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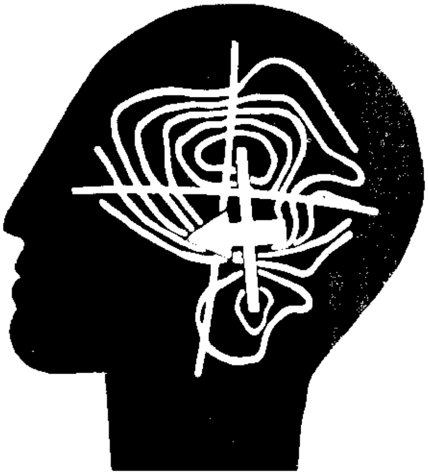
MAGNETIC FIELDS of BIOLOGICAL OBJECTS



MAGNETIC FIELDS OF BIOLOGICAL OBJECTS

АКАДЕМИЯ НАУК СССР

ИНСТИТУТ ВЫСШЕЙ НЕРВНОЙ ДЕЯТЕЛЬНОСТИ
И НЕЙРОФИЗИОЛОГИИ

Ю.А.Холодов А.Н.Козлов А.М.Горбач

МАГНИТНЫЕ ПОЛЯ БИОЛОГИЧЕСКИХ ОБЪЕКТОВ

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CONTENTS

TO FOREIGN READERS

Like other rapidly developing branches of science, biomagnet-ism is both an interdisciplinary — contributors of this book are a biologist, a physicist and an engineer — and an international area of research. Its international dimension is evident from the sizable number of international meetings which mark its advances and outline trends of its further development.

The Seventh International Conference on Biomagnetism was held in August, 1989 in New York.

In writing this book the authors were motivated by the need of concise presentation of the voluminous and continuously growing data on biomagnetism as well as by the need to advance their own ideas, primarily of the physiological nature, and to outline plans for the future development of supersensitive magnetometry application in biology.

In comparison with the Russian 1987 edition the book has been reworked and renewed for at least one third of its volume accommodating both the authors' own achievements and the latest publications.

In contrast to other overviews on the subject, the authors have used ideas not only from the biomagnetic field, well known to them, but also from the general electrophysiological principles and electromagnetic neurobiology.

The authors hope that the development of supersensitive magnetometry will make this promising technique widely applicable in the medical and biological laboratory research of biological objects. They also hope that their confidence will stimulate the readers to actively participate in the development of biomagnetism.

INTRODUCTION

Now the term "biomagnetism" may be frequently encountered in solid physical magazines and some biological publications. There has been developed the view that "biomagnetic measurements have constituted the main thrust of the supersensitive magnetometry development. It is in this domain that magnetometric hardware as well as measurement techniques, special approaches and apparatuses also applicable to a large number of other magnetometry functions have been improving most rapidly. This dimension of the biomagnetic research assures, apart from the progress of biology, the development of scientific research in other areas."[1]

If it is really the case this is exactly the rare situation when biological research aids physicists to upgrade their methods as they are directly interested in identifying biological regularities.

What actually gives modern biomagnetism such an advantage over other biological disciplines? It is a widespread view that the current progress in the detection of weaker magnetic fields (MF) of biological objects should be attributed to the advent of supersensitive magnetometers using the Josephson effect. Referred to as SQUIDs (Superconducting Quantum Interference Device) these magnetometers require liquid helium for their operation. Being quite unique and expensive SQUIDs appeared in the 1970's primarily in physical laboratories. Commercial production of biomagnetic systems in the USA, Canada, Italy, Japan and the Federal Republic of Germany as well as their advent to medical institutions began only recently.

Vvedensky V., Ozhogin V. *Supersensitive magnetometry and biomagnetism* Moscow, 1981, p. 5 (in Russian) [10].

To distinguish it from magnetobiology, studying the impact of external MF on the biosystems, the area of research in question was called biomagnetism. Intensity of biomagnetic field is millionfold weaker than that of the Earth's magnetic field, particularly if we deal

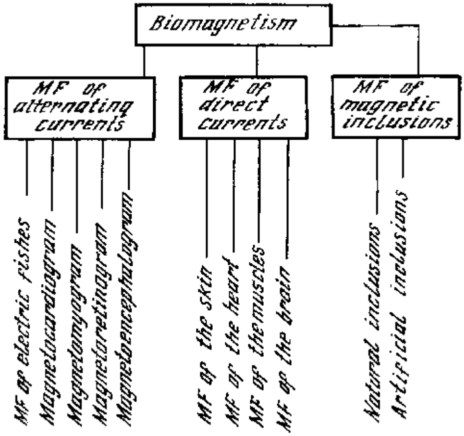

Fig. 1. **Research areas of modern biomagnetism**

with MF of the heart. Therefore, it can bemeasured either in a complex expensive shielded chamber available now in the USA, Finland and West Berlin, or with the use of the gradientometric system in which two closely positioned sensors are equally affected by distant MF sources and differently from nearby sources, which is applied more frequently. So, the noninvasive i.e. free of the contact to object's skin and passive i.e. free of any influence on the organism technique has produced magnetocardiogram (MCG) and magnetoencephalogram (MEG) and detected other MF in man (Fig. 1).Although many advances of the modern biomagnetism (let us use this term to distinguish it from other similar terms) have been associated with the application ofSQUIDs, the general progress in this area of the biophysics did not depend entirely on this apparatus. It would be appropriate to note that the first ever MCG [42, 83] and even the first ever MEG were recorded with the use of induction sensors (IS) which are practically out of use today.

Pneumomagnetism and sometimes detection of MF of the fishes are supported by fluxgates [1, 67, 119]. Most of the biomagnetic research in the USSR [21, 30-32, 56, 61-65] has been performed with the use of the optical pumping magnetometer (OPM). Other techniques for detecting MF of the biological objects [60] encompasses and is going to encompass an increasing range of phenomena as compared to those detected with SQUIDs.

The orthodox biomagnetism and the associated use of SQUIDs owe their rapid development to the enthusiasm of physicists whose list is topped by such names as D. Cohen and S. Williamson (USA), T. Katila and V. Lanuasmaa (Finland), B. Vasilyev and V. Vvedensky (USSR) and others. Research areas have been continuously expanding involving new names and countries. International meetings on the subject were held in Boston (USA, 1976), Grenoble (France, 1978), Berlin (West Berlin, 1980), Rome (Italy, 1932), Vancouver (Canada, 1984) and in Tokyo (Japan, 1987). While most of the reports at the first two meetings were dedicated to MCG (cardiomagnetism), the later conferences devoted more time to MEG (neuromagnetism).

The supersensitive magnetometry technique holds great promise in locating electrical sources of MF of the brain, i.e. in solving the inverse problem. The measurement of the MF intensity and vector in several points at the scull surface may indicate approximate depth and intensity of the source. The same information may be obtained by implanting electrodes into the brain provided one and the same dipole is the source of the magnetic and electric action. Assuming that a flexed nervous fiber is a source of MF of the brain as claimed by Soviet neurophysiologist A. Gutman [20] the magnetometry and electrometry techniques duplicate and complement one another. It may be noted that since the brain is a volume conductor electric potentials emerge in one region and proliferate across the entire brain which is not the case with the MF.

It was found that magnetic response of the brain to an auditory stimulus shows different polarity in the neighboring areas of the cerebral cortex. The effect cannot be traced in the electric response of the brain to the same stimulus. Magnetic responses from the right and left hemispheres of the brain feature different location and intensity of the electric sources of the MF providing more evidence about nonequivalence of the left and right hemispheres.

Continued applications of auditory stimulus gives rise to rapid variation of the electromagnetic action in the brain and slow variation of the MF in the course of the stimulus application. Even a brief list of advantages and additional data made available by magnetometry shows the high value of the technique to neurophysiology [136].

Still, there is another area of research where electrometry has a low chance of competing with magnetometry. This area refers to the action of magnetic inclusions in the biological system. Although the natural magnetite was detected for the first time in some bacteria in 1975 [128] with the help of the biochemical method, extensive identification of the ferromagnetic inclusions began with the advent of sensitive magnetometers. It refers, directly to pneumomagnetism involving evaluation of the residual magnetization of artificial ferromagnetic inclusions in the human lungs. The technique also involves evaluation of the residual magnetization of natural ferromagnetic inclusions in different tissues of various organisms. We will be mostly interested in the inclusions detected in the brain. The ferromagnetic particles have been found in the head of the domestic pigeon, in migratory fishes (tuna) and birds *(Erithacus rubecula),* in sea turtles, dolphins, rodents and in human beings. In rhesus monkeys the ferromagnetic material has been detected only in ancient sections of the brain.

In contrast to the orthodox biomagnetism this research has been biologically significant from the very beginning. Although the experiments are staged more often by physicists with American geologist J. Kirshvink [123, 124, 128] being the current leader in the field it is assumed that the magnetic inclusions are essential for sensing the geomagnetic field (GMF) by the organism.

A possible physiological role of the biological MF is not, however, mentioned by the prominent students of the biomagnetism. On top of that S. Williamson made a specific distinction between biomagnetism and magnetobiology. He pointed out that the biomagnetic field detected outside the organism is a few orders weaker than the external field known to cause the magnetobiologic effect. It is therefore maintained that the biomagnetic field is an abated echo of the functional state of the organism and that it plays no role in its functioning.[2] J. Wikswo has claimed [144] that only the MF over 200 mT can produce a biological impact.

However, F. Cope [102] maintains that the biological system is capable of sensing the MF on the basis of the Josephson effect and admits that the MF of biologic origin may be sensed.

The role played by the internal electromagnetic field (EMF) was convincingly described by the prominent American neurophysiologist W. Adey who wrote that the nerve fiber conduction and synaps activation were the significant elements of the brain function. At the same time there were at least three modes of the information process realization which should be also given adequate attention. They were the dendro-dendrite conduction, neuro-neuroglial interaction via the intercellular space and the sensing of weak electric and, perhaps, magnetic field.[3]

Without quoting other neurophysiologists speaking of the important part played by the brain field interaction we find it approprite to stress that the hypothesis on the electromagnetic compatibility of the biologic system with the environment could provide a uniform explanation of the hazardous effect of the amplified or attenuated EMF, compared with the natural field, on the organism.

The similarity in the structure of the nerve cell and the Thomson circuit enabled Academician A. Leontovich to propose as far back as in the 30's a hypothesis [27] suggesting that one neuron could sense the EMF generated by another. His follower B. Krayukhin [29] has reported detection of the MF of the nerve in the course of its stimulation. The idea of the biological significance of the internal EMF was positively accepted by Soviet Academicians P. Lazarev, V. Bekhterev and A. Ukhtomsky.

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[2] Williamson S., Kaufman L. Biomagnetism, *J. Magn. Mater.,* 1981, Vol. 22, No. 2, p. 131 [147].

[3] Adey W., *Physiology of Man.* 1975, Vol. 1, No. 1, p. 61 [72].

The current development of biomagnetism is still the domain of the physicists although the number of researchers in the medical and biological field dedicating their efforts to this challenging area of study is continuously growing. The list of active students of biomagnetism could be complemented by such neurologists as Academician M. Livanov (USSR) [30, 31], J. Beatty (USA) [86, 87], R. Hari (Finland) [57, 117].

It should be also noted that reports on biomagnetism appear mostly in separate physical publications. The authors of this monograph have made their contributions with the specific aim of summarizing the available publications and sharing their personal experience in researching this challenging area.

The authors take this pleasant opportunity to thank Academician M. Livanov for his interest in the biomagnetic research. We would also like to thank A. Korinevsky, V. Markin, K. Romanovsky, S. Sidelnikova, L. Tikhomirova, V. Trush, G. Elkina, V. Verkhlyutov, T. Baldveg, A. Bone, V. Konyshev and R. Maragey

ABBREVIATIONS

ECG —electrocardiogram
EEG — electroencephalogram
EMF —evoked magnetic field
EMG — electromyogram
EOG—electrooculogram
EP —evoked potential
ERG—electroretinogram
FEM — Faraday effect magnetometer
FM — fluxgate magnetometer
FT —flux transformer
GMF—geomagnetic field
IM - induction magnetometer
MCC - magnetocardiogram
MEG- magnetoencephalogram
MF- magnetic field
MMG- magnetomyogram
MOG- magnetooculogram
MRG- magnetoretinogram
OPM-optical pumping magnetometer
SQUID- superconducting quantum interference device

Part I
THE PRINCIPAL APPROACHES TO STUDIES OF THE MAGNETIC FIELD OF BIOLOGICAL OBJECTS

The modern biology of the organism is based primarily on the biochemical data and the biophysical provisions related mostly to membranology. The researchers have always tried to attain the standard involving the description and location of certain biochemical processes. Going that way they often feel the need to learn magnetic properties of certain substances and better understand the essence of chemical processes. All that gives rise to a new field within biochemistry titled as magnetochemistry which could be referred to the modern biomagnetism. The generally recognized regulation of the numerous biological processes may be often attributed to the same biochemical reactions.

However, it has been learned lately that in the regulation process in the organism participate electric currents and the EMF supported by the energy drawn out of the same biochemical processes. Owing to the modern technological progress it has become possible to detect the weakest MF organic to a certain biological process.

The passive noninvasive technique of detecting certain physiological functions of the organism may provide a new insight into the biological object and help evaluate the dynamics and localize certain integral processes.

It should be recognized that meaningful progress in this area has been made by the physicists. While the fundamental review by S. Vonsovsky published in 1971 [17] did not mention the possible use of the magnetism in biology and medicine, the general report presented by K. Schmidt-Jedermann to the 1984 International Conference on Magnetism [139] was almost in half devoted to biomagnetism. Here we speak not of the specific biomagnetic research which has been extensively discussed at the appropriate conferences on biomagnetism but rather about qualifying this scientific area as an outstanding achievement in a particular field.

Although some original predictions on the likely advent of biomagnetism as a crucial technique for the study of biological objects and the significance of MF to individual vital activities have been made on many occasions in the course of ,the 20th century, modern biomagnetism has not yet become the favorite child of biology and medicine.

Chapter 1
GENESIS OF MODERN BIOMAGNETISM

According to the information available to us, in 1832 the British physicist J. Dawy was the first to detect a biological MF with a compass by applying a stimulus to an electrical fish. In the experiment it was possible to magnetize a steel needle. However, the subsequent efforts to magnetize a needle by placing it next to a stimulated muscle or nerve were fruitless.

The first reports on detection of MF from the stimulated nerve of the frog with the induction sensor appeared in the 1920's. Evaluating the volume of research performed by the Leontovich school A. Ukhtomsky wrote: "The bold idea that the transfer of nervous influence is realized through the electric induction from one neuron to another has acquired a solid foundation. At the same time certain light has been shed on the many unexplained aspects of the nervous system functions.^

B. Krayukhin [27] has detected the current from the frog's nerve with the help of 200-loop induction coil. Experiments with telephone, loudspeaker and string galvanometer made it feasible to hear and record, relying on induction

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Ukhtomsky A. *Coll. works.,* Moscow, Leningrad. The USSR Ac. of Sc. Publ. House. 1954. Vol. 5, p. 74 (in Russian) [54].

sensing, the nerve currents similar to the ones registered with the contact electrodes. Unfortunately, the above publications did not specify the magnitude of generated signals. No reference to these experiments is made in the modern publications on biomagnetism although more relevant data has been published later(1944, 1958).

Similar results were also published by Seipel and Morrow [140] and other researchers [114, 115] but they failed to win general acceptance until J. Wikswo *et al.* [145] have made quality research of MF of the nerve with SQUID. The new thrust of research was titled cytomagnetism [145].

It may be concluded that IS originally used in the detection of MF from the stimulated nerve of the frog has brought little success to cytomagnetism.

Application of IS in cardiomagnetism for the MCG sensing has yielded quite a different result. The publication of the relevant article by McFee and Baule in 1963 can be viewed as the beginning of the modern biomagnetism. The first Soviet publication on the subject appeared one year later in Voronezh [53]. In 1967 V. Provorotov presented his candidate's thesis "The study of the bioelectromagnetic field of the heart and its importance to diagnosis of the left and right ventricle and total miocardial hypertrophia." That stage of the yet unnamed biomagnetism is described by the beginning of the research of humans (can be also named anthropomagnetism) and the distinct diagnostical thrust.

Using the similar approach other directions may be classified into zoomagnetism, phytomagnetism and bacteriomagnet-ism corresponding to the study of the magnetic properties of animals, plants and microorganisms.

Designation of the magnetic material is clear only in bacteria. The first magnetotactic bacteria have been discovered by Blakemore [128] in the sediments from Wood Hall. He found that they always floated to the North Pole and that direction of their navigation could be altered by changing the external MF.

Natural magnetic inclusions have been recently discovered. in various species of flora and fauna. This subject will be considered, however, in a separate chapter.

Detection of MF elicited by alternating currents appears to be in the mainstream of the modern biomagnetism. Practically all the biomagnetic phenomena detected within this area are reciprocated by the similar bioelectric phenomena. The lists of the bioelectric and biomagnetic phenomena, signal amplitudes and frequencies, first registration date and author of the pioneer publication are presented below in Table 1. Certain purely biomagnetic phenomena are specified in the mid-bottom part of the table. It should be mentioned that some presented publications are not in the list of references and the biomagnetic phenomena named belong to the class

Table 1 Bioelectric and Biomagnetic Phenomena (Katila, 1981)

Bioelectric phenomena	Amplit. HV	Biomagnetic phenomena	Amplit. PT	Frequency range
ECG (Wouller,1887)	1000	MCG (Baule, McFee, 1963)	50	0.5-100
ECG of fetus (Cremer, 1906)	5-50	MCG of the fetus (Karinieli et al. , 1974)	1-10	0.5-100
EEG (Berger, 1924)	50	MEG (Cohen, 1968)	1	0.5-30
Evoked potentials	10	Evoked magnetic fields	0.1	0-60
- visual (Walter et al. 1946)		Cohen, 1975		
- somatic (Dawson et al. 1950)		Brenner et al. 1978		
- auditory (Davis et al. 1939)		Reite et ak. 1978		
		Internel MF of the fetus (Baum et al. 1984)		
EMG (Adrian, 1929)	1000	MMG (Cohen, 1972)	10	0-200
EOG (Du Bois-Reymond, 1894)		MOG (Karp et al. 1976)	10	0
ERG (Holmberg, 1895)	100	MRG (Aittoniemi etal. 1978)	0.1	0.1-30

Magnetic inclusions in the lungs (Cohen, 1973)
Magnetoplethysmography (Wikswo et al., 1974)
Amount of iron in human body (Harris et al., 1978)

of anthropomagnetism. Therefore, magnetic parameters of discharge of the electrical fish [43, 44] and characteristics of the nerve signal MF are omitted from the table.

In humans the strongest signal among those elicited by the alternating biocurrents is generated by the heart. The first MCG was recorded 76 years after the first ECG. An average R-wave measures 50 pT in the MCG and 1000 uV in the ECG. Owing to the relatively high signal magnitude and the importance of cardiac studies (of human pathologies in particular) magnetocardiological research accounts for substantial part of the modern biomagnetic studies.

Significance of these studies increased owing to the human fetus MCG registration accomplished 68 years after taking the first ECG of the fetus. This is a vivid demonstration of the MCG advantage in comparison to the ECG over a corresponding study with the adults.

Spontaneous and evoked by various stimula magnetoencephalograms are intensively studied now. The first spontaneous MEG was produced 44 years after the first EEG of the man. At the same time MF of the brain evoked by somatic stimuli was first detected 28 years after the first registration of the corresponding electric signal. Simple correlation of these events shows that the time gap between the first detection of electric and magnetic signals from the human body tends to reduce dramatically.

Interestingly, auditory evoked magnetic field of the human fetus was first detected in 1984. As we failed to trace a report on the similar use of the EEG technique it may be implied that the magnetographic method has outstripped the electrographic one in this field.

Analyzing the table further it should be noted that the largest interval between registration of the electric and magnetic signals falls on the registration of oculogram (127 years) and retinogram (113 years).

Finally, the time gap between the first registration of electrogram and magnetogram in the human organism is 43 years.

All the above facts clearly indicate that the electrographic registration of the alternating biocurrents from different organs of the human organism has the advantage of long experience, finely developed methods and approaches to analysis procedures. Registration of electrograms has been performed on animals as well.

These conclusions are not related to the bottom section of the table naming the events accomplished with the magneto-metric technique. They carry a reference to artificial magnetic inclusions into the human lungs and fails to mention magnetic inclusions into the digestive tract and the blood channel. They also refer to possible registration of the cardiac output with the use of natural magnetic properties of the blood as well as the natural iron inclusions into the liver. An additional reference should be also made to the natural magnetite inclusions into the adrenal glands and the nasal bones.

Table 2.
General Characteristics of the Magnetobiologic and Biomagnetic Phenomena

MF magnitude, T	MF source or type	Magnetometer type	Research area
10^{-2}	Maximal permissible level		Magneto-biology
10^{-3}	in the industrial areas		
10^{-4}	Geomagnetic field	Hall cell	
10^{-5}			
10^{-6}			
10^{-7}			
10^{-8}	Communal magnetic interference	Fluxgate	
10^{-9}	Magnetobiologic reaction threshold		
10^{-10}	Fish electric organ signal	Induction	
	Ferromagnetic inclusions		
	Geomagnetic noise		
	Heart		
10^{-11}	Skeletal muscles	OPM	
	Eye		
10^{-12}	Spontaneous brain activity		Biomag-
	Evoked brain activity		metism
10^{-13}	Retina		
10^{-14}	SQUID sensitivity	SQUID	

The general description of the quantitative, instrumental and functional aspects of the biomagnetic and magnetobiological phenomena is presented in Table 2.

It may be seen from the table that the researchers in the medical and biological field show considerable interest in the MF intensity with the magnitude of ten orders ranging from the maximal permissible GMF in industrial areas to the magnetoretinogram. Higher intensities are permissible under the short-time experimental impact. Magnetic fields of the biologic origin of the magnitude weaker than specified in the table may be detected only under special experimental conditions.

It may be observed that the distinction between magneto-biology and biomagnetism blurs at the level of electrical fishes' MF where the functional role of biomagnetic field is considered to be a proven fact. The functional role of other biologic MF is quite problematic, with the exception of the natural magnetic inclusions believed to be a part of the GMF sensing mechanism.

The presently available literature on biomagnetism contains over 1000 publications which for obvious reasons cannot be all named in this book. However, some references rather to a publication as a whole than to an individual article will be made. An interested reader might care to use the Soviet and foreign reference magazines and, perhaps, the reference index *Biological effect of electromagnetic, magnetic and electric fields* published by the Library of biological publications of the USSR Academy of Sciences since 1976.

In 1970 D. Cohen *et al.* [96] published the first results of the SQUID-based biomagnetic research. Over the last 20 years D. Cohen has been continuously publishing pioneer studies in various fields of magnetometry and substantially expanded the uses of magnetometry. He may be named the father of the modern biomagnetism for his pioneer research and active participation in the conferences on biomagnetism being specific milestones of the modern biomagnetism progress.

The first workshop was organized in August 9-11, 1976 by D. Cohen and his colleague N. Cuffin in Boston, USA. During the workshop there have been considered the practical and theoretical problems of cardiomagnetism (Table 3). The reports covering this and the next workshops were published in the *Journal of Electrocardiology* in 1976 and 1979. Neither the US nor the Soviet MCG pioneers were present at the first and the subsequent conferences. Results of the IM magnetometry were presented only by the French researchers [125, 126].

Other speakers, however, presented the data obtained with SQUIDs in a magnetically shielded chamber (D. Cohen) or in suburbs with low industrial interference (P. Karp, T. Katila; Finland).

In fact it was an international conference although only four countries actively participated in it. They were the USA, Finland, France and Canada being the present leaders in the biomagnetic research (Table 4). Some reports were presented by international groups of authors or by spokesmen of various teams from one country.

It was agreed at the first conference to measure MF induction not in Gauss but rather in Tesia according to the International System of Units. It was also decided to use the 6X6 MCG lead grid on the chest surface as proposed by Finnish researchers. The Conference proceedings were not published.

The Second International Workshop on Biomagnetism was held in August 30-September 1, 1978 in Grenoble, France. Eight countries participated in the second conference. Although

Table 3

Statistics of Reports on Various Fields of Biomagnetism at Five Conferences

Field of biomagnetism	Conference				
	1	2	3	4	5
Cardiomagnetism	4	8	10	17	16
Neuromagnetism	-	6	19	23	26
Pneumomagnetism	-	6	4	9	10
Instruments	-	5	4	8	8
Theory	2	3	1	3	3
Inter alia	-	-	1	3	7
Total	6	28	39	63	70

the scope of the discussion has expanded and new researchers have joined the studies the proceedings were not published either. The general report on the workshop was titled"Progress in magnetocardiography" [126]. The Third Workshop on Biomagnetism held in 1980 in West Berlin marked the quantitative and qualitative progress of the related knowledge. According to the statistical data presented in Tables 3 and 4 the number of active participants has increased and the geography of the actively working teams expanded. The emphasis of the scientific interest was clearly shifted from cardio- to neuromagnetism [84, 143]. As the proceedings of this and the subsequent workshops have been presented in appropriate digests and the interested readers can see them, the detailed review of their topics would be quite unneccesary.

Table 4
Speakers Statistics at Five International Conferences on Biomagnetism

Country		Conference				
		1	2	3	4	5
1	USA	3	9	16	25	23
2	Finland	1	8	9	8	14
3	France	1	3	1	2	2
4	Canada	1	3	3	3	8
5	West Berlin	-	-	2	2	6
6	Italy	-	1	2	6	5
7	Belgium	-	1	2	3	2
8	Czechoslovakia	-	1	-	1	1
9	Japan	-	-	1	6	6
10	Poland	-	-	1	1	1
11	UK	-	-	1	1	1
12	USSR	-	-	-	3	1
13	Brazil	-	-	1	-	-
14	Denmark	-	-	-	1	-
15	New Zealand	-	-	-	1	-
16	Yugoslavia	-	-	-	-	1
	Total	6	26	39	63	70

The Fourth Workshop on Biomagnetism was held in September 14-16, 1982 in Rome, Italy. It was proceeded by a week-long School on Biomagnetism also held in Italy. The digests of these two conferences contain the recent (up to 1982) data on a wide scope of the biomagnetism subject [8, 85, 110, 111].

The Fifth Conference was held in August 27-31, 1984 in Vancouver (Canada). The proceedings of the Conference have been recently published [86, 109].

The Sixth International Conference on Biomagnetism was held in 1987 in Tokyo, Japan [87].

It should be mentioned that although international conferences on biomagnetism actually reflect the main trends in this area they fail to encompass all studies conducted in this field scattered in various publications or proceedings of other biological, physical or technical conferences. Compiling a full list of references on the modern biomagnetism appears to be an independent and difficult task.

For example, following the conferences' proceedings an interested student will not learn about the development of biomagnetism in the German Democratic Republic although the Jena University has been publishing works on biomagnetism with the emphasis on cardiomagnetism since 1980 [79]. Similar publications from Prague and Bratislava (Czechoslovakia) have been appearing since 1977 [25, 131].

MF of humans, MCG and spontaneous MEG included, has been studied in the Institute of Higher Nervous Activity and Neurophysiology since 1976 with the optical pumping magnetometer built in the Institute of the Earth's Magnetism, Ionosphere and Radiowaves Propagation of the USSR Academy of Sciences. The first results of these studies were published in 1978 [30]. The results of MCG registration with SQUID were published from the United Institute of Nuclear Research in 1979 [7, 23]. After that detailed reports were published from the Kurchatov Institute of Atomic Energy [9-13], the Physical and Technological Institute of Low Temperatures of the Ukrainian SSR Academy of Sciences [21], and the Institute of Radio Technology and Electronics of the USSR Academy of Sciences [19, 22, 34]. In 1982 a conference was held in Pushchino-na-Oke on the biologic effect of EMF with one seminar dealing with the subject "Physical field of biological objects" [24, 32, 62]. The First Soviet-Finnish seminar on magnetometry and biomagnetism was held in 1984 in Moscow.

Thus, coordination of research into the modern biomagnetism has been improving in individual countries and regions and on the international scale. However, the coordination still falls short of the desired institutional level implying the establishment of an appropriate scientific society and publication of a special magazine. Perhaps, these arrangements will be soon made.