spindles). From the external picture of the change in cortical biopotentials, the reactions to EMF can be divided into two clear groups: the desynchronization reactions are faster, occurring with a latent period of less than one second at turn-on and turn-off, and lasting not more than 10 sec; the syn-

chronization reactions are slower, occurring with a latent period of 5-90 sec and lasting from 20 sec up to several minutes.

Since the EEG reactions of rabbits to external heating in our tests were manifested as prolonged desynchronization, we assumed that the forms of the EEG reaction to EMF that we have noted are essentially the result of a nonthermal mechanism of the effect of EMF on the CNS.

The Effect of an SHF Field on the Rabbit EEG After  
Sectioning at the Level of the Midbrain

The assumptions stated above needed support from the side of the physiological mechanism of the effect of an SHF field of nonthermal intensity. Therefore, the next stage of our investigations was a clarification of the question regarding the direct effect of an SHF field of nonthermal intensity on the structures of the forebrain and diencephalon. The experiments were conducted on an isolated preparation, cerveau isolé.

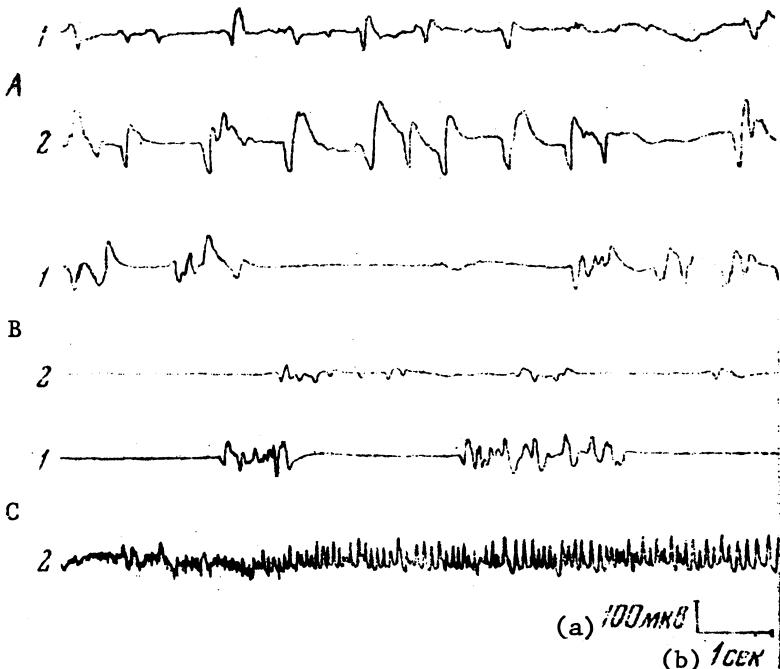


Figure 31. Forms of the EEG Changes During the Influence of a Pulsed SHF Field on an Isolated Rabbit Brain Preparation. A = Increase in Potential Amplitude; B = Decrease in Potential Amplitude; C = Appearance of Convulsive Discharges; 1 = Before Exposure; 2 = After Exposure. Key: (a) 100  $\mu$ v; (b) 1 Sec.

Although the spontaneous EEG rarely changed towards predominance of slow waves after the stated operation, the character of the change in the electrical brain activity during exposure remained as before. In most cases (71% of all reactions), we observed an increase in the biopotential amplitude (Figure 31, A), in 19% of the cases we observed its decrease (Figure 31, B) and in 10% of the cases, convulsive discharges appeared (Figure 31, C). In comparison with an intact brain, there was a relative increase in the cases in which convulsive dis-/90 charges occurred in the cortex during exposure (10% versus 4%).

The number of desynchronization reactions at turn-on and turn-off of the field decreased to 3-4%, the number of basic reactions (stability) increased from 30% to 55%, and the number of reactions to turn-off remained practically unchanged (15% versus 13%).

Thus, if we judge from the degree of stability of the basic reaction, deafferentation of the brain increases its sensitivity to a pulsed SHF field (as to a UHF field), which indicates the important role of the direct effect of this factor on the structures of the diencephalon and telencephalon.

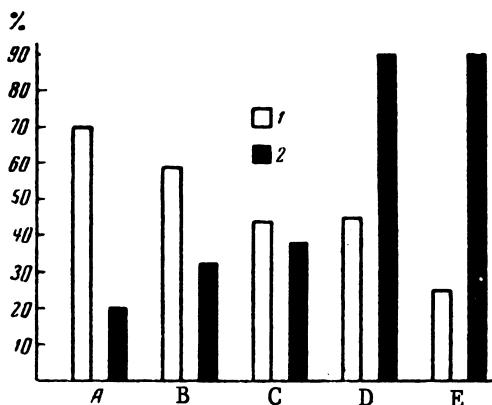
The question arose as to whether the increase in reaction stability after sectioning at the midbrain level can be explained by deafferentation or by the stimulation induced by mechanical trauma. It seemed to us that an analysis of /91 the change in the reaction stability depending on the time that passed after sectioning would help to answer this question to some degree. It was observed that 1 hour after the operation, the stability of the basic reaction was 46%, after 2 hours it had increased to 53%, and after 3 hours, it had reached 70%. This fact forces us to assume that the basic cause of the increase in sensitivity of an isolated brain to an SHF field is deafferentation, and not just the stimulation caused by trauma.

#### The Dependence of the EEG Reaction of an Intact and an Isolated Brain on the Intensity of an SHF Field

Until now we have discussed general data on the effect of a pulsed SHF field. It is time to investigate the dependence of the physiological effect on the field intensity. We determined this dependence from the average stability and the average latent period of the basic reaction. From Figure 32 it is evident that, as the intensity of the pulsed SHF field increases, the average latent period of the basic EEG reaction of an intact rabbit brain decreases, but its stability increases. If we combine the results on the effect of pulsed and constant SHF fields with different wavelengths, we shall note that when the power flux density is from 2 to 200 mw/cm<sup>2</sup>, there is an increase in the reaction stability from 20 to 90%, and a shortening of the average latent period.

Finally, we showed that the intensity of the EEG reaction of the rabbit /92 brain increases as the intensity of the SHF field is increased, but the mathematical character of this dependence is still not clear.

After sectioning at the midbrain, the average latent periods of the reactions did not change significantly, and the reaction stability increased at each



**Figure 32.** Dependence of the Average Latent Period (1) and Stability (2) of EEG Reactions on the Intensity of the SHF Field. A =  $2 \text{ mw/cm}^2$ ; B =  $10 \text{ mw/cm}^2$ ; C =  $50 \text{ mw/cm}^2$ ; D =  $200 \text{ mw/cm}^2$ ; E =  $1,000 \text{ mw/cm}^2$ .

cess of summation; in other cases (Figure 33, C, rabbit no. 3) we observed adaptation; and, in total, during exposure to nonthermal and thermal doses, the reaction was randomly distributed regardless of the result of the previous influence. The statistical character of the EEG reaction to an SHF field probably cannot be explained by just the weak nature of the stimulus, because we sometimes observed such a strong reaction as convulsive discharges. However, the appearance of this form of cortical biopotential in a normal animal did not change the latent period or the reaction stability. In other words, by itself, the reaction could be very strong, but the triggering mechanism of the reaction did not operate during each exposure. It is probable that the formations on which the EMF act are responsible for this triggering mechanism. The possibility of a direct effect of an SHF field on the structures of the diencephalon and telencephalon allows us to assume that just these structures, which are not specialized receptors, bear the justification for the statistical character of the reaction. Consequently, by affecting these structures in some manner, we can increase the reaction stability.

The Effect of Caffeine on the EEG Reaction of an Intact and an Isolated Rabbit Brain During the Influence of an SHF Field

/93

We already know that the reaction stability increases as the SHF field strength is increased, after injection of caffeine, after mechanical damage to the cortex (isolation of a strip), and after sectioning at the midbrain level.

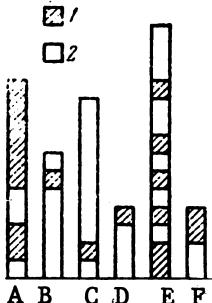


Figure 33. Dynamics of the Appearance of EEG  $^2$  Reactions to a  $50 \text{ mw/cm}^2$  SHF Field on Separate Rabbits. 1 = Presence of the Reaction; 2 = Absence of the Reaction; A-F = Different Rabbits.

We decided to find out whether the effect of these influences is additive, like the injection of caffeine and sectioning at the midbrain level, during the influence of an SHF field of nonthermal intensity ( $10 \text{ mw/cm}^2$ ).

These experiments were conducted on 25 animals. The first group consisted of normal rabbits, the second group was injected with caffeine, the third group was sectioned at the midbrain level and, finally, the fourth group contained rabbits that were injected with caffeine after the midbrain had been sectioned. The method of recording the EEG and its treatment was the same described above. Caffeine sodium benzoate was injected intramuscularly in the left thigh,  $50 \text{ mg/kg}$ , which relates to the doses that caused an increase in the excitability of the higher levels [Kalinina, Tsobkallo, 1962]. Our control tests on 3 rabbits showed that this dose of caffeine reduces the amplitude and increases the frequency of cortical potentials, but it does not cause convulsive discharges.

We have already described the character of the rabbit EEG changes during total-body unilateral exposure to a pulsed SHF field. In this series of tests, it was interesting to follow the quantitative relationship of the different forms of the EEG reaction, which depended to a great degree on the initial functional state of the animal. The general results of this series of experiments are given in Table 12.

/94

TABLE 12. STABILITY OF THE EEG REACTION TO AN SHF FIELD IN AN INTACT AND AN ISOLATED RABBIT BRAIN AFTER INJECTION OF CAFFEINE.

Test conditions	Number of rabbits	Number of exposures	Number of convulsive reactions	Stability %	Number of all reactions	Stability %
normal animal	9	50	2	4	16	32
norm + caffeine	5	36	2	6	18	50
isolated brain	4	50	6	12	31	62
isolated brain + caffeine	7	63	35	56	54	86

As Table 12 shows, in normal rabbits the reaction stability is 32%, after injection of caffeine it increases to 50%, after sectioning at the midbrain it increases to 62%, and under the combined effect of these two forms of intervention, it reaches 86%. In other words, the sensitivity of rabbits to an SHF field increases significantly after pharmacological and surgical intervention in the activity of the CNS. However, sectioning at the midbrain increased the sensitivity to a greater degree (approximately 2 times) than injection of caffeine (approximately 1.5 times), and the combined effect of these factors increased the sensitivity by more than 2.5 times.

It is interesting to note that the increase in reaction stability in the last series of tests occurred only through an increase in the number of convulsive reactions, while the number of other forms of reaction was the same as in the norm (29 and 28% respectively). In the second and third series, the increase in reaction stability occurred due to both convulsive reactions and other forms of EEG changes. Thus, the increase in the sensitivity of rabbits to an SHF field following our interventions is manifested not only as an increase in the number of EEG reactions during the influence of the field, but also as an increase in the sharper, convulsive forms of the reaction.

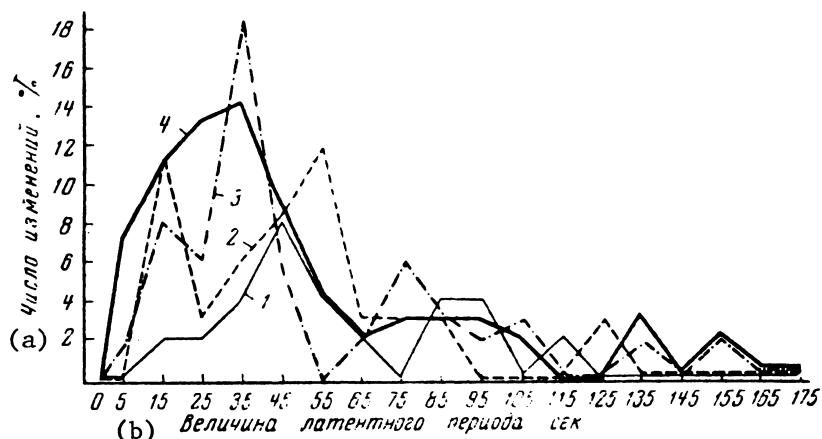


Figure 34. Distribution of the Latent Periods of the EEG Reactions to a Pulsed SHF Field in Normal Rabbits (1), After Injection of Caffeine (2), in an Isolated Brain (3) and in an Isolated Brain After Injection of Caffeine (4). Key: (a) Number of Changes, %; (b) Length of the Latent Period, Sec.

As we go to an analysis of the latent periods of the reaction, we should /95 note that it is difficult to characterize this index by an average magnitude since the distribution of the values of the latent period is not a normal distribution. However, as Figure 34 shows, the shortest periods are observed after the combined effect of sectioning and caffeine, then come the latent periods of the reactions that occur after sectioning, behind them the latent periods of the reactions after injection of caffeine and, finally, the reactions of normal rabbits have the longest latent periods. It is important to emphasize that the

shortest latent periods of the reactions are very rarely less than 15 sec. Consequently, even under the best conditions, EEG reactions to an SHF field retain the properties that distinguish an SHF field from other stimuli that affect specialized receptors. Thus, the stability, form and latent period of the EEG reaction of rabbits, consistently attest that the sensitivity of the animal to an SHF field increased after injection of caffeine, sectioning at the midbrain, and the combined effect of both these factors.

We will not analyze the EEG reactions that occur at the moments the generator is turned on and off since these changes were insignificant in the different series of tests. We decided to illustrate the change in the intensity and duration of the basic reaction with a graph in which the results of the first and last series of tests are compared. Figure 35 shows the dynamics of a number of slow and sharp waves that occur in the rabbit EEG. The changes were calculated for each 10-second interval of the recording. The figure shows the total picture obtained as a result of applying 50 exposures to a normal rabbit (1) and 50 exposures to an isolated brain preparation after injection of caffeine (2). In this calculation, each slow and sharp wave was given a value of one, and if convulsive discharges occupied the entire 10-second interval, they were given a weight of 5. In other words, the presence of a change in a 2-second recording of the EEG was taken as unity. Considering the great arbitrariness of this quantitative evaluation of the EEG, we still decided to conduct it because we were interested in a relative comparison of the background with the influence on a normal rabbit, and on an isolated brain preparation after injection of caffeine.



Figure 35. Dynamics of Slow and Sharp Waves in the Electrical Brain Activity of a Normal Rabbit (1) and in an Isolated Brain Preparation After Injection of Caffeine (2) in the Background and Under the Influence of a Pulsed SHF Field. The Arrows Indicate the Moments the Generator was Turned On and Off. A = Before Exposure; B = During Exposure; C = During the Aftereffect. Key: (a) Number of Changes; (b) Time, Sec.

From the graph, it is clear that the number of slow and sharp waves in the EEG of a normal rabbit before the start of the exposure varied around 10, but after 45 sec of exposure, it had increased by 3.5 times, which is a statistically reliable change ( $p < 0.001$ ). However, in spite of the fact that exposure continued, the number of waves had a tendency to decrease, and before the generator was turned off, they exceeded the background number by only 2.5 times.

Some 15–25 sec after turn-off, we saw a new rise in the number of slow and sharp waves, which characterizes the previously de-

scribed reaction to turn-off [Kholodov, 1962a].

In the isolated brain preparation, after injection of caffeine, the changes in cortical biopotentials during exposure were revealed more clearly than in the normal rabbit. The difference was that the increase in the changes in the EEG occurred earlier and more sharply than in normal rabbits. In the background, the number of changes in a 10-second interval averaged 15, 35 sec after the start of exposure this number had increased by 5 times, and after 95 sec, by almost 6 times. Some 15-25 sec after exposure ended, as in the normal rabbit, we noted the reaction to turn-off. However, while the number of slow and sharp waves began to approach the background in normal rabbits after the exposure ended, in the isolated brain preparation after injection of caffeine, the number of changes exceeded the background by almost 4 times just one minute after the exposure ended. Thus, the increase in sensitivity to an SHF field after operative and pharmacological intervention was also manifested as an increase in the intensity of the basic reaction and as an increase in the aftereffect reaction.

The fact that the effects of caffeine and sectioning are additive, i.e., during their combined effect the stability of the EEG reaction to an SHF field increases to a greater degree than during the effect of one factor, forces us /97 to assume different mechanisms to explain the increase in sensitivity. As was shown previously, by themselves these factors cause different changes in the rabbit EEG. Caffeine quickens the biopotential oscillations and reduces the amplitude, and sectioning at the midbrain level leads to the appearance of slow high-amplitude oscillations. Caffeine probably increases the sensitivity of elements that react to an SHF field, and sectioning reduces the inhibition of afferent effects that possibly interfere with the occurrence of a reaction to the SHF field.

### Discussion

We can increase the stability of a reaction to a UHF field by increasing the power flux density of the field, or the sensitivity of the CNS, but even at the optimal limit of the reaction, its stability does not exceed 90%. If we do not disregard the remaining 10%, we should acknowledge that the statistical character of the reaction is retained in all our experiments, as is its prolonged latent period. Consequently, these properties characterize the reaction of the CNS to an SHF field of any of the strengths we used. It is difficult to explain these properties of the reaction without knowing the essential biophysical mechanisms of the effect of a field on the cell. However, the thermal effect, which we tried to avoid by using a field of nonthermal intensity, still was not fully precluded by these tests. The supporters of only the thermal effect of an SHF field can explain the obtained facts as selective heating of separate elements of the CNS. The statistical character of the reaction and its prolonged latent period can also be explained by heating. We saw the final answer to the question concerning the specific effect of EMF in the use of constant magnetic and electric fields, which fully excluded the thermal effect. The next chapter is devoted to these questions.

The form of the bioelectric reaction of the brain to SHF fields of different

wavelengths, different power flux densities and different character (constant, interrupted and pulsed) was identical and similar to the form of the bioelectric reaction to a UHF field. Other investigators [Gvozdikova et al., 1964a, b; Zenina, 1964] have noted polymorphism of the EEG reactions of rabbits to an SHF field, but changes towards predominance of slow waves occurred more frequently. This fact testifies to the existence of a nonspecific electrical reaction of the brain to radio-frequency EMF. Being a rather sensitive method for determining the presence of an effect of EMF, electrography of the brain did not give us unequivocal testimony on the predominance of one or another nervous process. At /98 the different power flux densities, the external picture of the EEG reaction was similar, but from the reactance curves, the changes in excitability of the cortical terminations of the visual analyzor were directed differently. It is possible that the nonspecificity of the EEG changes is explained by the absence of differences in the effect of pulsed and constant fields, although certain authors [Abrikosov, 1958], using different methods of investigation, have observed diametrically opposed effects of constant and pulsed UHF fields on the CNS.

By recording the electrical activity in an isolated brain preparation and in a neuronally-isolated cortical strip, we were able to prove the existence of a direct reaction of the brain to an SHF field. The isolated brain sections reacted to an SHF field, as to a UHF field, more rapidly than an intact brain.

The depth of penetration of microwave energy into the tissue of the mammalian head at a frequency of 2,400 MHz is about 1 cm [Presman, 1963], which ensures a direct effect of EMF not only on the cortex, but also on the subcortical formations of the brain. Since the depth of penetration is increased at a frequency of 600 MHz, we should conclude that in our experiments involving SHF fields, the conditions for the direct effect of the field on the brain tissue did exist.

The final integrated reaction of an organism, the electrical brain activity, is determined by both reflex and direct effects of environmental factors. Judging from the fact that only reactions in the form of an increase in the number of slow waves and spindles occurred during the influence of strong SHF fields on the head of a rabbit, we can essentially speak about a central effect of an SHF field in our experimental conditions. Let us recall that an EEG reaction, of reflex origin, to a UHF field was expressed in the occurrence of desynchronization.

The results of experiments described in this chapter support our observations concerning the presence of a reaction to EMF turn-off. The existence of an off-effect is an important index of the functioning of many receptor systems [Granit, 1957]. The long latent period (several seconds) of the reaction to turn-off forces us to assume that some slow systems react to EMF. According to this index, the basic reaction and the reaction to turn-off differ little from each other. The latent period of the reaction to turn-off is somewhat smaller than the latent period of the basic reaction. On the other hand, after sectioning at the midbrain level and after isolation of a cortical strip, the stability and the latent period of the basic reaction changed, but the corresponding indices of the reaction to turn-off remained unchanged. These facts testify /99 to a certain independence of the analyzed reaction.

We should note that the aftereffect appeared not only during the off-effect, but also during the prolonged change of the electrical brain activity after the SHF generator was turned off.

In studying the effect of an SHF field on the electrical activity of the rabbit, we called attention to the brief desynchronization reactions that occur at the moments the generator is turned on and off. These reactions were also observed during the influence of a UHF field, but they were not analyzed in detail. We consider these reactions to be orienting reactions that occur regardless of the basic character of the EEG reactions to EMF. A special analysis showed that these orienting reactions are not connected with sound stimuli that occur during operation of the generator [Zenina, 1964].

The use of caffeine showed that pharmacological analysis expands the possibilities of investigating the mechanism of the effect of an SHF field on the CNS. The appearance of convulsive discharges in the cortex after its excitability was increased by caffeine shows that an SHF field can cause significant changes in the activity of the CNS. From this point of view, the report [Zenina, 1964] that prolonged exposure (1-2 months) to decimeter and centimeter waves can create epileptoid readiness in the CNS, which is realized during sensory and electromagnetic provocation in the form of epileptoid bioelectric activity and sometimes in the form of convulsions is of interest.

In a study on the sensitivity of the CNS to SHF fields of different ranges and different power flux densities, it was established that the sensitivity is increased as the wavelength is increased from the centimeter to the meter range and as the power flux density is increased in all ranges. The curve of CNS sensitivity to an SHF field is close in form to the classical Weiss-Lapique curve for electrical stimulation [Gvozdikova et al., 1964a, 1964b]. We cannot now name the threshold intensity of an SHF field, although it is below  $0.02 \text{ mw/cm}^2$ .

We must mention that EEG investigations on the effect of an SHF field on the CNS have only begun, and we can shortly expect the appearance of many interesting works in this area.

### Conclusions

/100

1. The effect of a constant SHF field (wavelength, 12 cm) with power flux densities from 100 to 1,000  $\text{mw/cm}^2$  or a pulsed SHF field (wavelength, 52 cm) with power flux densities from 2 to 50  $\text{mw/cm}^2$  on the rabbit caused an increase in the number of slow high-amplitude and spindle-shaped oscillations of cortical biopotentials. Sometimes the SHF field caused the appearance of convulsive discharges in the cortex. The stability and the average latent period of the basic reaction depended on the power flux density of the field. As the power flux density was increased, the stability changed from 20 to 90%, and the average latent period changed from 70 to 25 sec. The reaction to a pulsed field transpired with a shorter latent period than the reaction to a constant SHF field.

The excitability of the cortical termination of the visual analyzor increased during exposure to an SHF field with a power flux density of 100-300 mw/cm<sup>2</sup> and decreased during exposure to an SHF field with a power flux density of about 1,000 mw/cm<sup>2</sup>, at which time the phase effect of the field appeared.

2. Besides the basic EEG reaction to an SHF field, we noted a reaction to turn-off (the off-effect) with a stability 13-20% and an average latent period of 15-20 sec. Furthermore, at the moment of turn-on (in 31% of the cases) and at the moment of turn-off (in 12% of the cases) of the generator, brief desynchronization occurred in the electrical brain activity, which reflected an orienting reaction of the animal to the stimulus.

3. The electrical reaction of the brain to an SHF field was improved after sectioning at the level of the midbrain. The electrical activity of a neuronally-isolated cortical strip changed during exposure more rapidly than the EEG of an intact brain.

4. Intramuscular injection of caffeine shortened the latent period of the EEG reaction to an SHF field, increased its stability and increased the number of cases when convulsive activity appeared under the influence of the field.

5. Like a UHF field, an SHF field caused electrical reactions in the rabbit brain that transpired with a long latent period and a prolonged aftereffect and that essentially occurred due to the direct effect of the field on the brain tissue.

CHAPTER 3. THE EFFECT OF A CONSTANT MAGNETIC FIELD ON THE  
ELECTRICAL ACTIVITY OF THE RABBIT BRAIN

/101

While we referred our study of effects of UHF and SHF fields on the electrical activity of the rabbit brain to the widely acknowledged existence of a biological effect due to electromagnetic oscillations in these ranges, when we go to an investigation on the effect of a constant magnetic field (CMF), we first of all discuss the question concerning the presence of a biological effect due to this physical factor. The fact is that many authoritative investigators deny the possibility of an effect of a magnetic field on biological processes. The following statements can be given as an illustration.

1901. "Life has not developed special organs to perceive magnetic stimulation because the magnetic effect does not exist as a stimulus for protoplasm" [Danilewsky].\*

1928. "We must admit that until now no bases for acknowledging the effect of a constant magnetic field have been obtained" [Rozenberg].\*\*

1936. "Not enough is currently known regarding the effect of pure magnetism. The organism does not have a sensitivity to magnetic fields" [Zeyfrits].\*\*

1948. "Magnetic fields are not perceived by an organism and, therefore, they cannot play the role of stimuli" [Nasonov].\*\*\*

1961. "Thus, to the question of whether a constant magnetic field affects living matter, we must presently answer no" [Blyumenfel'd].†

1964. "Evidently, there is no sensory or metabolic reaction to a magnetic field" [Akkerman].††

However, together with these statements, more and more experimental works have appeared that have proved the presence of a biological effect due to magnetic fields. We shall try to briefly and chronologically examine the course of the study on the effect of magnetic fields on biological objects.

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\*\*Cited by V. I. Karmilov: The history of the question regarding the biological and therapeutic effect of a magnetic field. In the collection: Biologicheskoye i lechebnoye deystviye magnitnogo polya i strogo-periodicheskoy vibratsii. (Biological and Therapeutic Effect of a Magnetic Field and Strictly Periodic Vibrations.) Perm, 1948, p. 9.

\*\*\*Nasonov, D. N.: O prirode vozbuздheniya. (On the Nature of Excitation.) Moscow, 1948, p. 4.

†Blyumenfel'd, L. A.: On the problem of biomagnetism. Nauka i zhizn' 7: 90, Moscow, 1961.

††Akkerman, Yu.: Biofizika. (Biophysics.) Izd-vo "Mir", Moscow, 1964, p. 554.

Before the XX century, many investigators had acknowledged the biological effect of a magnetic field. We have taken the most detailed information on this question from the book of N. I. Grigor'yev, "Metalloscopy and Metal Therapy," published in St. Peterburg in 1881.

In the XIX century, the study of the therapeutic effect of a magnetic field was conducted on a scientific basis and was not surrounded by the mysticism that distinguished similar investigations in preceding centuries.

Maggiorani (1869) concluded that "If tests are conducted on healthy people, on some a magnet will have its effect, and on others it will not. Hysteriacs, those with ataxia, and diabetics are most sensitive to a magnet. The phenomena caused by a magnet consist of a temperature rise, convulsions, tonic spasms, anesthesia and hyperesthesia."\*

A large series of works, which were begun by Charcot, were devoted to the effect of a magnetic field on hysteriacs. It was noted that a magnet: 1) causes itching, a creeping sensation, and twitching or pain at the exposure site [Müller, 1879; Drozdov, 1879]; 2) restores the destroyed sensitivity of the skin [Westphal, 1878; Gamgee, 1878]\* and of the retina [Charcot, Renard, 1878]\* or induces a "transfer" of anesthesia from the ill side of the body to the healthy side [Jacond, 1880; Deboe, 1880]\*; 3) destroys [Müller, 1879]\* or reduces paralysis, spasms and contractures [Vigouroux, 1878]\*; 4) relieves pains of diverse origin [Benedict, 1879\*; Drozdov, 1879] or causes an increase in pain [Botkin, 1879]; 5) causes general weakness, headache and somnolence [Landouzy, 1879\*; Sprimon, 1879; Elenburg, 1911].

It can be seen that a brief listing of the various therapeutic effects of a magnetic field indicates its predominant effect on the functions of the nervous system. This property has also been noted by such authoritative physicians as S. P. Botkin and J. M. Charcot.

However, the therapeutic properties of a magnetic field turned out to be less effective in comparison with the new electrotherapy methods (d'arsonvalization, diathermy, a UHF field, etc.).

In the XX century, we turn up only scattered reports on the therapeutic effect of a magnetic field; these works describe the favorable effect of a magnetic field on cancerous diseases [Spude, 1937; Barnothy, J., 1960; Ukolova, Khimich, 1960], on radiation sickness [Barnothy, M., 1963; Audo et al., 1960], for projected pain after amputation of the extremities, in clausalgia, nephritis/103 and eczema [Karmilov, 1948], for internal diseases [Seleznev, Bobrova, 1948a] and cardiovascular diseases [Nemanova, 1948]. In recent years, there have been reports of investigations on magnetism for hypertensive disorders by Romanian and Japanese doctors.

Unfortunately, the certain revival of interest concerning the therapeutic

\*Cited by N. I. Grigor'yev: Metalloskopiya i metalloterapiya. (Metalloscopy and Metal Therapy.) St. Peterburg, 1881.

effect of a magnetic field is not connected with any theoretical achievements in this region. Until now, the mechanism of the effect of a magnetic field on a biological object remains unclear, which explains the predominantly empirical direction of the works on the biological effect of a magnetic field.

In experiments on single cells, some investigators have noted a decrease in the intensity of movement, and a suppression of growth and multiplication [Cheneveau, Bohn, 1903; Grenet, 1903; Kimball, 1938; Buksa, 1950; Platunova, Korotkova, 1955; Gerencser et al., 1962], and others have noted no biological effect of a magnetic field [Luyet, 1935; Jennison, 1937].

In a series of works, P. F. Savostin (1928, 1937) showed that a magnetic field changes protoplasmic streaming in plant cells (similar results were noted by Ewart, 1903), increases the rate of root growth and cell membrane permeability. In tests on plants, it was observed that corn roots turned toward the south pole of the magnet as they grew [Krylov, Tarakanova, 1960], watercress roots were deflected toward the side with the least magnetic field strength [Audus, 1960], and the seeds of many plants grew faster in a magnetic field [Murphy, 1942], especially when they were oriented along the magnetic force lines [Pittman, 1962, 1963].

In a magnetic field, the harvest of apples was increased [Karmilov, 1948] and their ripening was accelerated [Boe, Salunkhe, 1963], photosynthesis in leaves was reduced [Tarchevskiy, 1964; Zabotin, Nazarova, 1964], and the orientation of volvox changed [Palmer, 1963].

In the majority of works on the effect of a magnetic field on plants, it has been stated that the observed effect is achieved through enzymatic processes.

In a culture of chick embryo heart tissue, placed in a magnetic field, atypical cells, sometimes multicellular and of giant dimensions [Lengyel, 1934], cellular migration in the direction of the electromagnet poles [Huzella, 1934], and sometimes only a weak tendency toward protoplasmic disintegration [Payne-Scott, Love, 1936] have been observed. Cultures of tumorous cells required less oxygen in a magnetic field [Reno, Nutini, 1963], and after 18 hours in the field, a large part of the cells had fully degenerated [Mulay and Mulay, 1961].

A culture of mouse embryo kidney tissue required 87% less oxygen in a magnetic field, although this effect was not revealed in tissue from adult mice /104 [Reno, Nutini, 1963].

In studies on the effect of a magnetic field on a frog neuromuscular preparation, some investigators have shown that this physical factor does not have a stimulating effect, although its chronaxy exhibits a two-phase change, initially increasing, and then decreasing, and parabiosis is removed [Petrov, 1930; Erdman, 1955]. Other investigators deny any effect of a magnetic field on a neuromuscular preparation [Liberman et al., 1959].

From approximately 1938, questions regarding the biological effect of a magnetic field were intensively formulated in the Perm Medical Institute. In vitro, it was noted that during the effect of a magnetic field: 1) according

to some authors [Kyuntsel' and Karmilov, 1947], the blood coagulation time increases, but according to others [Tishan'kin, 1948] this rate decreases; 2) the erythrocyte sedimentation rate slows down [Mogendovich, Sherstneva, 1947; Mogendovich, Sherstneva, 1948a; Mogendovich, Tishan'kin, 1948a, b]; 3) sinking of a drop of blood in a copper sulfate solution (the microgravitational effect) is accelerated [Mogendovich, Sherstneva, 1948b]; 4) leukocyte phagocytosis increases [Sherstneva, 1950].

In her dissertation, O. S. Sherstneva (1951) noted that a magnetic field affects the phagocytes of an intact organism primarily through the CNS. This explains the greater sensitivity of the entire organism to a magnetic field in comparison to isolated organs and tissues.

It has been noted that the lower invertebrates, such as the planaria and gastropods, can orient along an artificial magnetic field that exceeds the natural magnetic field of the earth by only several times. It has been noted that this orientation depends on the diurnal, lunar and solar cycles [Brown, 1962; Prosser, Brown, 1961; and others]. In a magnetic field, the reproduction of Daphne [Luczak, 1961] and Drosophila [Livengood, Shinke, 1962] is inhibited and the mortality rate of exposed Drosophila [Forssberg, 1940] increases. Orientation of flies and termites has been noted in both a natural and an artificial magnetic field [Becker, G., 1963a, b].

The possibility of an orienting effect of the earth's magnetic field has been studied particularly intensely on such migrating fauna as birds and fish.

In 1885, the Russian Academician A. T. Middendorf, while studying the periods of spring migration of certain Siberian birds, expressed the concept concerning the possible orientation of birds along the earth's magnetic field.

The American physicist Yeagley (1947, 1951), experimentally proved that pigeons orient with respect to the earth's magnetic field and the Coriolis force.<sup>/105</sup> He trained pigeons to return to their loft from remote distances. Then the pigeons were transported thousands of kilometers away to a place where the earth's magnetic field and Coriolis force were similar to what they were at the training ground. When they were released in this unfamiliar locality, the pigeons were able to find their loft.

The possibility of pigeons perceiving the earth's magnetic field was checked in experiments in which magnets were tied to the wings of test pigeons, and copper plates were tied to the wings of control pigeons. From an equal distance, the control pigeons returned to their loft sooner than the pigeons bearing magnets.

However, numerous repetitions of Yeagley's tests have not supported these results [Gordon, 1948; Van Riper, Kalmbach, 1952; Griffin, 1955; and others]. Attempts to develop a conditioned reflex to a magnetic field in pigeons were unsuccessful [Orgel, Smith, 1954, 1956; Neville, 1955; Kholodov, 1959]. However, in tests employing a maze, the weak effect of a magnetic field on the behavior of birds was noted [Neville, 1955], and in tests with the food-getting method (these tests were similar to those described below), there was an increase in the intersignal reactions and inhibition of the developed conditioned re-

flexes to light [Kholodov, 1959]. A magnetic field increased the motor activity of certain sparrows [El'darov and Kholodov, 1964]. These positive results force us to assume that the question of the effect of a magnetic field on the behavior of birds requires further experimental clarification.

Experiments involving the development of conditioned reflexes to a magnetic field in fish were more successful. Simultaneously and independently, Lissman (1958) did this on the Nile electric fish (*Mormirus*), and Kholodov (1958b) on carp. Furthermore, it was shown that a magnetic field can be a conditioned-inhibiting stimulus in tests on stickleback, and can inhibit developed conditioned reflexes to light and sound in bullhead and flounder [Kholodov, Verevkina, 1962]. The sensitivity of stickleback to a constant electrical current was reduced by 45% [Kholodov, Akhmedov, 1962] and their motor activity was increased [Kholodov, 1959] during the influence of a magnetic field.

Thus, the hypothesis concerning the ecological significance of the earth's magnetic field has directed investigators to study the behavior of animals under the influence of this physical factor, and the important role of the CNS has become clearer here than in investigations on radio-frequency EMF.

We have begun our description of the effect of UHF and SHF fields on the CNS with the results of observations of people who work under conditions of /106 prolonged exposure to these factors.

In people subjected to the prolonged effect of magnetic fields (hands in a 350-3,500-Oe field, but head in a field less than 150-250 Oe) for 20-60% of their working time, deviations were most frequently noted in the nervous system [Vyalov et al., 1964]. These deviations were characterized by headaches, pains in the heart region, fatigability, a reduced and unstable appetite, insomnia, increased sweating, and sensations of itching and burning on the hands.

When the EEGs of these people were investigated, a tendency was noted toward predominance of the process of cerebral inhibition. Slow waves and spindles of  $\alpha$ -rhythm were noted during rest and during the light test.

Otoneurological investigations most frequently indicated the central origin of suppression of this apparatus (paravestibular destruction). A tendency toward bradycardia was noted during an investigation of the cardiovascular system. The authors assume that magnetic fields most frequently cause the first stage of parabiosis according to W. Ye. Wwendensky (a change in lability) in the autonomic nervous system. Although it is concluded that the observed changes do not exceed the physiological limits of change, one can see that the tendency toward change of the organism's functional state is the same as during the influence of physiologically stronger stimuli, such as UHF and SHF fields.

We should remember that the magnetic field also has a sensory effect on the visual analyser. D'Arsonval (1893) first showed that the phenomenon of phosphene occurs in man during the influence of a variable magnetic field. This fact was later noticed in many works [Danilewsky, 1905; Thompson, 1910; Mognisson, Steven, 1911; Barlow et al., 1946; Mogendovich, Skachedub, 1957; and others]. Phosphene can be produced during a constant magnetic field or in its absence, and also during the influence of a variable magnetic field with a frequency of 10-100 Hz.

It is considered that the sensation of phosphene is a result of retinal stimulation [Mogendovich, 1956; Mogendovich, Skachedub, 1957].

It was assumed that the phenomenon of phosphene occurs only due to an induced electromotive force; however, in the work of N. A. Solov'yev (1963), it was shown that the magnitude of phosphene depends on the exposure duration to the magnetic field.

Besides phosphene, other changes were noted in the activity of the visual analyser under the influence of a magnetic field. In a variable magnetic field, the stability of clear vision was reduced in man [Mogendovich and Skachedub, 1957]. A constant magnetic field applied to the occiput of the subject changed the visual images that were suggested in hypnosis (Féré, 1885; Binet, Féré, /107 1887; Vasil'yev, 1921] and reinforced the visual hallucinations caused by mescaline intoxication [Perikhanyants, Terent'yev, 1947].

Although the important role of the nervous system in the reactions of vertebrates to a magnetic field is emphasized in many works, the changes which occur are not limited to just this system.

During total-body exposure to a magnetic field, the Perm investigators have noted an increase in the number of leukocytes and a lowering of the resistance of erythrocytes in guinea pigs [Karmilov, 1948], a 10% increase in the body weight of mice in comparison with controls [Karmilov, 1948] and a reduction in their oxygen requirement [Tishan'kin, 1950]. An increase in the acidity of the gastric juice [Seleznev, Bobrova, 1948b] and an increase in peristalsis of the large intestine [Suvorova, 1948] have been noted in people under the influence of a magnetic field.

Investigations of the osmotic processes in muscle [Bekker, Mogendovich, 1948] and the permeability of skeletal muscle by means of staining [Skachedub, 1948] showed that a magnetic field increases the permeability. However, other investigators [Troshina, 1951] do not support these results.

When guinea pigs were placed in a 700-Oe field 6 times for 30 min each, there was dilation of the vessels with subsequent hyperemia and hemorrhage, especially in the lungs, liver and CNS [Karmilov, 1948].

The effect of a constant 2,000-5,000-Oe magnetic field on mice has been studied most systematically by the American investigators, M. F. Barnothy and J. M. Barnothy, in 1954-1958 [Barnothy, 1960]. It was shown that pregnant females placed in a 2,500-Oe field gave birth to healthy offspring, but the young were approximately 20% smaller than those born previously of the same mothers. When a 3,100-Oe field acted on the pregnant females, the newborn lived only several days, and under a 4,200-Oe field the embryos were resorbed in the uterus. Young that were placed in a field at 3-4 weeks of age grew more slowly than control animals, and the males grew slower than the females. A strong field (5,000 Oe) greatly delayed growth. The magnetic field had practically no effect on the weight of adult mice.

If mice were placed in a field before they attained full growth, they could adapt to and develop in the magnetic field, but adult, 7-week-old males died af-

ter 10 days in a field. However, not one female died during these experiments.

In the males that died in the field, the weight of the liver was 50% lower than in the control animals, although the weight of the lungs, heart, kidneys and testicles did not change. In mice that had been subjected to a 4,200-Oe field for 5 weeks, and killed 3 months after the end of the experiments, neo- /108 blasts were found in the spleen.

The rectal temperature of mice was lowered 0.8°C in a magnetic field. This lowering of temperature was still retained months after exposure had ended. Following an exposure to a field, the motor activity of mice was increased by 50%. Animals that had been subjected to a field ate approximately 14% less food than the controls, and if we calculate the metabolic efficiency (food/motor activity), in the test animals it was 60% higher.

The fur of adult animals that had been in a magnetic field from youth was fully retained, while in control animals of the same age (1 year) full balding of the abdomen had occurred.

The menstrual cycle of females subjected to a field was disturbed, but it was immediately restored after the influence ceased. Impregnation was not observed when males and females were placed together in a 3,000-Oe field, but it could occur if one of the partners was not in the field.

The RBC did not change in the field, but the WBC was reduced by 30-40%. After the influence ceased, the WBC increased to 100% of the initial level, in the next two weeks it was somewhat below the initial level, and after months it had returned to normal. The number of lymphocytes increased only following the field influence.

The changes observed in the blood composition allow us to use a magnetic field as a means of preventing the development of radiation sickness, during which the WBC is sharply reduced. While the effect of radiation led to a 30% death rate, a preliminary stay in a magnetic field completely eliminated the lethal effect. If, however, radiation caused death in 80%, the death rate was not reduced, but mice that had stayed in a magnetic field died later than the controls.

After inoculation with breast tumor, mice that had stayed in a magnetic field lived  $43 \pm 9\%$  longer than the controls, but the weight of the tumor was 250% higher than in the control period. Autopsy revealed that the magnetic field prevents metastasis, but does not obstruct the growth of a primary tumor.

The effect of a magnetic field on development, blood picture or tumors was not observed by one author [Eiselein, et al., 1961]. However, works that support the Barnothy conclusions are more numerous. A decrease in the weight (7-9%) and the WBC in guinea pigs following a 24-hour exposure to a 200-Oe field with a frequency of 50 Hz has been noted by investigators from the Tomsk Medical Institute [Kurlov et al., 1963]. During similar exposures, other investigators from the same institute [Gorshenina, 1963] observed that the "shock organs," i.e., the organs in which the sharpest morphological changes are observed, are the spleen, testicles, and also the CNS. /109

Determining the absorption of oxygen by kidney tissue, Reno and Nutini (1963) noted a greater susceptibility to damage in embryonal tissue during the influence of a magnetic field. An increase in motor activity in a magnetic field was noted by T. I. Gorshenina in guinea pigs, and also by Yu. A. Kholodov (1959) in fish and birds.

Thus, we can see with each passing year, the number of reports indicating the existence of a biological effect of a magnetic field has increased.

The largest group of investigators working on this problem in our country is concentrated in the Tomsk Medical Institute. Since 1959, under the leadership of Corresponding Member of the USSR Academy of Medical Sciences I. V. Toroptsev, they have studied the morphological changes occurring in animals in a magnetic field. After 500 hours (at night, 12-hour sessions) in a constant 7,000-Oe field, necrotic processes connected with metabolic disturbances occurred in guinea pigs. The testicles were damaged most, then the spleen and, finally, the lungs. Disturbances in the hemodynamics and lymphodynamics were revealed with sufficient clarity [Toroptsev, Garganeyev, 1964b]. A variable (50-Hz) magnetic field with a strength of 200 Oe has a similar biological effect [Toroptsev, Garganeyev, 1964a]; during a single 7-hour exposure, this field not only caused morphological changes in the lungs (hemorrhage, edema), but it also disturbed the chemical composition of the stroma [Gorshenina, 1964].

Morphological changes in the spinal cord and skeletal musculature of mice under the effect of a magnetic field were particularly clearly revealed during functional loading in the form of swimming for 15 min [Rassadin, 1964]. A single 6-hour exposure to a field did not bring about visible qualitative changes in the morphological and histochemical aspects of immunogenesis [Vasil'yev et al., 1964], but multiple 6-hour exposures for 15 days lowered the natural resistance of white mice to Listeria [Odintsov, 1964]. N. V. Vasil'yev (1964) showed that a variable or a constant magnetic field affects immunogenesis, intensifying it in some cases (the formation of hemagglutinin) and suppressing it in others (the development of antiviral immunity).

The development of magnetobiology (or biomagnetism) can be illustrated by the increase in the number of scientific conferences where questions on the biological effect of magnetic fields are discussed. The First International /110 Symposium on Biomagnetism was held in 1961 in Chicago [Barnothy, 1962]; 8 reports were presented and discussed. The second such symposium was held in 1963, and 17 reports were presented. The material from this symposium is reflected in the collection, "Biological Effects of Magnetic Fields", edited by M. F. Barnothy, which was published in 1964. This book significantly supplements the reports concerning the biological effect of magnetic fields found in the Russian collection, "The Biological and Therapeutic Effect of a Magnetic Field and Strictly Periodic Vibrations", which was published in 1948. In October, 1963, at the Institute of Labor Hygiene and Occupational Diseases of the USSR Academy of Medical Sciences (Moscow), the first Soviet symposium on the biological effect of a constant magnetic field and static electricity was held. In 1964, there was a scientific conference of the Tomsk Medical Institute, which included a section entitled "The Effect of Magnetic Fields on an Organism"; 14 reports were presented. The second such conference was held in June, 1965. The Third International Symposium on Biomagnetism was held in March, 1966, in Chicago (USA).

A bibliography of works on the biological effect of magnetic fields [Davis et al., 1962], which reflects the interest of many scientific workers in the evolution of this problem, has been published in the U.S.

A survey of the achievements of magnetobiology testifies to the complexity of the problem and to the significant successes in the area of proving the existence of the biological effect of a magnetic field.

The effect of a magnetic field on electrical brain activity has been studied by us [Kholodov, 1963a, b; Kholodov, Luk'yanova, 1964] and by Romanian investigators [Dinculescu et al., 1963], who revealed an increase in the Δ-rhythm in man during the influence of a weak constant magnetic field. The American biologist, R. Becker (1963), reported on the appearance of slow high-amplitude oscillations in the electrical brain activity of a salamander during the influence of a constant magnetic field with a strength of several thousand Oe.

#### The Effect of a Constant Magnetic Field on the Rabbit EEG

Before we speak about the presence or absence of an electrical reaction in the rabbit brain to a CMF, we should find out what indices must be evaluated to reflect such an effect. The study of the rabbit EEG reaction to UHF and SHF fields has shown that changes are most frequently manifested as an increase in the number of spindles and slow waves. However, we have not conducted a detailed analysis of the other EEG changes under the effect of these EMF.

Since the biological effect of a CMF is considered to be weaker, we conducted a stricter treatment of the EEG in experiments involving this physical factor. Besides spindles (or EEG changes resembling spindles) and slow waves (biopotential oscillations with a frequency less than 4 Hz and an amplitude at least twice the background amplitude), S. N. Luk'yanova, in experiments on 13 rabbits, also considered the dynamics of cycles, sharp waves and sections of the recording of electrical activity with reduced amplitude or with increased amplitude without frequency changes and with desynchronization, i.e., decrease in amplitude and increase in frequency of the potentials in the background and during a 1-minute exposure to a CMF. /111

The data were statistically treated by the previously given method, and the results of evaluating the difference (in the corresponding indices of electrical activity in certain brain sections) between the 1-minute recording of the background and during exposure to 400-Oe CMF are given in Table 13. The table gives the total result of 1,270 exposures on 13 normal rabbits, utilizing the Student criterion. Values of this criterion that exceeded 1.9 (underlined in the table) were considered reliable ( $p < 0.05$ ). During the influence of the CMF, a number of characteristics of the electrical activity frequently increased. The numbers noted with asterisks testify to a decrease in the corresponding changes of electrical activity under the influence of a CMF. A dash indicates that changes were not observed in the given lead. /11

The tabular data show that the most frequent and reliable result of exposure to a CMF is an increase in the number of spindles, slow waves and sometimes sharp waves. The other indices of electrical brain activity did not reveal significant changes during the influence of a CMF. /11

TABLE 13. THE VALUE OF THE STUDENT CRITERION DURING A COMPARISON OF A NUMBER OF DIFFERENT INDICES OF ELECTRICAL ACTIVITY IN CERTAIN SECTIONS OF THE RABBIT BRAIN, FOR 1-MINUTE RECORDINGS OF THE BACKGROUND, AND EXPOSURE TO A CMF ON THE ANIMAL'S HEAD.

Character of the EEG change	Hypothalamus	Sensorimo-tor cortex	Parietal cortex	Specific cortex	Nonspecific thalamus	Hippocampus	Reticular forma-tion of the midbrain
spindles . . . . .	<u>9.3</u>	6.8	<u>6.3</u>	<u>5.0</u>	<u>4.9</u>	1.3	<u>3.4</u>
slow waves . . . . .	<u>2.9</u>	0.03	<u>2.7</u>	1.3*	<u>2.2</u>	<u>6.0</u>	0.6
sharp waves . . . . .	<u>3.7</u>	0.9	0.1	1.2*	1.7	1.2*	<u>2.2</u>
peaks . . . . .	0.5	0.5	0.8	1.0	-	0.7	-
increased amplitude .	1.0	1.6*	0.3	1.7	0.5	1.2	0.8*
decreased amplitude .	1.8	1.3	0.1	0.8	0.2	1.6	0.5
desynchronization . .	0.1	0.5	0.06*	0.5	0	0.5	0.5

Note: the underlined numbers in the table are explained in the text.

Thus, as during the influence of UHF and SHF fields on the rabbit head, a CMF affects electrical brain activity, increasing the number of spindles and slow waves. In the further analysis of the rabbit EEG reaction to a CMF, we shall be limited to a consideration of only these indices.

The table also shows that the most intensive reaction is observed in the hypothalamus. However, we consider it more expedient to discuss below the question concerning the participation of different sections of the brain in the reaction to a CMF. At this stage of the analysis, it is sufficient to know that the EEG of the sensorimotor and visual regions of the rabbit cortex change under the influence of an 800-1,000-Oe CMF, and that from the results for 100 exposures on 12 rabbits, this change is manifested as an increase in the number of spindles (30% of the cases) and slow waves (19% of the cases), and sometimes (4% of the cases) in the appearance of sharp waves (Figure 36).

After establishing the character of the rabbit EEG reaction to a CMF, it was rather easy to determine the dynamics of the EEG changes that made up the reaction, the reaction stability and the latent period, and also to analyze the aftereffect, i.e., to repeat the analysis that we used during the influence of UHF and SHF fields on the rabbit head.

Figure 37 gives the results of counting the number of changes, i.e., the number of spindles and slow waves, for each 10 seconds of the EEG recording. This graph is composed from the results of 100 3-minute exposures to a 1,000-Oe CMF on 12 rabbits. Although we saw sharp, at least 30 second long, changes in the EEG with a definite latent period in only 53% of the cases (stability), adding up of all the influences shows that when the electromagnet is turned on,

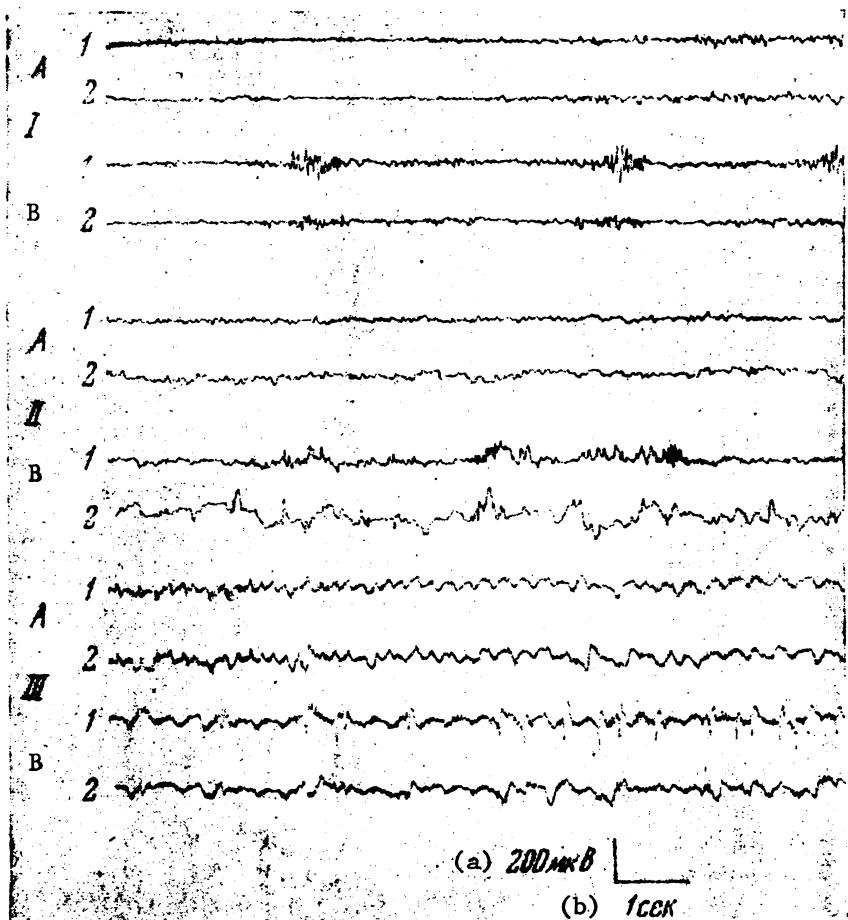


Figure 36. Forms of the EEG Changes During the Influence of a CMF on an Intact Rabbit. I = Increased Number of Spindles; II = Increased Number of Slow Waves; III = Increased Number of Sharp Waves; A = Before Exposure; B = During Exposure; 1 = EEG of the Sensorimotor Cortex; 2 = EEG of the Visual Cortex. Key: (a) 200  $\mu$ v; (b) 1 Sec.

we observe a significant (by a factor of 2) and statistically reliable ( $p < 0.001$ ) increase in the number of changes. We must call attention to the fact that in the background recording the number of changes was approximately identical in each 10-second interval. The significant rise in the curve begins at the 15th second of exposure, but, having achieved a maximum at the 45th second, the number of spindles and slow waves begins to decrease, regardless of the continuing influence of the magnetic field.

It is interesting that immediately after the electromagnet is turned off, the number of changes decreases. At the moment the electromagnet is turned off, as when it is turned on, we sometimes observe a brief desynchronization reaction in the EEG. However, 15-25 seconds after turn-off there is a statistically re-

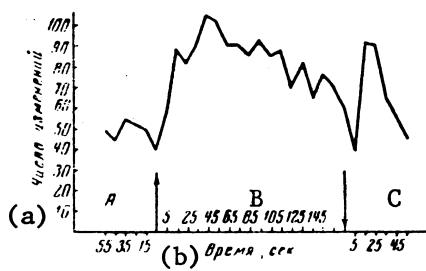


Figure 37. Dynamics of Slow Waves and Spindles in the Electrical Brain Activity of a Normal Rabbit, in the Background and During Exposure to a 1,000-Oe CMF. A = Before Exposure; B = During Exposure; C = During the Aftereffect.  
Key: (a) Number of Changes;  
(b) Time, Sec.

of the assimilation reaction to light flashes of increasing brightness was  $18 \pm 0.4$  sec in the background,  $20.4 \pm 0.4$  sec under the influence of a 200-Oe magnetic field, and  $20.0 \pm 0.5$  sec 30 seconds after the electromagnet was turned off. The difference between these figures, as evaluated employing the Student criterion, is statistically reliable ( $p < 0.001$ ). Consequently, a magnetic field causes a reduction in excitability of the cortical terminations of the visual analyser and this effect continues for some time after the electromagnet is turned off.

We obtained similar results during the influence of a strong SHF field, in which case this effect could be explained by heating. The present experiments testify to the possibility of an inhibiting effect of EMF without heating.

In determining the latent period of the reaction, we usually counted only the stable EEG changes, i.e., the changes that lasted at least 30 seconds. Such changes occurred in 53% of the cases, which characterizes the reaction stability. However, in comparing the distribution of the latent periods of stable and unstable (changes lasting less than 30 sec) reactions, we found that the curves repeat themselves. This fact points out that the formal separation of stable changes does not fully characterize the EEG reaction to a CMF. Nevertheless, since we distinguished only the prolonged EEG changes as reactions during exposure to UHF and SHF fields, we will most frequently consider only the stable reactions in the future. /116

We see that the latent period distribution curve of the EEG reactions to a CMF has three peaks (see Figure 39). The first peak occurs at the 25th second of the influence, the second, at the 55th second, and the third, at the 115th second. The presence of several peaks testifies to the periodicity of the reaction or to the participation of several mechanisms in its effectuation. The small size of the third peak allows us to disregard it in subsequent investiga-

tion ( $p < 0.001$ ) increase in the number of spindles and slow waves, which almost approximates the basic reaction in intensity, but lags behind it in duration. This reaction to turn-off (Figure 38) sometimes occurs in the absence of the basic reaction.

The above results of statistical treatment allow us to assert with a high degree of reliability that a CMF of the applied strength has an effect on the functional state of the CNS; it increases the number of spindles and slow high-amplitude oscillations. Some physiologists connect these changes in the EEG with the appearance of inhibition. We decided to determine the directivity of the nervous process that occurs under the influence of a magnetic field by using M. N. Livanov's method of reactance curves.

We recorded the reactance curve 90 times from 3 rabbits. The time for the appearance of the assimilation reaction to light flashes of increasing brightness was  $18 \pm 0.4$  sec in the background,  $20.4 \pm 0.4$  sec under the influence of a 200-Oe magnetic field, and  $20.0 \pm 0.5$  sec 30 seconds after the electromagnet was turned off. The difference between these figures, as evaluated employing the Student criterion, is statistically reliable ( $p < 0.001$ ). Consequently, a magnetic field causes a reduction in excitability of the cortical terminations of the visual analyser and this effect continues for some time after the electromagnet is turned off.



Figure 38. The EEG Reactions Which Occur When the Electromagnet is Turned Off. A, B = Different Rabbits; 1, 3 = EEG of the Sensorimotor Cortex; 2, 4 = EEG of the Right and Left Visual Cortex. The Arrows Designate the Moments the Electromagnet is Turned Off. Key: (a) 200  $\mu$ v; (b) 1 Sec.

greater at turn-off than at turn-on. Experiments involving a slower turn-on and turn-off of the electromagnet by means of a rheostat led us to the same conclusion. In this case, it is significant that reactions during turn-on and turn-off are encountered more rarely. In a series of tests conducted by R. A. Chizhenkova, in which an electromagnet was turned on for 2-3 sec, only the desynchronization reaction was observed.

These experimental results show that the induced electromotive force which occurs when an electromagnet is turned on and off does not play a significant

tions when the time of exposure to the CMF was shortened to 1 min. The EEG reaction to a CMF has a long latent period, measured in seconds, and in this respect it is similar to the EEG reaction during the influence of UHF and SHF fields.

While the effects obtained under the influence of UHF and SHF fields can be explained to some degree by heating, the effects obtained under the influence of a CMF could be explained by simple induction of an electrical current. If an electromotive induction force plays the main role in the EEG reactions under the influence of a CMF, then we should see the greatest change on the EEG at the moment the electromagnet is turned on or off, when the induced electromotive force has its greatest magnitude; in actuality, however, at the moments /117 the electromagnet is turned on and off we sometimes observed only an unprolonged (2-10 sec) desynchronization reaction (Figure 40). For 175 exposures in 15 rabbits, the stability of the desynchronization at turn-on is calculated as 14%, and the stability of the same reaction at turn-off, 24%. The more frequent reactions at turn-off (in comparison with those at turn-on) can testify that these desynchronization reactions are caused by the induced electromotive force, which is

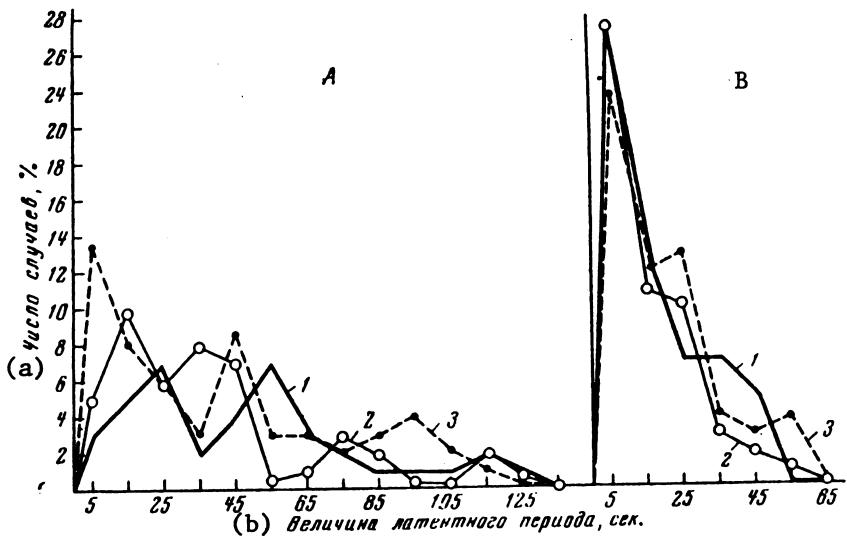


Figure 39. Latent Period Distribution Curves of the Basic Electrical Reactions (A) and the Reactions to Turn-Off (B) of a CMF and an Intact Brain (1), in an Isolated Brain Preparation (2) and in a Neuronally-Isolated Cortical Strip (3). Key: (a) Number of Cases, %; (b) Length of the Latent Period, Sec.

role in generating the basic EEG reaction to a CMF. The basic reaction occurs more frequently, has a longer latent period and a different electrographic manifestation than the EEG reaction that occurs at turn-on and turn-off.

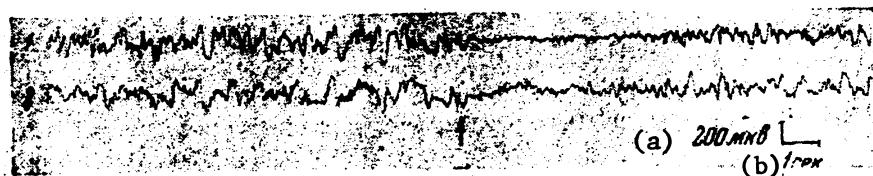


Figure 40. Changes in Cortical Biopotentials Occurring at the Moment the Electromagnet is Turned On. 1 = Sensorimotor Region; 2 = Visual Region; the Arrow Indicates the Moment the Electromagnet is Turned On. Key: (a) 200  $\mu$ v; (b) 1 Sec.

The possibility that the effect of a CMF is effected by the mechanism of an electromotive force induced in the moving elements of the organism is not precluded. The effect of a CMF on the blood flowing through the vessels is especially probable. In the case of the effect of a CMF on the hind legs of a rabbit, we did not observe changes in the EEG, while the effect of a weaker CMF on the head of the same animal caused the usual EEG reaction. Of course, these experiments do not answer the question concerning the participation of an induced

electromotive force in the observed reactions to a CMF, but they definitely testify to the high sensitivity of the rabbit head to a CMF in comparison with other sections of its body.

Finishing our analysis of the EEG reactions occurring at turn-on and turn-/118 off, we must note that the observed phenomena can possibly occur with no connection to the physiological process of an induced electromotive force, but are an expression of a negative physiological reaction that occurs at the beginning and after the end of the influence of many stimuli [Sokolov, 1958]. However, a final judgment regarding the mechanism of the described reactions will become possible after additional experimental material has been accumulated.

We have already spoken of the reaction to turn-off when we discussed the EEG reaction to UHF and SHF fields, and also when we described the dynamics of the EEG changes under the influence of a CMF. This reaction was electrographically similar to the basic reaction, i.e., it was manifested as an increase in the number of spindles and slow waves. In the distribution of the latent periods of the reaction to turn-off, the mode appeared at 15 sec (see Figure 39, B). Thus, the reaction to turn-off has a shorter latent period than the basic reaction.

We should note that in evaluating the reactions to turn-off, we basically considered unstable changes, i.e., EEG changes that lasted less than 30 sec. Therefore, in comparing the stability of the basic reaction and the reaction to turn-off, we should consider all changes in both cases. While the stability of the basic reaction in such an evaluation reached 95%, the stability of the reaction to turn-off attained 58%, i.e., it was 2/3rds as stable as the basic reaction.

Thus, the reaction to turn-off is an independent reaction. It cannot be considered a form of the reaction that occurs at some stage after the electromagnet is turned on regardless of whether we turn it off or not. The reaction to turn-off occurs with a similar latent period after exposures of 30 sec, 1 min, 3 min and 15 min to a CMF. Since it is not observed after an exposure that lasts 2-3 sec or 30 min, it depends on the duration of the CMF exposure. In our experiments, the stopping of the exposure is the determinant for this reaction.

On the other hand, the reaction to turn-off is not connected with an induced electromotive force since: 1) this reaction has a long latent period; 2) it is retained during slow switching-on of the electromagnet by means of a rheostat; 3) it is absent following exposure to a CMF that lasts 2-3 sec. It is probable that some slow processes connected with the CMF exposure also slowly normalize after the exposure has ended, and this fact finds expression in the reaction to turn-off. The presence of this reaction proves the existence of a biological effect due to a CMF, and indicates that it is difficult to identify this effect with the effect of an electrical current.

#### The Effect of a CMF on the EEG of an Isolated Brain

/119

To clarify the mechanism of the effect of a CMF, we conducted a series of tests on an isolated rabbit brain preparation obtained after sectioning at the

level of the midbrain. Since the EEG reactions to a CMF in a brain preparation did not change after additional bilateral sectioning of the olfactory and optic nerves, we combined all the results obtained after sectioning at the midbrain and after additional deafferentation into one group.

Sectioning was conducted on 11 rabbits, which were then exposed 209 times to a CMF.

The character of the EEG reactions to a CMF after sectioning consisted of an increase in the number of spindles and slow waves (40% of the cases). Sometimes convulsive discharges occurred during the influence (12%), or we observed the disappearance of these discharges (9%) if they existed in the background (Figure 41).

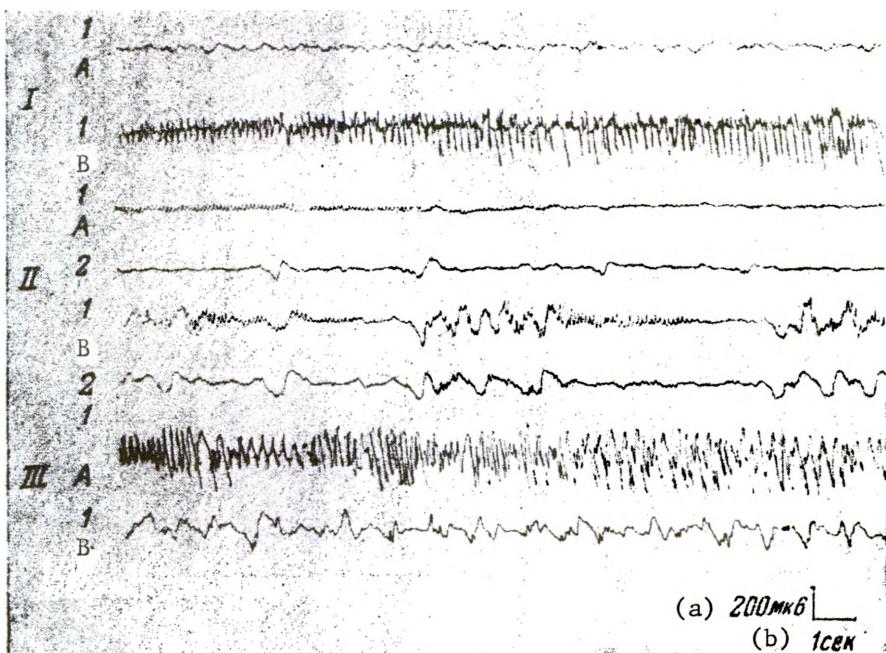


Figure 41. Forms of the EEG Changes During the Influence of a CMF on an Isolated Rabbit Brain Preparation. I = Increased Number of Sharp Waves; II = Increased Number of Slow Waves and Spindles; III = Increased Number of Sharp Waves; A = Before Exposure; B = During Exposure; 1 = EEG of the Sensorimotor Cortex; 2 = EEG of the Visual Cortex. Key: (a) 200  $\mu$ v; (b) 1 Sec.

Here the reaction stability is evaluated from the stable EEG changes. After sectioning, we observed a tendency towards an increase in the stability of stable reactions to a CMF from  $52 \pm 5\%$  to  $61 \pm 5\%$ , which, however, is not a statistically reliable increase. The stability of unstable reactions did not change after sectioning, remaining equal to 95%.

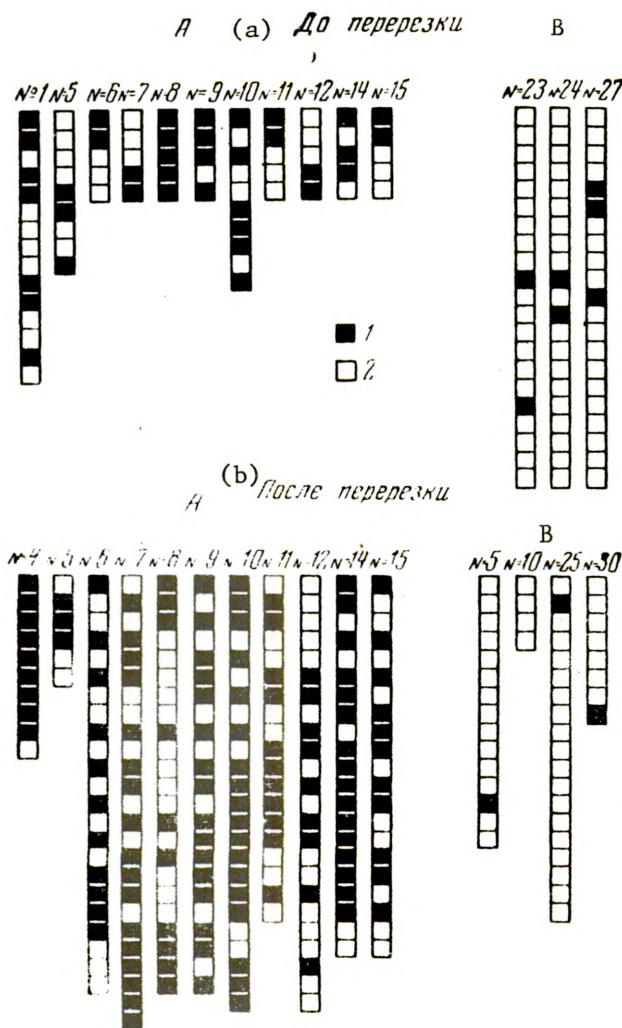


Figure 42. Dynamics of the Appearance of EEG Reactions in Rabbits During the Influence of a CMF Before and After Sectioning at the Midbrain. In the Control Experiments, We Administered "False" Exposures. A = Test Animals; B = Control Animals; the Numbers Indicate the Number of the Rabbit; 1 = Presence of the Reaction; 2 = Absence of the Reaction. Key: (a) Before Sectioning; (b) After Sectioning.

peaks in the latent period distribution curve of the EEG reactions to a CMF, which can testify to the phase character of the reaction.

It is interesting to note that the reaction to turn-off in the isolated

The number of stable reactions to a CMF and similar changes in the rabbit EEG during "false" exposures for a normal and an isolated brain is shown in Figure 42. Each column on the figure includes the number of exposures for one rabbit. A crosshatched square designates the presence of a reaction, and a blank square, its absence. Except for rabbits no. 1 and 4, we investigated the reaction to a magnetic field in the normal brain and after sectioning at the midbrain in the same rabbits. As a comparison shows, EEG changes similar to the reaction were encountered in the controls 5 times less often than in the test with normal rabbits, and 10 times less often than in an isolated brain preparation. Thus, the isolated brain reacted more frequently to a CMF than a normal brain.

Comparing the different columns, we could not observe the process of adaptation or summation in the normal brain. In the isolated brain we observed a tendency toward an increase in the stability of the reaction to a CMF as the time after sectioning increases. This fact indicates the definite value of deafferentation for improving the reaction to a CMF in comparison with surgery.

The improvement of the EEG reaction to a CMF in an isolated brain was also expressed in a shortening of its latent period. While in a normal rabbit, the mode in the latent period distribution occurs at 25 sec, in the isolated brain it shifts to 15 sec (see Figure 39, A). However, in the normal and isolated brain, we observe 2 basic/120

brain was the same in stability and latent period as the same reaction in an intact brain (see Figure 39, B). This fact forces us to assume the presence of different mechanisms for effectuation of the basic EEG reaction to a CMF and the reaction to turn-off. Upon isolation of the brain, the mechanism of the basic reaction changes somehow, but the mechanism of the reaction to turn-off remains the same.

Thus, the structures of the diencephalon and telencephalon, deprived of nervous connection with all receptors, react to a CMF sooner, more sharply and more frequently than a normal brain. The question arose as to whether any section of the brain will react to a CMF in an equal degree, or whether there are sections of the brain more reactive to this stimulus. To answer this question, we conducted experiments involving the exposure of a neuronally-isolated strip /122 of the rabbit cortex to a CMF and simultaneous recording of electrical activity from several sections of the brain during the influence of a CMF.

#### The Effect of a CMF on the Electrical Activity of a Neuronally-Isolated Strip of the Cerebral Cortex

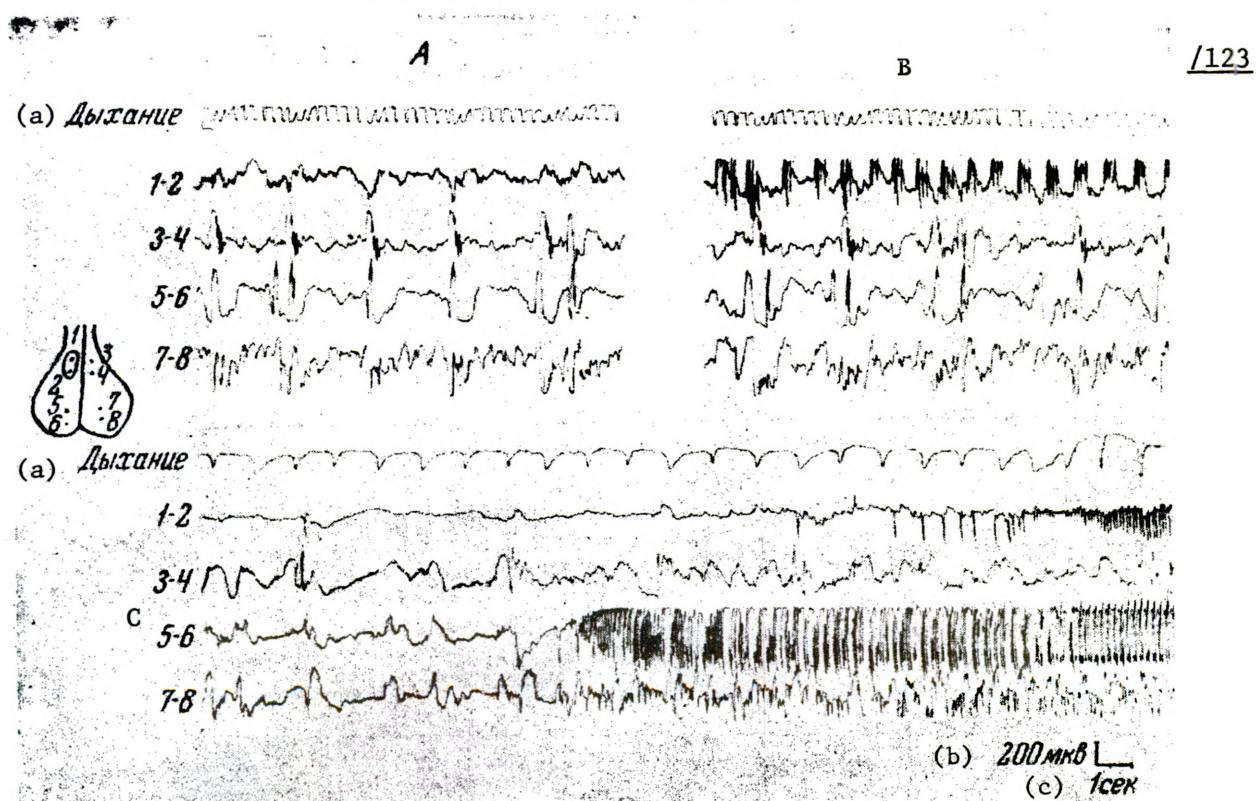


Figure 43. Electrical Reaction to a CMF in a Neuronally-Isolated Cortical Strip and Adjacent Sections of an Intact Brain. A = Before Exposure; B, C = During Exposure. The Numbers Designate Electrocorticogram Leads (See the Diagram). Key: (a) Respiration; (b) 200  $\mu$ v; (c) 1 Sec.

The method of isolating the strip was described previously. In all, 7 rabbits were given 157 1-to-3-minute exposures to a 200-Oe CMF. As is evident from Figure 43, under the influence of a CMF, convulsive discharges sometimes appeared in the strip later than in the other sections of the cortex, and sometimes the reaction occurred only in the strip. There were cases when the electrical activity of the strip did not change during exposure to the CMF. The reaction stability was 46%. The distribution of the latent periods of the reaction in the strip to a CMF (Figure 39, A) shows that the electrical reaction in the strip occurs sooner than the EEG reaction of an intact brain.

The reaction to turn-off was observed in 53% of the cases; 12% of the cases exhibited only the reaction to turn-off. The mode of the latent period distribution of this reaction occurred at 5 sec. As is evident from Figure 39, in both the degree of stability and in the curve of the latent period distribution, the reaction to turn-off in the normal brain, the isolated brain and the cortical strip surprisingly coincided, although each total includes results from different rabbits; the data on the strip were obtained at a lower field strength. We should also remember that in the experiments on the strip, the EEG reaction was expressed most frequently in the appearance of convulsive discharges. Consequently, a change in the state of the cortex (isolation of the brain or a strip) affects only the form of the electrographic expression of the turn-off reaction, without changing its stability or latent period.

The above discussion on the form of the electrographic reaction can also pertain to the basic reaction, but its latent period and stability are more labile than the turn-off reaction. The latent period of the reactions in the strip and in the isolated brain preparation was shorter than in an intact brain, although the differences in the degree of stability were insignificant.

We should note that the operation of isolating a strip also affected the EEG reactions of the intact hemisphere under the influence of a CMF. At first, convulsive discharges also began to appear there.

Finishing the analysis of this series of experiments, we must note that the neuronally-isolated cortical strip changes its electrical activity during exposure to a CMF. However, we cannot decide whether the observed changes in electrical activity are a direct reaction of the cortical elements or whether they are caused by humoral effects from various subcortical levels. Experiments involving the simultaneous recording of electrical activity from several sections of the brain can answer this question.

#### The Electrical Reaction of Different Sections of the Rabbit Brain to a CMF

We have previously described the experimental method, the site where the electrodes were embedded, and the form of the electrical reaction during a one-minute exposure to a CMF. Therefore, we shall immediately go to the latent period and the reaction stability, as characterized by the number of spindle-shaped oscillations in cortical potentials. For our recording conditions (recording speed, 15 mm/sec), the electrical reaction to a CMF almost always occurred in all sections simultaneously (Figure 44). For 1,584 exposures involving 13 rab-

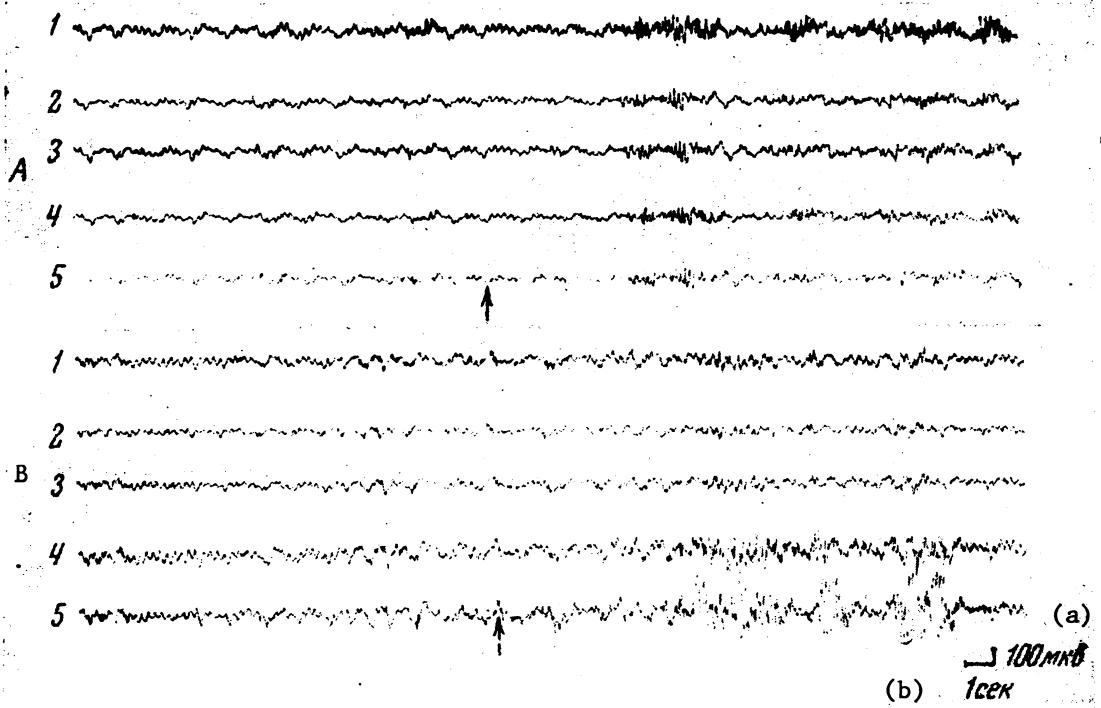


Figure 44. Electrical reaction in the Cortex and Subcortical Formations of the Rabbit Brain During the Influence of a CMF. The Arrows Designate the Moments the Electromagnet is Turned On; A, B = Different Rabbits; 1 = EEG of the Frontal Region of the Cortex; 2 = EEG of the Occipital Region of the Cortex; Electrograms of the Subcortical Formations; 3 = Nonspecific Thalamus Formations; 4 = Hypothalamus; 5 = Reticular Formation of the Midbrain. Key: (a) 100  $\mu$ v; (b) 1 Sec.

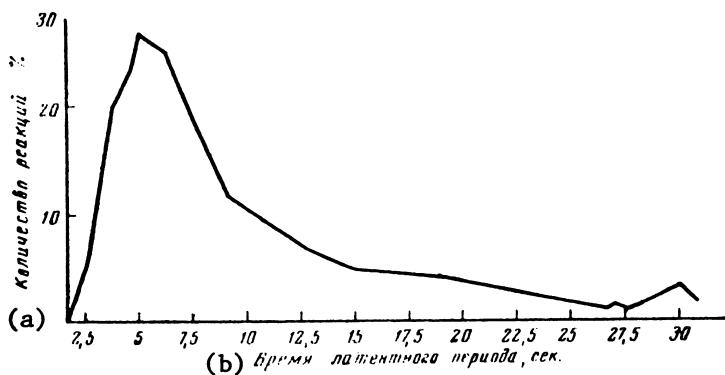


Figure 45. Distribution of the Latent Period of the Electrical CMF Reactions Which Occur in the Cortex and the Subcortical Sections of the Rabbit Brain. Key: (a) Number of Reactions, %; (b) Duration of the Latent Period, Sec.

bits, a reaction in just the sensorimotor cortex was noted in 25, in just the parietal cortex in 6, in only the hypothalamus in 30, and in only the reticular formation of the mid-brain in 2. Figure 45 gives the latent period distribution of the reactions taken simultaneously from all leads. We see that the mode on the latent distribution curve occurs at 5 sec. In comparison with the curve obtained during recording of the EEG reaction to a CMF using elec-

trodes that were driven into the bone (see Figure 39), the latent period of the reaction to a CMF in rabbits with embedded electrodes is significantly shorter even several weeks after the operation, although the reaction stability (including unstable changes) was less (66 versus 95%). It is probable that the degree of trauma inflicted by deeply embedding electrodes in the brain leads to a shortening of the latent period of the reaction to a CMF. We observed a similar effect during sectioning at the level of the midbrain and during isolation of a cortical strip.

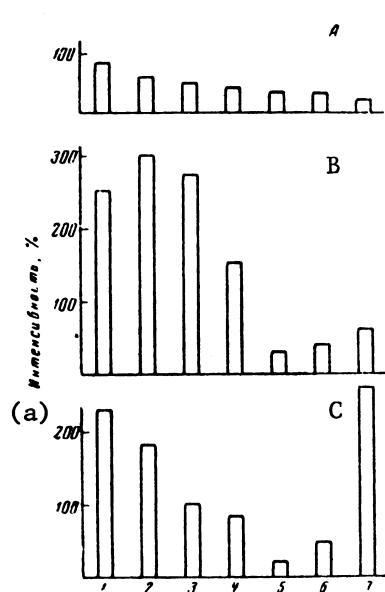


Figure 46. The Intensity (in %) of the Electrical Reactions in Different Sections of the Brain to a CMF in the Norm (A), After Injection of Caffeine (B) and After Injection of Adrenalin (C). 1 = Hypothalamus; 2 = Sensorimotor Cortex; 3 = Parietal Cortex; 4 = Specific Nuclei of the Thalamus; 5 = Nonspecific Nuclei of the Thalamus; 6 = Hippocampus; 7 = Reticular Formation of the Midbrain.

Key: (a) Intensity, %.

increased in all leads, but the reaction of the cortex, especially the sensorimotor cortex, most sharply increased; the hypothalamus then occupied third place,

The different latent periods of the reactions to a CMF in different formations of the brain indicate that the reaction in any section has a prolonged latent period, measurable in seconds. With this type of experiment we could not clarify whether the reaction is formed in all sections of the brain simultaneously or whether it occurs at some lead point, from which it is propagated to the other sections of the brain via a neuronal pathway (with a velocity that cannot be measured by an EEG recording). Experiments involving isolation of the structures of the forebrain and the diencephalon and with isolation of a cortical strip sway us toward the first opinion, i.e., that the reaction to a CMF is formulated independently in each section of the brain, and then it occurs in the isolated strip. Of course, the discussed pathways of the reaction to a CMF do not exclude each other and can coexist.

In any case, if the different sections of the brain react relatively identically to a CMF in their latent period, there is a definite hierarchy in the intensity of the reaction, i.e., the relative (%) increase in the number of spindles during exposure in comparison with the background recording.

Figure 46 shows that normally the most intensive reaction to a CMF is observed in the hypothalamus, then come the sensorimotor cortex, the parietal cortex, the specific nuclei of the thalamus, the nonspecific nuclei of the thalamus, the hippocampus and the reticular formation of the midbrain. Based on these results, we can consider that just the hypothalamus is the lead point in the reaction to a CMF.

However, an intramuscular injection of caffeine, 50 mg/kg, into 3 rabbits changed the intensity of the reaction to a CMF. The intensity increased in all leads, but the reaction of the cortex, especially the sensorimotor cortex, most sharply increased; the hypothalamus then occupied third place,

followed by the specific nuclei of the thalamus, the reticular formation of the midbrain, the hippocampus and the nonspecific nuclei of the thalamus.

Intravenous injection of adrenalin, 0.03 mg/kg, into 3 rabbits also increased the intensity of the reaction to a CMF, only here the reticular formation of the midbrain, usually in last place, became the "lead point," followed by the hypothalamus, sensorimotor cortex, parietal cortex, specific thalamus, hippocampus and nonspecific thalamus.

Thus, the results of experiments involving the injection of caffeine and adrenalin testify in favor of the viewpoint that the CMF acts on each section of the brain, but the intensity of the reaction is determined by the reactance of the separate sections.

By artificially increasing excitability by means of pharmacological agents, we can arbitrarily make one or another section of the brain more reactive to CMF. According to pharmacological data [Val'dman, 1963], caffeine acts essentially on the cortex, and adrenalin, on the reticular formation of the midbrain. According to this we have obtained a greater intensity of the reaction to a CMF in the cortex or in the reticular formation of the midbrain.

Probably the hypothalamus and the cortex normally are the most reactive structures and, therefore, react most intensively to CMF.

The experimental results of R. A. Chizhenkova, who found that the electrical reaction of the cerebral cortex to CMF did not change significantly after destruction of the hypothalamus, thalamus or reticular formation of the midbrain, also indicates the absence of "lead points" in the reactions to CMF.

Turning to the results of experiments on an isolated cortical strip, we can now assume, with a better basis, that the observed changes in the electrical activity of the strip are caused by the direct effect of a CMF on it. What cellular elements in the cortex react to a CMF? We have proposed that recording the impulses of the cortical neurons during exposure to a CMF can answer this question.

#### The Effect of a CMF on the Pulsed Electrical Activity of Cerebral Neurons

/128

S. N. Luk'yanova made an extracellular recording of the electrical activity of 352 neurons of the sensorimotor cortex, parietal cortex, hypothalamus, specific formations of the thalamus, hippocampus and the reticular formation of the midbrain in tests on 5 rabbits. Exposure to a 1,000-Oe CMF on the animal's head lasted one minute. The electrical activity of the neurons was continuously recorded for 20 sec. The recording periods were distributed over time as follows. The first 20-second interval was recorded with no exposure, then followed a 30-second interval. The second recording included 10 seconds of background and 10 seconds after the electromagnet was turned on. The third recording, which characterized the influence period, was taken after a 10-second interval. The fourth recording, beginning after a 10-second break, contained 10 seconds of exposure, the moment the magnet was turned off and 10 seconds of the aftereffect. The

fifth and last 20-second recording, which characterized the aftereffect period, was taken after a 30-second break. The results of two or more exposures on certain neurons were recorded.

Such an experimental method allowed a comparison of the results obtained by the microelectrode technique with the results of EEG investigations, in which a continuous 3-minute recording of the electrical activity was made with the period of field influence located in the middle minute.

In treating the experimental results, the number of spikes for each 10-second recording was counted in such a way that 10 numbers were provided for each test. Table 14 shows the additive results for the number of spikes for neurons in different sections of the brain. This addition makes it possible to display reactions of cortical neurons to stimulation, in particular to light stimulation [Kondrat'yeva, 1964].

TABLE 14. TOTAL NUMBER OF RECORDED DISCHARGES FROM NEURONS IN DIFFERENT SECTIONS OF THE RABBIT BRAIN DURING 10-SECOND INTERVALS IN THE BACKGROUND, DURING EXPOSURE TO A CMF, AND AFTER THE EXPOSURE.

/129

Section of the brain	No. of neurons	Background			Influence period				Aftereffect period		
		1	2	3	4	5	6	7	8	9	10
hypothalamus	51	2804	2865	2826	2620	2832	2715	2788	2679	2339	2650
hippocampus	40	1621	1632	1666	1747	1731	1903	1606	1805	1640	1903
reticular formation of the midbrain	46	2495	2060	2690	2553	2061	1980	2376	2228	2362	2201
specific nuclei of the thalamus	36	1546	1593	1799	1663	1626	1965	2089	2915	2761	2636
sensorimotor cortex	81	3369	3346	3378	3329	3404	3853	3482	3710	3468	3384
parietal cortex	98	3829	3727	3715	3895	4041	3900	3731	3621	3406	3501
total	352	15664	15223	16074	15807	15695	16316	16072	16958	15976	16275

As the lower line of Table 14 shows, during the influence of the CMF, there were no significant changes in neuronal impulses. This conclusion is valid not only for the total data, but also for the separate sections of the brain. Only in the thalamus do we note a tendency toward an increase in neuronal impulsion after the electromagnet is turned off.

Comparing the additive results for neuronal impulses with the results of a

similar addition (counting the number of spindles and slow waves) of the electrical activity recorded by microelectrodes in the same sections of the brain, we see that the electrical activity of the brain tissue changes during the influence of a CMF, but the total number of neuron spikes does not undergo a change. Hence, the conclusion follows that neurons perhaps do not participate /130 in the initial reaction of the brain to a CMF. We shall put aside a final judgment on this question until we have obtained results from different methods of treating the data.

In studying the reaction of separate neurons to different stimuli, investigators quite frequently divide the neurons into groups. In these experiments, neurons were considered excited if the frequency of their impulses increased twice every 10 seconds (group I). The same quantitative reduction in the impulse frequency characterized inhibited neurons (group II). All the remaining neurons, which did not significantly change their impulse frequency, were placed in the third group. We have treated the results obtained both during the influence of a CMF and in its absence according to this classification. The change in the number of neurons that retain their impulse frequency during exposure to a CMF allowed us to make a conclusion about the presence of a reaction.

The obtained data are given in Table 15. First of all, we should note that in comparing the average electrical activity of neurons for all sections of the brain without the influence of a CMF (the first and the last columns), the number of group III neurons varied slightly (65 and 70% respectively). The averages characterizing the sections of electromagnet turn-on (74%) and turn-off (79%) are close to the previous figures, which indicates the absence of significant changes in the activity of neurons during changes in the CMF. However, in comparing both the average data and the results of investigating each section of the brain separately, which were obtained by recording 20-second intervals of neuronal impulsation without the influence of a CMF as well as during the middle period of the influence (the third column of the table), we see that the number of neurons in group III decreased approximately twice. This fact indicates that the impulses of cerebral neurons acquire a longer latent period (more than 10 sec) under the influence of a CMF.

A comparison of the results of the first and third columns of Table 15 makes it evident that under the influence of a CMF, the number of group III neurons changes most in the hypothalamus (by 33%) and least in the reticular formation of the midbrain (by 8%), which coincides with the data on the reactance of these formations to a CMF, obtained by means of recording the electrical activity with microelectrodes.

The decrease in the number of group III neurons is accompanied by an approximately identical increase in the number of group I and II neurons, which coincides with the data of Table 14 and testifies that the total activity of neurons does not change under the influence of a CMF. We should note that in tests on 7 rabbits, L. L. Pragina observed similar reactions to a CMF from 28 neurons of the sensorimotor and parietal regions of the cortex.

Investigators usually base the grouping of neurons on several reactions of /131 the same neuron. Since the exposure was prolonged in our experiments, we rarely managed to record the results of two CMF exposures on one neuron. Twenty-three

TABLE 15. THE RELATIVE NUMBER OF EXCITED (I), INHIBITED (II) AND UNCHANGED-ACTIVITY (III) NEURONS IN DIFFERENT SECTIONS OF THE BRAIN IN THE BACKGROUND, DURING EXPOSURE TO A CMF, AND AFTER EXPOSURE.

Section of the brain	Number of neurons	Groups of neurons	Number of Neurons, %				
			Background (10 sec) with background (10 sec)	Background (10 sec) with exposure (10 sec)	Background (20 sec) with exposure (20 sec)	Exposure (10 sec) with aftereffect (10 sec)	Aftereffect (10 sec) with aftereffect (10 sec)
hypothalamus	51	I	12	6	24	18	2
		II	22	14	43	14	25
		III	66	80	33	68	73
hippocampus	40	I	13	6	30	12	15
		II	13	3	25	3	9
		III	74	91	45	85	76
reticular formation of the midbrain	46	I	22	22	26	8	14
		II	28	22	32	14	12
		III	50	56	42	78	74
specific thalamus	36	I	9	6	24	12	24
		II	21	6	29	6	6
		III	70	88	47	82	70
sensorimotor cortex	81	I	16	20	25	7	26
		II	17	19	31	12	23
		III	67	61	44	81	51
parietal cortex	98	I	18	19	24	9	18
		II	17	14	36	12	9
		III	65	67	40	79	73
averages	—	I	15	13	25	11	16
		II	20	13	33	10	14
		III	65	74	42	79	70

neurons received 2 exposures: 7 of them did not change their activity either time, 8 neurons changed their activity only under one of the two influences, 4 neurons decreased their impulsion both times, and 2 increased it. Thus, to increase the clarity of neuron classification, in the future we must apply a larger number of exposures to the same neuron.

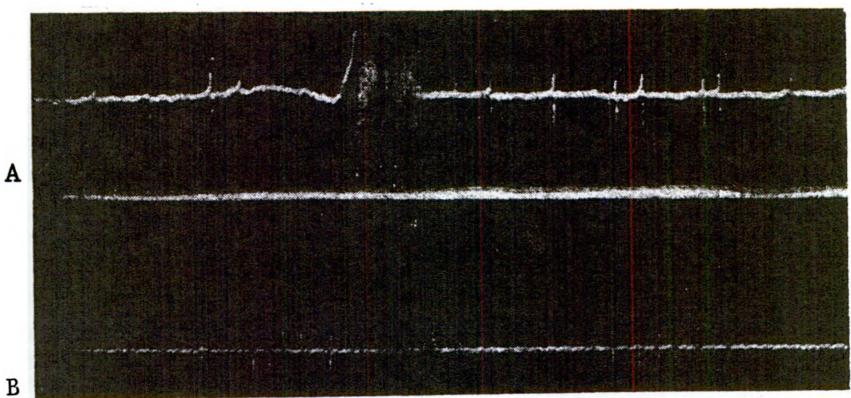


Figure 47. Changes in the Electrical Activity of Neurons at Turn-On (B) and Turn-Off (A) of the Electromagnet.

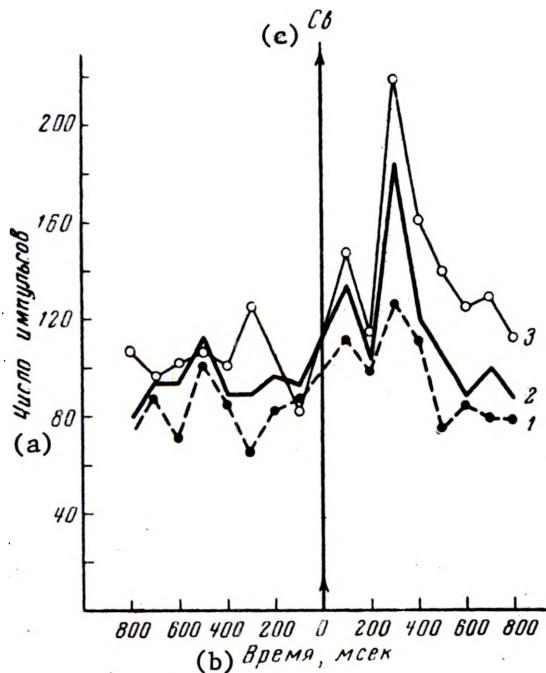


Figure 48. Frequency of Neuronal Impulsation to a Light Flash in the Background (1), During Exposure to a CMF (2) and After the Electromagnet was Turned Off (3). Key: (a) Number of Impulses; (b) Time, msec; (c) Light.

We have already mentioned that /132  
turning the electromagnet on and off  
does not cause sharp changes in the elec-  
trical activity of neurons (for example,  
see Figure 47), both in the addition of  
neuronal activity, as well as in neuron-  
al grouping. However, the data of Table  
15 show that while the reaction of neu-  
rons does not occur in the first 10  
seconds of the CMF exposure, the after-  
effect lasts for the first 10 seconds  
after the electromagnet is turned off.

A comparison of the electrical re-  
actions of the brain and separate neu-  
rons to a CMF shows that in both cases  
the reaction is distinguished by a long  
latent period and by a prolonged after-  
effect. The changes in electrical brain  
activity during the influence of a CMF  
were clearer than the changes in neuron-  
al impulsation. These facts force us to  
assume that not only the bodies of nerve  
cells, but also other formations of nerve  
tissue (dendrites, glia or blood vessels)  
participate in the electrical reaction  
of the brain to a CMF. The latent peri-  
ods of the neuron reactions are usually  
measured in milliseconds. In our case,  
this index is increased thousands of  
times, forcing us to think that neurons  
react late to a CMF.

Let us recall that the electrical reaction of the brain to a CMF was ex-

pressed most clearly when test light stimuli were used. This fact served as the basis for experiments conducted together with I. N. Kondrat'yeva that involved recording the pulsed activity of neurons that react to light. The recording lasted 2-3 sec. We investigated the reaction of 23 neurons in the visual cortex to a light flash before, during and after exposure to a 200-Oe CMF on the animal's head. During each stage of the investigation, we administered 106 flashes. /133

The total dynamics of neuronal activity are given in Figure 48. Analyzing the curves before the start of the light effect, one can see that the number of neuronal impulses increased somewhat under the influence of the CMF, but this increase was not statistically reliable ( $p > 0.05$ ). The increase in neuronal impulsation after the electromagnet was turned off was statistically reliable ( $p < 0.05$ ).

The neuronal reaction to a light flash intensifies both during exposure to a CMF and, in particular, after the electromagnet is turned off.

The obtained results show that a CMF affects neuronal activity in a particularly strong way during the functional loading caused by light stimulation. A CMF causes a sharply expressed aftereffect. In control experiments on 36 neurons, without exposure to a CMF, we did not observe a dependence of the reaction to the flash on the number of preceding flashes.

#### Discussion

/134

In studying the electrical reaction of the rabbit brain to a CMF, we revealed its significant similarity to the reactions to UHF and SHF fields. It is possible that the physical basis of this similarity is the fact that the magnetic component of EMF has a more significant biological effect [Khazan and Goncharova, 1959; Presman, 1960; Nikonova, 1963, and others]. On the other hand, the probability of the presence of a nonspecific physiological reaction of the CNS to any penetrating physical factor is not precluded. We should note that a CMF is a weaker factor than a UHF or SHF field. The stability of the EEG reaction increases as the field strength increases, but at 1,000 Oe it does not exceed 52%.

It is possible that oscillations at the metabolic level, which are reflected in superslow oscillations of brain potential [Aladzhalova, 1962], can explain the statistical nature of the electrical brain reaction to different fields. Depending on the phase of the potential oscillation, the sensitivity to a CMF changes, and we may not obtain a response, although the external experiment conditions remain identical. As the number of exposures increases, the probability increases of coincidence of the exposure with increased excitability of the brain by a CMF, which leads to a statistically reliable change in electrical brain activity.

Our observations show that a predominance of spindles and slow waves in the background reduces the probability of the appearance of a reaction to a CMF. If we artificially increase the number of spindles or slow waves on the EEG by intramuscular injection of 12 mg/kg of aminazine or by intraperitoneal injection of 13 mg/kg of sodium amyral, then the electrical reaction of the brain to a CMF

disappears. As we have already said, artificially increasing the excitability by injection of caffeine or adrenalin significantly intensifies the reaction of the CNS to a CMF. Consequently, tests involving the injection of pharmacological substances support the assumption that the statistical nature of the electrical brain reaction to a CMF can depend on unconsidered variations in the excitability of the nervous system.

However, if the effect of a CMF depends on variations in brain excitability, we can "capture" increased excitability by increasing the exposure time to the CMF. Experiments of this type were conducted on 4 rabbits, from which we recorded the EEG of the sensorimotor and visual regions of the cortex by the monopolar method with electrodes embedded in the bone. The CMF attained a strength of 300 Oe and acted on the animal's head for 3 hours a day. The experiment lasted 2 weeks.

Under the prolonged influence of a CMF on the head of a rabbit, the EEG /135 changed differently than during brief exposures to the same field, and the changes were not limited to just the electrical brain activity. The treatment of the results was not as thorough as for the brief exposures, but a tendency was revealed toward predominance of low-amplitude (less than 50  $\mu$ v) potentials on the EEG both during exposure to the CMF and in the background recording, as the number of prolonged exposures increased (Figure 49). We should note that on the 8th day, high-amplitude (above 100  $\mu$ v) potential oscillations predominated, but later on the biopotential amplitudes began to decrease. The observed amplitude changes in the EEG during exposure to a CMF resemble the phase reaction of the cerebral cortex to a weak dose of ionizing radiation [Livanov, 1962].

Besides the changes on the EEG, we observed an increase in excitability in these rabbits, manifested as a marked increase in motor reactions and a reduction in total body weight by 9-17% during the two-week period. The control rabbits, which were also harnessed on the stand for a long time and subjected to the influence of the same CMF, but for 1-3 min with an interval of 10-15 min, did not exhibit changes in weight or motor activity, and their EEG changes were of a different type, which we have described previously.

The obtained results cannot be explained only by the fact that during prolonged exposure to a CMF, the effect depends to a lesser degree on variations in brain excitability. While the reaction to each subsequent brief exposure to the CMF did not depend on the preceding brief exposure, during prolonged exposures we observed a clear summation effect. It is probable that the repair processes in the CNS cope quickly and easily with the degree of alteration inflicted by a 1-3 minute exposure to a CMF. However, the repair processes are significantly disturbed after a 3-hour exposure to a CMF since a 24-hour break in the field does not allow restoration to the initial EEG. The described results show that we have still devoted little attention to the duration of the EMF exposure. In subsequent investigations, consideration of this factor will promote a deeper analysis of the mechanism of the effect of EMF on the CNS.

Recording the electrical activity with macroelectrodes and microelectrodes from different sections of the brain showed that the reactions to a CMF, as to a UHF or an SHF field, occur with a long latent period for all the structures recorded. However, the hypothalamus occupies first place in reactance to a CMF.

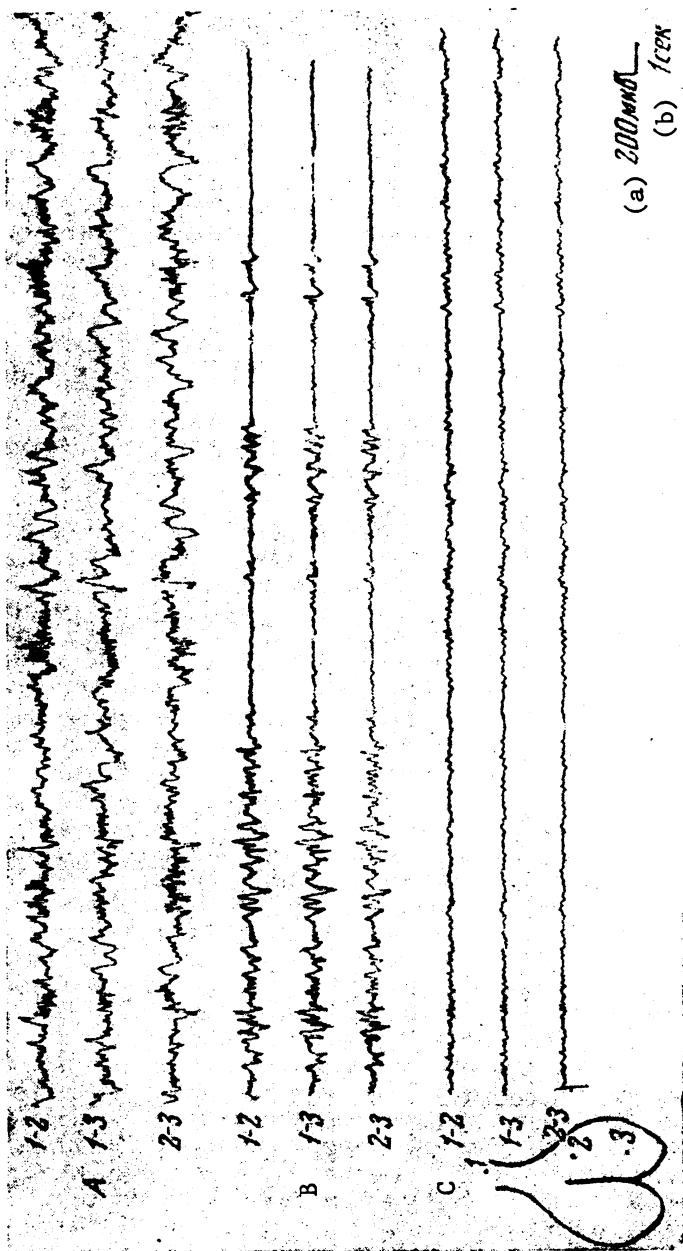


Figure 49. Electrical Activity of the Rabbit Cortex After a 3-Hour (A), 30-Hour (B) and 60-Hour (C) Stay in a CMF. The Numbers Indicate the EEG Leads (See the Diagram). Key: (a) 200  $\mu$ v; (b) 1 Sec.

It is possible that this section of the brain is also more sensitive to EMF, but we will make our final judgment on this conclusion following experiments which /137 determine the CMF thresholds for different sections of the brain. At this time it is appropriate to note that the hypothalamus, where the higher autonomic centers are located, is considered the structure most reactive to the effect of penetrating factors [Popov, 1940; Aladzhalova, 1962; and others].

The cortex follows the hypothalamus in reactance to a CMF. After prolonged exposures to high-frequency [Tolgskaya, Nikonova, 1964], UHF [Shvarts, 1945] and

SHF [Pitenin, 1962; Tolgskaya, Gordon, 1964] fields, morphologists have found the most significant histological changes in the neurons in just these sections of the brain.

Recording neuronal impulsation has shown that, in contrast to such stimuli as light, sound or an electrical current, a CMF causes a neuronal reaction with a longer (more than 10 sec) latent period. It is possible that the neuronal reaction involves a secondary means, i.e., the CMF causes some changes in the metabolism of the brain tissue and the neurons react to this chemical factor. The absence of change in neuronal activity at turn-on and turn-off, and also the existence of an aftereffect, speak in favor of this assumption.

The changes in the electrical activity of the rabbit brain indicate the presence of a biological effect of a CMF. This effect was intensely revealed by means of test stimuli (the reactance curve and the reaction of visual cortex neurons to a light flash) and by increasing the excitability by pharmacological (injection of caffeine or adrenalin) and surgical (isolation of a cortical strip) means.

Similar changes in the electrical brain activity during exposure to a CMF, which were manifested as an increase in the number of slow high-amplitude oscillations, were observed in salamanders [Becker, 1963] and in humans [Dinculescu et al., 1963; Vyalov et al., 1964].

Thus, both our data and the reference data indicate the effect of a CMF on the CNS.

### Conclusions

1. During a 1-3 minute exposure to a 200-1,000-Oe CMF on the head of a rabbit, we observed a statistically reliable increase in the number of spindles and slow high-amplitude oscillations in the electrical brain activity. The latent period of this basic reaction varied from 5 to 100 sec, and the stability attained 52%. A brief desynchronization reaction sometimes occurred in the cortex at the moments the electromagnet was turned on and off. After the electromagnet was turned off, we observed an off-effect with an average latent period of 15 sec that resembled the basic reaction in the form of the changes in electrical activity. The time for the appearance of assimilation to light flashes of increasing brightness increased during exposure to a CMF on the animal's head.

2. The electrical reaction of the cortex to a CMF occurred more frequently, more intensely and with a shorter latent period after sectioning at the level of the midbrain. The reaction to a CMF was also retained in a neuronally-isolated cortical strip.

3. Experiments with embedded electrodes showed that all the recorded sections of the brain react to a CMF. The most reactive were the hypothalamus and cortex, and the least reactive was the reticular formation of the midbrain.

4. By recording the neuronal impulsation in different sections of the brain, we observed that a CMF does not change the total activity of all the

studied neurons, but with a latent period of more than 10 sec it inversely reduces the number of neurons that do not change their activity. Under a CMF, the number of excited and inhibited neurons increases by approximately the same degree. The impulsation reaction of visual cortex neurons to a light flash during exposure to a CMF increased its intensity. This effect was retained in the aftereffect.

5. A CMF causes a nonspecific electrical reaction in the rabbit brain that is similar to the reaction which occurs during exposure to UHF and SHF fields.

## CHAPTER 4. THE EFFECT OF AN ELECTROSTATIC FIELD ON THE RABBIT EEG

The biological effect of an electrostatic field (ESF) has been studied since the invention of an electrostatic machine by von Gerich in 1672 up to the present time [Ostryakov, Vorob'yev, 1964; Solov'yev, 1962], but the mechanism of this effect remains unclear [Anikin, Varshaver, 1950]. It is considered that the physiological effect of an ESF on the nervous system is accomplished by means of reflexes. By stimulating the endings of the trigeminal and other nerves, an ESF can cause changes in the functional state of the CNS. Airborne ions formed in a silent discharge reach the mucosa of the respiratory tract and skin and have a stimulating effect on their receptors. With this we observe a /139 change in the skin sensitivity, stimulation of capillary blood circulation, normalization of the vascular tonus, a change in the morphological state of the blood, and improvement in gaseous interchange during the activity of the gastrointestinal tract [Finogenov, 1963]. In physiotherapy, the method of therapeutically using an ESF is called franklinization. We should remember that, besides an ESF, the airborne ions and ozone formed in an ESF can affect animals and man. However, we shall only be interested in the effect of an ESF on the rabbit EEG during a local one-minute exposure to this factor on the animal's head employing

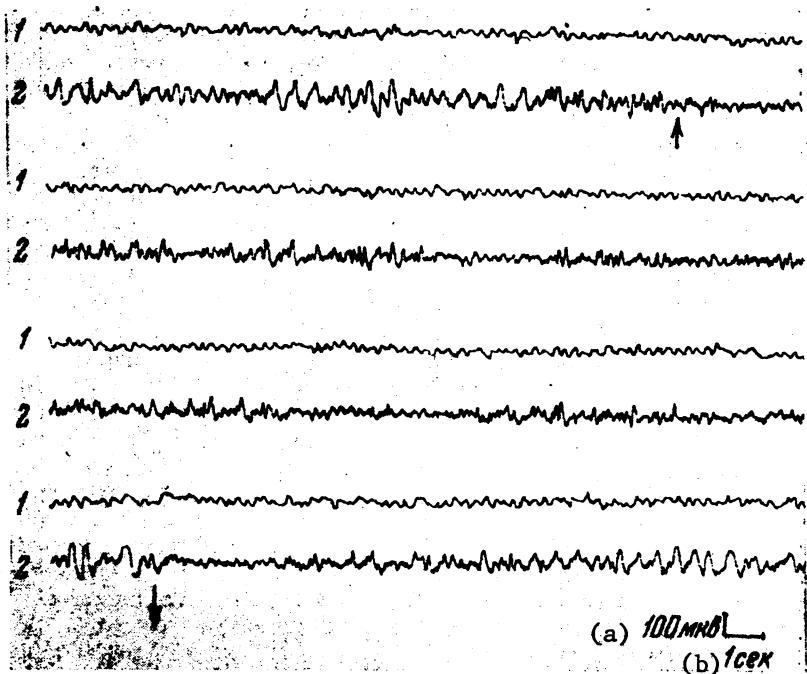


Figure 50. Change on the Rabbit EEG During the Influence of an ESF on the Animal's Head. Continuous Recording. The Arrows Designate the Moments of Generator Turn-On and Turn-Off; 1 = Sensorimotor Cortex; 2 = Visual Cortex. Key: (a) 100  $\mu$ v; (b) 1 Sec.

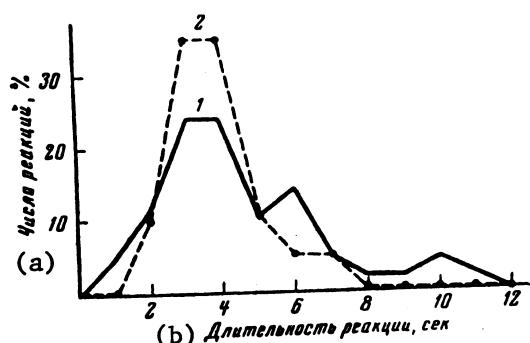


Figure 51. Distribution of the Duration of Desynchronization Reactions at Turn-On (1) and Turn-Off (2) of an ESF. Key: (a) Number of Reactions, %; (b) Duration of Reactions, Sec.

action lies between 1.25 and 2.50 kv/cm.

A detailed analysis of the desynchronization reaction during the influence of a 5.00 kv/cm ESF showed that this reaction occurred at turn-on in 61% of the cases, and at turn-off, in 31%. The latent period of these reactions was equal to a fraction of a second and, therefore, by recording the EEG on a recording electroencephalograph we could not measure it. The duration of the reactions varied from 1 to 11 sec, but most often it was 3-4 sec. Figure 51 shows distribution curves of desynchronization reactions with different duration at turn-on and turn-off of the ESF. The similarity of these curves, on which the mode is at 3 or 4 sec, draws our attention. From this we can conclude that the desynchronization reactions at turn-on and turn-off of the ESF are caused by a similar mechanism. The only difference is that the reaction occurs twice as frequently at turn-on as at turn-off. In this sense the effect of an ESF resembles the effect of an SHF field, in which the reaction at turn-on occurred in 31% of the cases and at turn-off in 12%. However, the desynchronization reactions during the influence of an ESF occurred twice as frequently as during the influence of an SHF field.

An analysis of the dynamics of the number of spindles and slow waves on the EEG, which allowed us to reveal the basic reactions to the previously investigated CMF, showed that, in contrast to the effect of a 1,000-Oe CMF, no statistically reliable changes occurred in the rabbit EEG at ESF exposures of 1.25 and 5.00 kv/cm (Figure 52). Only the desynchronization reaction at turn-off of the 5.00 kv/cm ESF reveals a drop in the number of spindles and slow waves on the EEG in the first 10 sec of the exposure. Even this drop did not occur during the influence of the 1.25 kv/cm ESF. The results of the ESF experiments given in Figure 52 can serve as a control for tests with a CMF, and once more indicate the presence of an EEG reaction to a CMF.

It is possible that M. N. Livanov et al. (1960) studied the effect of an ESF on the rabbit EEG that occurred when an x-ray machine was turned on. We

brief intervals (1-5 min).

We investigated the effect of an ESF on the rabbit EEG together with N. A. Solov'yev. As in the preceding tests, we recorded the EEG by the monopolar method from the sensorimotor and visual regions of the cortex. The field strength, as recorded by a voltmeter, was 1.25, 2.50 and 5.00 kv/cm. The duration of exposure was one minute.

First of all, we found that a desynchronization reaction frequently occurred in the rabbit cortex when the ESF was turned on and off (Figure 50); this reaction occurred at field strengths of 5.00 and 2.5 kv/cm, but was not observed at 1.25 kv/cm. Consequently, the ESF threshold for the desynchronization re-

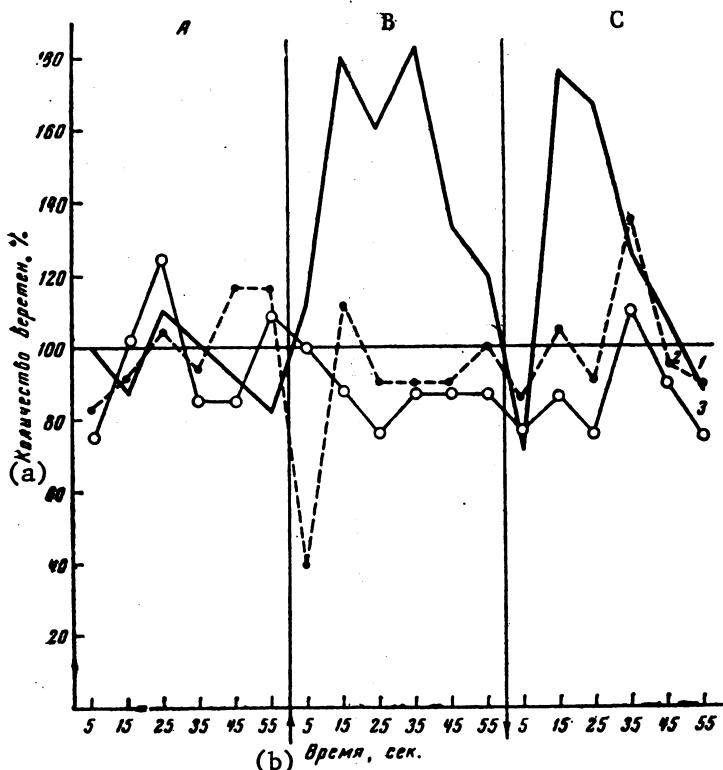


Figure 52. Dynamics of the Number of Spindles and Slow Oscillations of Rabbit Cortical Potentials in the Background and During Exposure to a CMF (1) and an ESF with a Field Strength of 5 kv/cm (2) or 1.25 kv/cm (3). A = Before Exposure; B = in the Influence Period; C = in the Aftereffect. Key: (a) Number of Spindles, %; (b) Time, Sec.

during exposure to an ESF.

2. In contrast to UHF, SHF or CMF, an ESF did not increase the number of spindles and slow oscillations of potential in the cortex either during the exposure or after it.

#### Synopsis

At the end of the part devoted to the electrographic method of investigating the effect of EMF on the CNS, we should review the results described in the preceding chapters.

Although we used EMF of different ranges and different intensities, nevertheless we obtained similar results by using the same methods of investigation. The similarity was observed in the form of the EEG reaction: the low stability

conclude this from the report concerning the presence of a desynchronization reaction with a duration of 2-8 seconds during an 8-15 second exposure to the field -- this reaction occurred less often in our experiment involving other fields -- and from the similarity of the threshold values of the field. In the stated work, the effect is reduced when the cable is at a distance from the animal, and also when the voltage in the machine is lowered from 60 to 10 kv. /142

Thus, the effect of an ESF on the rabbit EEG is of a different type than the effect of high frequency, UHF, SHF and CMF.

#### Conclusions

1. A one-minute exposure to a 5 kv/cm ESF on the head of a rabbit caused a desynchronization reaction in the electrical activity of the cortex at the moments the generator was turned on and off. Significant changes were not observed on the EEG

and the long latent period of the reaction, the existence of desynchronization reactions that occur at the moments of generator turn-on and turn-off, the presence of reactions to turn-off, the direct effect of EMF on the structures of the telencephalon and diencephalon, and also on an isolated cortical strip. Since we did not set ourselves the task of a detailed comparison of the EEG reactions to different EMF at the start of the investigation, there may be certain omissions in the discussion of these questions, but the general picture is sufficiently clear.

#### The Form of the EEG Reactions

It turned out that during exposure to a field, there was a statistically reliable increase in the number of spindles in the anterior sections of the cortex, and of the number of spindles and slow waves in the posterior sections. During the influence of UHF and SHF fields, we frequently recorded the EEG only from the posterior sections of the cortex and analyzed only the slow waves. However, because of the diffuse nature of the EEG reaction to EMF and the functional relationship of spindles and slow waves, the reactions which we evaluated from different indices and in different sections of the cortex had much in common.

The appearance of slow waves on the EEG and an increase in potential amplitude are most frequently described in the literature as the result of the effect of different EMF. However, other forms of the reaction have also been observed. Sh. K. Pardzhanadze (1954) noted a quickening of the waves and an increase in their amplitude on the rabbit EEG during exposure to a UHF field. L. Sinisi (1954) noted an increase in voltage and bursts of theta-waves on the EEG of some people. M. S. Bychkov (1957) and I. N. Zenina (1964) reported the appearance of a different form of change in rabbit and cat EEGs depending on the power flux density and the duration of the exposure to an SHF field. M. Baldwin et al. (1960) noted the appearance of slow waves (a rhythm of 5 Hz predominated) on the simian EEG during exposure to a 225-400 MHz SHF field on the animal's head.

Slow waves and spindles appeared on the rabbit EEG in our tests during the influence of a UHF field [Kholodov and Yanson, 1962a, b], a constant [Bavro and Kholodov, 1962] and a pulsed [Kholodov, 1962a] SHF field, and also during the influence of a CMF on the animal's head [Kholodov, 1963a]. An increase in the amplitude of slow waves on the rabbit EEG also occurred under the influence of a high-frequency field (500 kHz) [Nikonova, 1963].

Thus, the enumerated results of a few experimental works on the effect of EMF of different ranges on the EEG show that in the majority of cases the reaction was manifested as an increase in amplitude, but sometimes as a decrease in frequency of the cortical potentials. Many investigators have noted that this reaction is diffuse in nature and has a significant aftereffect. The majority of investigators recorded the EEG after exposure.

Clinical studies involving the recording of the EEG from people who have undergone prolonged exposure to different EMF in industrial conditions are a somewhat isolated phenomenon. All such works presently testify that pathological forms of bioelectric activity are recorded in the EEG of these subjects in the form of slow delta-waves and beta-waves, frequently sporadic in character [Drogichina et al., 1962; Klimkova-Deycheva and Rot, 1963; Svacina, 1963;

Ginzburg, 1964; Vyalov et al., 1964]. We should note that, soon after different total-body x-ray irradiation of rabbits, there was an increase in the amplitude of bioelectric oscillations, and sometimes changes in the frequency spectrum of different directivity, in the cerebral cortex [Livanov, 1962].

In sum, we find that the most diverse EMF cause similar nonspecific changes on the EEG of different vertebrates. Since the primary biophysical processes are different during exposure to different EMF, we assume that the described EEG reaction reflects a common final result of the interaction of the organism with the field. Let us explain this by means of an example. The sensation of phosphene in man can be caused by adequate (light), electric and mechanical stimulation of the retina. However, it does not follow that the enumerated stimuli act on the retina in an identical manner. /144

What is the functional significance of the forms of the EEG reactions that are observed most frequently during exposure to EMF? It is known that slow waves and spindles appear in the cortex of sleeping animals. Therefore, it is reasonable to assume that EMF cause inhibition in the CNS. This assumption is supported by certain facts, for example: the results of our tests on determining the threshold of assimilation for a rhythm of flashing lights of increasing brightness in rabbits during the influence of a CMF; the statement regarding somnolence in certain people who work in EMF [Grigor'yev, 1881; Klimkova-Deycheva and Rot, 1963]; the lowering of the sensitivity in an electrical current during exposure to a magnetic field on the human occiput [Nikolayev, 1960]. However, although EMF have a predominantly inhibiting effect on the CNS during normal conditions, when there is an increase in excitability due to injection of caffeine or mechanical stimulation of the brain, EMF can cause convulsive discharges on the EEG, which is an index of the limiting excited state.

In the partially discussed experiments on the effect of a SHF or a constant magnetic field on the rabbit EEG in which a cortical strip was isolated in the sensorimotor region of the left hemisphere, the following interesting fact appeared.

TABLE 16. CHARACTERISTICS OF THE EPI-LEPTOGENIC EFFECT OF DIFFERENT STIMULI.

Stimulus	Number of rabbits	Number of exposures	Number of convulsive electrographic reactions			Stability of convulsive electrographic reactions, %		
			basic	turn-off	total	basic	turn-off	total
200-Oe CMF	7	109	73	19	92	67	17	84
200 mw/cm <sup>2</sup> SHF field	5	26	17	3	20	65	12	77
light	7	32	15	5	20	47	16	63
sound	7	44	8	8	16	18	18	36

Apart from the stated fields, we used light from an electric light and sound from a ZG-10 generator as stimuli. These stimuli were of moderate strength, but they always caused a desynchronization reaction in the EEG of an intact rabbit brain. However, during their influence on a damaged brain these stimuli were less epileptogenic factors than EMF. The experimental results are given in Table 16.

The far right of the table shows that the most epileptogenic stimulus for /145 the intact brain was the weakest stimulus, the CMF, followed by the SHF field, light and, finally, sound.

These experiments clearly demonstrate the presence of the effect of EMF on the CNS. They show that discussions on the weak nature of EMF as stimuli, and on their predominantly inhibiting effect, pertain only to the normal functional state. If, however, the excitability is increased, if by additional exposures we cause a paradoxical parabiotic phase in the CNS, EMF cease to be weak and inhibiting stimuli and provoke the strongest excitation. In connection with this, we should note that the seizures of so-called "television epilepsy" [Pallis and Louis, 1961; Mawdsly, 1961] that have occurred in certain people when they tuned a television set are possibly provoked not only by the light stimulus, but also by the electromagnetic stimulus that is more intensive close to the set.

#### The Reaction to Turn-Off

Table 16 shows that, in contrast to the basic reaction, the electrographic reaction to turn-off occurs in an almost equal number of cases after different stimuli are turned off. The reaction to turn-off was an unexpected event. It was first noted in tests on the effect of a UHF field on an isolated cortical strip. In experiments involving the effect of an SHF field on electrical brain activity, it was shown that this reaction actually exists, and in investigations of the effect of CMF on the CNS, it was described with sufficient detail from a quantitative point of view.

First of all, the existence of reactions to turn-on and turn-off leads to the thought concerning the similarity of such reactions to the regularities established for a direct current acting on a neuromusculature preparation. The difference was that during exposure to an EMF, reactions were observed not only for a change in the field, but simply for its presence as well.

The functional significance of the reaction to turn-off remains unclear not only in our experiments on the effect of CMF on the CNS, but also in the discussion of most of the presently accumulated facts on this question [Granit, 1957]. It seems that the presence of a system with a turn-on and turn-off effect characterizes many receptor formations, but it occurs most clearly in the reactions of the visual receptor. It is assumed that the turn-on and turn-off effects are connected with the activity of different mechanisms. In certain cases, the /146 turn-off effect is absent on the periphery of the analyzer (the Limulus and the mammal auditory organ), but it can appear in its central formations. It is possible that an impulsion in response to turn-off, similar to the so-called Sherrington release reflex, can occur as a result of the interaction of central structures that have a contradictory effect on one and the same neuron [Granit, 1957].

The difference between our results and classical concepts regarding the effect of turn-off is that, like the basic reaction to EMF, the reaction to turn-off is effected by some slow system, since the latent period of the reactions is measured in seconds.

A second difference is observed in the identical form of the changes on the EEG during the basic reaction to EMF and during the reaction to turn-off.

On the other hand, our results can indicate a certain independence of the mechanisms responsible for the basic reaction and the reaction to turn-off. One reaction can be realized regardless of the presence or absence of the other. Although the stability of the reaction to turn-off was usually less than the stability of the basic reaction, we cannot say that turn-off of the EMF is the weaker stimulus. In the experiments whose results are shown in Table 16, immediately after isolation of a cortical strip we did not observe a convulsive EEG reaction to EMF. After some time has passed, convulsive discharges appeared on the EEG only after the EMF was turned off. Then, for a long time, convulsive discharges appeared both at turn-on and at turn-off of the EMF, but in the subsequent period only turn-off caused the described reaction. Finally, the convulsive discharges disappeared.

Thus, in certain cases, the reaction to EMF turn-off can appear more sharply than the reaction to turn-on.

The stability of the reaction to turn-off is especially noticeable. For example, the stability of this reaction and its latent period during exposure to an SHF or a constant magnetic field did not change after sectioning the mid-brain, although the corresponding indices of the basic reaction underwent significant changes.

At the start of our description of the reaction to turn-off, we indicated its nonspecific character; light, sound, an SHF field and a CMF caused similar reactions. In this connection we should note that a similar reaction to turn-off was noted after exposure to ionizing radiation [Grigor'yev, 1963]. In tests on an isolated frog retina, it was shown that the reaction to turning on a light carries information about the strength of the stimulus, and the reaction to turn-off, about its duration [Val'tsev, 1964]. We feel that clarification of the role of the reaction to turn-off is an interesting neurophysiological problem. /147 Certain general mechanisms for the reaction of excited structures to different stimuli find expression in this event. More than likely, this reaction is related to the tracking processes.

#### Reactions at the Moments Electromagnetic Fields are Turned On and Off

Certain investigators of the biological effect of EMF have noted reactions to generator turn-off [Popov, 1940], but these were frequently reactions with a short latent period. Consequently, the noted effects cannot be the reaction to turn-off we have described above. Most likely, these were reactions similar to the desynchronization reactions of the EEG that occur at the moment the generator is turned on and off. The reactions to turn-on and turn-off were studied in greatest detail in the experiments on the effect of a CMF on the CNS, since

there we spoke about the possible induction of an electrical current in the brain. However, this type of reaction occurred even more frequently during the influence of UHF and SHF fields on the rabbit head. For example, in experiments on the effect of a pulsed SHF field with a power flux density of  $10 \text{ mw/cm}^2$ , we observed the desynchronization reaction at turn-on in 31% of the cases, and at turn-off, in 12%. We should note that the corresponding indices at electromagnet turn-on and turn-off were 7 and 19%.

Some part of the reactions at the moment of turn-on and turn-off can be explained by the effect of the clicks that appear when the generator is turned on and off. But control tests with "false" switching, when there was a sound, but no field, with silent switching of the generator and with deafened rabbits, showed that the analyzed reactions occurred primarily during the appearance and disappearance of EMF.

Are these reactions connected with the basic reaction and the reaction to turn-off? We feel they are not, and this is why. The reactions to turn-on and turn-off can appear independently of each other and of other reactions, which does not indicate that the electrographic reactions during changes in the field contradict the basic reaction and the reaction to turn-off. Furthermore, after sectioning of the midbrain, the number of reactions occurring during changes in the EMF decreases sharply, which can testify to their peripheral, reflex origin. It is fully probable that these reactions are a result of an effect of EMF on the receptors.

In their latent period (equal to a fraction of a second) and their electrographic expression in the form of desynchronization, the reactions that occur during a change in EMF are similar to the EEG reactions observed during the appearance and disappearance of such known stimuli as light, sound, an electrical current, etc. The difference was that the desynchronization reaction during change in the EMF occurred very rarely in comparison with similar reactions to known stimuli. /148

Finishing our analysis of the EEG reactions that occur during change in the EMF, we must say that these reactions are inherent to all the fields we studied, both variable and constant. Such reactions can hardly be explained by an induced electrical effect since an ESF causes these reactions only at the beginning of exposure and immediately after its cessation. The observed effects are probably nonspecific changes in the EEG that reflect the orienting reaction.

We can assume that reflex effects play a large role in the appearance of the desynchronization reactions. The tests with an ESF showed that reactions can occur at the moment of turn-on or turn-off when the basic reaction was absolutely not observed, i.e., the mechanisms of the formation of these reactions are probably different. We have already noted the possibility of different mechanisms for the basic reaction and the reaction to turn-off. We can formally separate three types of EEG reactions in response to the influence of EMF: 1) desynchronization reactions, which occur at generator turn-on and turn-off and which are evidently effected by one mechanism; 2) the basic reaction, which is manifested as an increase in the number of spindles and slow waves during the whole time of exposure; 3) the reaction to turn-off, which is externally similar to the basic reaction, but differs from it in the mechanism of its appearance

and in quantitative characteristics. After this general survey of the EEG reactions to EMF we can proceed to a more detailed characterization of the basic reaction.

### The Basic Reaction

The strengthening of spindle-shaped activity in the rabbit EEG that occurs during exposure to EMF on the animal's head can also be recorded in the absence of this influence. There are probably many other unconsidered stimuli that, like EMF, can cause spindle-shaped activity on the EEG. Only localization of the influence over time allows us to statistically separate the useful signal from the noise level. Consequently, the unstable character of the reaction to EMF can be explained not only by a variation of excitability, but also by the effect of unconsidered stimuli on these structures, although more than likely these two circumstances are two sides of the same process.

It is widely accepted that spindles are recorded on the EEG during sleep, /149 during light barbiturate anesthesia, in a classical isolated brain preparation (*cerveau isolé*) and during low-frequency electrical stimulation of the nonspecific formations of the thalamus. Although it is possible to observe a difference in the form and frequency of spindles produced by different methods, for now we shall speak of the general mechanism of their generation. It is probable that the spindles that occurred in our experiments during exposure to an EMF on the animal's head are also generated by this general mechanism [Gusev'nikov et al., 1963].

Spindles can be recorded in all sections of the brain down to the upper portions of the spinal cord. When the subject changes to localization of the section of the brain from which spindle-shaped activity is generated, some authors point to the subcortical formations [Morison and Bassett, 1945; Kennard and Nims, 1949; Schneider et al., 1952; etc.], others to the cortex [Jouvet et al., 1959; Robiner, 1961; etc.], and others emphasize the necessity of thalamocortical connections for the appearance of spindle-shaped activity [Okuma et al., 1954; Narikashvili, 1962; Serkov et al., 1960; etc.]. Since spindle-shaped activity is frequently noted in the EEG of dogs upon restoration after clinical death, there is an opinion that this activity is determined by the level of metabolism in the brain cells [Gurvich, 1964].

Recent works indicate the appearance of spindle-shaped activity in response to the influence of different stimuli. Thus, in response to an audio click spindles have appeared in the auditory cortex, the medial geniculate body and the reticular formation of the midbrain in cats drugged with curare [Kawamura and Jamamoto, 1961].

During electrical stimulation of the radial nerve with square pulses with a frequency of 5 Hz and a pulse length of 0.5 m/sec, the appearance of spindles in the cortex was observed in an unanesthetized cat at a stimulation intensity of 0.3 v, whereas changes in blood pressure and the appearance of muscle currents were not observed. At a stimulation intensity of 0.5 v, a desynchronization reaction occurred immediately in the cortex, the blood pressure changed and movements appeared. It is assumed that the reaction to weak electrical stimulation occurs due to inhibition of the ascending activating system [Pompeiana, 1963].

Discussing the results of these works, Magoun (1963) noted that spindles can be produced in the cortex during electrical stimulation of the pre-optic region or the caudate nucleus, and also after injection of glucose in the blood of a hungry dog. The increase in synchronization and the number of spindles in the EEG are sometimes connected with internal Pavlov inhibition since these electro-pathic pictures occur during extinction of conditioned reflexes, and development of differentiation and subsequent inhibition. Before the work of Pompeiana, the/150 appearance of spindles and slow waves was explained as stimulation of the non-specific thalamocortical system, but now it has been shown that such a response can be caused along specific paths. In conclusion, Magoun notes that the thalamocortical inhibiting system is in a reciprocal relationship with the reticular ascending system.

The cooling of separate sections of the reticular formation with butane or propane can produce spindles in the cortex of the ipsilateral hemisphere that disappear after stimulation by the gas has stopped [Naquet, 1963]. If the skull is opened over one hemisphere of a cat that is under fraxidilic narcosis, spindles appear in the opened hemisphere after several hours. These data support the hypothesis that the cortex plays an active role in the formation of spindles [Naquet, 1963].

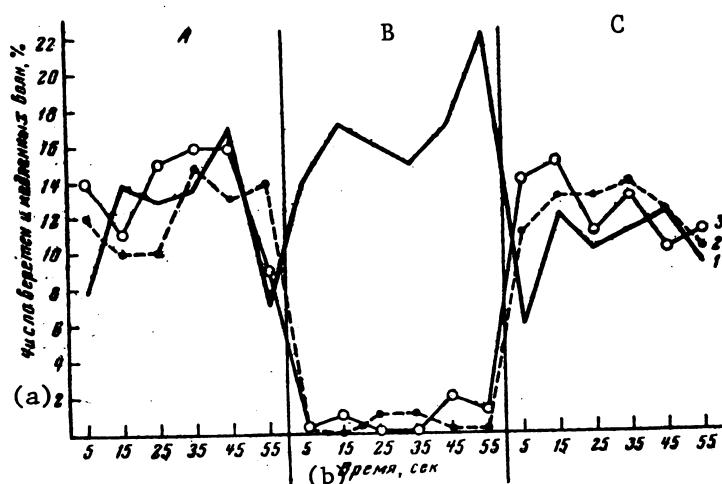


Figure 53. Dynamics of the Number of Spindles in the Electrical Activity of the Rabbit Cortex in the Background and During Exposure to a CMF (1), Light (2) or Sound (3). A = Before Exposure; B = in the Influence Period; C = in the Aftereffect Period. Key: (a) Number of Spindles and Slow Waves, %; (b) Time, Sec.

Luk'yanova alternately gave the same rabbit 40 one-minute exposures to CMF, light and sound. The dynamics of the number of spindles and slow waves indicate that during the exposure, light and sound sharply reduce the number of these EEG indices, but a CMF has a tendency to increase their number.

Summing up this brief discussion on the mechanism of the appearance of spindles on the EEG, we should note that the appearance of spindle-shaped activity is a result of complex intercenter relationships, including specific and nonspecific systems. The appearance of this form of electrical brain activity in response to external stimuli has been noted only in several recently published works. Our results of tests with embedded electrodes support the hypothesis concerning the participation of many brain structures in the formation of spindle-shaped activity.

The comparative results /151 of EEG reactions to a CMF, light and sound of average intensity are given in Figure 53. In her tests, S. N.

However, when R. A. Chizhenkova exposed a rabbit for one minute to a sound with an intensity on the human audible threshold, there was an increase in the number of spindles on the EEG, although the dynamics of these changes differed from the corresponding index for a CMF. Certain reference data [Pompeiana, 1963] and the experiments of Chizhenkova indicate that the primary desynchronization reaction cannot be observed on the EEG in response to a weak stimulus, but rather an increase in the number of spindles and slow waves. We should probably speak of the general regularities of a 3-phase effect of stimuli (weak, average, strong) in addition to the known 2-phase effect (average, strong), which has found expression in the Arndt-Schultz law. This question has already been discussed in the references [Simonov, 1962], and the study of the effect of EMF on the CNS can render a large contribution to resolving the general biological problem of the phase nature of the influence of stimuli.

To conclude our discussion of the basic EEG reaction occurring during exposure to an EMF, we should say several words about its latent period. In all experiments involving UHF, SHF and constant magnetic fields, the latent period of the EEG reaction varied from 1 to 100 sec. We have already discussed the possible physiological significance of one or another peak on the latent period distribution curve. Here, we only want to say that, changing within certain limits, depending on the functional state, the intensity, and other physical characteristics of the EMF, the latent period remains long. We have the impression that the EEG reaction to EMF is effected by some slow regulatory system. It is possible that this slow system is analogous to the one indicated in the investigations of N. A. Aladzhalova (1962) and certain American authors [Becker et al., 1962].

#### The Direct Effect on the Brain

We consider the most important fact in our investigations to be the clarification of the presence of a direct effect of EMF on isolated structures of the brain. Until now, proof of the direct effect of EMF on the CNS was seen in the more intensive reaction during local exposure on the animal's head, in the leading role of the exposed hemisphere (during a unilateral exposure), in the development of functional changes, and in the predominance of effects on the contralateral side of the body with respect to the exposed hemisphere [Bychkov, 1962; and others].

Experiments on an isolated brain preparation and a neuronally-isolated cortical strip showed that SHF, UHF and CMF have a direct effect on the brain tissue. Furthermore, this effect was more ably revealed in the isolated sections than in the intact brain.

The very fact of a direct effect of certain stimuli on the CNS has been noted by many investigators. The effect of an electrical current and certain chemical substances is a common fact. "Compounds circulating in the blood stimulate primarily the chemoreceptors of tissue and vessels (and possibly also formations similar to chemoreceptors in the brain tissue)." \* R. Granit (1957) indicated the possibility of certain receptors being doubled in the brain to improve the regulatory system.

\*K. M. Bykov: Isbv. proizvedeniya. (Selected Works.) Volume 1, 1953, p. 6-7.

By directly affecting the basic link of the regulatory processes, we can control the activity of the entire organism. The importance of a direct effect of a stimulus on the CNS is indisputable; we can speak only of the propagation of this phenomenon, of its normal or pathological character. Speaking of its propagation, we must consider both organisms with different levels of biological organization and factors of a different physical nature. It is known that one-celled animals perceive any stimulus directly with their one cell. Only after a significant period of development do multicellular organisms acquire sensory organs. In the vertebrate lancelets, for example, light is still perceived by the brain itself.

Thus, the form of the interaction of an organism with the medium in which we are interested is an old method and the only method of interaction in the lower stages of evolutionary development. Each living cell of a complex organism, regardless of its high degree of specialization, retains the ability, to some degree, to react directly to separate factors of the environment. Finally, among the cells of different systems, the nerve cell occupies one of the foremost positions in this respect.

Even such stimuli as light and sound, perceived by complexly organized special receptors, also act directly on the CNS. Thus, light acts on the diencephalon of fish [Frisch, 1911; Scharrer, 1928], amphibians [Dodd, 1963] and birds [Benoit, 1955], and sound acts directly on the spinal cord [Nasonov and Ravdonik, 1950]. Therefore, it is not surprising that stimuli for which there /153 are no specialized receptors can be perceived by such an "ancient" method, i.e., directly on the CNS.

In the future, when there is an increase in the intensity or the duration of the effect, EMF can also affect other systems and organs. Therefore, for a full description of the process of interaction of an organism with the medium, we must consider all the possible effects on the receptors, the nervous system and other systems of the organism.

We have limited our problem to a study of the effect of EMF on the CNS. But even this fragment of the complex process of interaction of an organism with the medium is not uniform. We have already noted that the structures of the hypothalamus and cortex are most reactive to the influence of CMF. It is pertinent to recall that many physiotherapists [Shcherbak, 1936; Slavskiy, 1937; and others] have noted the special sensitivity of the higher autonomic centers in the diencephalon to physical factors.

There are electrophysiological investigations of the effect of diathermy procedures. Simultaneous recording of the electrical activity of the cortex and the diencephalon has been conducted. In their analysis of the site of diathermy application, the authors state: "It is possible that bitemporal diathermy causes changes in the higher autonomic centers of the hypothalamus region. The fact that all the observed changes are most significant and constant in the diencephalon, and that changes in the cerebral cortex either follow behind those in the diencephalon, or generally do not exist, also allows us to consider the changes in the diencephalon after bitemporal diathermy as primary. The changes in the cerebral cortex are the result of secondary effects of diathermy through

the centers of the diencephalon."\*

As our experiments with a CMF have shown, the presence of the most intensive reaction of the diencephalon still cannot be considered direct proof of the priority of just this section of the brain in the reaction. We can assume that the changes in electrical activity occur synchronously in all sections of the brain, that the changes in the diencephalon are of secondary origin, but more intensive, etc. However, the certain similarity in the electrical reaction of the brain to EMF and high-frequency currents allows us to assume that the reactions we have studied are nonspecific.

As for the question regarding the precedence of the appearance of an electrical reaction in the cortex or the diencephalon, we should note that an isolated cortex can react to EMF. We shall try to clarify the role of the diencephalon in experiments on fish, in which the cortex is lacking.

In concluding our discussion of the results obtained by means of electrographic methods, we want to note that the methods we applied are rather artificial, are necessarily connected with considerable intervention in the behavior of animals, and are frequently just acute tests (isolation of different sections of the brain). The unavoidable harnessing of the animal created additional stimulation, not to speak of the embedded electrodes, which, by themselves, induced definite trauma and also necessitated the removal of the scalp from the upper surface of the skull. /154

But, like any other method, electrography also has its advantages. Only by means of this method could we show the direct effect of EMF on many structures of the brain, establish the participation of neurons in the reaction to EMF, and distinguish the reaction to turn-off. We look for further study on the physiological effect of EMF on the CNS: on the one hand, in investigations of the morphological changes caused by EMF in the brain; and on the other hand, in an analysis of the physiological reactions of an intact organism to EMF by the method of conditioned reflexes, as well as by other methods.

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\*Blagovidova et al.: Byull. Eksperiment. Biol. i Med. 53(5): 12, 1962.

P A R T   I I .   T H E   C O N D I T I O N E D   R E F L E X  
M E T H O D   O F   S T U D Y I N G   T H E   E F F E C T  
O F   E L E C T R O M A G N E T I C   F I E L D S   O N  
T H E   C E N T R A L   N E R V O U S   S Y S T E M

/155

We would like to begin this section of our investigation with a statement by the well-known Soviet physiologist, L. A. Orbeli. "Until now, we have experimentally studied the effect of these ultrahigh frequencies from a narrow practical point of view: their application in technology, their use in medicine, etc.; but now they have become one of the possible factors in the evolutionary process. We must therefore study ultrasonic frequencies, electromagnetic waves of different frequencies, and ultraviolet light not only from the point of view of their effect on individual functions and individual organisms, but we must also study them from the point of view of their possible role in the evolutionary process, and the role that they have played in the evolutionary process, thereby clarifying how they can affect future generations."\*

The evolutionary approach to the study of the biological effect of electromagnetic fields has just begun. There are now fragmentary reports concerning the participation of EMF in the basic processes of the origin of life [Miller, 1955], the effect of EMF on the formation of biological rhythms [Brown, 1962], the ontogenetic development of the organism [Barnothy, 1960], the effect of EMF on the higher invertebrates [Brown et al., 1960], and the orienting effect of a CMF on migrating birds and fish [Yeagley, 1947, 1951]. In the light of the fragmentary data on the effect of natural-state EMF on the functions of the entire organism, we set before ourselves the basic task of studying the effects of EMF on the most sensitive index of the activity of an animal, i.e., on its behavior. As an adequate method of investigation, we selected the Pavlov method of conditioned reflexes, which has been successfully used in studying the properties of many stimuli which act on exteroceptors and interoceptors, as well as directly on the CNS.

In studying the biological effect of EMF, the effect of different fields on/156 pre-developed positive and negative conditioned reflexes to light and sound has most frequently been investigated. Detailed reports on such studies are given in the beginning of the first chapters of this part of the book. It seemed to us that the most complete data on the physiological effect of any factor can be obtained by using it as a conditioned stimulus.

This type of work has been carried out on man during the development of a conditioned electrodefensive reflex to low-frequency EMF [Petrov, 1952], on fish during the development of motor (feeding) conditioned reflexes to a CMF [Lissman, 1958] and on white mice in the development of electrodefensive conditioned reflexes to an SHF field [Malakhov et al., 1963]. In all these cases, the authors managed to develop a conditioned reflex to EMF, but it was distinguished by its late appearance and instability.

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\*L. A. Orbeli: Izbrannyye trudy. (Selected Works.) Volume 1. Moscow and Leningrad, Izd-vo AN SSSR, 1961, p. 65.

## EXPERIMENTAL METHODOLOGY AND TREATMENT OF RESULTS

The tests were conducted on rabbits, pigeons and fish (carp, goldfish, stickleback, flounder and bullhead). Rabbits were used in order to compare the results obtained by the electrographic and conditioned reflex methods, and pigeons and fish were selected because of their ability to orient themselves along the earth's magnetic field during long migrations. This explains why we used a CMF in most tests. Besides a CMF, we studied the effect of a UHF field and  $\gamma$ -radiation only in the experiments with fish, on which the essential part of the investigations was carried out.

### Procedure for Development of Conditioned Reflexes

Considering the results of electrophysiological tests that proved the presence of the biological effect of a CMF, we tried to develop conditioned defensive reflexes in rabbits by the shaking-off method [Bolokhov and Obraztsova, 1958], using a 300-Oe CMF. Numerous experiments that involved recording the rabbit EEG have shown that a CMF does not cause unconditioned motor reflexes in animals. The sound stimulation (a 500-Hz tone produced by a ZG-10 generator) used as a control also did not cause movements. Unconditioned electrical stimulation from the ZG-10 generator was applied to the rabbit's ear. During the tests, the animal was harnessed to a stand just as in the electrophysiological experiments. Its head was placed between the poles of an electromagnet. Head /157 movements were recorded on a kymograph with the aid of an electrical contact, the closing of which caused the movement of an ink stylus.

The isolated effect of the conditioned stimulus lasted 7 sec, and its joint effect with the unconditioned stimulus lasted 3 sec. During a test, we administered 10 combinations with an interval of 5-10 min. A total of 14 tests were conducted on an individual rabbit, so that each received 70 exposures to sound and magnetic stimuli.

In the tests on birds and fish, we used the food-getting method developed in the laboratory of Professor L. G. Voronin. The essence of this method is that before the animal received food reinforcement, it had to make a special food-getting motion during the influence of the conditioned stimulus: in particular, the pigeon had to peck at a handle. The fundamental description of this method is given in the works of L. G. Voronin (1953, 1954, 1957); the specific method for fish, in the works of N. V. Prazdnikova (1953); and for birds, in the work of A. V. Baru (1953).

The diagram of the apparatus for developing conditioned food-getting reflexes in pigeons is given in Figure 54. During the influence of the conditioned stimulus, the pigeon pecks at a handle, thereby closing an electrical contact, or pecks at a tin plate fastened to a Marreyev capsule, and this conditioned reflex movement is noted on the kymograph drum via air transmission through another Marreyev capsule. The conditioned stimuli were light from a 40-w electric lamp, a gurgling sound, and a 200-Oe CMF created by a solenoid wrapped around the chamber. Most frequently the food reinforcement was hemp

seeds. The exposure time to the conditioned stimulus was 20 sec. Reinforcement was given immediately after the conditioned reaction was accomplished. The conditioned stimuli were applied in intervals of 1-3 min. In a test we applied the conditioned stimuli 10-20 times. To develop conditioned inhibition after the conditioned food-getting reflexes had been developed without a stereotype, the pigeons were exposed to a combined stimulus (a CMF + light) 2-3 times during a test; for this the solenoid was turned on 10 sec before the light was turned on, but both stimuli were turned off simultaneously. The combined stimulus was not accompanied by food reinforcement.

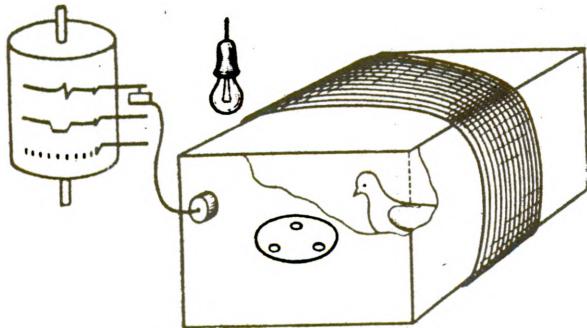


Figure 54. Diagram of Apparatus for Developing Food-Getting Conditioned Reflexes in Pigeons.

The diagram for developing conditioned food-getting reflexes in fish is shown in Figure 55, A. By pulling the bead in response to the conditioned stimulus, the fish closes an electrical contact, which is recorded on the kymograph drum with the aid of an electromagnetic marker. The conditioned stimuli that we used were the light from a 50-w electric lamp placed over the aquarium, the sound of an electric bell attached to the wall of the aquarium, and a CMF. The CMF was created by a permanent magnet and also by switching on an electromagnetic or a solenoid.

The diagram of the apparatus for developing the electrodefensive conditioned reflex is shown in Figure 55, B. As in the method of J. P. Frolov (1925), the conditioned reflex response is the general motion of the fish recorded on the kymograph drum with the aid of two Marreyev capsules. To do this, one end of a thread was attached to the dorsal fin of the fish and the other end was fastened to the handle of one Marreyev capsule. The conditioned stimuli were the light of a 50-w bulb, the sound of an electric bell, and the variable 50-Hz magnetic field of the solenoid wound around the aquarium. The exposure to the conditioned stimulus was noted by an electromagnetic marker on the second (from the top) line of the kymograph. Unconditioned electrical reinforcement was applied through electrodes immersed in the aquarium; current was fed to them from the secondary winding of the induction coil. The moment the unconditioned reinforcement was turned on was noted on the kymograph by means of an electromagnetic recording on the third line from the top. As in the tests employing the food-getting method, the time was noted on the bottom line of the kymograph in 5-sec intervals.

Not all the fish were easily secured with a thread to the handle of the Marreyev capsule. Therefore, in tests with flounder and bullhead, we did not record the conditioned reflex movements of the fish on the kymograph.

The movements of the fish were also recorded with a probe floating on the water; the needle transducer that transformed mechanical oscillations into

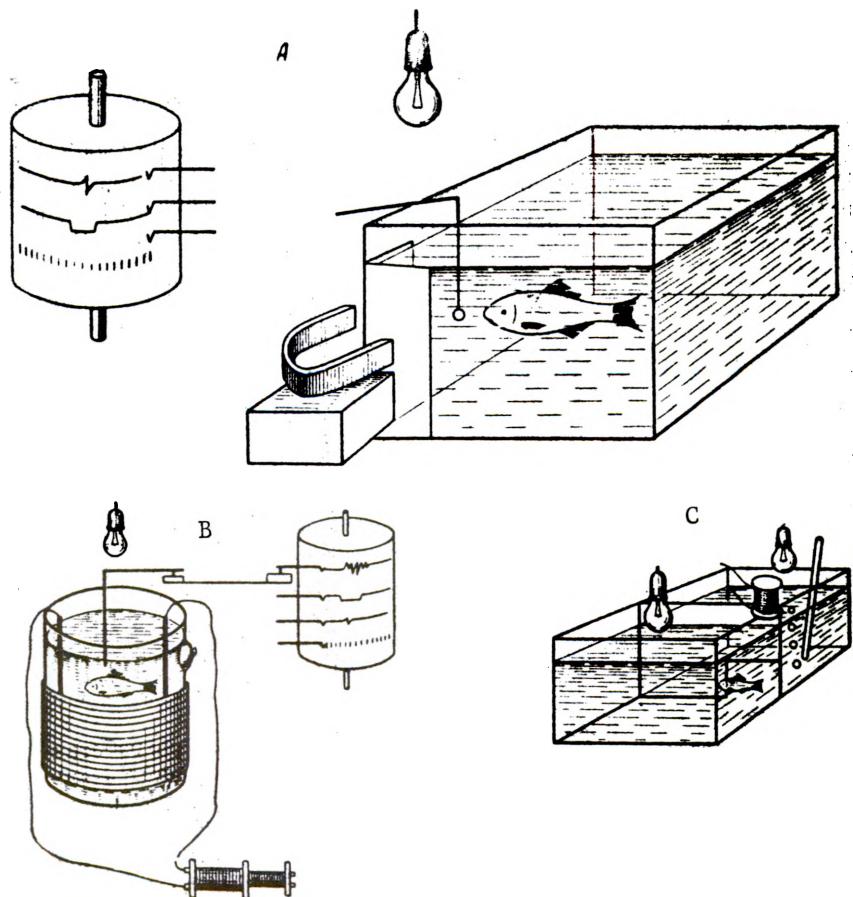


Figure 55. Diagrams of Apparatus for Developing Conditioned Reflexes in Fish by the Food-Getting (A), Electro-defensive (B) and Defensive (C) Methods.

electrical oscillations was attached to it. As a result of the motion of a fish the water began to oscillate, and the probe with it, which caused the transducer to move. An electrical signal was fed from the transducer to the input of an amplifier, and then to a recording oscilloscope. The feeding of conditioned and unconditioned stimuli were automatically recorded. The conditioned stimulus for this method was total-body  $\text{Co}^{60}$  gamma-irradiation in a dose of 0.5–0.1 R/sec (designated below as irradiation) and a 500 v/m UHF field created by a UVCh-40 (UHF-40) generator.

We also used another defensive method, the diagram of which is given in Figure 55,C. In this method, the conditioned reflex movement is the swimming of the fish from one half of the aquarium to the other. The fish swam through an opening in a partition that divided the aquarium into two equal parts. The /160 conditioned stimulus was the light of a 50-w electric lamp; one light was placed

over each half of the aquarium. The conditioned stimulus consisted of turning off the light in the half of the aquarium where the fish was at the given moment and turning on the light in the opposite half. A CMF created near the partition by turning on an electromagnet or a solenoid, or by setting up a permanent magnet, also served as the conditioned stimulus. The unconditioned reinforcement consisted of mechanical stimulation with a finger or with air bubbles passed through a plastic hose.

In the development of a positive conditioned reflex by the food-getting method, the conditioned stimulus lasted 30-40 sec, and by the defensive method, 10-15 sec. In the latter case unconditioned reinforcement was given for 7-10 sec only if there was no conditioned response. In the development of conditioned inhibition, the magnetic field was created 10 sec before the positive conditioned stimulus was given, and it was turned off together with this stimulus. Tests were conducted once or twice a day. Conditioned stimuli were applied 10-20 times in each test, of which 1-5 inhibiting stimuli were applied without a stereotype. All the tests were recorded. The lag period was determined by a stop watch with an accuracy to 0.1 sec.

#### Surgical Methodology

To determine the physiological mechanism of EMF perception in fish, we performed denervation of the lateral line organ, enucleation and destruction of different sections of the brain. We compared the results on the development of conditioned reflexes in intact and operated fish. In certain tests the operation was conducted after preliminary development of the conditioned reflexes.

Denervation of the lateral line organ was performed by bilateral section of the n. lateralis and n. suborbitalis according to the method described by G. A. Malyukina (1955). The fish was taken from the water and wrapped in a wet cloth. The nerves were dissected and transected. When the fish was put back in the aquarium it did not differ in external behavior from intact fish. The described method did not achieve full denervation of the lateral line organ and our problem was to clarify the question of how partial denervation of the lateral line organ affects the conditioned reflex activity of fish.

Enucleation was accomplished by sectioning the optic nerve and completely removing the eyeball from the orbit. Immediately after the operation the fish developed motor restlessness and ran into the walls of the aquarium. However, after several days the external behavior of the blinded fish did not differ /161 from the behavior of intact fish, although they could always be distinguished by the darker coloring of their skin surface.

The operations to remove different sections of the brain were conducted by the method described by A. I. Karamyan (1949). A fish was taken from the aquarium and wrapped in a damp cloth in such a way that its head remained free. After 1-3 min in air the fish ceased to move. Holding the fish in the left hand, with scissors in the right, we made a transverse section of the skull bone behind the line connecting the posterior edges of the eyes. Then we made two parallel longitudinal incisions back from the edges of the transverse section.

The piece of bone was raised, but left attached to the rear side; the fatty tissue was removed with cotton swabs and the brain was exposed.

The brain of a goldfish (Figure 56) is divided by sharp boundaries into forebrain, midbrain (visual tegmenta) and the cerebellum. The forebrain could be removed and the visual tegmenta damaged with sufficient ease because of their surface position. Complete removal of the cerebellum was complicated by the fact that its valve is located under the visual tegmenta. Destruction of the diencephalon, which composes the basic part of the brain under the visual tegmenta, was a more complex operation. We destroyed the anterior part of the diencephalon after removal of the forebrain.

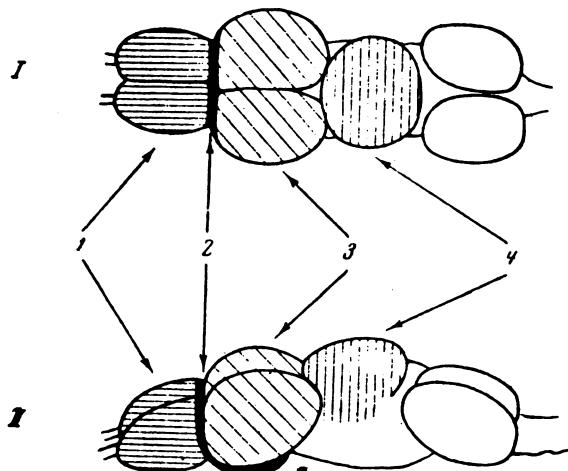


Figure 56. Diagram of the Structure of the Goldfish Brain. 1 = Forebrain; 2 = Diencephalon; 3 = Midbrain; 4 = Cerebellum; I = Top View; II = Side View.

The results of the operations /162 to remove the cerebellum were controlled very strictly because the main role in accomplishing the fixing functions in fish is ascribed to this section of the brain [Karamyan, 1949; Malyukina, 1955]. The results of operations to remove the forebrain and the visual tegmenta were checked visually on an intact brain. The results of operations to remove the cerebellum were checked on a series of brain sections of dead fish. Removal of the cerebellum was complete. The morphological work was conducted in the CNS Morphology Section of the Department of the Physiology of Higher Nervous Activity at Moscow State University under the direction of Professor G. I. Pol'yakov and his research associate, V. M. Svetukhina.

After removal of the necessary section of the brain, the opening in the skull was covered with the bone and smeared with a mixture of beeswax and vaseline (in a 2:3 ratio). We evaluated the changes caused by the extirpations from the character of the movements of the fish immediately after the operation, from how they related to food, but basically from the results of the development of conditioned reflexes to a magnetic field, and to light and sound. The rate of formation and the stability of the conditioned reflexes after extirpation of separate sections of the brain were compared with the corresponding indices for intact fish.

During destruction of the midbrain, each visual tegmentum was peeled off the brain and cut along the edges with an eye knife. For several hours immediately after the operation the fish lay immobile on the surface of the water. Some of them were in a contorted position. The fish swam in circles, rolled from side to side, accelerated rapidly and slowed down, and sometimes they turned around the longitudinal axis of the body. These disturbances in

movements are probably related to primary or secondary damage to the cerebellum. After the operation the fish did not actively take food, but they would swallow insects placed in their mouths.

To remove the valve of the cerebellum, the visual tegmenta were moved slightly, the valve was freed from under them, raised upwards, and cut from the body of the cerebellum by a vertical section. The body of the cerebellum was separated from the remaining brain by a horizontal section. For some time immediately after the operation the fish lay on their sides on the surface of the water. The first motions of the fish were uncoordinated, i.e., they swam in the lateral position, and made circles and corkscrew movements. However, after several days some fish assumed their normal body position and began to swim, rolling slightly. The operated fish did not begin to actively take food for two weeks after the operation. In the same period of time we managed to develop relatively stable conditioned reflexes in them, although the appearance of conditioned reflexes could also be observed sooner.

The operation of removing the forebrain is simple and easily withstood by /163 fish. After opening the skull, we separated the large hemispheres from the remaining brain mass with a vertical section and removed them from the skull. After the operation the fish immediately assumed their normal position, moved about normally, and began to actively take food after several minutes. Conditioned reflexes could be developed immediately after the operation, although we usually started to develop them after several days.

We destroyed the diencephalon after preliminary removal of the forebrain by a section backwards and downwards into the base of the brain under the visual tegmenta. In doing this, we basically destroyed the hypothalamic part of the diencephalon [Kappers et al., 1936; Zelikin, 1957]. The behavior of the fish after the operation was the same as after the removal of the forebrain, although in certain fish we observed brief disturbances in movements, and these fish began to actively take food later. The vision of certain fish was destroyed and their coloring became darker.

#### Methods of Treating the Results

A conditioned reflex is primarily characterized by its rate of formation. Here we consider the rate of its appearance, i.e., the number of applications of the conditioned stimulus necessary for the first performance of the reflex, and the rate of its fixation, i.e., the number of applications of the conditioned stimulus after which the conditioned reflex appears five times in a row. We calculated the stability of the conditioned reflex, i.e., the percentage ratio of the number of applications of the conditioned stimulus that caused a conditioned response to the total number of applications of the stimulus, within one test and also in 50 and 100 applications of the stimulus. The stability of the conditioned reflex in the first 50 or 100 applications of the conditioned stimulus was used as an index in comparing the conditioned reflexes to one stimulus in different animals and the reflexes to different stimuli in the same animal. In calculating the lag period of the conditioned response we usually counted only the applications of the conditioned stimulus that caused a response.

The average of the lag period was calculated within one test, and in 50 or 100 applications of the stimulus.

Although intersignal reactions were observed in all experimental animals in the development of conditioned reflexes by different methods, we analyzed the intersignal reactions only in tests according to the food-getting method. Intersignal reactions in the form of intermediate salivation were noted even in the first works of the Pavlov school; however, they became the object of a special study comparatively recently [Voronin, 1954; Skipin, 1947; Shirkova, 1956; Meshcherskiy, 1957; and others]. It has been noted that the number of intersignal reactions depends not only on the type of nervous system, the character and degree of the unconditioned stimulus, but also on the conditioned stimulus. This fact forces us to analyze the dynamics of intersignal reactions with particular care in order to clarify the properties of the factor used as the conditioned stimulus with respect to all indices.

The listed indices of conditioned reflex activity were tabulated and expressed graphically. The test results were sometimes illustrated by kymograms or test records.

## CHAPTER 5. THE DEVELOPMENT OF CONDITIONED REFLEXES TO ELECTRO-MAGNETIC FIELDS IN RABBITS, PIGEONS AND FISH

Although representatives of the mammals, particularly the dog [Pavlov, 1927, 1951], served as the classical subject in the study of higher nervous activity, the basic regularities of behavior are common for mammals, birds and fish [Bayandurov, 1937; Frolov, 1941; Voronin, 1957; Thorpe, 1956; Bull, 1957]. The method of conditioned reflexes has been used especially widely to determine the receptor possibilities of different species of animals.

### The Development of Conditioned Reflexes to a Constant Magnetic Field in Rabbits

Figure 57 shows the results of experiments on the development of conditioned shaking-off reflexes to sound and CMF in one rabbit. We can see that in the first 4 tests, when intersignal reactions abounded, certain movements could coincide with the influence of the CMF 1-2 times per test. Later, the conditioned reflexes to sound tended to increase, and a reaction of the rabbit did not occur in response to turning on the electromagnet. These tests were conducted by R. A. Chizhenkova on 3 rabbits. Not one of the animals developed a conditioned reflex to a CMF.

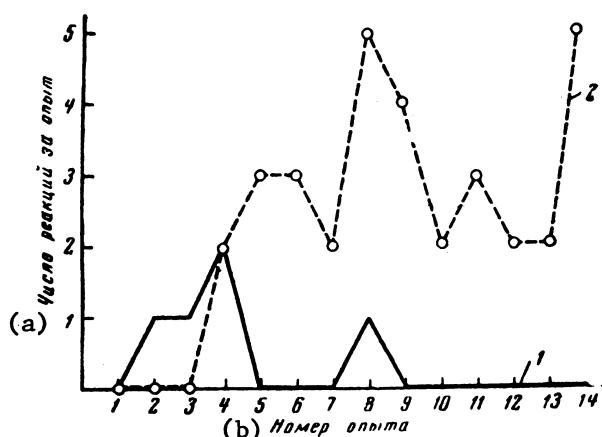


Figure 57. Dynamics of the Development of Conditioned Defensive Reflexes in Rabbits to a Magnetic Field (1) and to Sound (2). Key: (a) Number of Reactions per Test; (b) Test Number.

Although we cannot now make a final conclusion about the possibility<sup>/165</sup> of developing conditioned reflexes to a CMF in rabbits, since only 70 combinations were given and the strength of the CMF was low, the test results testify to the weaknesses of a CMF as a stimulus in comparison with sound.

Since we frequently observed EEG changes after a 7-second exposure to a CMF, it is possible that the duration of the isolated influence of the CMF as the conditioned stimulus was insufficient. However, increasing the duration would introduce additional complications into the process of developing a conditioned reflex. Changing to the feeding method would require huge new sources of CMF. Therefore, we decided to conduct experiments with conditioned reflexes on smaller animals, representatives of other classes of vertebrates.

### The Development of Conditioned Reflexes to a Constant Magnetic Field in Pigeons

We tried to develop a positive conditioned reflex to a CMF and conditioned inhibition to a combination of stimuli (CMF + light) in pigeons. The tests were conducted according to the food-getting method.

#### The Development of a Positive Reflex to a Constant Magnetic Field

The results of a series of experiments conducted on 4 pigeons showed that a positive conditioned reflex to a CMF could not be developed in pigeons, although each bird was given from 190 to 427 combinations. The conditioned reflex to light appeared in the same pigeons after 7-16 combinations and became fixed after 18-26 combinations. /166

In calculating the number of intersignal reactions we found that when light was used as the conditioned stimulus 41, 135 and 52 intersignal reactions arose in 3 pigeons for 100 applications, but when a CMF was used, 133, 208 and 128 intersignal reactions arose. This fact cannot be explained by a difference in food excitability since both the CMF and light were reinforced with food. The excess of intersignal reactions also cannot be explained by an orienting reaction to a new stimulus because in pigeon no. 1, for example, during 400 applications of the stimulus the number of intersignal reactions during the development of a conditioned reflex to a CMF was approximately 3 times greater than the number of intersignal reactions during development of a light conditioned reflex. We can conclude that the physiological effect of a CMF is revealed by the increase in the number of intersignal reactions. However, the cases of intersignal reactions we considered occurred in the intervals between exposures and can be explained only by the aftereffect.

We felt it was important to check whether the increase in the number of intersignal reactions occurred during the application of the CMF. We managed to do this on 2 pigeons (no. 3 and 4) in a series of experiments in which a positive conditioned reflex to light was developed in 10 tests, and in 10 other tests we switched on the solenoid for 10 seconds before the start of the light effect and switched it off together with the light. The tests in which the CMF was used were irregularly mixed with tests in which only the manipulations accompanying switching of the solenoid were performed, but current was not fed to the solenoid. Each application of light with or without a CMF was reinforced with food. We calculated the total number of intersignal reactions per test and the number of intersignal reactions for the 10 seconds before the light was turned on, i.e., for the period of time when the CMF operated independently. The test results are given in Table 17.

In some pigeons the number of intersignal reactions for the whole test with the influence of a CMF exceeded the number of intersignal reactions for the whole test without the influence of the magnet. However, this excess becomes insignificant or completely disappears if we subtract the total number of intersignal reactions for the 10 sec before the light was turned on from the

TABLE 17. NUMBER OF INTERSIGNAL REACTIONS IN PIGEONS  
DURING THE INFLUENCE OF A CMF AND IN ITS ABSENCE.

Test Number	For the 10 sec before the light was turned on				For the whole test			
	pigeon no. 3		pigeon no. 4		pigeon no. 3		pigeon no. 4	
	with the CMF	without the CMF	with the CMF	without the CMF	with the CMF	without the CMF	with the CMF	without the CMF
1	22	12	33	2	45	34	4	6
2	9	5	1	2	16	18	2	3
3	22	0	1	0	50	1	1	2
4	13	1	2	0	26	7	3	1
5	7	5	5	1	13	10	7	2
6	9	2	3	6	15	8	5	13
7	6	3	3	0	13	21	6	0
8	5	9	5	0	10	29	9	2
9	31	7	0	0	60	20	0	2
10	11	3	0	0	23	27	1	0
Total	135	47	23	11	271	175	38	31

total number of intersignal reactions for all 10 tests. For pigeon no. 3 this difference is  $(271 - 135) - (175 - 47) = 136 - 128 = 8$  intersignal reactions, and for pigeon no. 4  $(38 - 23) - (31 - 11) = 15 - 20 = -5$  intersignal reactions.

Consequently, the difference in the number of intersignal reactions in the test and in the control basically appears during the influence of the CMF. Actually, in pigeon no. 3 the number of intersignal reactions during the influence of the magnet was approximately 3 times greater (135 vs. 47), and for pigeon no. 4, approximately 2 times greater (23 vs. 11) than in similar periods of time in the tests without the application of the magnet. This series of tests shows that during the influence of a CMF the number of intersignal reactions increases significantly. In the intervals between applications of the magnet we do not find an increase in the number of intersignal reactions and we explain this by the fact that the magnet acts together with the light in this case.

Finishing our discussion of the question concerning the effect of a CMF on the number of intersignal reactions, we must note that a CMF increases the number of intersignal reactions both during its influence and in the intervals between applications of the stimulus, when it is applied without the light.

Consequently, the physiological effect of a CMF also appears after the end of its physical action.

#### The Development of Conditioned Inhibition to a CMF + Light Stimulus

The lack of success in developing positive conditioned reflexes to a CMF in pigeons forced us to try to develop conditioned inhibition to this factor. The tests were conducted on 3 pigeons. We applied a combined CMF + light stimulus after fixation of the light-conditioned reflex.

In pigeon no. 2 the CMF caused an inhibiting effect in the first application.

In pigeons no. 1 and 3 the inhibiting effect of a CMF appeared on the 5th application. As an illustration we give the kymograms of the tests, on which one can clearly see the presence of the inhibiting effect of a CMF (Figure 58).

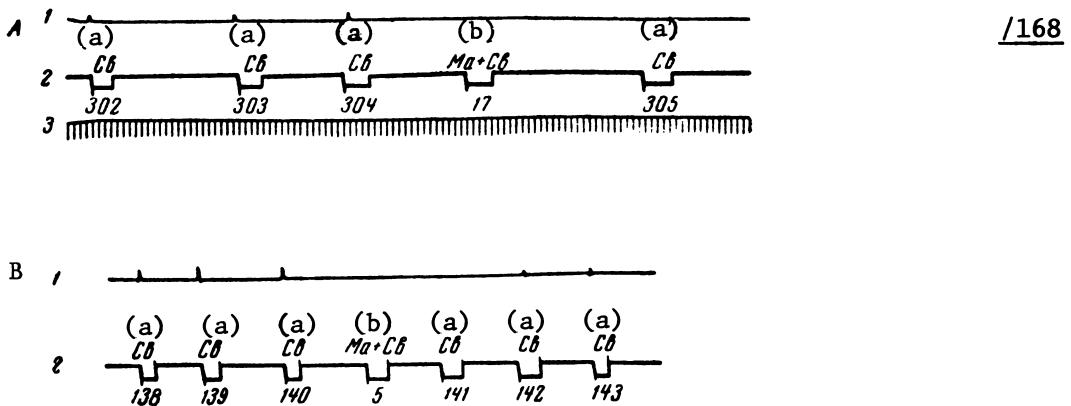


Figure 58. The Inhibiting Effect of a Constant Magnetic Field on a Light Conditioned Food-Getting Reflex. A = Pigeon No. 2; B = Pigeon No. 1; 1 = Marking of the Food-Getting Motion; 2 = Marking of the Effect of the Conditioned Stimulus; 3 = Time Marking with a 5-Second Interval; MF = Magnetic Field; L = Light; the Numbers Indicate the Number of the Stimulus Application. Key: (a) L; (b) MF + L.

We should note that the effect of a CMF is sometimes exhibited not only in the time when the solenoid is turned on, but also during the next application of the light stimulus. This sequential inhibition strongly varied in intensity. Most frequently, it increased the lag period for the light stimulus following the CMF. The stimulus following the conditioning-inhibiting stimulus often did not cause a conditioned response. In pigeon no. 2 the CMF applied in the fourth position in the test inhibited not only the response to the light given together with the CMF, but also the reaction to the next 6 light stimuli. The

pigeon stopped pecking at food given to it, and tried to break out of the cage. Sometimes a negative behavior reaction to a CMF appeared: the pigeon walked away from the feeder, although usually, even in the intervals between stimuli, the pigeon stood near the feeder.

All the cases of inhibition are summarized in Table 18. The tabular data show that, although sequential inhibition was observed most frequently in pigeon no. 1, it appeared most intensively in pigeon no. 2, for which a third of all the cases of sequential inhibition are made up of full inhibition of more than 2 responses to light. In pigeon no. 3 sequential inhibition appeared less marked in both frequency and intensity than in the two other pigeons. /169

It is evident that in 9-19% of the cases the effect of a CMF appears only in the form of sequential inhibition. Cases of immediate inhibition are more frequent. The stability of the inhibiting reaction is essentially reflected in the last column of Table 18, where all the cases of the inhibiting effect of the magnet are totaled. We see that in pigeon no. 1 the magnet failed to cause an inhibiting effect in only 6 cases out of 70. In pigeons no. 1 and no. 2 the stability of the inhibiting reaction attained 60%.

In discussing the data obtained, we wondered whether the procedure of turning on the solenoid and the sounds that arise during this may cause the immediate inhibition, and whether the absence of food reinforcement under the influence of the magnet is the cause of sequential inhibition. To check these questions we conducted control tests on pigeon no. 2, for which sequential inhibition was most intensive. There were 35 tests in the series: 17 continued the development of conditioned inhibition in the normal manner, but in 18 tests the procedure of switching on the magnet differed in that there was no electrical current in the solenoid. During the pretended switching, as during the actual, food reinforcement was not given. During this series of tests 50 applications of the CMF + light stimulus and 50 false switchings plus light were given. Tests with the influence of the magnetic field were randomly mixed with tests accompanied by false switching of the solenoid. Table 19 gives the comparative characteristics of inhibition observed during the influence of the magnet and in the control tests.

The total number of cases of sequential inhibition under the effect of the magnet exceeded the number of cases observed during false switching by 3.5 times (28 vs. 8%) ( $p < 0.05$ ). Consequently, our assumption that the frequent displays of sequential inhibition with the CMF + light stimulus are caused by the properties of the magnetic field, and not by the absence of food reinforcement of the preceding light stimulus, is valid.

Sequential inhibition after application of a CMF was not only observed more frequently, but it appeared with greater intensity. Thus, we see that in almost half (6 out of 14) of the cases of sequential inhibition after the influence of a CMF we observed full inhibition of one or several conditioned responses to light. After the procedure of false switching, sequential inhibition was most frequently expressed in an increase of the lag period of the conditioned reaction to the following stimulus. /171

TABLE 18. CHARACTERISTICS OF THE INHIBITING EFFECT OF A CMF DURING DEVELOPMENT OF CONDITIONED INHIBITION TO A CMF + LIGHT STIMULUS IN PIGEONS.

Pigeon no.	No. of CMF exposures	No. of cases of immediate inhibition		No. of cases of sequential inhibition				No. of cases of sequential inhibition alone		Total no. of inhibiting effects of a CMF	
		raw	%	increase in the lag period	absence of the response to the light stimulus	total	raw	raw	%	raw	%
1	70	51	73	28	7	2	3	40	57	13	19
2	87	42	48	14	4	3	11	32	37	8	9
3	73	35	48	16	9	0	0	25	34	9	12

TABLE 19. CHARACTERISTICS OF THE INHIBITING EFFECT OF A MAGNETIC FIELD AND OF THE PROCEDURE OF SWITCHING THE SOLENOID ON THE CONDITIONED LIGHT REFLEX IN PIGEON NO. 2.

Character of influence	No. of exposures	Number of cases of immediate inhibition		No. of cases of sequential inhibition				No. of cases of sequential inhibition alone		Total no. of inhibiting effects of a CMF	
		raw	%	increase in the lag period	absence of the response to the light stimulus	total	raw	raw	%	raw	%
magnetic field	50	24	48	8	4	0	2	14	28	6	12
false switching of the solenoid	50	4	8	3	1	0	0	4	8	1	2

The ancillary stimuli that arise when the solenoid is turned on may cause inhibition of the response to the light that is applied together with the magnet, but, as Table 19 shows, the conditioned light reflex is inhibited 6 times more frequently during the influence of the magnet than during false switching ( $p < 0.05$ ).

We can consider that inhibition of the conditioned reflex to light is the clearest physiological property of a magnetic field. Sequential inhibition also characterizes the physiological effect of a magnetic field, although to a lesser degree. Sometimes the CMF caused only immediate inhibition, more frequently it caused immediate and sequential inhibition, and sometimes it caused only sequential inhibition. The most complete characterization of the inhibiting effect of a CMF is a total of the cases of immediate and just sequential inhibition, which is reflected in our tables.

We should note that there was not only a quantitative, but also a qualitative difference in the conditioned response to light under the influence of the magnet and when just the solenoid switching procedure was performed. Since the lag period of the conditioned response to light averaged 2 sec, we considered a lag period of more than 3 sec to represent inhibition, and a lag period of less than 1 sec to represent acceleration. Table 20 shows the qualitative difference between the real and the false applications of the magnet.

TABLE 20. CHARACTER OF THE LAG PERIOD OF THE CONDITIONED RESPONSE TO LIGHT UNDER THE INFLUENCE OF THE MAGNETIC FIELD OR THE SOLENOID SWITCHING PROCEDURE.

Character of the influence	Number of applications	Number of cases					
		acceleration		normal		inhibition	
		raw	%	raw	%	raw	%
magnet	50	0	0	26	52	24	48
false solenoid switching	50	8	16	38	76	4	8

When the solenoid switching procedure was carried out, the lag period of the conditioned reflexes did not change in most cases (76%), decreased in 16% of the cases, and increased only in 8% of the cases. Under the influence of the CMF in approximately half of the cases we observed an increase in the lag period, but, characteristically, we did not encounter even one case of a decrease in the lag period.

Under the influence of a CMF the response to light, if it existed, was ex- /172  
pressed in a single pecking motion. The response usually occurred within the first 3 sec, and in the remaining time of the application of light with the magnet, i.e., 17 sec, the pigeon did not peck the bar. When only the solenoid switching procedure was performed, the pigeon pecked the bar throughout the time of the light effect. Thus, the inhibiting effect of a magnetic field on pigeons appeared once more.

The widespread opinion that both a positive and a negative conditioned reflex can be developed for any stimulus that the animal perceives did not agree with our results. Therefore, we decided to check whether development, i.e., the formation of the inhibiting process during the time when we did not reinforce the CMF + light stimulus with food, occurred at all. The basic index for the magnitude of the positive reflex in our tests is the lag period of the conditioned reflex to the conditioned stimulus. Changes of this index during the tests on development of conditioned inhibition to a magnet must characterize the process of forming a time relationship. To calculate all the cases of the response to the CMF + light stimulus we designated the absence of the conditioned response by a lag period equal to 25 sec, although the conditioned stimulus acted for only 20 sec. This allowance was made for convenience of numerical treatment of the material and it could help explain why there is only a tendency towards a definite change in the magnitude of the response lag period under the influence of the CMF + light stimulus. The results of each test were treated in the following manner. We determined the average lag period of the conditioned reaction to light before the application of the CMF in the test, i.e., we calculated the lag period of the reactions in which sequential inhibition from the influence of the CMF could not result. Furthermore, we calculated the average (for the test) lag period of the response to the CMF + light stimulus. Thus, on the graph we obtained 2 curves that characterized the dynamics of the lag periods of the response to light under the influence of the magnet and in its absence. But the lag periods of the conditioned responses change over a significant range from test to test, and determining the direction of the change required additional treatment of the results. We applied the graphic distribution method of treating the results: the method of the moving average. The majority of separate indices participate several times in the formation of the average index. Thus, we found the average value of 6 indices. We obtained the first point on the graph by determining the average magnitude of the lag period from the 1st to the 6th test, the 2nd point from the 2nd to the 7th test, the 3rd point from the 3rd to the 8th test, etc. The curves of the response lag periods thus developed for 3 pigeons are shown on the graphs of Figure 59. These graphs clearly show that in all pigeons the lag period of the response /174 to the CMF + light stimulus exceeds the lag period of the response to light, i.e., the inhibiting effect of the magnet is observed throughout the tests. The degree of the inhibiting effect depends upon the characteristics of the individual pigeons, but the intensity of this inhibition did not increase as the number of combinations increased. If we compare the average graph for the 3 pigeons, we will see that the curve of the lag period of the response to CMF + light has a tendency towards rectilinearity, i.e., conditioned inhibition does not develop in pigeons.

But if conditioned inhibition is not formed, then the CMF acts according

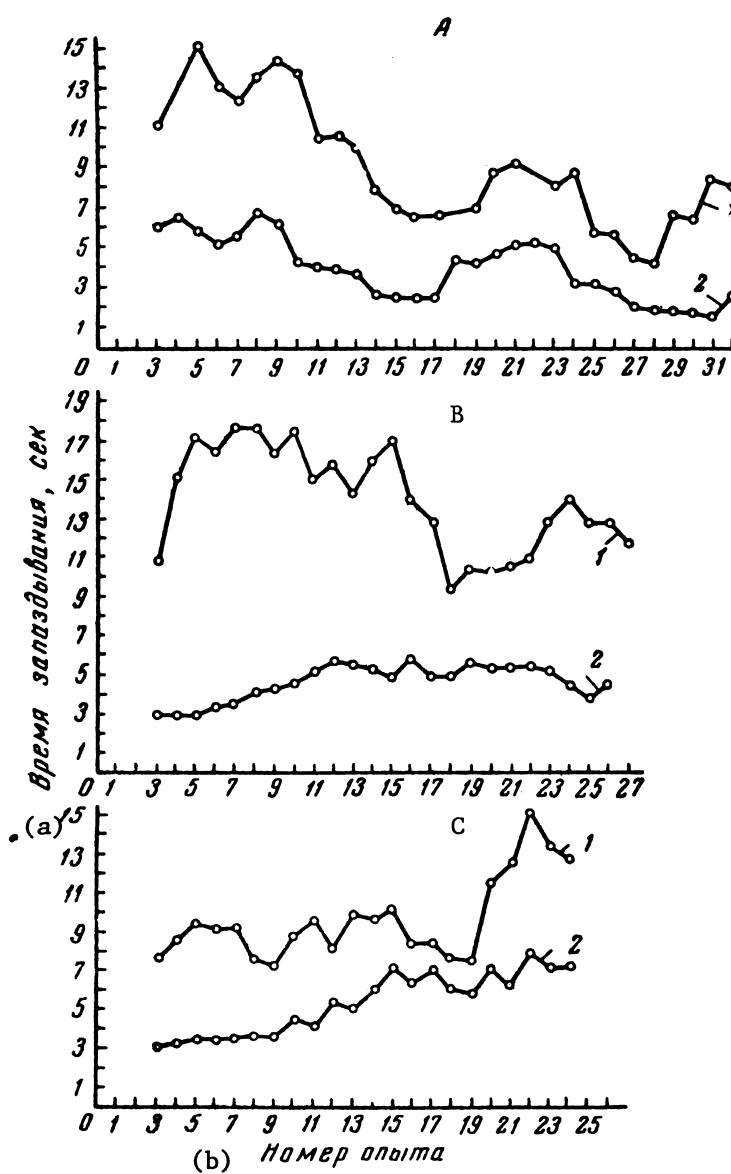


Figure 59. Dynamics of the Averaged Lag Period of the Conditioned Responses to a Constant Magnetic Field + Light (1) and to Light (2) in Pigeon No. 1 (A), No. 2 (B) and No. 3 (C).  
Key: (a) Lag Time, Sec.; (b) Number of the Test.

+ light stimulus was sometimes equal to the lag period of the response to light, sometimes it exceeded it, but most often it was less than it. In selecting the

to the principle of external inhibition. Then, an increase in the lag period of the conditioned response must also occur during food reinforcement of the effect of the CMF + light stimulus. We observed this in pigeon no. 2. As the number of combinations of the CMF + light stimulus with food increased, the lag period of the response did not decrease, but even increased somewhat, although the lag period of the response to light remained at the same level.

To check whether the conditioned response to light is inhibited under the influence of any additional stimulus, we applied light together with a gurgling sound, beginning this sound stimulus, like the CMF, 10 sec before the light was turned on and stopping it together with the light. Figure 60 shows the magnitudes of the lag period of the response to light, CMF + light and gurgling + light observed during one test. Alternating these stimuli allows us to combine them in 5 groups, each of which includes the magnitude of the lag period of the response to all 3 different stimuli. Among the groups, the lag period of the response to the CMF /175 + light stimulus always exceeded the lag periods of the responses to the other stimuli. The lag period of the response to the gurgling

average (for the test) magnitudes of the lag period, we should note that the lag period of the response to CMF + light exceeded the analogous indices of the response to light and to gurgling + light by 2 times. The lag periods of the response to light and to gurgling + light differed insignificantly, so that they can be considered equal.

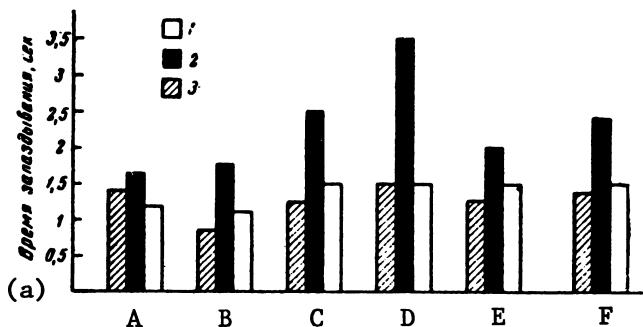


Figure 60. Lag Periods of the Conditioned Response to Light (1), a Constant Magnetic Field + Light (2), and Gurgling + Light (3), for One Test. A-E = Different Measurements During the Test; F = Averaged Indices. Key: (a) Lag Time, Sec.

reflexes to a magnetic field in pigeons allows us to conclude that in our tests we observed only the unconditioned effect of a magnetic field on birds, which was expressed in inhibition of the conditioned reflex to light and in an increase in the number of intersignal reactions.

#### The Development of Conditioned Reflexes to Electromagnetic Fields in Fish

The basic subjects for investigation in this series of tests were carp, goldfish and stickleback. Positive conditioned reflexes were developed to a CMF, a variable magnetic field with a frequency of 50 Hz, a UHF field and ionizing radiation. The electrodefensive method was basically used.

In this series of tests we developed both positive and inhibiting conditioned reflexes to a magnetic field using both the food-getting and defensive methods.

#### Development of a Positive Conditioned Reflex

The food-getting method. Table 21 gives the results of developing food-getting conditioned reflexes to a CMF in five goldfish. As the CMF source we used a cobalt magnet and a battery-powered electromagnet. A CMF was created in the aquarium with a field strength gradient from 2 to 200 Oe. /176

TABLE 21. CHARACTERISTICS OF THE POSITIVE CONDITIONED REFLEX TO A MAGNETIC FIELD IN GOLDFISH.

Fish number	Number of combinations		Within the first 100 combinations		
	before the appearance of the reflex	before the fixation of the reflex	stability,	lag period, sec	number of intersignal reactions
1	5	20	53	11.5	234
2	4	37	74	12.5	114
3	5	12	54	13.3	56
4	3	23	70	8.7	61
5	8	40	55	15.0	35
averages	5	26	61	12.2	100

Judging by the rate of fixation of the conditioned reflex, the degree of stability and the magnitude of the lag period, the response to the magnetic field is similar to the response to light. But we observe a sharp difference between these reflexes in the number of intersignal reactions. While during the development of the conditioned reflex to light there was an average of 38 intersignal reactions to 100 combinations, during the development of the reflex to the magnet the average number of intersignal reactions for the same number of combinations was 100. This difference in the number of intersignal reactions is observed not only for the first 100 applications of the conditioned stimulus, but it is retained over several hundred applications.

The possibility of developing a food-getting conditioned reflex to a CMF in fish (Figure 61) is illustrated by the kymograms of the tests.

The electrodefensive method. In most tests by this method we used a variable magnetic field with a strength of 100 Oe created by a solenoid that was fed from a city power line. The conditioned electrodefensive reflexes developed to a variable magnetic field appeared at the same rate as the corresponding reflexes to a CMF and differed only in greater stability. Therefore, we assumed that a constant magnetic field and a 50 Hz variable field have a similar mechanism of effect on fish and in future tests we did not compare the effect of these physically different agents. All tests were conducted on carp 6-10 cm long.

The positive conditioned reflex was developed in all fish. The possibility of developing a positive conditioned reflex is illustrated by the kymograms of the tests (Figure 61, B). The results of the tests are combined in Table 22. If we compare them with the results of developing a positive conditioned reflex to a magnetic field in goldfish through the food-getting method (Table 21), we

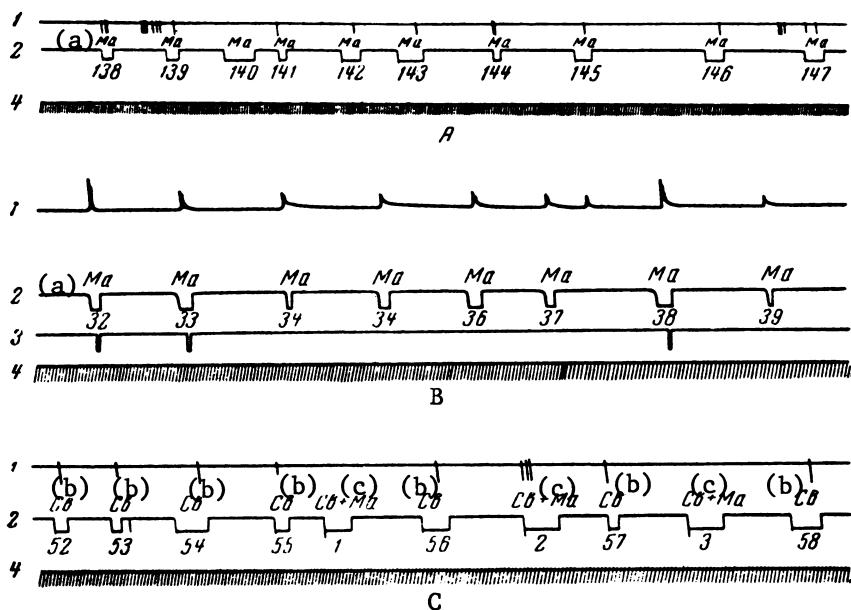


Figure 61. Kymograms of Tests Concerning Development of Time Relationships to a Magnetic Field in Fish. A = Development of the Positive Conditioned Reflex by the Food-Getting Method; B = Development of the Positive Conditioned Reflex by the Defensive Method; C = Development of Conditioned Inhibition by the Food-Getting Method; 1 = Marking of the Conditioned Reaction; 2 = Marking of the Influence of the Conditioned Stimulus; 3 = Marking of Reinforcement; 4 = Time Marking with a 5-Second Interval. The Remaining Designations are the same as in Figure 58. Key: (a) MF = Magnetic Field; (b) L = Light; (c) L + MF = Light + Magnetic Field.

note that with the food-getting method the reflex is formed more quickly and is more stable. With the food-getting method the reflex to a magnetic field, on the average, appears after 5 combinations, becomes fixed after 26 combinations and attains a stability of 61%, but with the electrodefensive method the reflex appears, on the average, after 11 combinations, becomes fixed after 57 combinations and attains a stability of 39%.

To compare the effect of a magnetic field with the effect of other stimuli on fish, we give the results of another series of tests on the development of positive conditioned reflexes to light and to a bell in fish (Table 23).

The introduced data allow us to conclude that conditioned reflexes to light and to a bell are formed in fish, on the average, at an identical rate: they appear after 8-9 combinations and are fixed after 15-20 combinations; but the reflex to light is more stable (56%) than the conditioned reflex to the bell (42%). /178

Comparing the results of Tables 22 and 23, we see that the conditioned reflex to a magnetic field yields in both rate of development and degree of

TABLE 22. CHARACTERISTICS OF THE POSITIVE CONDITIONED REFLEX TO A MAGNETIC FIELD IN FISH, DEVELOPED BY THE ELECTRODEFENSIVE METHOD.

Fish No.	Number of combinations		Stability, %	Fish No.	Number of combinations		Stability, %
	before appearance of the reflex	before fixation of the reflex			before appearance of the reflex	before fixation of the reflex	
1	12	97	23	9	11	33	30
2	17	79	37	10	2	55	38
3	20	37	58	11	3	40	41
4	11	24	34	12	6	48	52
5	12	87	38	13	7	49	36
6	9	102	24	14	5	76	52
7	11	24	52	averages	11	57	39
8	25	47	28				

TABLE 23. CHARACTERISTICS OF POSITIVE CONDITIONED REFLEXES TO LIGHT AND TO A BELL IN FISH WHEN THE ELECTRODEFENSIVE METHOD IS USED.

/179

Fish No.	Bell			Light			Stability, %	
	Number of combinations		Stability, %	Number of combinations		Stability, %		
	before appearance of the reflex	before fixation of the reflex		before appearance of the reflex	before fixation of the reflex			
1	-	-	-	21	21	70		
2	-	-	-	6	30	50		
3	4	?	23	3	51	50		
4	27	27	42	2	2	56		
5	-	-	-	6	?	49		
6	2	29	32	6	22	57		
7	7	27	52	7	30	56		
8	7	29	37	16	23	35		
9	14	31	37	11	?	53		
10	2	16	55	7	14	62		

TABLE 23. (Continued)

Fish No.	Bell			Light			Stability, %	
	Number of combinations		Stability, %	Number of combinations		Stability, %		
	before appearance of the flex	before fixation of the reflex		before appearance of the reflex	before fixation of the reflex			
11	9	18	34	10	12	46		
12	16	16	39	19	?	32		
13	6	6	57	25	25	56		
14	7	?	31	2	18	70		
15	2	26	52	5	7	67		
16	2	21	40	11	11	56		
17	8	8	63	3	3	91		
averages	8	21	42	9	19	56		

Note: the dash indicates that the reflex was not developed, the ? indicates that it was not fixed.

stability to the light and sound reflexes, which characterizes the magnetic field as a weak stimulus.

#### Development of Conditioned Inhibition to the CMF + Light Stimulus

Development of conditioned inhibition to a magnetic field was conducted on 5 goldfish by the food-getting method and on 7 fish (3 goldfish and 4 stickleback) by the defensive method. The overall results are given in Table 24.

The data of Table 24 show that with the use of different methods the rates of formation of the conditioned reflex in goldfish are approximately identical. With the food-getting method, on the average, the reflex appears after 3 combinations and is fixed after 20 combinations of light with food, and with the defensive method it appears after 5 and is fixed after 23 combinations of light with the mechanical stimulus. In stickleback the conditioned reflex is fixed somewhat later (on the average, after 32 combinations) than in goldfish (on the average, after 23 combinations). The stability of the conditioned reflex to light is approximately identical and it averaged 60% in both species of fish when different methods were used.

The lag period of the reaction to light is somewhat longer in stickleback /179

TABLE 24. CHARACTERISTICS OF THE CONDITIONED REFLEX TO LIGHT, THE DEVELOPMENT OF WHICH PRECEDED THE FORMATION OF CONDITIONED INHIBITION.

Species of fish	Fish No.	Number of combinations		Stability, %	lag period, sec	No. of inter- signal reac- tions for 100 applications of the condi- tioned stimulus
		before appear- ance of the re- flex	before fixa- tion of the re- flex			
Food-Getting						
Goldfish	4	3	9	72	11.9	56
	5	3	13	56	15.0	20
	6	2	7	66	15.8	68
	7	2	15	56	16.2	18
	8	4	44	54	17.0	28
Defensive						
Stickle- back	9	10	31	58	3.1	-
	10	3	10	71	4.9	-
	11	3	29	59	5.9	-
	1	3	22	68	7.9	-
	2	16	25	50	6.3	-
	3	4	11	82	5.5	-
	4	2	72	50	5.3	-

TABLE 25. RATE OF FORMATION OF CONDITIONED INHIBITION TO THE CMF + LIGHT STIMULUS IN FISH.

Species of fish	Fish No.	Number of stimu- lus applications	
		before ap- pearance of inhibition	before fix- ation of inhibition
Food-Getting			
Goldfish	4	5	5
	5	1	3
	6	2	14
	7	1	18
	8	1	26

TABLE 25. (Continued)

Species of fish	Fish No.	Number of stimulus applications	
		before ap- pearance of inhibition	before fix- ation of inhibition
Defensive			
Gold- fish	9	1	8
	10	3	15
	11	1	11
Stickle- back	1	1	?
	2	1	5
	3	1	14
	4	1	1

(on the average, 6.1 sec) than in goldfish (on the average, 4.6 sec). The average number of intersignal reactions in the first 100 combinations is 38.

We began to apply the magnetic field after fixation of the conditioned reflex to light. Table 25 gives the rate of the appearance and fixation of conditioned inhibition to CMF + light.

In most of the fish studied, inhibition appeared during the application of the CMF + light stimulus which indicates the effect of the CMF as external inhibition, and was fixed within 15 applications of this combination of stimuli. Inhibition appeared and was fixed somewhat more rapidly in stickleback and in goldfish.

The possibility of the appearance of inhibition to a CMF is illustrated 181 by the kymograms of the tests taken during use of the food-getting method (Figure 61, C), and the records of tests conducted by the defensive method.

In fish no. 7 and 8 we sometimes observed a general negative reaction during the influence of the CMF. Usually the fish swam in no particular directions during the influence of the stimuli and in the intervals between them, but during the influence of the magnet they sometimes swam rapidly to the opposite corner of the aquarium as if they were trying to get as far as possible away from the magnet. After removal of the magnet the fish never repeated these movements.

The material introduced shows that conditioned inhibition to a CMF is easily formed in fish. As is evident from the test recordings, the inhibiting effect of a magnetic field is frequently not limited to the time of application of the magnet, but also appears in sequential inhibition. This sequential

TEST NO. 13, GOLDFISH NO. 9, 4 MAY 1954

Stimulus number	Time of the start of the stimulus influence	Stimulus	Lag period, sec	Notes
161	11 hr 04 min 00 sec	light	4	
162	11 hr 4 min 30 sec	"	5	
163	11 hr 5 min 10 sec	"	2	
164	11 hr 5 min 50 sec	"	2	
27	11 hr 6 min 30 sec	CMF + light	12	
165	11 hr 7 min 10 sec	light	1	
28	11 hr 7 min 40 sec	CMF + light	-	
166	11 hr 08 min 15 sec	light	9	
167	11 hr 9 min	"	4	
29	11 hr 9 min 30 sec	CMF + light	-	
168	11 hr 10 min 00 sec	light	1	
30	11 hr 10 min 50 sec	CMF + light	-	
169	11 hr 11 min 30 sec	light	9	sequential inhibition

TEST NO. 16, GOLDFISH NO. 10, 10 SEPTEMBER 1954

Stimulus number	Time of the start of the stimulus influence	Stimulus	Lag period, sec	Notes
280	9 hr 13 min 00 sec	light	3	
281	9 hr 15 min 00 sec	"	3	
282	9 hr 17 min 00 sec	"	3	
283	9 hr 19 min 00 sec	"	8	
284	9 hr 21 min 00 sec	"	6	
285	9 hr 23 min 00 sec	"	9	
21	9 hr 25 min 00 sec	CMF + light	-	
286	9 hr 27 min 00 sec	light	3	
22	9 hr 29 min 00 sec	CMF + light	-	
287	9 hr 30 min 30 sec	light	3	
23	9 hr 33 min 00 sec	CMF + light	-	
288	9 hr 34 min 30 sec	light	4	
24	9 hr 36 min 00 sec	CMF + light	13	
289	9 hr 39 min 00 sec	light	-	
25	9 hr 41 min 00 sec	CMF + light	-	sequential inhibition
290	9 hr 42 min 30 sec	light	3	

TEST NO. 14, GOLDFISH NO. 11, 8 SEPTEMBER 1954

Stimulus number	Time of the start of the stimulus influence	Stimulus	Lag period, sec	Notes
251	17 hr 28 min 00 sec	light	3	
252	11 hr 29 min 00 sec	"	7	
253	11 hr 31 min 00 sec	"	3	
254	11 hr 32 min 30 sec	"	7	
255	11 hr 34 min 00 sec	"	5	
11	11 hr 35 min 30 sec	CMF + light	10	
256	11 hr 37 min 00 sec	light	5	
12	11 hr 38 min 30 sec	CMF + light	-	
257	11 hr 40 min 00 sec	light	12	
13	11 hr 41 min 30 sec	CMF + light	-	sequential inhibition
258	11 hr 43 min 00 sec	light	15	
14	11 hr 44 min 30 sec	CMF + light	-	sequential inhibition
259	11 hr 48 min 00 sec	light	12	
15	11 hr 49 min 30 sec	CMF + light	-	sequential inhibition
260	11 hr 51 min 00 sec	light	6	

TEST NO. 6, STICKLEBACK NO. 1, 21 JUNE 1956

Stimulus number	Time of the start of the stimulus influence	Stimulus	Lag period, sec	Notes
71	15 hr 00 min 00 sec	light	12	
72	15 hr 00 min 50 sec	"	4	
73	15 hr 1 min 20 sec	"	2	
74	15 hr 2 min 00 sec	"	2	
2	15 hr 2 min 40 sec	CMF + light	-	
75	11 hr 3 min 25 sec	light	15	
76	11 hr 4 min 20 sec	"	4	
77	11 hr 5 min 00 sec	"	7	
78	11 hr 5 min 40 sec	"	4	
3	11 hr 6 min 25 sec	CMF + light	-	
79	11 hr 7 min 30 sec	light	-	
80	11 hr 8 min 20 sec	"	10	sequential inhibition

## TEST NO. 11, STICKLEBACK NO. 4, 23 JUNE 1956

Stimulus number	Time of the start of the stimulus influence	Stimulus	Lag period, sec	Notes
101	9 hr 00 min 00 sec	light	2	
102	9 hr 1 min 00 sec	"	2	
103	9 hr 1 min 20 sec	"	4	
104	9 hr 3 min 00 sec	"	3	
6	9 hr 4 min 15 sec	CMF + light	-	
105	9 hr 6 min 00 sec	light	12	
106	9 hr 7 min 30 sec	"	7	
7	9 hr 8 min 45 sec	CMF + light	15	sequential inhibition
107	9 hr 10 min 00 sec	light	-	
108	9 hr 11 min 15 sec	"	-	
109	9 hr 12 min 20 sec	"	-	
110	9 hr 13 min 25 sec	"	2	

inhibition observed in tests with the use of the defensive method cannot be explained by the fact that the conditioned-inhibiting combinations of stimuli are not reinforced and thereby suppress the conditioned reflex to light. As was stated in the description of the defensive method, the conditioned stimulus was not reinforced if the conditioned response was observed during its influence. Consequently, the fact of sequential inhibition can only be explained by the influence of the CMF itself.

To quantitatively characterize the observed properties of the magnetic field, in Table 26 we have generalized all the cases of inhibition encountered in developing conditioned inhibition to a CMF in fish.

The tabular data show that sequential inhibition is encountered in stickleback more often (on the average 73% of the cases) than in goldfish (on the average, 36%). In the latter, sequential inhibition is encountered more frequently with the use of the food-getting method (on the average, in 47% of the cases) than with the use of the defensive method (on the average, in 36% of the cases). We obtain similar comparative data in an analysis of the intensity of sequential inhibition. Sequential inhibition is expressed in complete inhibition of one or several reactions to light more frequently in stickleback than in goldfish. An intensive sequential inhibition is observed in goldfish significantly more often with the food-getting method than with the defensive method.

The data of Table 26 indicates that cases of sequential inhibition alone are encountered approximately 10 times less often than cases of immediate inhibition of the conditioned light reaction. But cases of sequential inhibition alone are encountered more frequently in goldfish with the defensive method, i.e., in just those cases when the general inhibiting effect of the magnetic

TABLE 26. CHARACTERISTICS OF THE INHIBITING CMF + LIGHT STIMULUS DURING DEVELOPMENT OF CONDITIONED INHIBITION IN FISH.

Method	Species of fish	No. of exposures	Number of cases of immediate inhibition	Number of cases of sequential inhibition				Number of cases of an inhibiting effect alone				
				raw	%	lag increase in period of exposure	for one stimulus	for two	for more than two	raw	%	raw
Food-getting	Goldfish	4	70	56	80	3	20	7	3	33	47	5
		5	12	11	92	1	5	2	0	8	67	0
		6	28	21	75	0	9	2	1	12	43	3
		7	89	62	70	11	15	0	0	26	20	6
		8	59	43	73	7	17	1	3	28	47	5
Defensive	Stickleback	9	41	33	80	15	0	2	0	17	42	2
		10	67	38	57	12	6	0	0	18	27	11
		11	67	49	73	15	12	0	0	27	40	3
		1	4	4	-	0	2	2	0	4	-	0
		2	12	12	-	1	10	0	0	11	-	-
		3	22	20	-	5	3	2	2	12	-	1
		4	7	7	-	0	1	3	2	6	-	0
Total for stickleback		45	43	96	6	16	7	4	33	73	1	2
												44
												98

field is expressed more weakly. As in the analysis of the number of cases of sequential inhibition, in an analysis of the general inhibiting effect of a CMF we are surprised to find that the effect of the magnet is observed in stickleback more frequently (on the average, 98%) than in goldfish (on the average, 78%), and in goldfish the inhibiting effect of the magnet is observed more frequently with the food-getting method (on the average, 89%). It is evident that in stickleback the inhibiting effect appears almost with each application of the CMF, and that this effect is most frequently expressed in immediate inhibition of the conditioned light response. Cases of the magnet delaying both the immediate and a subsequent light response are encountered rather frequently, and once we noted the effect of the CMF appearing only in sequential inhibition.

Sometimes the effect of the magnetic field was not limited to immediate and sequential inhibition. After the initial applications of the CMF we observed a stable disturbance of the conditioned response to light, lasting several days and appearing even in cases when the CMF was not applied. In the analysis of this disturbance of the stability of the light reflex, our material is distributed just as in the analysis of the other indices of the inhibiting effect of the CMF, i.e., the stability of the light reflex is disturbed most strongly in stickleback; to a lesser degree in tests on goldfish conducted by the food-getting method; and the stability of reflexes in goldfish almost does not change, or is even increased, with the use of the defensive method. /185

As the tests with pigeons showed, the inhibiting effect of a CMF cannot be accompanied by the development of a time relationship. Therefore, as we did during treatment of the results of tests on pigeons, we made special calculations of the lag period of the response to CMF + light during development of conditioned inhibition in fish no. 4, 5, 6, 7 and 8. Figure 62 shows that, although the inhibiting effect of the magnetic field appears during the first applications of the complex CMF + light stimulus, this effect becomes more intensive as the number of applications of the complex stimulus without food is increased. Consequently, the external inhibition arising in the first applications of the combination of CMF + light stimuli passes into internal inhibition as a result of not reinforcing this combination. Thus, the development of both positive and negative conditioned reflexes to a magnetic field occurs in fish. But the magnetic field retains the properties that appear in the tests on pigeons: i.e., development of a positive conditioned reflex to the magnet is characterized by an excess of intersignal reactions, and the magnetic field exerts primarily an inhibiting effect on predeveloped conditioned reflexes. /187

We should also note that several tests conducted together with G. L. Verevkina concerning the effect of a magnetic field on conditioned reflexes. These investigations were conducted on 4 fish: 2 bullheads and 2 flounders. Using the defensive method, in these fish we developed positive conditioned reflexes to light and sound. We alternated applications of sound and light throughout the test. If there was a response to the conditioned stimulus, we did not give reinforcement. After the reflexes were developed, in separate tests with the aid of a solenoid we created a 100-200-Oe CMF. The solenoid was switched on 20 sec before the conditioned stimulus and was switched off together with it.

The effect of the CMF on conditioned reflexes is illustrated in Figure 63.

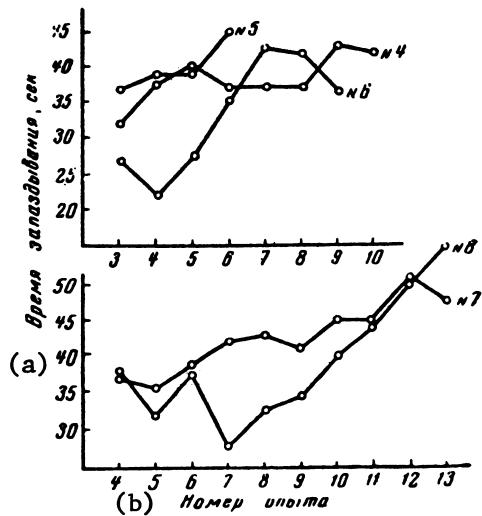


Figure 62. Dynamics of the Lag Period of Conditioned Reflexes to CMF + Light in Goldfish During Development of Conditioned Inhibition to this Stimulus. The Number of the Fish is Shown on the Curves. Key: (a) Time of Lag, Sec; (b) Number of the Test.

cases for both the light and the sound conditioned reflexes, and an increase in stability is encountered more frequently with the sound reflex (22%) than with the light reflex (7%).

Thus, a CMF applied 1-4 times during the tests and throughout the tests has primarily an inhibiting effect on predeveloped time relationships.

We conducted a series of tests to determine the threshold of perception of a magnetic field in fish during development of a positive conditioned reflex to this stimulus. The tests were conducted on 3 fish by the food-getting method /189/ (goldfish no. 1, 2 and 3) and on 3 fish by the electrodefensive method (carp no. 11, 13 and 14). We varied the magnetic field strength with a rheostat. Similar results were obtained on all 6 fish. From the test records which follow it is evident that the conditioned reflex to a magnetic field disappears at a current of 0.25-0.37 amp which corresponds to a magnetic field strength of 10-30 Oe.

The threshold strength of the magnetic field (10-30 Oe) was approximately 10 times lower than the highest strength which we used in our tests to obtain a conditioned positive reflex and conditioned inhibition in fish.

In the tests with goldfish no. 2, in which we developed the food-getting positive conditioned reflex to a magnetic field with a strength of approximately

In each test in which the magnetic field was applied the stability of the light reflex was reduced in bullhead no. 1. The stability of the sound reflex was reduced in two cases of the application of the magnetic field, but in one test we observed an increase in the stability of the auditory reflex during the influence of the CMF.

With flounder no. 3 the stability of the light conditioned reflex was reduced during each application of the magnet, and the reflex to the bell was inhibited in 3 out of 5 cases. Sometimes the magnet destroyed all conditioned-reflex activity (tests no. 25 and 32), although each conditioned stimulus was accompanied by unconditioned reinforcement.

The general results show that a CMF /188/ most frequently inhibits conditioned reflexes, and that the reduction in stability of the light conditioned reflex appears more sharply than that of the sound reflex. Thus, the stability of the light reflex is reduced in 85% of the cases, and that of the sound reflex in 70%. Absence of any effect from the magnetic field is observed in 7% of the

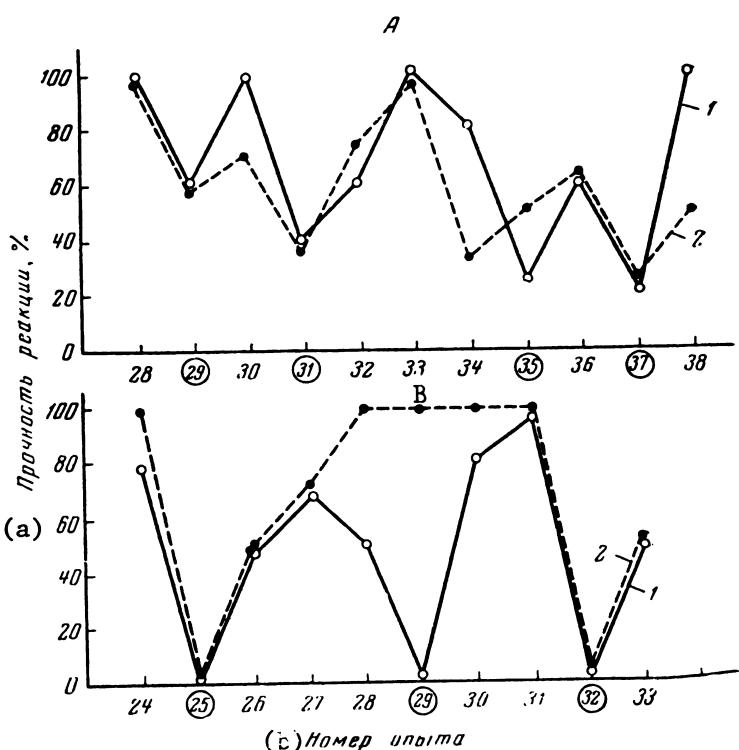


Figure 63. The Effect of a Magnetic Field on the Stability of Light (1) and Sound (2) Conditioned Reflexes in Fish. A = Bullhead No. 1; B = Flounder No. 3. The Number of the Tests in Which a Magnetic Field was Applied are Circled. Key: (a) Stability of the Reaction, %; (b) Number of the Test.

100 Oe, in 8 tests (110 applications) we later used a constant magnetic field on the order of 10,000 Oe created by a special electromagnet at the physics department of Moscow State University.

The basic indices of the conditioned reflexes to the 100 and 10,000-Oe magnetic fields are compared on Figure 64. It is evident that the stability of the conditioned reflex did not change with the sharp increase in the intensity of our stimulus, but the average lag period was reduced from 14.8 to 10.5 seconds and, what is particularly interesting, the number of intersignal reactions increased by approximately one and a half times. Of course, the increase in the number of intersignal reactions can be explained by a variety of reasons, but we tried not to change the test conditions, except for increasing

Application of the stimulus	Time of turning on the solenoid	Current, amp	Presence of the conditioned response	Fixation
Food-Getting Method				
goldfish no. 2, test no. 51, 18 December 1954	543    12 hr 56 min 15 sec 544    12 hr 58 min 10 sec 545    13 hr 01 min 546    13 hr 03 min 25 sec 547    13 hr 05 min 30 sec 548    13 hr 07 min 50 sec	0.37 0.37 0.25 0.37 0.37 0.37	+ + - + + +	+

TABLE (Continued)

Application of the stimulus		Time of turning on the solenoid	Current, amp	Presence of the conditioned response	Fixation
Food-Getting Method					
goldfish no. 2, test no. 51, 18 December 1954	549	13 hr 11 min	0.25	-	+
	550	13 hr 14 min 05 sec	0.37	+	+
	551	13 hr 16 min 30 sec	0.37	+	+
Defensive Method					
carp no. 11, test no. 27, 30 December 1954	303	18 hr 21 min 30 sec	0.50	+	-
	304	18 hr 23 min 15 sec	0.50	+	-
	305	18 hr 25 min 00 sec	0.50	+	-
	306	18 hr 26 min 45 sec	0.25	-	-
	307	18 hr 29 min 15 sec	0.37	+	-
	308	18 hr 31 min 00 sec	0.37	+	-
	309	18 hr 33 min 15 sec	0.25	-	-
	310	18 hr 35 min 16 sec	0.25	-	-
	311	18 hr 38 min 00 sec	1.00	+	-

the intensity of the stimulus; therefore, we relate the increase in the number of intersignal reactions to the increase in the magnetic field intensity, although additional experimental material is needed for a final judgement.

Thus, the stability of conditioned reflexes to a magnetic field did not change when the intensity of the stimulus was increased by two orders of magnitude. We did note a certain increase in the number of intersignal reactions. In other words, a quantitative increase in the intensity of the magnetic field did not bring it close in physiological effectiveness to such stimuli as light or sound.

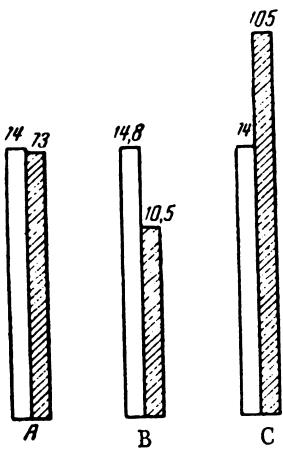


Figure 64. Stability in % (A); Lag Period in Sec (B) and Number of Intersignal Reactions (C) During Development of the Food-Getting Conditioned Reflex to a 100-Oe (1) and 10,000-Oe (2) Magnetic Field.

Development of Conditioned Reflexes to a  
UHF Field in Fish

The experiments were conducted on 6 carp, of which 2 were preliminarily blinded (no. 3 and 5) and the forebrain was removed from one (no. 6). The general results of the tests are given in Table 27. It is evident that, on the average, the reflex appears after 12 combinations, does not become fixed in all fish and attains a stability of 45%.

TABLE 27. CHARACTERISTICS OF THE ELECTRODEFENSIVE CONDITIONED REFLEX TO A 500 v/m UHF FIELD IN FISH.

Fish No.	Number of combinations		Stabil- ity, %	Average lag pe- riod, sec
	before the appearance of the re- flex	before the fixation of the reflex		
1	24	?	42	3.0
2	11	?	44	3.0
3	9	84	53	3.6
4	8	65	42	3.5
5	10	49	47	3.5
6	8	?	45	3.2
aver- age	12	?	45	3.3

Development of Conditioned Reflexes to  
Ionizing Radiation in Fish

Contemporary physiology affirms that many types of energy (mechanical, thermal, electrical, etc.) can affect an organism as stimuli under definite conditions. However, the question of whether ionizing radiation is a stimulus /191 or not is still debated. In the radiobiological literature there are works (although sometimes contradictory) showing the ability of ionizing radiation to cause behavioral reactions in animals [Tsypin, 1964].

The phenomenon of so-called radiophosphene was established early in the development of radiobiology [London, 1904; Lipetz, 1955; Pape and Zakovsky, 1954; and others]. This phenomenon is defined as the sensation of a weak glow during the impingement of a beam of ionizing radiation on the dark-adapted human eye. Another group of works [Hug, 1958; Born, 1960; Andrews and Cameron, 1960; Overall et al., 1959; Khrushchev, Darenetskaya and Pravdina, 1961; and others] introduced facts concerning the defensive reaction of animals to radiation. In this case, the reaction is manifested as the animal's avoiding the

radiation beam or in characteristic protective maneuvers. Finally, a third group of works indicates that it maybe possible to develop conditioned reflexes in animals through the use of ionizing radiation as an unconditioned stimulus [Movsesyan et al., 1954; Livshits, 1961; Garcia et al., 1957; and others].

The problem of this investigation was to check the possibility of using ionizing radiation as a conditioned stimulus. This work was conducted together with A. B. Tsypin.

The tests were conducted on 11 yearling carp. The use of fish as the subjects for our studies is explained by their facile development of conditioned reflexes to different stimuli, and also by the convenience of recording conditioned responses in fish, which could move freely about the aquarium.

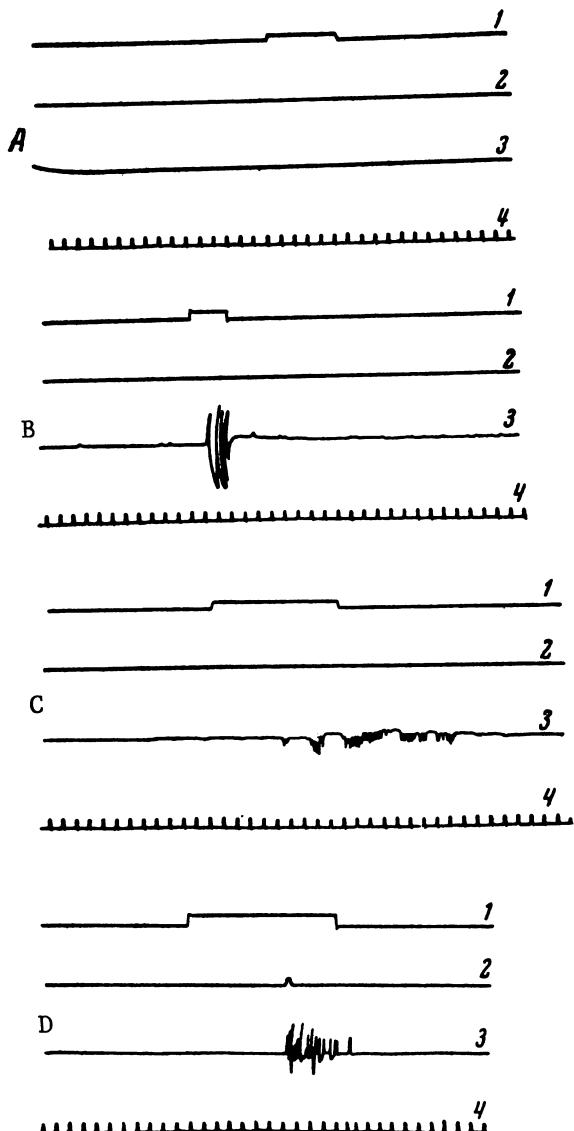
Irradiation of the fish before development of conditioned reflexes did not/192 cause motor reactions (Figure 65, A). After several combinations of irradiation with an electric stimulus the fish began to move during irradiation alone (Figure 65, B). The appearance of a conditioned reflex was observed following 4-13 combinations (Table 28); however, we did not manage to obtain a stable conditioned reflex in any fish, although some of them were given up to 250 combinations. In 4 fish, we could observe fixation of the conditioned reflex, but in the remaining fish it was not fixed.

TABLE 28. CHARACTERISTICS OF CONDITIONED REFLEXES TO IRRADIATION IN NORMAL AND OPERATED FISH

Fish No.	Number of combinations		Stabil- ity, %
	before the appearance of the re- flex	before the fixation of the reflex	
Normal fish			
1	7	14	51
2	4	-	39
3	8	32	45
4	8	74	50
5	13	-	31
6	5	-	43
Blinded fish			
7	5	15	52
8	5	-	45
Fish with hemispheres removed			
9	53	-	23
10	20	-	12

The stability of the conditioned reflexes varied from 31 to 51%. This stability was already observed from the 3rd through the 5th test. In subsequent tests, in spite of the increase in the number of combinations, the number of conditioned responses did not increase. Sometimes we even noted a decrease in the stability of the conditioned reflex as the number of irradiations increased. It is possible that in this case the overall effect of irradiation leads to suppression of the conditioned reflex to irradiation itself.

These results definitely demonstrate the possibility of developing conditioned reflexes to irradiation in fish. While confirming the effect of irradiation on the behavior of fish, our data also indicate the peculiarities of this effect. Although it appears strongly, the conditioned reflex is poorly fixed and it does not attain the stability that is observed in the development of conditioned reflexes to ordinary stimuli.



Since there is proof that it is /194 possible to perceive  $\gamma$  irradiation through the visual analyser, our first assumption about the mechanism of the effect of irradiation on a fish was a hypothesis concerning the effect of irradiation through the retina. However, tests with 2 blinded fish that had the entire eyeball removed on both sides showed that conditioned reflexes to  $\gamma$  irradiation also developed in these fish. The conditioned reflexes of blinded fish did not differ at all from those of intact fish (Table 28).

The next stage of our work was development of conditioned reflexes to irradiation in fish after removal of the forebrain. This series of experi-

Figure 65. Kymograms of Tests on Developing Electrodefensive Conditioned Reflexes to Ionizing Radiation in Fish. A = Absence of the Defensive Reaction to Irradiation before Development of the Reflex; B = Conditioned Reflex to Irradiation in a Normal Fish; C = Conditioned Reflex to Irradiation in a Fish that had its Brain Hemispheres Removed; D = Absence of the Conditioned Reflex to Irradiation in a Fish with a Damaged Diencephalon; 1) Marking of Irradiation; 2) Marking of the Electric Stimulus; 3) Motor Reaction of the Fish; 4) Time Marking with an Interval of 1 Sec.

ments was necessary because of questions concerning the direct effect of  $\gamma$  irradiation on the brain hemispheres. Along with this series of tests, we answered the question about the participation of the olfactory analyser in the perception of  $\gamma$  irradiation.

These tests were conducted on two carp. A morphological check showed that the forebrain was completely removed. As is evident from the data of Table 28, conditioned reflexes arose later in the operated fish than in normal fish; however, the conditioned reflex developed clearly (Figure 65, C) and its stability increased as the number of combinations increased, although during 200 combinations it did not attain the stability that characterizes normal fish. These results testify that the forebrain does not play the basic role in perception of  $\gamma$  irradiation.

We also decided to check how destruction of the diencephalon affects these conditioned reflexes in fish, since the literature contains many indications of the important role of the diencephalon in reactions to radiation effects. In carp no. 7 we could not develop a conditioned reflex to irradiation after destruction of the diencephalon (Figure 65, D), although we gave 200 combinations of the conditioned and unconditioned stimuli. After destruction of the diencephalon in carp no. 8 the previously developed conditioned reflexes to  $\gamma$  irradiation disappeared and we could not restore them during 200 combinations. Thus, destruction of the diencephalon completely precluded the possibility of developing conditioned reflexes to  $\gamma$  irradiation in fish.

The experiments conducted by A. B. Tsypin on rabbits [Tsypin and Kholodov, 1964] support the tests described above. Conditioned electrode-defensive reflexes to  $\gamma$  irradiation were developed in 10 adult rabbits. To exclude the effect of the weak sound stimuli arising during switching of the cobalt source, 1-1.5 months before the start of the experiment bilateral destruction of the inner ear was surgically performed on all rabbits. The conditioned stimulus was  $\gamma$  radiation in a dose of 0.5-0.1 R/sec. Electric stimulation of the hind legs /195 was used as reinforcement. The influence of the conditioned signal lasted 3-4 sec. The unconditioned stimulus was given with a lag of about 3 sec and lasted about 0.5 sec. Five combinations were given each day. The motor reactions of the rabbits were recorded with the aid of a special electric transducer.

Defensive motor conditioned reflexes to the influence of  $\gamma$  irradiation occur in all test animals after 15-50 combinations. However, as in the tests on fish, a stable reflex was not obtained. Furthermore, when the total absorbed dose exceeded 150-200 R, the preformed conditioned reflex connection began to weaken. This was evident in the fact that the number of positive responses began to decrease gradually. If, however, the animal was given several days of rest, the conditioned reflex activity improved again. Thus, the tests on rabbits supported the supposition that ionizing radiation can exert an effect as a weak stimulus.

The tests with extirpations showed that the distance exteroceptors (vision, smell, hearing) do not play a large role in the perception of  $\gamma$  irradiation. This was proven with respect to vision and smell in direct experiments on fish with removal of the corresponding analysors. As for hearing, direct experiments

were conducted with destruction of the middle ear in rabbits, and indirect data were obtained in experiments with fish. The fact is that after destruction of the diencephalon, conditioned reflexes to sound are retained in fish [Kholodov, 1959]. The disappearance of conditioned reflexes to irradiation in fish after destruction of the diencephalon shows that the possible accompanying auditory stimuli do not play roles in the development of the reflex to irradiation and that the auditory analyser has no importance in the process of radiation perception. The basic role in the reactions to irradiation belongs to the diencephalon. This conclusion is supported by additional facts. It turned out that after the tests on development of conditioned reflexes to irradiation, the coloring of the test fish became darker than that of control fish in conditions of the same illumination. This phenomenon can be explained by the effect of irradiation on the diencephalon where the coloration center is located in fish [Puchkov, 1954].

#### Discussion

In presenting the material on the development of conditioned electrode-defensive reflexes to penetrating factors in fish, we observed a similarity in the effect of these stimuli. This similarity appears especially clearly in a comparison of the average magnitudes of the conditioned reflexes to UHF and constant magnetic fields,  $\gamma$  irradiation, light, sound and tactile stimulation /196 (Table 29).

TABLE 29. AVERAGE INDICES OF CONDITIONED-REFLEX ACTIVITY TO DIFFERENT STIMULI IN NORMAL FISH.

Stimulus	Fish No.	Number of combinations		Stabil- % ity,
		before the appearance of the reflex	before the fixation of the reflex	
light	8	4	13	90
sound	8	3	14	80
tactile	3	3	8	76
$\gamma$ irradiation	8	7	-	45
UHF field	6	12	-	45
magnetic field	20	10	-	39

The data of Table 29 show that with respect to all indices our stimuli are divided into two groups. Conditioned reflexes are well developed to stimuli for which specialized receptors are known (light, sound and the tactile stimulus), but the reflexes developed poorly to stimuli for which receptors are not known. Furthermore, responses to these penetrating stimuli were not fixed in all fish,

i.e., we did not manage to obtain five responses in a row in all fish.

Although it is difficult to compare the effects of stimuli of different modalities, from the data of Table 29 it follows that, within the limits of each of the two groups of stimuli, the differences between them are insignificant. We can assume that the electrodefensive method reveals only the most general properties of the stimuli and that the two groups mentioned are reflected in this rough evaluation.

In the Pavlov school, the problem of the qualitative characteristics of conditioned stimuli was stated in connection with a study of temperature conditioned stimuli. The investigators working with this stimulus [Voskoboinikova-Ganstrem, 1906; Solomonov, 1910; Shishlo, 1910; Vasil'yev, 1912] noted that the temperature conditioned reflex was difficult to develop, soon disappeared in spite of an increase in the number of combinations, and even began to reduce the reaction to other conditioned stimuli. Dogs became drowsy and stopped responding to all conditioned stimuli. This phenomenon was called the soporific reflex. Discussing the results of tests with temperature stimuli, in 1910, I. P. Pavlov wrote: "It has become apparent that a definite agent of the external world can bring about somnolence in an animal and extinction of its higher nervous activity, in just the same lethal and unconditional manner as that by which other agents cause certain complex-nerve functions. To put it differently, together with diverse active reflexes there are passive soporific reflexes".\*

However, a qualitative uniqueness of temperature stimuli was cast into doubt by the work of Rozhanskiy (1913) who, using special methods, developed a stable conditioned reflex to a temperature stimulus. Although this did not directly negate the qualitative difference of temperature stimuli from any other stimuli, the difference in the effect of conditioned stimuli began to be explained from the point of view of their quantitative differences. "The difference in the magnitude of the effect of our ordinary conditioned stimuli which refer to various analyzers is caused by the difference in the strength of these stimuli and is not connected with the qualities of the cells of different analyzers".\*\*

Over the next 50 years, conditioned temperature reflexes were studied very little. The well-known work of N. N. Dzidzishvili (1953) supports the conclusions of earlier works of the Pavlov School about temperature conditioned stimuli: "The unique flow of conditioned-reflex activity in response to temperature stimulations of moderate and high strength should be explained by the fact that the temperature stimulus differs in its character from other exteroceptor stimuli; as I. P. Pavlov affirmed, it is an agent that causes a well expressed fatal inhibition".\*\*\*

\*I. P. Pavlov: Dvadtsatiletniy opyt ob "yekтивnogo izucheniya vysshey nervnoy deyatel'nosti zhivotnykh. (Twenty Years' Experience in the Objective Study of Higher Nervous Activity in Animals.) Moscow, 1951, p. 83.

\*\*I. P. Pavlov: Lektsii o rabote bol'sikh polushariy golovnogo mozga. (Lectures on the Work of the Cerebral Hemispheres.) Leningrad, 1927, p. 236.

\*\*\*N. N. Dzidzishvili: Ob uslovnykh refleksakh na teplovye razdrazheniya kozhi. (Concerning Conditioned Reflexes to Thermal Stimulation of the Skin.) Trudy Instituta Fiziologii AN Gruz. SSR. (Transactions of the Institute of Physiology of the Georgian Academy of Sciences.) 9: 94, 1953.

The predominantly inhibiting effect of a magnetic field observed during development of conditioned stimulus in fish and pigeons makes this reflex approximate temperature conditioned stimuli. Like the temperature stimuli, a magnetic field can be classified as a weak stimulus. However, we should note that the predominantly inhibiting effect of electric and tactile stimuli [Yerofeyeva, 1912; Podkopayev, 1932; V. K. Fedorov, 1954] is observed in the region of threshold intensities, but the inhibiting effect of temperature and magnetic stimuli is observed at intensities that greatly exceed threshold intensities.

The similarity of the magnetic stimulus and the temperature stimulus is elicited not only in their predominantly inhibiting effect, but also in the fact that their application increases the number of intersignal reactions, although this property of temperature stimuli has not been specially investigated. The appearance of salivation in the intervals and the increase of somnolence /198 in dogs occurred in parallel in tests with temperature stimuli [Solomonov, 1910; Shishlo, 1910]. Intermediate salivation is explained by the disinhibiting influence of the aftereffect from the temperature stimulus. Together with the predominance of the inhibition process, the increase in the number of intersignal reactions was noted during the influence of weak electric stimuli [Yerofeyeva, 1912], subsensory sound stimuli [Chistovich, 1949] and in tests with covering [Vinogradov, 1954].

Studying the effect of stimuli of different strengths on the delayed conditioned reflex, I. P. Pavlov showed that weak stimuli disinhibit the inert phase of this reflex, stronger stimuli disinhibit the inert and inhibit the active phase and, finally, strong stimuli inhibit the active phase of the delayed reflex. The stimulus we analyzed probably should be classified among those that disinhibit the inert and inhibit the active phase of the delayed reflex, since both a magnetic field and a temperature stimulus inhibit the conditioned reflexes developed to other stimuli and disinhibit the response to the situation, i.e., increase the number of intersignal reactions.

An unstable conditioned reflex can usually be developed to such weak stimuli. In our tests with fish a relatively stable conditioned reflex to a magnetic field was developed by the food-getting method and a less stable one by the electrodefensive method. In the tests with pigeons we did not manage to develop either a positive or an inhibiting conditioned reflex to a constant magnetic field, and in the tests with rabbits our attempt to develop a positive reflex was not successful. We propose that a magnetic field is a stronger stimulus for fish than for pigeons or rabbits. In pigeons the effect of a constant magnetic field is revealed only in induced inhibition of positive light-conditioned reflexes and in an increase in the number of intersignal reactions.

Consequently, under certain conditions the stimulus can be perceived, but its strength will be insufficient for the formation of a conditioned reflex. In other words, the receptor possibilities of an animal can be determined most precisely not by development of a conditioned reflex to the investigated stimulus, but by a study of its effect on previously formed conditioned reflexes. The effect on animals of a UHF field [Livshits, 1958], ionizing radiations [Lebedinskiy, 1955], and stimulations of different internal organs [Bulygin, 1952] has been studied by this means.

Stimulations that by themselves do not cause reflex activity have been called /199 correcting stimuli, in contrast to triggering stimuli. It seems to us that the effect of a magnetic field on the behavior of pigeons can be an example of the effect of a correcting stimulus. The correcting effect has been studied most thoroughly by N. A. Bulygin, who "established that during stimulation of the interoceptors the correcting effects precede triggering effects and continue after them so that they can be observed by themselves, without triggering effects (the underline is mine -- Yu. Kh.), while the latter are always accompanied by the former and, consequently, the triggering effects from interoceptors to the motor and salivary centers are only a higher stage of the correcting effects".\*

It is probable that in pigeons we managed to see only the correcting effect of a magnetic field, but in fish the magnetic field could also cause a triggering effect, i.e., become a conditioned stimulus.

The tests in which we studied the effect of a CMF on the reactance curve in rabbits (see Part I) also demonstrate the presence of a directing effect of this factor on mammals. From this we can assume that a CMF will have an effect on developed conditioned reflexes in mammals. Having become a conditioned stimulus for fish, the magnetic field revealed its correcting effect in an increase in the number of intersignal reactions and in a predominantly inhibiting effect rather sharply in comparison with other stimuli.

In our opinion, the results of all these tests give a sufficiently valid affirmative answer to the question about whether a magnetic field is a stimulus for an organism. By the conditioned-reflex method it was observed that a magnetic field is perceived by fish and pigeons, but its correcting effects are projected more clearly than its triggering effects.

### Conclusions

1. We did not manage to develop a positive defensive conditioned reflex in rabbits or a food-getting conditioned reflex in pigeons to a CMF. The effect of a CMF on pigeons was revealed in an increase in the number of intersignal reactions and in inhibition of a previously developed light conditioned reflex.

2. In fish we managed to develop positive electrodefensive conditioned /200 reflexes to a magnetic field, a UHF field and  $\gamma$  irradiation. The developed reflexes appeared later and were less stable than the conditioned reflexes to light or sound. Inhibiting reflexes to a magnetic field were developed better than to light or sound. The effect of the magnetic field on fish was also expressed in an increase of the number of intersignal reactions and in inhibition of previously developed light- and sound-conditioned reflexes.

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\*N. A. Bulygin: O zakonomernosti i mekhanizmakh vliyanii s interroretseptorov na reflektornyyu deyatel'nost' spinnogo i golovnogo mozga. (Concerning the Regularities and the Mechanisms of Effects from the Interoceptors on the Reflex Activity of the Spinal Cord and the Brain.) Doctoral Dissertation, Leningrad, 1952, p. 19.

3. The threshold of perception of a magnetic field by fish during development of a positive electrodefensive conditioned reflex was 10–30 Oe.

4. From the character of their effect, a magnetic field, a UHF field and  $\gamma$  irradiation can be classified as weak correcting stimuli.

## CHAPTER 6. ANALYSIS OF THE MECHANISM OF THE FORMATION OF CONDITIONED REFLEXES TO A MAGNETIC FIELD IN FISH

The fact that we did not manage to develop conditioned reflexes to a CMF in rabbits allows us to assume that this physical factor somehow acts differently on fish than on mammals. Since the basic data about the mechanism of the effect of a CMF was obtained on rabbits through the use of the electrophysiological method, this assumption forced us to conduct a special analysis of the mechanism of perception of a CMF in fish. In this series we investigated the roles of the lateral line organ, the retina, and also different structures of the brain in the formation of conditioned reflexes to a CMF in fish. Most of the experiments were conducted by the electrodefensive method.

### The Effect of Denervation of the Lateral Line Organ on the Conditioned Magnetic Reflex in Fish

Lissman (1958) assumed that a CMF acts on fish by induction of an electromotive force and that the basic role in perception of this electromotive force is played by the lateral line organ. Although it is known that the basic function of this organ in fish is the perception of infrasonic oscillations [Malyukina, 1955], we can assume that the perception of a magnetic field is among the additional functions of this organ. For an experimental check of this assumption we denervated the lateral line organ in goldfish no. 1 and 2 and in carp no. 11.

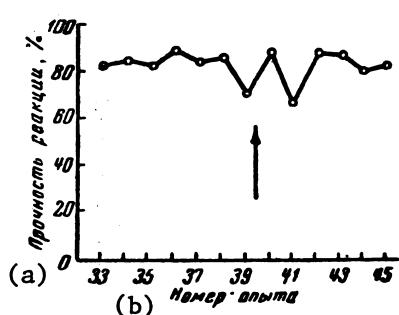


Figure 66. Dynamics of the Food-Getting Conditioned Reflex to a Magnetic Field in Fish After Partial Denervation of the Lateral Line Organ. The Arrow Notes the Moment of the Operation. Key: (a) Reaction Stability, %; (b) Number of the Test.

On Figure 66 one can see that bilateral transection of n. lateralis, which was conducted after Test No. 39 on goldfish no. 2, absolutely did not disturb the stability of the conditioned reflex to a magnetic field. Large variations in reflex stability are observed both before the operation and after it. In goldfish no. 1 we checked the stability of the conditioned reflex to a magnetic field on the day of the operation. The reflex did not change. In carp no. 11 we denervated the lateral line organ after bilateral enucleation. During the operation we performed bilateral transection of n. lateralis and n. suborbitalis. A test of the stability of the conditioned reflex to a magnetic field conducted on the same day showed that a response was observed in 9 out of 10 applications of the magnet.

Consequently, denervation of the lateral line did affect perception of a magnetic field by fish. Separate observations show that denervation of the lateral line organ also does not change the conditioned light reflex. Of course, these tests do

not answer the question about the participation of the integument in perception of a magnetic field. However, the difficulty of fully precluding the skin analyser forced us to turn our attention to a determination of the central link in the reflex arc for the reaction of fish to a magnetic field.

#### Similarity in the Effects of Light and a Magnetic Field on Fish

Having decided to look for the anatomic locus of the conditioned reflex to a magnetic field, we began to develop in our fish, in addition to the existing conditioned magnetic reflex, conditioned reflexes to the flash of an electric light and the sound of an electric bell. These conditioned reflexes served as the control during various surgical procedures.

Before the operations we determined the effect of a magnetic conditioned reflex on the light conditioned reflex. In goldfish no. 1, 2 and 3, in which a conditioned reflex to a magnetic field had already been developed, the reflex light appeared and became fixed during the first application in goldfish no. 1 and 2, and it appeared at the 3rd combination and became fixed after the 6th combination in goldfish no. 3 (Table 30).

TABLE 30. CHARACTERISTICS OF THE FOOD-GETTING AND ELECTRODEFENSIVE POSITIVE CONDITIONED REFLEXES TO LIGHT AND SOUND DEVELOPED IN FISH AFTER THE FORMATION OF A CONDITIONED REFLEX TO A MAGNETIC FIELD.

Fish No.	Light			Bell			Stabil- ity, %	
	Number of combinations		Stabil- ity, %	Number of combinations				
	Before ap- pearance of the reflex	Before fixation of the reflex		Before ap- pearance of the reflex	Before fixation of the reflex			
food-getting method								
1	1	1	65	5	39	55		
2	1	1	72	1	—	72		
3	3	6	63	10	27	48		
electrodefensive method								
51	7	14	97	2	29	70		
88	1	1	91	4	15	82		
89	1	1	100	1	7	85		
90	1	1	85	1	1	79		

In comparison with Table 24, which gives the characteristics of the positive conditioned reflex to light in goldfish in which time relationships had not been previously developed, the data of Table 30 indicate not only the rapid appearance of the light reflex, but also its greater stability. The average stability of the light conditioned reflex for goldfish in Table 24 was 60%, and in

Table 30, 67%. These regularities are revealed even more sharply in carp through the use of the electrodefensive method. Here the stability of the light reflex exceeds 95% in comparison with a stability of 56% (Table 23) when the light reflex was developed first.

The clear generalization of the reflex during application of the light stimulus cannot be explained only by the fact that the reflex to light was developed after the conditioned reflex to the magnetic field. For example, although the conditioned reflex to the bell was developed after the reflexes to the magnetic field and to light were fixed, the reflex to the bell does not show such a degree of generalization. Under ordinary conditions, as we have stated before, the reflex to light and to the bell are formed at an identical rate (Table 23).

We assumed that the presence of a conditioned reflex to a magnetic field accelerates subsequent development of a conditioned reflex to light and we conducted special tests to check this assumption. In fish no. 11 and 12 we developed a conditioned reflex to a magnetic field, and once in the test we applied light without reinforcement. At first neither the magnet nor the light caused the conditioned response, but as soon as the conditioned reflex to the magnetic field became fixed, the response also appeared to the application of light. To illustrate this phenomenon we give the record of Test No. 9 with carp no. 12. /203

TEST NO. 9. CARP NO. 12, 21 DECEMBER 1954.

Stimulus number	Time of switching on the stimulus	Stimulus	Conditioned response	Unconditioned reinforcement
86	11 hr 13 min 00 sec	magnet	-	+
87	11 hr 15 min 00 sec	"	+	+
88	11 hr 17 min 00 sec	"	-	+
89	11 hr 19 min 30 sec	"	+	-
90	11 hr 23 min 00 sec	"	+	-
9	11 hr 25 min 15 sec	light	+	-
91	11 hr 28 min 30 sec	magnet	+	-
92	11 hr 32 min 00 sec	"	+	-
93	11 hr 35 min 00 sec	"	+	+
94	11 hr 38 min 00 sec	"	+	+
95	11 hr 41 min 00 sec	"	+	+
1	11 hr 43 min 00 sec	bell	-	-

The response to light observed during development of the conditioned reflex to a magnetic field cannot be explained by the general increase in excitability of the nervous system, since the application of the bell in the same test did not cause the response. It is interesting to note that the response to light was observed only at a definite degree of stability of the conditioned reflex to the magnetic field. When the stability was low, there was no response to light.

TEST NO. 11. CARP NO. 14, 25 DECEMBER 1954. THE TEST BEGAN AT 11:29.

Stimulus number	Time of switching on the stimulus	Stimulus	Conditioned response	Unconditioned reinforcement
111	11 hr 29 min	light	+	-
112	11 hr 32 min	"	+	+
113	11 hr 38 min	"	+	+
114	11 hr 42 min	"	+	-
115	11 hr 44 min	"	+	-
8	11 hr 46 min	magnet	+	-
116	11 hr 48 min	light	+	-
117	11 hr 50 min	"	+	-
118	11 hr 52 min	"	+	-
119	11 hr 54 min	"	+	-
120	11 hr 56 min	"	+	-
1	11 hr 59 min	bell	-	-

In carp no. 14 we developed a conditioned reflex to light, and sometimes we applied a magnetic field without reinforcement. The obtained results are well illustrated by the introduced test record.

The test results show that during development of the conditioned reflex to light we observe a reaction to a magnetic field the application of which was never accompanied by an electric shock. At the same time the application of the bell did not cause a response. Based on this material we can conclude the presence of a definite similarity in the physiological effects of light and a magnetic field.

#### Retention of the Conditioned Magnetic Reflex in Fish After Enucleation

Since the mechanism of the effect of light on animals is well known, we decided that a magnetic field is perceived just as light is, i.e., by the retina. This position was supported by data in the literature concerning the possibility of producing the sensation of phosphene during the influence of a magnetic field on man [Mogendovich and Skachedub, 1957]. It is natural, therefore, that the next stage in our tests was a check on the retention of the conditioned reflex to a magnetic field and the possibilities of its development after bilateral enucleation.

In carp no. 11 and 12, in which we had developed the conditioned reflex to a magnetic field, we disturbed the visual receptor by destroying the retina (carp no. 12) or sectioning the optic nerves (carp no. 11). The tests began on the day of the operation or on the next day.

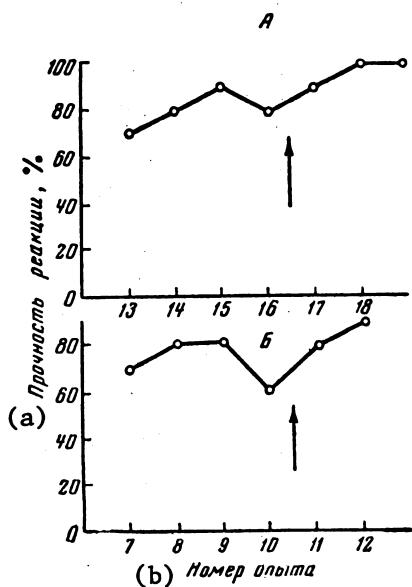


Figure 67. Dynamics of the Conditioned Electrodefensive Reflex to a Magnetic Field in Fish After Bilateral Enucleation. A = Carp No. 11; B = Carp No. 12, The Arrows Designate the Moment of the Operation. Key: (a) Reaction Stability, %; (b) Number of the Test.

lag period; thus the remaining photoreceptors perceive light less perfectly than the retina.

After the possibility of light perception by blinded fish had been affirmed [Kholodov, 1958a], we decided to find out how the general nature of the perception of light and a magnetic field changes in enucleated fish.

In 3 blinded carp (no. 1, 2 and 3) we simultaneously developed conditioned reflexes to light and to a magnetic field, alternating the stimuli in the test, and in 2 blinded carp (no. 4 and 5) we developed the reflex to light and checked its generalization for a magnetic field. The results of simultaneous development of conditioned reflexes to light and to a magnetic field are given in Table 32 and Figure 68.

The data of Table 32 show that the conditioned reflexes to light and to the magnetic field appear simultaneously, but the reflexes to light are fixed sooner. At the same time in the fish with vision the conditioned reflex to light appeared and was fixed much sooner than the reflex to the magnet. Consequently, the similarity in the effects of light and a magnetic field was increased.

As Figure 67 shows, after destruction of the visual receptor the conditioned reflex to a magnetic field did not disappear, but even increased /205 somewhat. The results obtained put the hypothesis about the similar effects of light and a magnetic field on the retina in doubt. Therefore, we assume that light and a magnetic field can be perceived in fish not only by the retina. This assumption was based on the data about the possibility of fish perceiving light with the aid of the skin analyser [Parker, 1905] or directly by the diencephalon [Scharrer, 1928; Jung, 1935].

We began to develop conditioned reflexes in the blinded fish 1-10 days after the operation. Table 31 gives the test results on the development of conditioned reflexes to white light in 7 fish after blinding.

From the data of Table 31 it follows that the rate of formation of the conditioned reflex to light in blinded fish differs little from the corresponding index for fish with vision, but the reflex stability is lower in the blinded fish.

The test results clearly show that light acts on fish not only through the eye, but through other means whose activity can be successfully studied by the method of conditioned reflexes. A less stable conditioned reflex is formed to the light that is perceived by the receptor left in fish after enucleation; it appears with a longer

lag period; thus the remaining photoreceptors perceive light less perfectly than the retina.

After the possibility of light perception by blinded fish had been affirmed [Kholodov, 1958a], we decided to find out how the general nature of the perception of light and a magnetic field changes in enucleated fish.

In 3 blinded carp (no. 1, 2 and 3) we simultaneously developed conditioned reflexes to light and to a magnetic field, alternating the stimuli in the test, and in 2 blinded carp (no. 4 and 5) we developed the reflex to light and checked its generalization for a magnetic field. The results of simultaneous development of conditioned reflexes to light and to a magnetic field are given in Table 32 and Figure 68.

The data of Table 32 show that the conditioned reflexes to light and to the magnetic field appear simultaneously, but the reflexes to light are fixed sooner. At the same time in the fish with vision the conditioned reflex to light appeared and was fixed much sooner than the reflex to the magnet. Consequently, the similarity in the effects of light and a magnetic field was increased.

TABLE 31. CHARACTERISTICS OF THE CONDITIONED REFLEXES TO LIGHT IN BLINDED FISH.

Fish No.	Number of Combinations		Lag period, sec	Stability, %
	Before appearance of the reflex	Before fixation of the reflex		
1	11	24	6.1	38
2	7	7	5.3	43
3	17	22	4.0	60
4	8	21	5.7	65
5	3	10	4.9	82
6	2	13	8.0	28
7	4	15	7.2	30
Averages	7.4	16.0	5.9	49.0

ed in the blinded fish. This similarity can be seen more completely in Figure 68, where the curves of the stability of the conditioned reflex to a magnet almost completely duplicate the curves of the stability of the conditioned reflex to light for each fish.

TABLE 32. RATE OF DEVELOPMENT OF CONDITIONED REFLEXES TO LIGHT AND TO A MAGNETIC FIELD IN BLINDED CARP.

Fish No.	Light		Magnet	
	Number of combinations		Number of combinations	
	Before appearance of the reflex	Before fixation of the reflex	Before appearance of the reflex	Before fixation of the reflex
1	11	24	11	64
2	7	7	7	48
3	17	22	19	38

We can illustrate the generalization of the conditioned light reflex under /207 the effect of the magnetic field by the record of Test No. 6 on fish no. 49.

From the record it follows that generalization of the light conditioned reflex under the effect of a magnetic field in blinded fish appears very clearly. Similar results were obtained in tests with carp no. 48. The generality of the

TEST NO. 6. CARP NO. 49, 15 JUNE 1955. THE TEST WAS BEGUN AT 10:00.

Stimulus number	Time of switching on the stimulus	Stimulus	Conditioned response	Unconditioned reinforcement
55	10 hr 00 min 00 sec	light	+	+
56	10 hr min sec	"	+	-
57	10 hr min sec	"	+	-
58	10 hr min sec	"	+	-
59	10 hr min sec	"	+	+
8	10 hr min sec	magnet	+	-
60	10 hr min sec	light	+	-
61	10 hr min sec	"	+	-
62	10 hr min sec	"	+	-
63	10 hr min sec	"	+	-
64	10 hr min sec	"	+	-
9	10 hr min sec	magnet	+	-

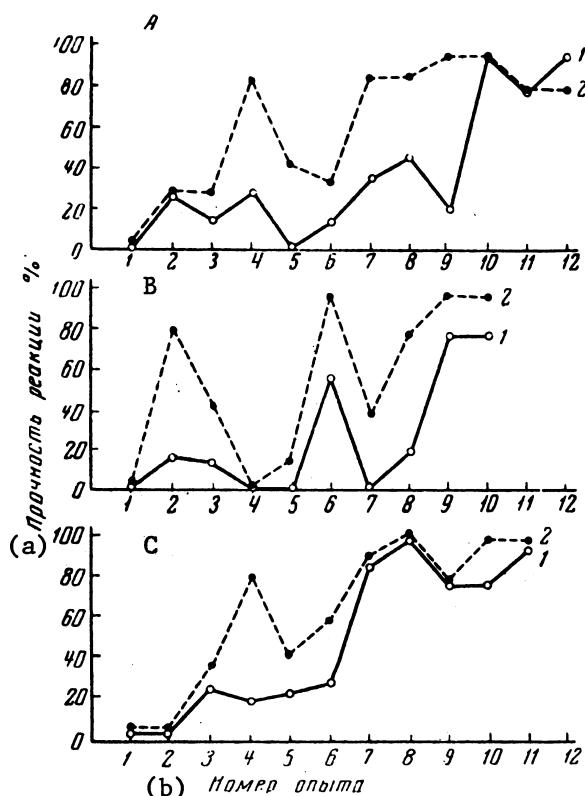


Figure 68. Dynamics of the Stability of Electrodefensive Conditioned Reflexes to a Magnetic Field (1) and to Light (2) in Blinded Carp. A = Carp No. 1; B = Carp No. 2; C = Carp No. 3. Key: (a) Reaction Stability, %; (b) Number of the Test.

effect of light and a magnetic field after blinding of fish not only did not decrease, but even increased. Therefore, the idea of a similar mechanism for the effect of light and a magnetic field remains dominant in our later tests.

The Role of Different Sections of the Fish Brain in the Realization of a Conditioned Electrodefensive Reflex to a Magnetic Field

/208

The localization of the fixing function in the fish brain has not been sufficiently studied. Since this class of vertebrates lacks a cortex, certain investigators have assumed that fixing is accomplished in fish in the midbrain and the diencephalon [Beritov, 1932; Frolov, 1941; Bykov, 1952]. Based on the results of other works we can conclude that the fixing of conditioned reflexes in fish occurs in the cerebellum [Karamyan, 1949, 1956; Malyukina, 1955].

We decided to clarify the role of the 4 basic sections of the fish brain (midbrain, diencephalon, visual tegmenta and cerebellum) in the realization of the conditioned defensive reflex to a magnetic field. As a control we developed conditioned reflexes to light and to a bell. In one test we usually gave 10 combinations of the magnet, 3 combinations of the light and 3 combinations of the bell with the unconditioned electric stimulus.

Development of Conditioned Reflexes After Damage to the Visual Tegmenta

TABLE 33. SUMMARIZED DATA ON FISH AFTER DAMAGE TO THE VISUAL TEGMENTA.

Fish No.	Date of the operations, 1955	Date the tests started, 1955	Day the reflex to the CMF appeared	Number of tests	Date of death, 1955	Survival after operation, in days
1	Jan. 25	Jan. 28	1	4	Feb. 7	13
2	Jan. 25	Jan. 28	2	3	Feb. 8	14
3	Jan. 25	Jan. 28	1	6	Feb. 18	24
4	Mar. 1	Mar. 7	1	3	Mar. 10	10
5	Mar. 14	Mar. 29	1	4	Apr. 8	25
6	Mar. 7, 1956	Mar. 20, 1956	2	9	Mar. 31, 1956	24

We began the tests on extirpation of separate parts of the fish brain with removal of the visual tegmenta since this section of the brain takes part in the effectuation of the conditioned response to light [Baru, 1955], whose effect is /209 similar to that of a magnetic field.

Conditioned reflexes were developed in 6 carp after removal of the visual

tegmenta. Table 33 gives the summarized data on the operated fish.

The data of Table 33 show that regardless of the length of the postoperative period, which varied from 3 to 15 days, reflexes to the magnetic field are formed on the 1st or 2nd day after the beginning of the tests. It is characteristic that the survival of the fish after the operation was brief (from 10 to 25 days) and that all the fish died. We explain this by the fact that either during the operation or, more likely, because of the inflammation forming after the operation, the functions of the lower-lying sections of the brain were disturbed.

The results of the tests on development of conditioned reflexes in the operated fish are given in Table 34.

TABLE 34. CHARACTERISTICS OF THE CONDITIONED REFLEXES TO A MAGNETIC FIELD, LIGHT AND A BELL IN FISH AFTER REMOVAL OF THE VISUAL TEGMENTA.

Fish No.	Magnet			Light			Bell		
	Number of combinations		Stability, %	Number of combinations		Stability, %	Number of combinations		Stability, %
	Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex	
1	5	23	60	1	1	60	27	—	48
2	11	11	27	3	—	20	1	27	56
3	4	12	52	4	30	40	6	27	67
4	9	9	27	—	—	—	—	—	—
5	3	3	36	—	—	—	—	—	—
6	13	13	36	3	3	36	12	—	11

We managed to develop a conditioned reflex to a magnetic field in all fish, /210 although only 3-9 tests were conducted with each fish. The average stability of the conditioned reflex to the magnetic field (43%) somewhat exceeded the same index for intact fish.

We did not develop conditioned reflexes to other stimuli in all fish. Conditioned reflexes to light and to the bell were developed in 4 carp (no. 1, 2, 3 and 6). The stability of the conditioned light and sound reflexes was less than that in intact fish. We explained the appearance of a conditioned reflex to these stimuli during their first application, which was sometimes observed, by generalization since both the light and the bell were applied in the test after the magnetic field. The possibility of developing conditioned reflexes after removal of the visual tegmenta is illustrated by the kymograms of the tests (Figure 69).

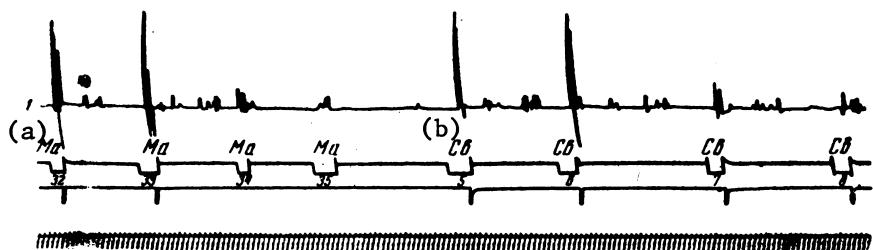


Figure 69. Kymograms of Tests on the Development of Electrodefensive Conditioned Reflexes to a Magnetic Field and to Light in Fish After Damage to the Visual Tegmenta. The Designations Are the Same as in Figure 61. Key: (a) Magnetic Field; (b) Light.

In one carp we destroyed the visual tegmenta after we had developed the conditioned reflex to the magnetic field. It turned out that the reaction to the magnetic field was retained. Thus, destruction of the visual tegmenta did not change the conditioned reflex to a magnetic field and reduced the stability of conditioned reflexes to light and to a bell.

#### Development of Conditioned Reflexes After Removal of the Cerebellum

Tests on the development of conditioned reflexes were conducted on 7 carp (Table 35).

TABLE 35. SUMMARIZED DATA ON FISH AFTER COMPLETE REMOVAL OF THE CEREBELLUM.

Fish No.	Date of operation	Starting date of tests	Day the reflex to a CMF appeared	Number of tests	Date		Lifetime, in days
					of death	of sacrifice	
1	[1955] Apr. 20	[1955] May 16	1	7	—	[1955] May 27	37
2	June 7	June 14	1	4	[1955] June 20	—	13
3	June 7	June 14 [1956]	1	2	June 17	—	10
4	Dec. 30 [1956]	Jan. 16	1	3	[1956] Jan. 20	—	21
5	Mar. 7	Mar. 20	2	13	—	[1956] Apr. 4	28
6	Mar. 7	Mar. 20	1	13	—	Apr. 4	28
7	May 16	May 26	1	3	May 29	—	13

The conditioned reflex to a magnetic field appeared in all fish. We obtained the most complete picture of the conditioned-reflex activity in the case /211 of 3 fish (no. 1, 5 and 6) that lived for more than 25 days after the operation and that were sacrificed for a morphological check of the completeness of removal of the cerebellum.

The characteristics of the conditioned reflexes of all fish are given in Table 36.

TABLE 36. CHARACTERISTICS OF CONDITIONED REFLEXES TO A MAGNETIC FIELD, LIGHT AND A BELL IN FISH AFTER REMOVAL OF THE CEREBELLUM.

Fish No.	Magnet			Light			Bell			Stability, %	
	Number of combinations		Stability, %	Number of combinations		Stability, %	Number of combinations				
	Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex			
1	3	3	54	1	12	80	1	—	—	—	
2	10	—	—	6	—	—	12	—	—	—	
3	4	—	—	4	—	—	7	—	—	—	
4	4	—	27	2	—	—	14	—	—	—	
5	24	78	33	13	13	50	16	23	36		
6	2	21	45	1	10	70	8	35	23		
7	10	—	—	1	—	54	—	—	0		

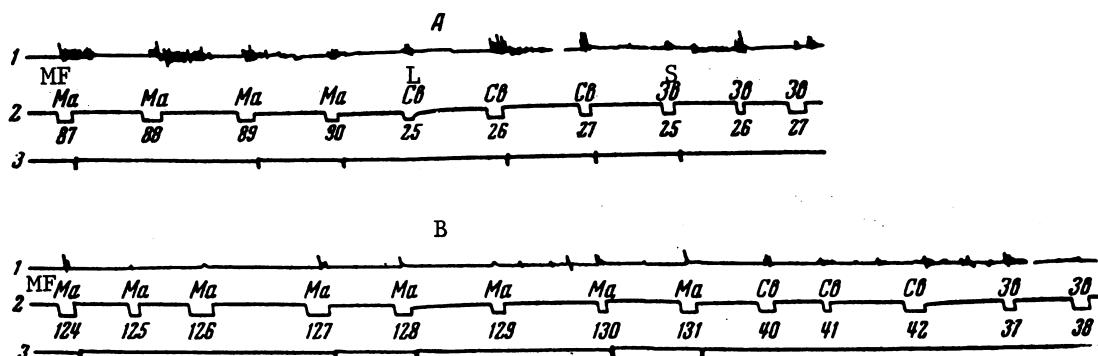


Figure 70. Kymograms of Tests on Developing Electrodefensive Conditioned Reflexes to a Magnetic Field, Light and Sound in Fish After Removal of the Cerebellum. A = Fish No. 5; B = Fish No. 6; MF = Magnetic Field; L = Light; S = Sound. The Remaining Designations Are the Same as in Figure 61.

In fish which lived long enough after the operation, we managed to develop a conditioned reflex to all stimuli. In the fish that died soon after the operation we observed the appearance of conditioned reflexes to all stimuli. The stability of the conditioned reflexes shows that after removal of the cerebellum the conditioned reflex to the bell is disturbed most severely. The stability /213 was not calculated for certain fish because the number of applications of the conditioned stimulus was not great enough. The possibility of developing conditioned reflexes in fish after removal of the cerebellum is illustrated by the kymograms of Figure 70.

We assume that the noncorrespondence of our results with the data of A. I. Karamyan can be explained by the low age of our fish (1-2 years) and their better survival rate after the operation, which reduced the effect of postoperative disturbances on the development of conditioned reflexes. The significant disturbance in the conditioned sound reflex after removal of the cerebellum may either be explained by the fact that sound reflexes are fixed in the cerebellum [Malyukina, 1955] or by the fact that the conducting paths of this reflex are tightly connected with the cerebellum [Kappers et al., 1936]. The second statement seems more probable to us.

#### Development of Conditioned Reflexes After Removal of the Forebrain

Although many works deny the effect of the forebrain on conditioned reflexes to light and sound in fish [Baru, 1955; Healey, 1957], we decided to try to develop a conditioned reflex to a magnetic field after removal of the forebrain from fish. The summarized data on 5 carp used in these tests are given in Table 37.

TABLE 37. SUMMARIZED DATA ON FISH AFTER REMOVAL OF THE FOREBRAIN.

Fish No.	Date of operation	Starting date of tests	Day the reflex to a CMF appeared	Number of tests	Date of sacrifice
1	Jan. 17, 1955	Jan. 24, 1955	1	8	Feb. 21, 1955
2	Jan. 17, 1955	Jan. 24, 1955	2	10	Feb. 20, 1955
3	Feb. 28, 1955	Mar. 29, 1955	1	7	May 24, 1955
4	Apr. 28, 1956	May 23, 1956	1	10	June 4, 1956
5	Nov. 9, 1956	Nov. 29, 1956	3	20	Mar. 24, 1957

The behavior of the fish changes little after removal of the forebrain. Reflexes to the magnetic field are developed in the first through the third test. Not one fish died.

The results of developing conditioned reflexes, given in Table 38, indicate that the higher nervous activity of the fish did not significantly change.

TABLE 38. CHARACTERISTICS OF CONDITIONED REFLEXES TO A MAGNETIC FIELD, LIGHT AND A BELL AFTER REMOVAL OF THE FOREBRAIN IN FISH.

Fish No.	Magnet			Light			Bell		
	Number of combinations		Stability, %	Number of combinations		Stability, %	Number of combinations		Stability, %
	Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex	
1	23	27	50	1	—	—	1	—	—
2	26	108	25	8	—	—	1	—	—
3	2	6	60	4	9	60	1	1	91
4	11	15	35	4	4	30	6	10	85
5	16	75	24	1	3	97	7	19	54

The rate of development of the conditioned reflexes to the applied stimuli /214 and their stability clearly show that, if we do not count a certain decrease in the stability of the conditioned light reflex after the operation, a fish without a forebrain differs little from an intact fish. Nevertheless, as a control, on carp no. 13, 15 and 20 we checked the retention of the conditioned reflexes after removal of the forebrain. After removal of the forebrain the developed reflex to a magnetic field in fish did not change.

#### Development of Conditioned Reflexes After Damage to the Diencephalon

The role of the diencephalon in the behavior of fish remains less known. The existing works on extirpation of the diencephalon concern the effect of this section of the brain on motion [Steiner, 1888] and respiration [Springer, 1928] of Selachii.

TABLE 39. SUMMARIZED DATA ON FISH AFTER DAMAGE TO THE FOREBRAIN AND DIENCEPHALON.

Fish No.	Date of operation	Starting date of tests	Day the reflex to a CMF appeared	Number of tests	Date of sacrifice
1	[1955] Jan. 12	[1955] Jan. 12	15	29	[1955] Mar. 21
2	Feb. 19	Feb. 19	8	21	Mar. 21
3	Feb. 19	Feb. 19	—	21	Mar. 21
4	Apr. 28, 1956	May 15, 1956	4	11	June 4, 1956
5	Nov. 9, 1955	Dec. 29, 1955	6	20	Mar. 23, 1956
6	Dec. 30, 1955	Feb. 11, 1956	2	18	Mar. 23, 1956

We conducted tests on developing conditioned reflexes in carp, the summarized data of which are given in Table 39.

We see that the conditioned reflex to a magnetic field either appears very late or does not appear at all (carp no. 3), although the fish withstood the operation very well and they all survived. Table 40, which gives the characteristics of the conditioned reflexes for operated fish, shows significant disturbances of the conditioned reflex to the magnetic field. In fish no. 3 we did not manage to form the conditioned reflex to the magnetic field in spite of 249 combinations of exposure to the magnetic field with an electric shock. In fish no. 4, 5 and 6, although the conditioned reflex to the magnetic field appeared, we could not fix it. In the fish in which fixation of the reflex occurred (no. 1 and 2), it was less stable than similar reflexes of intact fish or fish with other types of brain damage.

/21

TABLE 40. CHARACTERISTICS OF CONDITIONED REFLEXES DEVELOPED IN FISH AFTER DAMAGE TO THE Diencephalon.

Fish No.	Magnet			Light			Bell			Stability, %	
	Number of combinations		Stability, %	Number of combinations		Stability, %	Number of combinations				
	Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex		Before appearance of the reflex	Before fixation of the reflex			
1	46	173	2	1	33	20	1	6	53		
2	70	70	18	49	66	17	14	59	35		
3	?*	?	0	27	?	14	6	26	55		
4	35	?	17	4	4	74	3	3	65		
5	50	?	10	4	4	19	2	33	51		
6	16	?	22	3	?	18	2	14	71		

\* ? = designates absence of fixation of the conditioned reflex.

The conditioned reflex to light was developed more poorly than in intact fish or in fish after extirpation of other sections of the brain, but it was still better than the conditioned reflex to the magnetic field.

The conditioned reflex to the bell was developed in all operated fish and it differed little in its properties from the sound reflexes of intact fish. The test results are illustrated by the kymograms of Figure 71. Consequently, damage to the diencephalon leads to disturbances in the development of conditioned reflexes to the magnetic field and to light, but it changes the development of the conditioned reflex to the bell very little.

/21

The tests with damage to the diencephalon of blinded fish, in which condi-

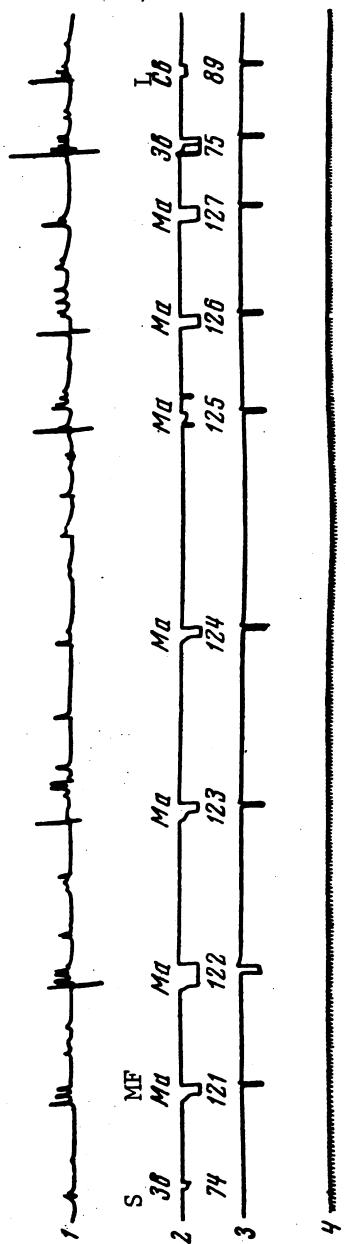


Figure 71. Kymograms of the Tests on the Development of Electrodefensive Conditioned Reflexes to a Magnetic Field, Light and Sound in Fish After Removal of the Forebrain and Diencephalon. S = Sound; MF = Magnetic Field; L = Light. The Designations Are the Same as in Figure 61.

tioned reflexes to light and to a magnetic field were preliminarily developed, show that the conditioned reflexes to the magnetic field and to light disappear after the operation.

#### Discussion

To clarify the general picture of the change in conditioned reflex activity of fish during different disturbances of the central nervous system, we composed summary Table 41.

In the future our conclusions will be based on the average magnitudes, which, of course, only approximately characterize the quantitative side of the conditioned responses, since the number of cases for which we calculated the averages was not great. Furthermore, in calculating the averages we disregarded the cases in which we did not manage to obtain a conditioned reflex, although these cases would be more correctly expressed by very large magnitudes (in the table they are designated by  $\infty$ ).

For a more detailed analysis of the results obtained we composed diagrams illustrating the effect of damage to different sections of the fish brain on separate indices that characterize the conditioned reflex. The character of the disturbances in the fish brain are noted on the abscissa, and the absolute or relative magnitude of the corresponding index of the conditioned reflex is shown on the ordinate. The rate of appearance, rate of fixation and the stability of the conditioned reflex enter into a number of these indices.

Figure 72,A shows the change in the absolute magnitude for the rate of appearance of the conditioned reflex to a magnetic field, light and a bell for different types of brain damage. The greatest disturbance of the conditioned reflex to a magnetic field and to light is observed after damage to the diencephalon. The reflexes to light and to the magnetic field change little after damage to the other sections of the brain. The conditioned reflex to the bell is disturbed after damage to the visual tegmenta and the cerebellum, but it changes little after damage to the forebrain and diencephalon. After almost all types of brain damage the conditioned reflex to the magnetic field appears later than the reflexes to the other stimuli, and the rates

TABLE 41. CHARACTERISTICS OF CONDITIONED REFLEXES TO A MAGNETIC FIELD,  
LIGHT AND A BELL IN NORMAL FISH AND AFTER DIFFERENT EXTIRPATIONS.

Conditioned response	Normal		Damage to the visual tegmenta		Removal of the cerebellum		Removal of the forebrain		Damage to the diencephalon	
	Light	net weight	Light	net weight	Light	net weight	Light	net weight	Light	net weight
2-25 (19)*	1-14 (8)	3-13 (6)	1-4 (4)	1-27 (4)	1-24 (7)	1-13 (7)	1-∞ (6)	2-26 (5)	1-7 (5)	16-∞ (6)
10	4	3	7	3	12	8	4	10	16	4
24-102 (15)	1-30 (7)	3-23 (6)	1-30 (3)	27 (2)	3-78 (3)	10-13 (3)	23-∞ (3)	6-108 (5)	3-9 (3)	1-19 (3)
58	12	14	12	11	27	34	12	20	46	5
24-52 (4)	85-97 (4)	70-85 (6)	27-60 (4)	11-67 (4)	27-54 (4)	54-80 (4)	0-32 (3)	24-60 (5)	30-97 (3)	54-97 (3)
39	94	80	43	40	45	40	64	20	40	62

\*The number of fish used in the tests during calculation of the given index is shown in parentheses.

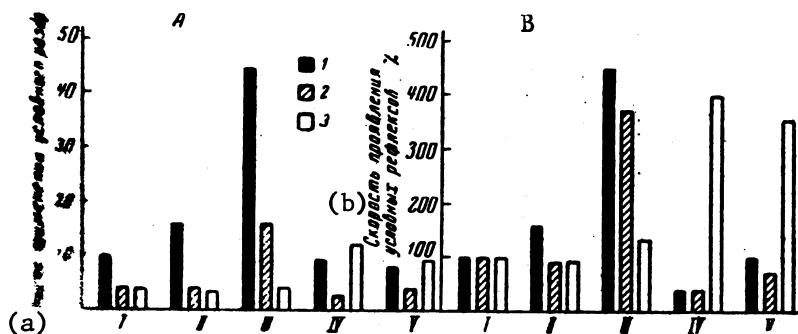


Figure 72. Absolute (A) and Relative (B) Changes in the Rate of Appearance of Electrodefensive Conditioned Reflexes to a Magnetic Field (1), Light (2) and Sound (3) in Fish in the Norm (I) and After Damage to the Forebrain (II), Diencephalon (III), Midbrain (IV) or Cerebellum (V). Key: (a) Number of Applications of the Conditioned Stimulus; (b) Rate of Appearance of the Conditioned Reflexes, %.

of appearance of the conditioned reflexes to light and to the bell in the normal fish and after removal of the forebrain are identical, which is again supported by the data of Table 23. It is interesting to note the coincidence in form of the diagrams for the rate of appearance of the conditioned reflexes to light and to the magnetic field. This similarity resembles the graph for the development of conditioned reflexes to light and to a magnetic field in blinded fish and again forces us to assume a generality of the action mechanisms of light and a 219 magnetic field. In order to judge the degree of change in the rate of appearance of conditioned reflexes to different stimuli after different types of brain damage, in Figure 72,B we show these changes in percentages, taking the rate of appearance of the reflexes in the norm as 100%. We see that the degree of disturbance in the rate of appearance of the conditioned reflexes is greatest in the reflex to the magnetic field (by 350%), then comes the bell (by 300%) and, finally, light (by 275%).

Figure 73,A shows the change in the absolute magnitude of the rate of fixation of conditioned reflexes to a magnetic field, light and a bell after different types of damage to the fish brain. As in Figure 72, the greatest disturbance in the conditioned reflex to a magnetic field and to light is observed after damage to the diencephalon, and in the reflex to the bell, after damage to the midbrain and the cerebellum. The conditioned reflex to the magnetic field is almost always fixed later than the conditioned reflexes to light and the bell in the norm and after removal of the forebrain.

The relative change in the rate of fixation of conditioned reflexes after damage to separate sections of the brain (Figure 73, B) also coincides with the graph of the relative change in the rate of appearance of conditioned reflexes, except that after removal of the forebrain the conditioned reflexes to all the applied stimuli are fixed sooner than in the norm, and after damage to the visual tegmenta the conditioned reflex to the magnetic field is fixed relatively sooner than the conditioned reflex to light.

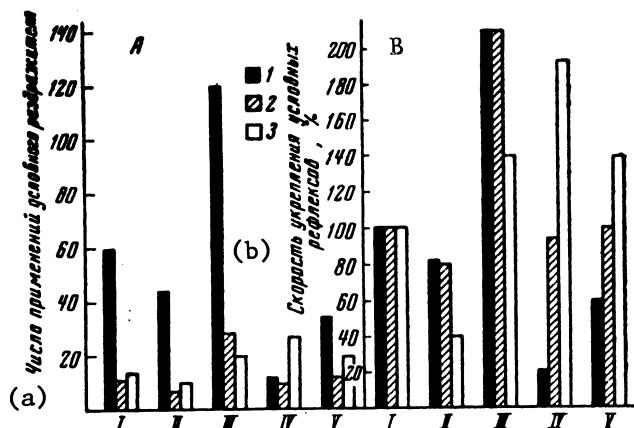


Figure 73. Absolute (A) and Relative (B) Changes in the Rate of Fixation of Electrodefensive Conditioned Reflexes to a Magnetic Field, Light and Sound in Fish After Damage to Different Sections of the Brain. The Designations Are the Same as in Figure 72. Key: (a) Number of Applications of the Conditioned Stimulus; (b) Rate of Fixation of the Conditioned Reflexes.

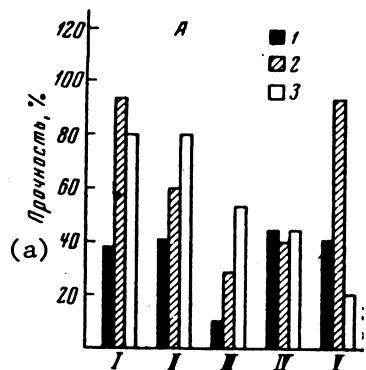


Figure 74. Absolute (A) Changes in the Stability of Electrodefensive Conditioned Reflexes to a Magnetic Field, Light and Sound in Fish After Damage to Different Sections of the Brain. Key: (a) Stability, %. The Designations Are the Same as in Figure 72.

In our opinion, a conditioned reflex is most completely characterized by its stability, and not the rate of formation of time relationships. But as Figure 74, A shows, in this case the change in stability of the conditioned reflexes to the applied stimuli after different types of brain damage supports the conclusions obtained in the analysis of the formation rate for the time relationships. The conditioned reflex to the magnetic field was the least stable reflex. Its stability changed only after damage to the diencephalon. The stability of the conditioned reflex to light is reduced after any brain damage. The greatest disturbance in the stability of the light reflex occurred after damage to the diencephalon. The greatest disturbance in the stability of the conditioned reflex to the bell occurred after removal of the cerebellum, but after removal of the forebrain the conditioned reflex to the bell was not disturbed at all. The relative change in the stability of the conditioned reflexes shows that the greatest disturbance occurs in the conditioned reflex to the bell after removal of the cerebellum.

To compare the investigated indices of the conditioned reflex we composed Table 42, which reflects the relative change in the conditioned reflex after different types of damage to the fish brain. We took the value of the index in the norm as 100%, and the deviations from the norm are expressed in positive or negative percents.

From the tables it follows that removal of the forebrain has little effect on the development of conditioned reflexes. If changes occur, they are small and not equivalent for different indices. Thus, if we judge from the rate of fixation, the conditioned reflex to the magnet in-

TABLE 42. RELATIVE CHANGES IN THE INDICES OF CONDITIONED REFLEXES AFTER DAMAGE TO DIFFERENT SECTIONS OF THE FISH BRAIN.

Stimulus	Index of the conditioned response	Character of the disturbance, %			
		Removal of the fore-brain	Damage to the dien-cephalon	Damage to the mid-brain	Removal of the cerebellum
magnet	rate of appearance	-60	-350	+ 30	+ 20
	rate of fixation	+20	-106	+ 80	+ 41
	stability	+ 2	- 66	+ 8	+ 2
light	rate of appearance	0	-275	+ 25	0
	rate of fixation	+58	-124	+ 8	0
	stability	-30	- 65	- 52	- 28
bell	rate of appearance	0	- 33	-300	- 266
	rate of fixation	+ 8	- 40	- 93	- 40
	stability	0	- 31	- 44	- 75

creased; if we judge from the rate of appearance, it decreased; and if we judge from the degree of stability of the reflex, it did not change.

Damage to the diencaphalon caused a decrease in the conditioned reflexes to all stimuli according to all indices. However, the degree of decrease was different for different stimuli.

According to all indices damage to the midbrain increases the conditioned reflex to the magnetic field a little, reduces the reflex to light a little and significantly reduces the conditioned reflex to the bell. Upon removal of the cerebellum, the conditioned reflex to the bell is strongly reduced; the reflex to light almost does not change in comparison with the norm, and the reflex to the magnetic field is increased a little.

On the basis of all tests with removal of different sections of the fish brain we can say that if we quantitatively characterize the fixing function, it is disturbed to some degree during damage of any section of the fish brain, but there is a definite localization of this function for different stimuli. Thus, the conditioned reflexes to light and to the magnetic field are disturbed most significantly after damage to the diencephalon, and the reflex to the bell, after damage to the midbrain or cerebellum. These facts coincide with the results of morphological investigations [Sepp, 1949] according to which the hindbrain is closely related with the auditory analyzer.

Our data do not answer the question about the localization of the fixing function in fish, since a special investigation is required for this, but we did clarify the role of different parts of the brain in the development of condition-

ed reflexes to a magnetic field in fish. However, if we quantitatively characterize the degree of disturbance of the fixing function after damage to different sections of the brain in the development of conditioned reflexes to a magnetic field, light and a bell, considering the rate of appearance, the rate of fixation and the stability of the reflexes, then our averages show that the fixing function is disturbed most after damage to the diencephalon and the midbrain, at least after damage to the cerebellum. After removal of the forebrain the fixing function is disturbed insignificantly, even during development of complex conditioned reflexes in fish [Kholodov, 1960].

After damage to the diencephalon the development of conditioned reflexes to a tactile stimulus is also disturbed in fish [Kholodov et al., 1961].

Our data about the possibility of developing conditioned reflexes in fish after removal of the cerebellum [Kholodov, 1959; Gusev'nikov and Kholodov, 1964] were recently supported in the work of V. L. Bianki (1962), in which it was shown that the formation of time relationships to sound, light and the stimulation of a floating bubble in fish is also possible after full removal of this section of the brain. For a final answer to the question about the localization of the fixing function in the fish brain we need further investigations with the parallel application of several methods, including the electrophysiological method.

### Conclusions

1. Denervation of the lateral line organ does not change the conditioned reflex to a magnetic field in fish.
2. A similarity is observed in the effects of light and a magnetic field; it is expressed in a generalization of the conditioned reflexes during interchange of these stimuli.
3. Bilateral enucleation does not change the conditioned reflex to a magnetic field in fish.
4. The similarity in the effects of light and a magnetic field is increased in blinded fish.
5. The conditioned reflexes to a magnetic field in fish were significantly disturbed after damage to the diencephalon and did not change after removal of the forebrain, cerebellum or visual tegmenta.

### Synopsis

Using the conditioned reflex method, we managed to elucidate certain properties of EMF as stimuli, which was also done in tests with the electrographic method. True, in the rabbit, the only object of the electrographic investigations, we did not manage to develop a conditioned reflex to a CMF. This fact can be explained by the late appearance of the basic electrographic reaction to a CMF in rabbits. Let us recall that the electrical reaction of both the whole

brain and separate neurons occurred with a latent period that exceeded 10 sec. With a 7 sec lag in reinforcement only the desynchronization reaction, which sometimes starts at the moment the electromagnet is turned on, can occur in the rabbit EEG. It is evident that this reaction cannot serve as the basis for development of a conditioned reflex. Consequently, the experiments on the development of conditioned reflexes supported our electrographic data concerning the long latent period of the reaction of the brain to EMF.

It is fully reasonable to explain the sharp inhibiting effect of EMF during development of conditioned inhibition in fish and pigeons by the longer (more than 10 sec) exposure to this factor. More likely, the inhibiting effect of EMF on previously developed conditioned reflexes is also expressed in the experiments on rabbits, since the inhibiting effect of a CMF on these animals was observed in tests on the reactance curve. Speaking about future experiments, we /224 should also note that recording the brain electrical activity of fish can also give substantial information on the peculiarities of the reactions of these animals to a CMF.

At the present time, it is difficult to understand the high sensitivity of fish to EMF (in comparison with birds and mammals). We can explain the development of conditioned reflexes to a CMF by the peculiarities of the brain structure (the diencephalon plays the main role in fixing the time relationships) and the environment (a CMF can act through water). However, a comparison of the results of tests on developing conditioned reflexes to EMF in fish and the tracings of electrical brain activity in rabbits shows a certain general similarity of the reactions to EMF in different classes of vertebrates. This includes the low stability of the reactions, the predominantly inhibiting effect of EMF and the prolonged aftereffect. While after the experiments with rabbits we spoke about the similar nonspecific effect of a CMF, a UHF and an SHF field, after the tests on fish we can speak about the similar nonspecific effect of a CMF, a variable magnetic field with a frequency of 50 Hz, a UHF field, light and irradiation. Thus, almost the whole spectrum of electromagnetic oscillations can have a nonspecific effect on the central nervous system.

In the analysis of the role of receptor formations in the reaction of fish to EMF, it was observed that denervation of the lateral line organ, enucleation and damage to the olfactory analyisor do not disturb these reactions; and of the different sections of the brain, the diencephalon plays the most important role. Let us recall that an isolated brain preparation reacted to EMF better than an intact brain, and that the hypothalamus was the most reactive structure. Thus, the predominant interest in the diencephalon appeared during the study of reactions to EMF in both rabbits and fish.

Whereas with the electrographic method there was danger that the effect of EMF could be transferred by means of the electrodes, so that we had to remove them during exposure in the control tests, the conditioned reflex method reliably indicates the direct effect of EMF on the organism.

It has already been said that conditioned reflexes to EMF are similar in their properties to the conditioned reflexes developed from the interoceptors of the internal organs. This circumstance can be explained by the direct effect of EMF on the brain tissue, where certain interoceptors are located. However, the

conditioned reflexes developed to weak stimulation of the exteroceptors also have similar properties. It is possible that the peculiarities of the conditioned reflexes to EMF can be explained not only by the direct effect of these stimuli on the central nervous system, but also by their physiologically weak nature.

I N G   T H E   E F F E C T   O F   E L E C T R O-  
M A G N E T I C   F I E L D S   O N   T H E  
C E N T R A L   N E R V O U S   S Y S T E M

Although we obtained the basic material on the effect of EMF on the function of the vertebrate brain by means of electrographic and conditioned-reflex methods, we also used other methods of investigation which provide additional information on the nature of the studied phenomenon.

This includes the method of determining the sensitivity to electrical and chemical stimulation, the method of recording motor activity, and histological investigations of the changes in the brains of animals subjected to EMF.

In contrast to the two preceding parts, in this part of the book we expound the results of experiments in which the effect of EMF was not limited to seconds, but lasted for minutes, hours and even days. This circumstance allowed us to reveal the more intensive EMF effects.

At the same time, we were limited to just a description of the obtained phenomena, without offering the physiological analysis which was used in the preceding chapters.

CHAPTER 7. THE CHANGE IN THE SENSITIVITY OF FISH AND  
AMPHIBIANS TO A MAGNETIC FIELD OR LIGHT

/226

We assumed that fish perceive a magnetic field, like light, directly by the diencephalon. It is known that chemical or electrical stimulation of the diencephalon leads to inhibition of the signaling reflexes in frog [Sechenov, 1863]. We decided to check whether a similar effect occurs during the influence of light or a magnetic field directly on the diencephalon.

Investigation of Sechenov Inhibition During the Influence  
of Light or a Magnetic Field on the Diencephalon  
of Frogs with Their Hemispheres Removed

The tests were conducted according to the following method. The upper jaw together with the eyes was cut away. The cerebral hemispheres were removed. The skin was removed from the remaining upper part of the skull. The trunk of the frog was fastened horizontally on a test plate and its hind legs were held in the vertical position. The entire frog was covered with a black opaque paper in which a hole was cut for illumination of the diencephalon. Either the light from a 25-w electric light passed through a water filter 6-8 cm thick, or a magnetic field with a frequency of 50 Hz and a strength of 500-800 Oe was employed on the region of the diencephalon. The magnetic field was created by an electromagnet with its core placed over the frog diencephalon.

The tests were conducted in a darkened room. The feet of the frog were stimulated with a 1.0-1.5% sulfuric acid solution. The glasses containing the acid were filled such that all the toes of the frog were immersed in the liquid. After the frog removed its foot from the acid, the stimulated foot was washed with water and the other foot was immersed in the acid after 1-2 min. The latent period of the signaling reflexes was measured with an accuracy up to 1 sec. A foot was stimulated only once.

The effect of light on the diencephalon was studied in 19 frogs. The general results of the tests are given in Table 43.

The data of Table 43 show that an increase in the time of the signaling reflex, i.e., Sechenov inhibition, is observed most frequently (in 77% of the cases) during the influence of light on the frog diencephalon. Inhibition of signaling reflexes has also been noted by other authors during total-body illumination of a frog [Johannes, 1930; Beburishvili, 1937].

/227

Figure 75 gives the results of the most typical test. We see that when there was no influence on the diencephalon, the latent period of the signaling reflex changed little over 5 min, being approximately equal to 10 sec. But, 1 min after the beginning of light exposure on the diencephalon, the latent period of the reflex increased by a factor of 3. Inhibition was complete in 4 min. The inhibiting effect caused by light is also retained after this stimulus is turned off. Only 10 min after the light is turned off does the length of the

TABLE 43. CHANGE IN THE LATENT PERIOD OF SIGNALING REFLEXES DURING THE INFLUENCE OF LIGHT ON THE FROG DIENCEPHALON.

Frog No.	# of tests	Character of the latent period change (number of cases)			Frog No.	# of Tests	Character of the latent period change (number of cases)		
		increase	absence of change	decrease			increase	absence of change	decrease
1	3	3	0	0	11	4	3	1	0
2	2	2	0	0	12	2	2	0	0
3	2	2	0	0	13	6	2	4	0
4	2	2	0	0	14	8	5	1	2
5	2	1	1	0	15	2	2	0	0
6	7	6	1	0	16	6	4	0	2
7	2	2	0	0	17	2	2	0	0
8	4	2	1	1	18	6	4	2	0
9	2	2	0	0	19	4	4	0	0
10	5	5	0	0					
Total:									
raw					71	55	11	5	
%					100	77	16	7	

latent period begin to return to the initial level. Since the observed effect has a reversible character, the results of this test indicate the presence of a light effect directly on the diencephalon. The effect of light appears after a definite latent period and is retained for a significant time after the light is turned off.

The change in the signaling reflexes was observed from 1 to 21 min after the start of the light exposure, but only in rare cases did it begin after 6 min. The time of the aftereffect varied from 3 to 57 min, but in most tests it was 10-20 min. The aftereffect was always longer than the latent period.

Table 43 shows 5 cases in which the influence of light directly on the diencephalon did not increase the time of signaling reflexes. However, this effect was noted during the exposure to light on the skin of the frog [Wwedenksy, 1879]. A detailed analysis of these tests showed that in all 5 cases the light acted on an inhibiting background. Figure 76 shows that under the influence of light there is inhibition of the signaling reflexes during stimulation of the right foot with acid and disinhibition during stimulation of the left foot in the same frog. Inhibition passes soon after the light is turned off, but the disinhibition is retained throughout the tests. Consequently, the effect of light depends on the initial functional state of the nervous system, and the instances of a decrease in the latent period of signaling reflexes must be related to tests that also support the perception of light during its direct effect on the diencephalon. Then, according to the data of Table 43, the number of tests

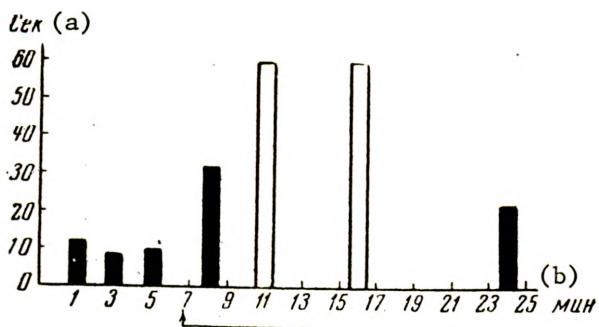


Figure 75. Increase in the Latent Periods of Signaling Reflexes During the Direct Influence of Light on the Frog Diencephalon. The Arrows Note the Beginning and the End of the Exposure; the Light Columns Designate the Absence of a Reaction over 1 Min; the Time of the Test (in Min) is Displayed Along the Abscissa, and the Time of the Latent Period (in Sec), Along the Ordinate. Key: (a) Sec; (b) Min.

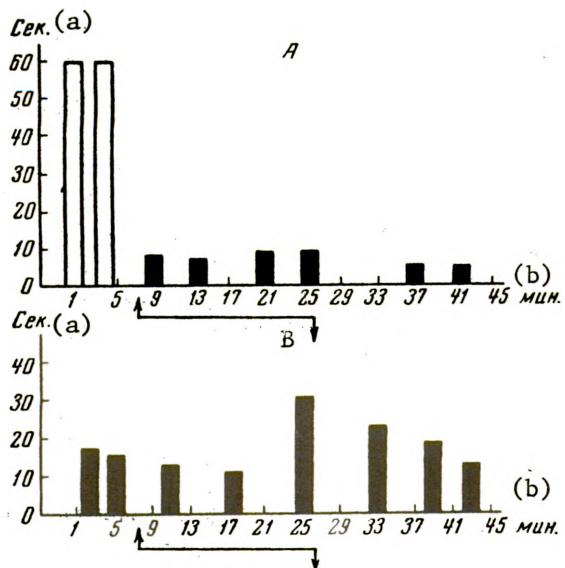


Figure 76. Changes in the Latent Periods of Signaling Reflexes in Two Feet of a Frog During the Influence of Light on the Diencephalon. A = During Acid Stimulation of the Left Foot; B = the Right Foot. The Remaining Designations are the same as in Figure 75. Key: (a) Sec; (b) Min.

that indicate the presence of a light effect will be  $77 + 7 = 84\%$ . In a detailed analysis of the cases involving an absence of a light effect, we revealed two factors: first, it was observed most frequently in males; second, the absence of a light effect was observed with a latent period for the signaling reflex of less than 5 sec, i.e., in cases when the acid was a very strong stimulus.

The effect of a variable magnetic field with a strength of 500 Oe was studied in 37 tests on 9 frogs (Table 44).

From Table 44, it follows that the latent period of signaling reflexes during the influence of a magnetic field increased in 58% of the cases, decreased in 13% and remained unchanged in 19%.

Figure 77 shows the results/230 of one of these tests. It is evident that the influence of a magnetic field causes inhibition of the signaling reflexes in the frog. An analysis of the length of the latent period and the time of aftereffect showed that the effect of a magnetic field occurs, on the average, 8 min after the electromagnet is turned on, and the aftereffect lasts approximately 5 min after it is turned off. Consequently, if we judge from the length of the latent period and the aftereffect, a magnetic field is a weaker stimulus than light.

An analysis of the cases in which the latent period of the signaling reflexes was reduced showed that, like light, a magnet changes the signaling

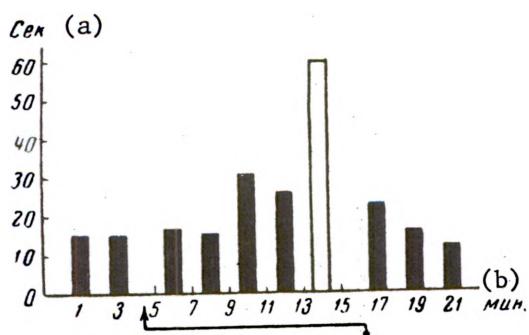


Figure 77. Increase in the Latent Periods of Signaling Reflexes During the Influence of a Magnetic Field on the Frog Brain. The Designations are the same as in Figure 75. Key: (a) Sec; (b) Min.

reflexes in a way that depends on the initial state. As the test results given in Figure 78 indicate, a magnetic field decreases the latent period of the signaling reflexes on an inhibiting background. In some cases this decrease is irreversible, while in other cases it is reversible in nature, i.e., the latent period again increases soon after the end of the exposure to the magnetic field.

As in the case of an increase in the latent period, the cases of a decrease in the latent period of signaling reflexes also indicate the presence of a magnetic field

TABLE 44. CHANGES IN THE LATENT PERIOD OF SIGNALING REFLEXES DURING THE INFLUENCE OF A MAGNETIC FIELD ON THE HEAD OF A FROG.

Frog No.	Total no. of tests	Character of the latent period change (number of cases)		
		increase	absence of change	decrease
1	6	4	2	0
2	2	2	0	0
3	8	6	2	0
4	6	0	3	3
5	4	3	0	1
6	6	6	0	0
7	2	1	0	1
8	1	1	0	0
9	2	2	0	0
Total: raw	37	25	7	5
%	100	68	19	13

effect. In total, we find that the effect of the magnetic field occurs with /231  $68 + 13 = 81\%$  of the exposures to this stimulus, i.e., a little less often than during the influence of light (84%).

We conducted tests on the effect of a magnetic field on frogs after removal of the diencephalon, but did not observe changes in the latent period of reflexes. This is in agreement with the data of other authors [Drozdov, 1879].

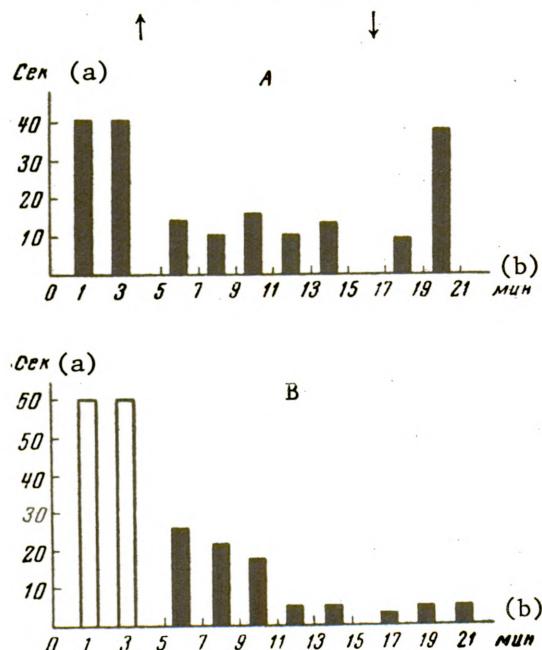


Figure 78. Reversible (A) and Irreversible (B) Decreases in the Latent Period of Signaling Reflexes During the Influence of a Magnetic Field on the Frog Brain. The Remaining Designations are the Same as in Figure 75.  
Key: (a) Sec; (b) Min.

other physical factors: light [Lisk and Kannwischer, 1964; and others], temperature [Euler, 1950; and others], ionizing radiation [Aladzhalova, 1962; and others] and a UHF field [Livshits, 1958; and others] during their direct effect on the brain. Thus, the question regarding the mechanism of the perception of a magnetic field has become part of the large problem concerning the receptor function of the hypothalamus.

The direct effect of stimuli on the central nervous system show that the reflex principle of nervous system activity should be more widely understood than the classical diagram of the reflex arc allows. The afferent part of the arc of certain reflexes can be reduced to extremely small dimensions, while the receptor part actually merges with the central juncture. In principle, the possibility of this diagram has been shown by numerous tests using electrical, mechanical and chemical stimulation of the central nervous system, and by tests on development of conditioned reflexes to electrical stimulation of the brain [Rozhanskiy, 1957; and others].

Although the electromagnet was placed above the diencephalon in all our tests, we could not strictly localize the magnetic field exposure, which was propagated to the surrounding tissue to some degree. However, the influence of the electromagnet on a section of the spinal cord did not cause Sechenov inhibition. Based on this, we concluded that the magnetic field acts directly on the diencephalon.

The direct effect of a magnetic field on the nervous system was noted at the very start of the experimental study of the physiological properties of this stimulus. More recent works contain indications of the possibility of a direct effect of a magnetic field on the brain [Sherstneva, 1951; /232/ Selivanova and Erdman, 1956]. Our data (which agree with the references) offer a somewhat more specific localization of brain sections most sensitive to a magnetic field. These should probably include the hypothalamus region of the diencephalon. It is interesting to note that the hypothalamus is also the site for perception of

The efferent part of the reflex arc can also be absent during the influence of certain stimuli. P. S. Kupalov (1949) called conditioned reflexes without an effector termination, class I conditioned reflexes, and reactions during direct stimulation of the central nervous system, class II conditioned reflexes.

The impossibility of developing conditioned reflexes to a magnetic field in pigeons shows that the effector part of the reflex arc is absent during the influence of a magnetic field. We found that the magnetic stimulus involves neither an afferent, nor an efferent part of the reflex arc, i.e., the effect of the magnetic field is limited to the central nervous system. Even within the limits of the central nervous system, a magnetic field does not cause spreading excitation. For example, in fish the conditioned reflex to a magnetic field is disturbed only following damage to the diencephalon, and does not change during damage to other brain sections. In a neuromuscular preparation, a magnetic field causes changes that do not spread, and reduces parabiosis [Petrov, 1930; Erdman, 1956].

The Effect of Light or a Magnetic Field  
on the Sensitivity of Fish and  
Axolotl to an Electric Current

/233

The change in the sensitivity of fish to an electric current during different exposures was most frequently determined by the change in the anesthetization threshold during exposure to a variable electric current [Puchkov, 1954; Vartanyan, 1958], i.e., from the change in the voltage that causes immobilization of fish. However, such a strong stimulus causes prolonged changes in the activity of the nervous system. We are supposing that the threshold of current perception can serve as the index of sensitivity of fish to an electric current because the very procedure of determining the sensitivity of fish to an electric current does not change the current perception threshold. This latter index, which has been determined for decades, remains at the same level [Kholodov and Akhmedov, 1962].

The investigation was conducted on different species of fish and on axolotl. The principle diagram of the device is shown in Figure 79. Lead electrodes were placed on two opposite walls of the aquarium. A direct current from battery (A) was fed to these electrodes through a rheostat (P). The circuit was switched with the aid of a key (K) and the applied voltage was measured by means of a voltmeter (B). Before determining the perception threshold of an electric current, we always placed the test animal in the center of the aquarium and directed it perpendicular to the plane of the electrodes with its head toward the cathode. By gradually increasing the voltage to the electrodes, we found the voltage that caused the primary tremor reaction in the fish. This determination was conducted 3 times in a row and, if the readings were close, the average of these measurements characterized the sensitivity of the fish to an electric current at the given moment.

Then the fish was subjected to the influence of the studied physical factor, light or a 50-200-Oe magnetic field. Illumination was accomplished with a 50-w electric light, and the magnetic field was created by switching on the solenoid wound around the aquarium.

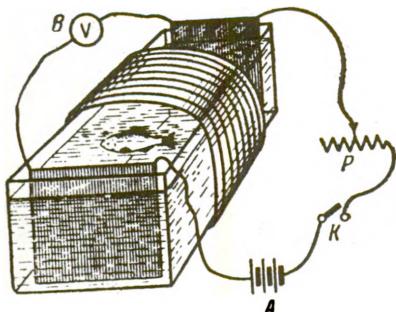


Figure 79. Diagram of the Device for Determining the Sensitivity of Fish to an Electric Current. See Text for a Description.

gated on 20 stickleback. The test results are shown in Figure 80, which gives the average perception thresholds for each 10 fish. We see that the magnetic field increases the threshold of perception of an electric current by 17-21% on the average. The fact that an increase in the perception threshold is observed only during the influence of the magnetic field, indicates the reliability of the obtained results. The test results on freshwater fish are given in Table 45.

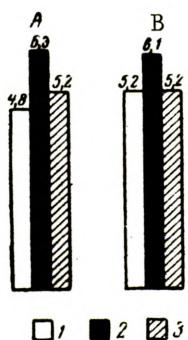


Figure 80. Average Sensitivity of Stickleback to an Electric Field Before (1) during (2) and after (3) exposure to a CMF. A = test No. 1 (stickleback No. 1-10); B = test No. 2 (stickleback No. 11-12).

creases it (Test No. 2), but the same magnetic field, acting on the background

During the influence of the studied factor, we determined the threshold of perception of an <sup>/234</sup> electric current by the fish according to the method described above. However, this determination of the perception threshold was conducted some time after the studied factor was switched off. We counted the readings of only the tests during which the sensitivity of fish to an electric current before and after exposure to the studied factor was approximately identical.

The tests were conducted on stickleback (the White Sea Biological Station of Moscow State University), bleak, quab, brook trout, Raja clavata, striped perch, bullhead, roach, Proximus, rudd, Leucaspis and carp (Zvenigorodsk Biological Station of Moscow State University).

The effect of the CMF on the sensitivity of marine fish to an electric current was investigated on 20 stickleback. The test results are shown in Figure 80, which gives the average perception thresholds for each 10 fish. We see that the magnetic field increases the threshold of perception of an electric current by 17-21% on the average. The fact that an increase in the perception threshold is observed only during the influence of the magnetic field, indicates the reliability of the obtained results. The test results on freshwater fish are given in Table 45.

From Table 45, it is evident that the effect of a magnetic field on the sensitivity of fish to an electric current is observed in all 9 species of fish. This effect is most frequently (65% of the cases) manifested as a decrease in the sensitivity of fish to an electric current, but there were tests in which the sensitivity was increased during the influence of the magnetic field. These include the tests on striped perch, bleak and Proximus. These fish were less able to withstand the conditions of the solenoid in the aquarium than the others, and they died soon after the tests. A high threshold of perception of an electric current was characteristic for them. To illustrate this, we offer the records of two tests on the same Proximus.

In the case of a low initial perception threshold, the magnetic field increases it (Test No. 2), but the same magnetic field, acting on the background

TABLE 45. CHANGE IN THE SENSITIVITY OF FRESHWATER FISH TO AN ELECTRIC CURRENT DURING EXPOSURE TO A MAGNETIC FIELD.

/235

Species of Fish	Number of tests	Change in sensitivity		Absence of the effect
		decrease	increase	
<u>Raja clavata</u>	7	6	1	0
quab	11	8	1	2
striped perch	2	0	2	0
bleak	6	1	3	2
bullhead	6	5	0	1
roach	2	2	0	0
brook trout	8	4	3	1
<u>Proximus</u>	2	2	0	0
rudd	2	2	0	0
Total:				
raw	46	30	10	6
%	100	65	22	13

RECORDS OF TESTS ON PROXIMUS NO. 2.

	Test no. 2		Test no. 3	
	time	perception threshold	time	perception threshold
before exposure	16 hr, 46 min	1.4	12 hr, 09 min	3.6
	16 hr, 51 min	1.4	12 hr, 11 min	3.7
	16 hr, 53 min	1.4	12 hr, 12 min	3.7
during exposure	16 hr, 58 min	1.7	12 hr, 16 min	3.3
	17 hr, 02 min	1.7	12 hr, 19 min	3.4
	17 hr, 04 min	1.8	12 hr, 21 min	3.0
after exposure	17 hr, 10 min	1.2	12 hr, 31 min	3.8
	17 hr, 13 min	1.4	12 hr, 35 min	3.6
	17 hr, 16 min	1.4	12 hr, 39 min	3.6

of lowered sensitivity of the fish to an electric current, causes a lowering of the perception threshold. Consequently, the result of an exposure to a magnetic

field is determined by the initial functional state of the nervous system of the fish and, to quantitatively characterize the effect of a magnetic field on the sensitivity of fish to an electric current, we must sum all the cases of a change in the sensitivity. Thus, the effect of a magnetic field is observed in 65 + 22 = 87% of the treated cases.

The general results of this series of tests are similar to the results of /236 tests on frogs. A change in the sensitivity of the animal to an external stimulus during the influence of a magnetic field is observed in both cases, but during both electrical and chemical stimulation, a magnetic field most frequently reduces the sensitivity. However, depending on the initial functional state, the magnetic field can also increase the sensitivity. Consequently, a magnetic field somehow regulates the sensitivity of an organism to different influences. This general regulation can be accomplished only through the central nervous system, and we can assume that the change in the function of the CNS is a result of the influence of the magnetic field.

We also checked the hypothesis regarding the similar effect of light and a magnetic field during the investigation of the sensitivity of fish to an electric current. The method of investigation in determining the effect of light on the sensitivity of fish to an electric current was the same as during the investigation of the effect of a magnetic field. The test objects were the same freshwater fish and also axolotl. The general test results are given in Table 46.

TABLE 46. CHANGE IN THE SENSITIVITY OF FISH TO AN ELECTRIC CURRENT DURING THE INFLUENCE OF LIGHT.

Species of Fish	Number of tests	Changes in sensitivity		Absence of the effect
		decrease	increase	
bleak	2	0	2	0
quab	9	4	3	2
brook trout	5	1	4	0
<u>Raja clavata</u>	2	0	2	0
bullhead	5	1	4	0
roach	2	0	2	0
<u>Proximus</u>	2	0	2	0
rudd	2	2	0	0
<u>Leucaspis</u>	2	0	2	0
carp	3	0	3	0
<b>Total:</b>				
raw		34	8	2
%		100	23	6
			24	71

The data of Table 46 show that most frequently (in 71% of the cases) light increases the sensitivity of fish to an electric current, rarely reduces it (23%) and only very rarely does not change the sensitivity (6%). The cause of the decrease in the sensitivity to an electric current observed in rudd and quab during the influence of light is still unclear. However, regardless of these cases, the general conclusion concerning the increase in the sensitivity of fish to an electric current during illumination remains in force.

Consequently, light and a magnetic field affect the sensitivity of fish to an electric current differently. This conclusion casts doubt on our assumption regarding the similar effect of a magnetic field and light on fish. However, in tests on development of conditioned reflexes, we established that the similarity in the effect of a light and a magnetic field is increased after the fish are blinded. Therefore, we decided to check how the sensitivity to an electric current changes during the illumination of 7 blinded fish.

All the tests gave an identical result: in blinded fish the sensitivity to an electric current was lowered during the influence of light. This shows that, first, light receptors remain in fish after blinding and, second, the photoreceptors of the blinded fish possibly are qualitatively different from the retina, which reduces the sensitivity of fish to an electric current.

The tests involving blinded fish showed that the similarity in the effect of light and a magnetic field is revealed only after removal of the specific light receptor, the retina. The operation of blinding, by itself, either generally did not change the sensitivity of fish to an electric current, or changed it in one or the other direction, but illumination always reduced the sensitivity to an electric current.

Figure 81 shows the results of tests conducted on the same day and on the same fish before and after blinding. Before blinding, the sensitivity to an electric current increased during the influence of light, and after blinding, it was reduced by an average of 1.0 v.

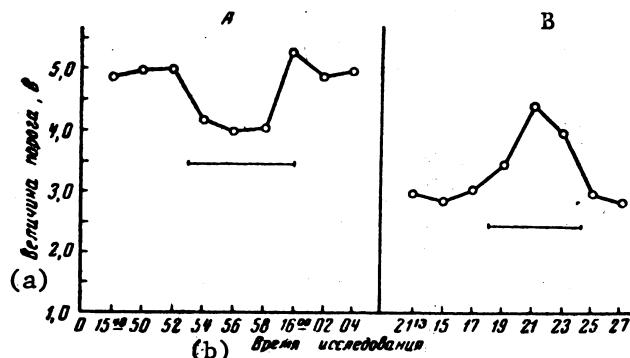


Figure 81. Change in the Threshold of Perception of an Electric Current in a Brook Trout During the Influence of Light Before (A) and After (B) Blinding. The Horizontal Line Designates the Time of the Light Influence. Key: (a) Threshold (b) Time of Test.

We obtained similar results not only in other species of fish, but also in axolotl. The sensitivity to an electric current in axolotl did not change after blinding. In both blinded and normal axolotl, the threshold of perception of an electric current was approximately 1 v. However, the change in the sensitivity during the influence of light in blinded and normal axolotl has a different direction, although approximately an identical magnitude. Consequently, following blinding in both axolotl and fish, light continues to have

an effect on the physiological state of the CNS.

### Discussion

Tests on the change in the sensitivity of fish to an electric current during the influence of a magnetic field or light again showed that a magnetic field has a physiological effect, that the character of this effect is similar to the character of the effect of light on blinded fish, and that its result is a change in the sensitivity to chemical and electrical stimuli. The different effects of light on blinded and normal animals force us to assume a dual nature of the influence of light on the organism. One mechanism of the influence, through the retina, basically ensures the function of objective vision; the other mechanism of the influence, which is effected through both the retina and other paths, affects many functions of the organism [Godnev, 1882; Svetozarov and Shtraykh, 1941; Markelov, 1948; Berkovich, 1953].

The obtained results show that a magnetic field can act not only on birds and fish, but also on amphibians. Generalizing our data and the reference data, we can speak of the possibilities of an effect of a magnetic field on all classes of vertebrates. While the sensitivity to a magnetic field plays some role in the long-range migrations of fish and birds, the development of this sensitivity occurred on the basis of a general (for all vertebrates) ability to perceive a magnetic field.

### Conclusions

1. During the direct effect of light or a magnetic field on the diencephalon of frogs without hemispheres, changes are observed in the length of the latent period of signaling reflexes.
2. The direction of the change in the latent period of signaling reflexes under the stated influences depends on the initial functional state of the nervous system. On an inhibited background, the signaling reflexes are accelerated, but on an excited background, they are inhibited; the last case is observed more frequently.
3. Judging from the latent period and the time of the aftereffect, light /23 affects the diencephalon more strongly than a magnetic field.
4. A magnetic field reduces the sensitivity to a constant electric current in marine and freshwater fish.
5. In normal fish and axolotl, light increases the sensitivity to a constant electric current, but in blinded animals, it reduces it.
6. The similarity in the effect of light and a magnetic field is revealed in the change of sensitivity in blinded fish.

## CHAPTER 8. THE CHANGE IN THE MOTOR ACTIVITY OF FISH AND BIRDS DURING THE INFLUENCE OF A CONSTANT MAGNETIC FIELD

In studying the effect of a magnetic field on fish by the development of conditioned reflexes to this factor, and also by determining the sensitivity to an electric current, we tried to investigate the activity of the whole organism. It seemed to us that to some degree this approach helped reveal the physiological effect of such a weak stimulus as a magnetic field. We also tried to find other methods of studying the activity of a whole organism in order to once again check the possibility of the physiological effect of a magnetic field on animals. One such method is that of determining the motor activity. These tests were conducted on fish and birds.

### The Change in the Motor Activity of Stickleback During the Influence of a CMF

We recorded the motor activity of the fish by a very simple method. The stickleback were placed in a tank around which a solenoid was wound; this solenoid, connected to a dc circuit, created a 50-150-Oe magnetic field. One end of a thread was tied to the dorsal fin of the fish, the other end was fastened to a lever whose motion was recorded on the smoked drum of a kymograph. This recording did not allow us to quantitatively characterize the motions that were observed during the influence of the magnetic field, but it demonstrated the presence of this effect with sufficient persuasiveness (Figure 82). On the kymogram, it is evident that during a 1-hour exposure to a magnetic field, the /240 motor activity of the fish was greater than before or after exposure. The influence of the magnetic field was not felt immediately after turn-on, but after 15 min had passed. The effect was also retained for some time after the magnetic field was turned off. However, we could not give a persuasive quantitative characterization of the effect of a magnetic field on the motor activity of a fish due to the imperfection of the method used. Therefore, we have summarized the test results in the form of Table 47, which shows how frequently the effect of the magnetic field was observed.

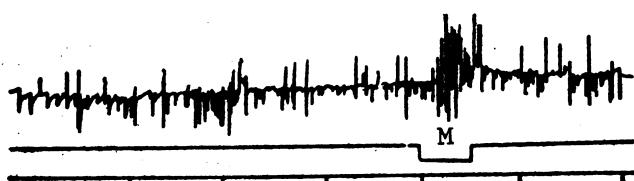


Figure 82. Increase in the Motor Activity of a Fish During Exposure to a CMF. M = Influence Period of the Magnetic Field. The Time Markings Equal 2 Hours.

Most frequently (64% of the cases) a magnetic field increased/241 the motor activity of stickleback. A decrease in motor activity during the influence of the magnetic field was rarely observed (in 15% of the cases). We observed the absence of an effect in 23% of the cases exposed to the magnetic field.

Consequently, a magnetic field increases the motor activity in fish and, in this, its effect

TABLE 47. THE EFFECT OF A MAGNETIC FIELD  
ON THE MOTOR ACTIVITY OF STICKLEBACK.

Fish no.	Number of tests	Character of the change in motor activity		Absence of the effect
		increase	decrease	
1	2	2	0	0
2	1	1	0	0
3	28	22	0	6
4	1	1	0	0
5	1	1	0	0
6	5	5	0	0
7	3	0	2	1
8	1	1	0	0
9	3	0	1	2
10	23	13	2	8
11	17	8	6	3
Total:				
raw	85	54	11	20
%	100	64	13	23

is similar to the known effect of light on the motor activity of fish [Jones, 1955; Voronin and Kholodov, 1962; and others]. The similar effect of a magnetic field and light in the change in motor activity forces us to assume that the effect of light on motor activity is realized not only by means of the retina, but by another means as well. Tests on blinded fish prove the assumption of Woodhead (1958).

#### The Change in the Motor Activity of Birds During the Influence of a CMF

The method of recording motor activity under laboratory conditions is applied most frequently in the study of the behavior of birds. Numerous methods of recording motor activity have been developed for this class of vertebrates. This index is frequently used by ornithologists and physiologists in studying the effect of external and internal factors on the behavior of birds. The method of determining the motor activity of birds allows us to quantitatively characterize the level of the organism's activity. Therefore, we decided to conduct experiments on the effect of a magnetic field on the motor activity of birds from the sparrow family (4 bullfinches, 2 greenfinches, 2 titmice, 1 crossbill and 1 chaffinch). This work was conducted together with A. L. El'darov.

The bird was placed in a wooden cage (Figure 83), the floor of which was suspended on rubber bands. The perches were fastened to the floor, and,

therefore, any movement of the bird from perch to perch forced the floor to oscillate. By dropping down, the floor closed electrical contact (K), which was switched into the circuit of the battery (A) and the electromagnetic marker (O). Deflection of the electromagnetic marker lever ensured rotation of the anchor wheel (An) by one tooth. The anchor wheel was set on the axis of the van wheel of the kymograph ( $Km_1$ ) such that 24 closures of the marker rotated the kymograph drum by 1 mm. The glass ink stylus was connected by means of blocks with the drum of the second kymograph ( $Km_2$ ) and moved vertically at a speed of 1 cm/hr.

Consequently, on the tape of the first kymograph we obtained a curve on whose horizontal the total number of motions of the bird during one test was recorded, and along the vertical, the time of the test. The test lasted 2 or 9 hours (from 0900 to 1800 hr).

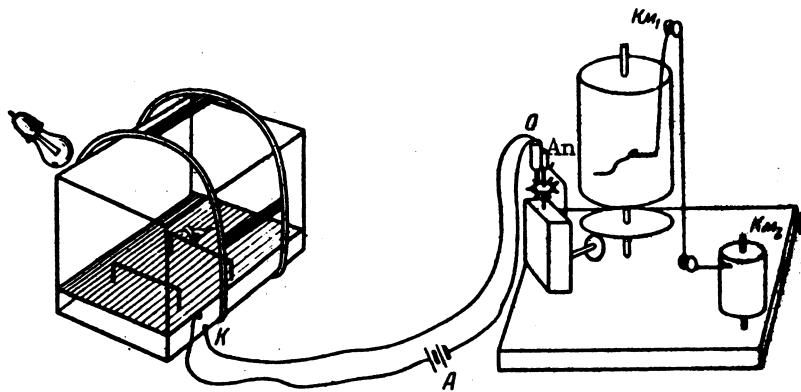


Figure 83. Diagram of the Device for Recording the Motor Activity of Birds (Description in the Text).

A constant 0.70-1.70-Oe magnetic field was created by switching Helmholtz /242 coils wound around the cage into the circuit of the battery. We began working with each bird in such a way that we could record its motor activity without the influence of a CMF by means of several tests. Then, one test was completely conducted with the Helmholtz coils turned on, and after this we again recorded the motor activity without a CMF for several days.

At the beginning of this work, we recorded the diurnal variations of the air temperature and humidity, and also atmospheric pressure. However, significant changes in the motor activity of birds were noted during stable environmental conditions, and they basically depended on the degree of illumination. The increase in bird motor activity during the influence of light has been noted by many investigators and, therefore, the increase in motor activity of bull-finches which we observed during the influence of a magnetic field during natural illumination (the cage stood on a windowsill) could be explained by the influence of illumination, the magnitude of which we did not measure. For a stricter clarification of the effect of a magnetic field, we conducted the basic

tests with artificial illumination. The artificial illumination was from a 50-w electric light placed over the glass ceiling of the cage. In another case, we created weak artificial illumination in the cage. We judged the effect of a CMF by comparing the number of bird movements during the test involving the influence of the CMF with the average number of movements during the test without this stimulus. The results of all tests are given in Table 48.

TABLE 48. INFLUENCE OF A MAGNETIC FIELD ON BIRD MOTOR ACTIVITY.

Species of bird	Duration of the CMF exposure, hr.	Number of tests	Character of the change in the motor activity		Absence of the effect
			increase	decrease	
bullfinch no. 1	9	12	12	0	0
bullfinch no. 2	9	2	2	0	0
bullfinch no. 3	9	9	6	2	1
bullfinch no. 4	9	4	4	0	0
greenfinch no. 1	9	1	1	0	0
<b>total:</b>					
raw		28	25	2	1
%		100	90	7	3
greenfinch no. 2	2	1	1	0	0
titmouse no. 1	2	7	5	2	0
titmouse no. 2	2	5	5	0	0
chaffinch no. 1	2	1	1	0	0
crossbill no. 1	2	6	5	1	0
<b>total:</b>					
raw		20	17	3	0
%		100	85	15	0
<b>total of both series:</b>					
raw		48	42	5	1
%		100	88	10	2

Most frequently (88% of the cases) the magnetic field, acting for 2 or 9 hours, increases motor activity. Tests in which there was a decrease in motor activity during the influence of the magnetic field, and in the absence of this effect, compose 12% of all exposures to the magnetic field and, what is interesting, all these involved females. It is possible that males are more sensitive to a magnetic field. /243

Comparing the results of these tests with similar tests on stickleback (see Table 47), we can conclude that the motor activity of birds during the

influence of a magnetic field changes more frequently than the motor activity of fish, although this comparison is very relative. However, although we cannot compare the results of the tests on stickleback and bullfinches from a quantitative point of view, we can qualitatively characterize them unambiguously, i.e., a magnetic field increases the motor activity of fish and birds.

Since the motor activity of birds strongly depends on illumination [Kalabukhov, 1951; Eyster, 1954; Segal', 1955], we conducted tests on the effect<sup>/244</sup> of a magnetic field during illumination of different intensities. Figure 84 shows the results of tests with bullfinch no. 1, on which we conducted experiments using natural (variable) illumination and constant artificial strong and weak illumination. The test results show that under any illuminating conditions, a CMF increases the motor activity of the bullfinch. The degree of this increase, however, depends on the initial amount of the motor activity, which is determined by both the intensity of illumination and by certain unconsidered factors, because the amount of motor activity varied rather widely under identical illumination.

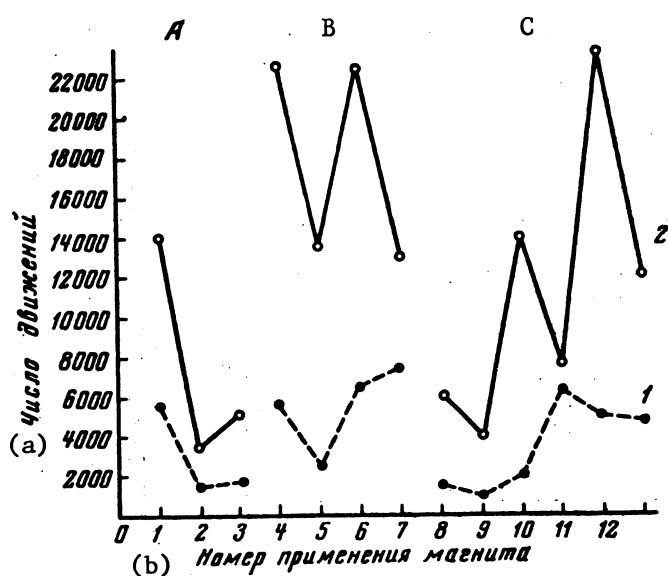


Figure 84. Motor Activity of Bullfinch No. 1 Before (1) and During (2) Exposure to a CMF Under Conditions of Natural (A), Constant Strong (B) and Weak (C) Illumination. Key: (a) Number of Movements; (b) Magnet Application Number.

ly under weak illumination (4.3 times).

Having established that a general increase occurs in the motor activity of bullfinches during the influence of a CMF, we decided to analyze the qualitative peculiarities of the increase by studying the dynamics of motor activity throughout the test. To do this, we constructed a graph of motor activity plotting

Under natural illumination, the average amount of motor activity during a test was 3,000 movements, under strong artificial illumination, 5,400, and under weak artificial illumination, 2,600. During the influence of the CMF, we recorded 7,500, 17,900 and 11,150 movements per test. From this it follows that the background motor activity is lower under weak, and higher under strong constant illumination, and during the influence of the magnetic field, the motor activity increases less under natural illumination and more under artificial illumination, i.e., the effect of the magnetic field is revealed better at some constant level of illumination, and the relative increase in the motor activity during <sup>/245</sup> the influence of the magnetic field is revealed most clearly under weak illumination (4.3 times).

time, expressed in hours, on the abscissa and the number of bird movements per hour on the ordinate. The graphs were constructed from the average values for all birds at the given illumination. One line designates the average values for all our background tests, and the other, the average values for all tests involving exposure to the CMF.

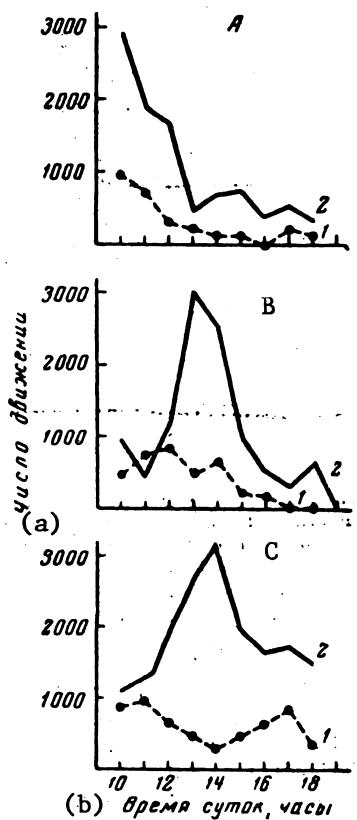


Figure 85. Dynamics of Motor Activity Throughout the Test in Bullfinch No. 1 Under Conditions of Natural (A) or Artificial Weak (B) and Strong(C) Illumination Before (1) and During (2) Exposure to a CMF. Key: (a) Number of Movements; (b) Time of Day, Hours.

field increases the motor activity of birds even during the first hour of its influence. We see that at 1000 hours, the motor activity is higher during exposure to the magnetic field than in the control tests. A detailed analysis of all tests on all birds shows that the latent period of the effect of the magnetic

In Figure 85, we see that the motor activity during artificial illumination has 2 peaks during the test, one at 1000 and the other at 1700 hours. Only the first peak, which coincided in time with the morning peak of the background tests, appeared during the influence of the CMF. During strong artificial illumination, the graph of bullfinch motor activity retained the peaks observed under natural illumination, but these peaks were flattened out and the morning peak was shifted from 1000 to 1100 hours. On this background, the influence of the CMF sharply changes the dynamics of motor activity. In this case, the motor activity increases from the morning, by 1400 hours it attains its maximum, and after this it slowly begins to drop. Under conditions of weak illumination the motor activity of the bullfinch continued only to 1500 hours, attained its maximum at 1200 hours. The CMF increased the duration of the motor activity to 1800 hours and shifted the activity maximum to 1300 hours.

The test results show that during conditions of constant artificial illumination, a CMF changes the dynamics of the motor activity during the test, causing a single-peaked curve with a maximum at 1300-1400 hours. During conditions of natural illumination, however, the effect of a CMF is manifested primarily as an increase in motor activity, retaining the same type of dynamics throughout the test. Consequently, both the quantitative and the qualitative changes in motor activity during the influence of a magnetic field are revealed more clearly during conditions of constant illumination.

From the results reflected in the graphs, we can conclude that a magnetic field increases the motor activity of birds even during the first hour of its influence. We see that at 1000 hours, the motor activity is higher during exposure to the magnetic field than in the control tests. A detailed analysis of all tests on all birds shows that the latent period of the effect of the magnetic

field is less than 6 min in any case. Our methodology did not allow a more accurate determination of the duration of the latent period. The results of tests involving a 2-hour exposure to a CMF showed that in 75% of the cases the increased motor activity of birds was retained for 2 hours after the exposure.

Under conditions of artificial illumination, the bullfinch usually stopped moving immediately after the light was turned off. In tests involving exposure to a CMF, however, switching off the light did not affect the motor activity of birds (Figure 86), which stopped only several minutes after the solenoid was turned off. This fact clearly demonstrates the presence of a magnetic field effect on the motor activity of bullfinches.

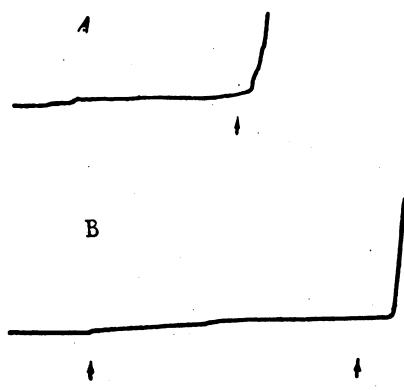


Figure 86. Retention of Motor Activity of Bullfinch No. 1 During Exposure to a CMF After the Light is Turned Off. A = Bullfinch No. 1, Test No. 27, January 31, 1957 (the Arrow Shows When the Light was Turned Off); B = Bullfinch No. 1, Test No. 28, February 1, 1957 (the Arrow to the Left Shows When the Light was Turned Off; the One to the Right, When the Magnet was Turned Off).

then it is probable that there is a similarity in these indices with respect to the internal mechanism. However, this can explain only part of the increase in motor activity, which includes the unconditioned responses of the animal. However, from the tests involving the change in sensitivity, we know that a magnetic field affects unconditioned responses, changing the sensitivity of the animal to unconditioned stimuli. It is fully probable that a magnetic field increases the sensitivity of the animal to external and internal unconditioned stimuli, and thereby increases its motor activity. These explanations are, of course, only working hypotheses whose reliability must be checked in experiments on the

### Discussion

In tests involving the application of other methods, we most frequently observed the inhibiting effect of a magnetic field, while in recording the motor activity its predominantly stimulating effect was revealed. While in the tests with birds /247 we can assume that a very weak field causes excitation and a stronger field causes inhibition, in the tests with stickleback the same field intensity caused inhibition of conditioned reflexes and an increase in motor activity. We cannot now fully explain the cause of these contradictory results, but we will give some commentary on this conclusion.

The increase in motor activity during exposure to a CMF and recorded in tests on 11 fish and 12 birds, again shows that a CMF acts as a correcting stimulus. In external appearance, the increase in motor activity during the influence of a magnetic field is similar to the increase in the number of intersignal reactions during development of a positive conditioned reflex to a magnetic field in goldfish and pigeons. If we consider that motor activity includes reactions to conditioned stimuli,

mechanism of the change in motor activity during the influence of different external and internal factors.

We again showed the similarity in the effect of light and a magnetic field, since both agents change motor activity uniquely. But, while light acted more strongly than a magnetic field during development of conditioned reflexes and measurement of sensitivity, the magnetic field acted more strongly than light during recording of the motor activity of bullfinches. Illumination increased the average number of movements from 3,000 to 5,400, but a magnetic field increased it to 7,500. Upon comparing the effect of a magnetic field on fish and pigeons when the conditioned-reflex method was used, we observed a greater sensitivity to this stimulus in fish. During the recording of motor activity, the magnetic field had a stronger effect on birds. An increase in motor activity during the influence of a magnetic field has been noted not only in birds [El'darov, Kholodov, 1964], but also in mice [Barnothy, 1960] and guinea pigs [Gorshenina, 1963]. During the influence of an SHF field of the meter range, a 20-30% increase was observed in human motor activity during sleep [Goncharuk and Pivovarov, 1964].

#### Conclusions

1. A constant magnetic field increases the motor activity of fish and /248birds.
2. In birds the effect of a CMF is manifested as both a general increase in the number of movements and a change in the dynamics of motor activity during the test.
3. The effect of a magnetic field appears most clearly during conditions of constant illumination.

## CHAPTER 9. CHANGES IN THE HISTOLOGICAL PICTURE OF THE BRAIN DURING THE INFLUENCE OF ELECTROMAGNETIC FIELDS

In recording the electrical brain reaction to different EMF, we noted the appearance of slow high-amplitude oscillations of potentials (see Part I). In recent years, certain investigators have attributed the main role in the formation of slow components of the EEG to glial elements [Galambos, 1961, 1962; Aladzhalova, 1962; Sokolov, 1962; and others]. Recording the electrical activity in the region of the medulla oblongata (area postrema), which basically contains glial cells, revealed a rhythm of 3-6 Hz and superslow oscillations [Aladzhalova, Kol'tsova, 1964]. Recording the electrical activity of separate brain neurons during the influence of a CMF provided less information on the changes which occurred than recording the EEG. This circumstance forces us to assume that not only neurons participate in reactions to EMF. Finally, morphological investigations of the brain following an animal's stay in different EMF, indicated a glial reaction to these influences. We noted a revived proliferation reaction of the microglia in the brain following exposure of the animals to an SHF field of average ( $40 \text{ mw/cm}^2$ ) and low ( $10-20 \text{ mw/cm}^2$ ) intensities, which indicated the stimulating effect of an SHF field. Swelling of separate nerve cells was observed at the same time [Tolgskaya et al., 1960]. A productive reaction of glia was frequently more explicit following a 5-minute exposure to an SHF field than after a 15-minute exposure [Dolina, 1961]. These changes in the glia are considered to be a nonspecific protective reaction of the central nervous system. Morphologists long ago noted the reaction of glia following exposure to ionizing radiation while neurons remained normal [Mogil'nitskiy and Podlyaschuk, 1929; Shefer, 1936; and others]. At the 1st Radiological Conference, L. O. Orbeli expressed an opinion concerning basic damage to glial cells and vessels /249 during irradiation. Studying the morphological structure of the brain from irradiated dogs, L. L. Vannikov (1956, 1964) concluded that the glial tissue (especially the astrocytes) and the vascular system connected with it suffers primary damage during irradiation. Especially acute degeneration of astrogliia was observed in the brain stem and in the region of the hypothalamus. Irradiation of the head by x-rays, 150-930 R/min caused necrosis of oligodendroglia which was maximal after 6-24 hours. There was no quantitative difference in the effects between the cerebral cortex and the brain stem, but the changes were expressed to a lesser degree in the cerebellum [Brownson et al., 1963]. Electron microscopic investigation of the brain of animals irradiated with a dose of 15,000 R showed that glial cells are more sensitive than neurons [Pitcock, 1962]. An opinion has been expressed that glia can function as a receptor with respect to a neuron [Hild, 1962].

These data serve as the basis for investigating the glia-neuron relationships in the brain of animals subjected to a CMF with a strength of 200-300 Oe. These tests were conducted together with Professor M. M. Aleksandrovskaya.

The reaction of neuroglia and neurons was determined by morphological methods: The astrocytes were stained by the Cajal or Snesarev methods, the oligodendrocytes and microglia by the Aleksandrovskaya method, and the nerve cells

by the Nissl method. The examination was conducted dynamically after the animals had stayed 1, 10 or 60-70 hours in a CMF. During these prolonged exposures the animal was in the CMF for 3-7 hours at a time. Rats were placed completely between the poles of the electromagnet, but only the heads of cats and rabbits were subjected to the influence of a CMF. The animals were killed immediately after exposure. The experiments were conducted on 9 rabbits (killed by the air embolism method), 5 cats (killed with nembutal) and 4 white rats (killed by decapitation). The control animals were killed simultaneously by the same methods. The animals were in a CMF 1 hour (3 rabbits), 10 hours (3 rabbits and 2 cats) and 60-70 hours (3 rabbits, 3 cats and 4 rats). The preliminary treatment of the experimental results based on an analysis of the histological picture of the sensorimotor cortex shows the following.

In rabbits, one hour after the start of the CMF influence, we noted a sharp productive reaction of the astroglia and oligodendroglia involving hyperplasia and hypertrophy of the cell bodies and processes. The neurons remained intact.

In rabbits and cats, 10-12 hours after the start of the influence the reaction of the glia remained productive, involving the presence of perivascular and marginal glial fibrosis, with swelling of the dendritic oligodendroglia and hypertrophy of the drainage glia. The neurons underwent reversible changes in /250 the form of swelling and hyperchromatosis.

In rabbits, cats and rats, 60-70 hours after the start of the CMF influence, we observed productive-dystrophic damage to the neuroglia involving swelling of the oligodendrocytes and the appearance of drainage cells. Dystrophic damage encompassed even the nerve cells. A picture of hypoxic encephalopathy with dystrophic changes of the glia was morphologically diagnosed (Figure 87).

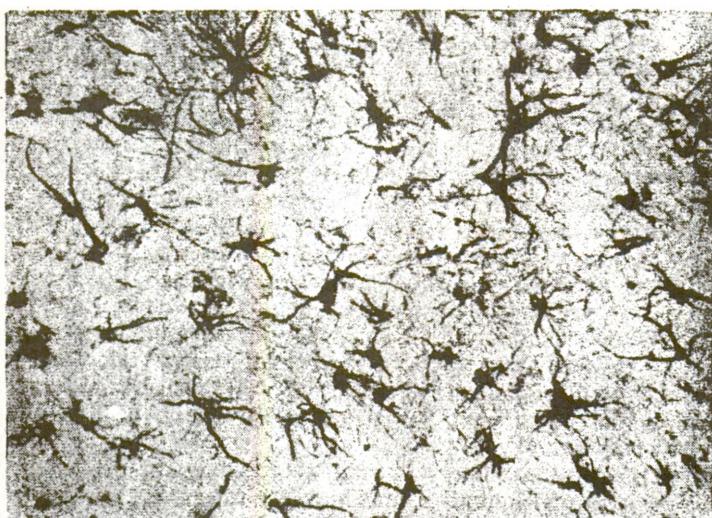


Figure 87. The Change in the Histological Picture of the Rabbit Brain Following a 10-Hour Stay in a CMF. The Productive Reaction of Astrocytes in the Sensorimotor Cortex (Magnification, 160).

This proffered material allows us to assume that primarily the neuroglia of the brain react to the influence of a CMF [Kholodov and Luk'-yanova, 1964]. A. I. Ryzhov (1964) noted a reaction of the peripheral glia to a CMF.

Since the glial formations are distinguished by a high metabolism, we can consider that the effect of a CMF on the brain is realized to a significant degree through changes in the metabolism of neuroglia.

The previously prevalent opinion that glia perform only a support function has been changed under the

influence of new facts. Three types of glia are distinguished: astroglia, cells with many processes and a large nucleus; oligodendroglia, cells with a small nucleus and few processes; and microglia. The first two types of glia are sometimes combined with the microglia. The closeness of glia to vessels forces us /251 to assume that glia are intermediaries between nerve and circulatory elements. The high metabolism of glia keeps the activity of neurons at a sufficient level. Galambos (1961) states that glial and neuronal elements are an entity and that it is impossible to separate them.

Rhythmic pulsation of glial cells in a tissue culture has been observed under electrical stimulation [Lumsden and Pomerat, 1951]. The glial cells contracted with a latent period of 1.5-4.0 min. The duration of the contraction varied from 1.4 to 3.4 min [Chang and Hild, 1959]. There are approximately 10 times more glial cells in the brain than neurons [Galambos, 1961; Blinkov and Glezer, 1964]. It is widely accepted that glia play an important role in various processes occurring in the brain in normal and pathological states, especially in the reaction of the brain to various damages, intoxications, infections, traumas, and metabolic disturbances [Aleksandrovskaya, 1950; Snesarev, 1959; Blinkov and Glezer, 1964]. Glia are distributed comparatively uniformly throughout the gray and white matter of the brain, although there are data concerning a significant predominance of glial cells in the rat hypothalamus in comparison with other brain sections [Nurnberger, 1958].

Studying the experiments on the effect of EMF on the CNS, we can explain many of the results by the effect of a CMF on the glia. The last two series of experiments, involving the recording of neuronal activity and a morphological analysis of the brain of rabbits subjected to a CMF, directly implicate the glia in reactions to a CMF. In all our experiments we noted a prolonged latent period, measured in seconds and tens of seconds. The long latent period indicates that neurons are not the primary elements reacting to the CMF since the latent period of their reactions is measured in milliseconds. A significant aftereffect also characterizes the reaction of glial elements.

By embedding electrodes in various sections of the brain, we showed that the most intensive reaction to a CMF is observed in the hypothalamus and in the cerebral cortex. Why do these particular sections of the brain react most strongly to a CMF? It was observed that, in contrast to other sections of the brain, in the hypothalamus and the cortex we recorded superslow oscillations of potential with variable parameters acting directly on the metabolism of the "neuroglia-neuron" system [Aladzhalova, 1962]. Consequently, the sensitivity of these formations to a CMF can be explained by heightened metabolic processes connected with the activity of glial elements.

Variations in the metabolic level, possibly reflected in superslow oscillations of potential, may explain the statistical character of the reactions to EMF. /252

The inhibiting effect of a CMF can also be explained via its influence on glial elements. Actually, it has been shown that staphylococcus intoxication, which causes a productive reaction of glia, is accompanied by the appearance of defensive inhibition [Gorsheleva, 1957]. One can consider that activation of the glia causes inhibition in the brain. The example also indicates the non-specific character of glial reactions, which we observed using various EMF.

### Conclusions

1. A one-hour exposure to a CMF causes a productive reaction of glia in the animal's brain. In such a case, the neurons remain inactive.
2. An increase in the exposure duration of the CMF to 60-70 hours led to productive-dystrophic damage of neuroglia. Dystrophic damage also encompassed the nerve cells.
3. The described results lead to a conclusion concerning the effect of EMF on neuron-glial relationships.

### Synopsis

The experiments introduced in this section involving the prolonged exposure of an organism to a CMF support and supplement the conclusions obtained during the study of the physiological effect of EMF by the conditioned-reflex and electrographic methods. Although we have studied only CMF, a comparison of the results with the reference data (see Part I) indicates the similar effect of UHF, SHF and constant magnetic fields. It is only necessary to recall the inhibition of signaling reflexes in frogs and the morphological picture of the changes which occur in the brain following exposure to different EMF.

By determining the sensitivity to an electric current in fish, and to chemical stimulation in frogs, we established that a magnetic field is a correcting stimulus which is essentially inhibiting in character. The reactions to a magnetic field are effected with a long latent period (minutes) and are distinguished by a prolonged aftereffect. A magnetic field and light have a similar nonspecific effect on the sensitivity of blinded animals. The mechanism of the reaction consists of the direct effect of these factors on the structures of the diencephalon. All these conclusions coincide with the results of experiments given in the first two parts of this book.

The data concerning the increase in motor activity of animals during exposure to a CMF are somewhat isolated. We also observed such a purely stimulating effect of EMF when we recorded the electrical brain activity (the appearance of convulsive discharges) and when we developed conditioned reflexes (the increase in the intersignal reactions). The predominance of one or another basic nervous process in the CNS is probably determined by the complex interaction of EMF with other weak and strong, external and internal stimuli that continuously act on the CNS.

The morphological changes caused in the brain during exposure to EMF indicate the paths for future analysis of this effect. It turned out that in the glia-neuron complex, which occupies the greater part of brain tissue, the glia undergo morphological changes sooner than the neurons. Since the neuron is considered an electrically excitable structure, and the glia more sensitive to chemical influences, we can assume that the primary effect of EMF is rendered on certain chemical reactions of brain tissue.

## GENERAL CONCLUSIONS

/254

A discussion of questions on the mechanism of the effect of different EMF on the organism should be initiated with the essential physicochemical processes occurring in a living cell during the influence of EMF. There can be several such processes and we have not tried to enumerate them all. Let us simply recall that EMF can induce an electrical current, and that variable EMF of high intensity can cause heating. Statements regarding the possibility of a resonance effect of EMF on biological objects are encountered. The effect of EMF on excitable structures can be connected with a change in the potassium-sodium gradient in the cell due to oscillations of water molecules, hydrated ions, and protein molecules in the surface layer of cell membranes [Presman, 1964b]. The possibility of an effect of EMF on the structure of water was shown in the engineering application of the so-called magnetic treatment of water, as a result of which the precipitation of the dissolved salts decreased [Myagkov, 1960; Lapotyshkina and Sazonov, 1961; and others]. EMF can polarize the side chains of a protein molecule, causing cleavage of the hydrogen bonds and changing the molecule hydration zone. There is a statement that strong CMF can affect the orientation of macromolecules, in particular, RNA and DNA molecules, and thereby change biological processes [Dorfman, 1962]. The increase in the activity of the enzymes trypsin [Cook and Smith, 1964; Wiley et al., 1964] and carboxydismutase [Akoyunoglou, 1964] under the effect of a CMF allows us to assume that chemical changes play the main role in the primary mechanisms of the effect of EMF.

The effect of EMF on excitable structures is similar to the effect of a dc anode. It did not cause contractions of a neuromuscular preparation, but it changed the chronaxy and reduced parabiosis. A UHF field [Vasil'yev and Lapitskiy, 1938], an SHF field [Bychkov, 1962] and a CMF [Petrov, 1930; Erdman, 1956] acted in a similar manner.

At a definite intensity and exposure duration, the informational sensory influence of an EMF on the organism predominates, and not its energy influence [Barnothy, 1964]. This can be explained by the primary effect of EMF on the functions of the CNS; in contrast to known neuronal impulsation, this effect is realized primarily through chemical processes in glial cells and is propagated by some nonpulsed slow system [Rusinov, 1954; Aladzhalova, 1962; Becker et al., 1962]. For example, in tests on lobster heart ganglia, it was shown that slow changes in the membrane potential of one giant cell affect the discharge frequency of the small cells located several millimeters away. This effect is achieved without participation of nervous impulses [Watanabe and Bullock, 1960]. We should note that the initial reactions of an organism to EMF are distinguished by their nonspecificity. In expounding our material, we have frequently indicated the nonspecificity of the effect of UHF, SHF and constant magnetic fields. We should add that a high-voltage industrial frequency electrical field [Sazopova, 1964], a low-frequency pulsed electrical field [Khvoles et al., 1962], EMF of the sonic and radio-frequency ranges [Boyenko, 1963; Saley, 1964] and a high-frequency field [Nikonova, 1964] have a similar effect on the CNS. Stimuli of a nonelectromagnetic nature can also have a similar effect on electrical

brain activity and on developed conditioned reflexes. Here we must indicate the nonspecific reaction of the CNS to a weak stimulus. It is possible that protection from stimulation is no less important for an organism than perception of stimulation, and during the influence of a weak stimulus of any nature we can observe reactions designated as preventative inhibition by certain authors [Simonov, 1962].

Prolonged exposure to EMF not only involves the nervous system in the reaction, but the hormonal, circulatory and other systems as well. For example, during the influence of an SHF field, prolonged changes in the sympathetic-adrenalin system have been observed [Yakovleva, 1964]. Consequently, the next stage of the effect of EMF on an organism can be considered the development of stress-type reactions [Sel'ye, 1960] which can also be observed during the morphological disturbance of certain organs. We have usually been limited to a study of the initial changes in the activity of the CNS. Since the majority of experiments were conducted with a magnetic field, it is reasonable to introduce certain results of the investigation of this factor.

Summary Table 49 provides a general characterization of the results of tests on the effect of a magnetic field on different physiological processes of vertebrates.

TABLE 49. THE EFFECT OF A MAGNETIC FIELD ON CERTAIN PHYSIOLOGICAL PROCESSES OF VERTEBRATES.

Character of the experiment	Fish			Amphibians			Birds			Mammals		
	no. of animals	stabil- ity		no. of animals	stabil- ity		no. of animals	stabil- ity		no. of animals	stabil- ity	
		increase	decrease									
development of a conditioned reflex	63	39	—	—	—	—	7	none	—	3	none	—
influence on conditioned reflexes	4	15	73	—	—	—	3	10	70	—	—	—
influence on sensitivity: to an electric current	31	21	66	—	—	—	—	—	—	—	—	—

TABLE 49. (CONTINUED)

Character of the experiment	Fish			Amphibians			Birds			Mammals		
	no. of animals	stabil- ity		no. of animals	stabil- ity		no. of animals	stabil- ity		no. of animals	stabil- ity	
		increase	decrease									
influence on sensitivity:												
to acid	—	—	—	9	14	67	—	—	—	—	—	—
to light	—	—	—	—	—	—	—	—	—	3	0	90
influence on motor activity	11	64	13	—	—	—	10	90	7	—	—	—
influence on the EEG	—	—	—	—	—	—	—	—	—	30	53	—

The dashes indicate that experiments of that type were not conducted. It should be noted that the number of animals only approximately characterized the volume of experimental work, since one animal was exposed many (up to hundreds) times. The reaction stability is expressed in a percentage ratio of the number of reactions to the number of exposures, and in the case of the influence of a magnetic field on some activity, we have separately noted the stability of the increase and decrease in this activity.

Table 49 shows that in an overwhelming number of experiments, we observed /256 the effect of a magnetic field on physiological processes. Only the tests on development of conditioned reflexes to a magnetic field in pigeons and rabbits are exceptions. In spite of hundreds of combinations of the influence of a field with food in pigeons and with electric stimulation in rabbits (the shaking-off method) a conditioned response did not occur, which indicates the weak nature of a magnetic field as a stimulus. Even if the conditioned reflex to a magnetic field was developed (in fish), its stability was 2 times less than the stability of such reflexes to light or sound [Kholodov, 1958b]. The stability of another reaction to a magnetic field (change in the EEG) was also low, being equal to 53% [Kholodov, 1963a].

However, when the magnetic field acted on the background of some physiological reaction, i.e., behaved as a correcting stimulus, then the reaction stability was increased approximately twice. For example, during development of a conditioned reflex to a magnetic field, the reaction stability was 39%, but during a study of the effect of a field on developed conditioned light and sound /257 reflexes the stability reached 88%. The time for the appearance of the

assimilation reaction on the rabbit EEG during the influence of interrupted light of increasing brightness increased with statistical reliability ( $p < 0.05$ ) during exposure to the magnetic field. The stability of this reaction was 90%, while changes on the spontaneous EEG during the influence of the field were observed in only 53% of the cases. We managed to reveal only the correcting effect of a magnetic field in pigeons by the conditioned-reflex method. Thus, we can conclude that a magnetic field is a weak correcting stimulus.

In what direction does a magnetic field change the current activity? In tests on frogs, it was observed that on a background of increased sensitivity to acid, a magnetic field reduced it, and on a background of reduced sensitivity, it increased it. Thus, the results of the field influence depends on the initial functional state of the CNS. However, under ordinary experimental conditions, we most frequently observed the inhibiting effect of the field. As is evident from Table 49, the conditioned reflexes and the sensitivity to different stimuli are reduced more frequently than increased. Only in the tests when we recorded the motor activity did we see a predominance of excitation during the influence of the field. However, in the development of conditioned reflexes to a magnetic field in fish, inhibiting reflexes (conditioned inhibition) were developed much better than positive reflexes, and in recording the electrical activity of the cerebral cortex during the influence of the field, we observed an increase in the number of spindles and slow waves, which also appear when the animal sleeps.

In different types of experiments, we observed an aftereffect immediately after the electromagnet was turned off. This was manifested as sequential inhibition during development of conditioned inhibition to a magnetic field, as a prolonged reduction in sensitivity (for several minutes) after the influence ceased, and also as the EEG reaction to turn-off.

In determining the threshold of perception of a magnetic field, we observed that in tests involving the recording of the rabbit EEG, it was approximately 100 Oe, in tests on development of conditioned reflexes in fish, it was 10-30 Oe, and in tests involving the recording of the motor activity of bullfinches, it was 1-2 Oe. It is possible that under natural conditions, the changes in the earth's magnetic field strength are threshold changes, and that what we obtained in our experiments can serve as a more or less successful model of natural processes.

In connection with this, let us mention the experiments of Tromp (1939), who showed that for certain people who can determine the presence of underground water by the inhibition of the motor reaction of holding a willow stick at arm's length, the threshold of perception of a CMF is below 0.001 Oe. Similar results were recently obtained by Rocard (1964). Thus, a magnetic field is a weak correcting stimulus, the reaction to which is effected following a significant /258 latent period and has a prolonged aftereffect. The threshold intensity is close to the strength of the earth's magnetic field.

In the electrophysiological experiments, we observed similar elements in the physiological effect of a UHF, an SHF and a constant magnetic field and ionizing radiation. In tests involving different methods, we observed a similarity in the effects of a CMF, light, a UHF field and ionizing radiation. If we

include the reference data concerning the characteristics of the development of conditioned reflexes to a temperature stimulus, then the whole range of electromagnetic waves enters the sphere of our attention. Thus, different sections of the spectrum of electromagnetic oscillations can have a similar physiological effect on the CNS of vertebrates. This similarity is revealed more clearly when specialized receptors for the perception of certain sections of this spectrum are absent. As an example, the similarity in the effects of light and a CMF on blinded fish is revealed more clearly than in intact fish.

The direct effect of EMF on the CNS serves as the physiological basis for this similarity. A greater response to EMF is inherent to the cerebral cortex and the diencephalon. In animals in which the cortex has not developed (fish), the diencephalon (especially the hypothalamus) is the most reactive structure.

The greatest effect of EMF on the main regulatory center of the brain, where the nervous and humoral paths of integration converge, forces us to assume that even weak influences on this center can cause significant physiological changes.

The insufficient attention devoted by neurophysiologists to the direct effect of stimuli on the CNS can be explained by many factors. The basic factor was the absence of methods for directly determining the functional state of the CNS. Experimental proofs of the direct effect of certain stimuli on the CNS were obtained only after the wide introduction of electrophysiological methods [Granit, 1957].

The predominance of morphological works for determining the relative participation of the CNS in the reactions of the organism to penetrating factors has led certain foreign investigators to an opinion concerning the high stability of the CNS in comparison with other systems of the organism.

The introduction of different concepts regarding sensitivity and stability [Livanov, 1962] can probably reconcile the opinions of morphologists and physiologists concerning the position of the CNS in the reactions of an organism to penetrating factors. The CNS remains extremely sensitive in a physiological sense and stable in a morphological sense. Therefore, the CNS can react first /259 to a stimulus for which there is no specialized receptor and, perhaps, to a stimulus for which a receptor exists. Then, the effect of any stimulus can be examined as a polyreceptor effect. For example, in fish, the retina, the skin, and the diencephalon can react to light. An increase in the intensity of a UHF field can, apart from the CNS, lead to the involvement of thermal receptors, pain receptors, and even muscle tissue in the reaction.

The subsensory character of the effect of penetrating factors is one of the preventing reasons for not ascribing the properties of a physiological stimulus to these factors. In this respect, the reception of EMF resembles the activity of interoceptors. The slowness of the reaction to subsensory stimuli does not allow us to attribute a signaling importance to them. It is on the basis of this latter phenomenon that the fast motor reactions of an animal are formed. Only in fish did we manage to develop conditioned reflexes to a magnetic field, but in their stability these reactions significantly yielded to light and sound conditioned reflexes. It is possible that EMF are the signals that determine many rhythmic processes of an organism.

Two centuries have not yet passed since the time when the tests of Galvani began electrophysiology. Now, electrophysiology is an important, essential physiological science, but its development continues. The study of the role of electromagnetic fields in the processes of vital activity must be considered one of the most promising directions in this development. This should include both investigations of the effect of electromagnetic fields on the functions of animals and plants and the clarification of the roles of EMF that occur during different physiological processes. This book is devoted to this first direction of these investigations. The investigation of the magnetic field created in a nerve when a nervous pulse passes through [Seipel and Morrow, 1960] and the recording of high-frequency electromagnetic fields during contraction of the human skeletal muscles [Volkers and Candib, 1960] can be related to the latter direction.

The study of the biological role of EMF involves an examination of certain general positions of physiological science, especially of neurophysiology. We can already ask questions on the existence of slow regulatory systems, the presence of a receptor function in the brain, and about the polyafferent effect of stimuli. This aspect of electrophysiology can provide an important contribution to the development of subsensory stimulation and orientation of animals during long-range migrations.

The problems of the biological effect of EMF, which was stated at the beginning of this century by V. J. Danilewsky, can now be solved thanks to the successes of electronics and computer technology, and also thanks to contemporary methods of biological experimentation.

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