number of leads from the sleeping subject and the use of one-channel instrument.

MEG and EEC recording in the delta-rhythm band is difficult because artefacts related to signals from the heart were elicited exactly in this band. The use of high spatial resolution magnetometer showed no MEG and EEG correlation in that band [85].

Magnetic signals in the beta- and gamma-frequency bands can hardly be distinguished from noise at the normal state. They become detectable at the 23-25 Hz frequencies following the use of tranquilizers by the patients [85]. Similarly to EEG of the same frequency range MEGs are found to be more pronounced in frontal areas. Apparently, improved techniques of the measuring system noise reduction will promote detailed studies of these rhythms.

Magnetic mu-rhythm was detected from a subject engaged in motor activity such as making a fist by the hand ipsilateral or contralateral to the left hemisphere. Contraction of the hand on the contralateral arm caused 2.5-fold attenuation of the signal amplitude at 8 Hz while contraction of the ipsilateral hand entailed no appreciable effect. This is the basic information on the main MEG rhythms.

Having adjusted the SQUID based biomagnetic system we performed direct MEG recording from the subject with eyes opened and closed. All experiments were staged in a room on the fifth floor of our institute at maximal distance to sources of possible industrial interference. The obtained results are presented in Fig. 25 showing that MEG is similar to EEG and changes on opening and closing of the eyes.

MEG and EEG data processing in "Labtam" computer revealed a pronounced peak in the alpha-rhythm band (10 Hz) in the MEG spectrum at the eyes closed. Verification test performed without the subject revealed no such peak (Fig. 26).

Preliminary mapping of MEGs was done on the basis of data from three subjects. MEG spectra in the alpha-band had more frequency components than EEC spectra. Presence of certain spectral components was related to the system of MEG leads. Mapped distribution of average amplitude of the main peak was used to identify two limited areas featuring 0.3-0.8 pT maximal average amplitude. The maps also indicated that alpha-activity on MEGs was recorded only from the occipital and parietal areas.

It was not traced in the temporal and frontal areas.

Secondary mapping of MEGs of the same subjects one month later showed that the basic spectra configurations and spatial distribution of the MEG average amplitudes remained the same.

Varying phase relationship between MEG and EEG from the same lead supported the assumption that they reflected the function of synchronously operating sources localized in different areas, or of the same sources producing different frequency components. The situation was clarified by detailed analysis of the extremums location on MEG and EEG maps for two subranges of the alpha-rhythm: low- and high frequency.

Foci of alpha activity of MEG maps were identified in 11 subjects from the group of 13 (number of MEG leads from 60 to 150). The remaining two appeared to have no such foci. A complex pattern of MF foci distribution was characteristic of all the 11 subjects. MEG extremums were detected only in the parieto-occipital area while the activity in the frontal and central areas was at the noise level.

Field extremums were symmetrical relative to the sagittal line with the accuracy up to 5 mm in 9 subjects. Mirror-like field symmetry was detected in 6 subjects. Except for one case, there were found no extremums above the sagittal line on maps. The MEG amplitude in both hemispheres was more or less similar in 9 subjects. The left hemisphere was dominating in one and the right in another subject.

Preliminary localization of sources by low- and high frequency components of the alpha activity on MEGs was performed for all subjects. Calcarine fissure and temporal parieto-occipital areas (TPA) were found to be the most frequent locations of the alpha activity generator on MEGs.

Coinciding positions of extremums on MF maps drawn for two independently selected alpha-rhythm subranges supported the assumption that one and the same source of MEG can generate alpha-rhythms of different frequencies.

Relative covariance (RC) rates were estimated for subjects of the first group and used to draw isocovariance maps in order to detect correlation of the MEGs and EEGs recorded simultaneously from the same source. Two extremums of RC with opposite polarity were detected in one group of subjects over each hemisphere. Positions of extremums on the MEG amplitude and isocovariance maps coincided. Isocovariance maps drawn for other subjects pointed out to possibility of having one extremum of RC in each hemisphere.

All subjects were classified into three subgroups by level of alpha-activity on MEG as follows: a) extremums of MF occurred mostly in occipital leads, b) in parietal leads, c) mixed group.

Analyzing the spatial distribution of MF foci with due account of sensitivity of MF maps to the interhemispheric fissure (symmetric position of foci and pattern of isomagnetic lines relative to the sagittal head line) it may be assumed that the abovementioned positions of MF extremums are primarily related to individual anatomic features of cerebral cortex in the parietal and occipital aress.

Assuming that loci of visual field cortex are the sources of alpha-rhythm, the interindividual variability of foci on MEG maps may be attributed to individual geometry of fissures and gyri and to cortex fields distribution on them.

Lack of extremums on MEGs of the central and frontal areas in all subjects may be interpreted as follows:

—sources creating the frontal focus of alpha-rhythm on EEG are radially oriented;

— no powerful alpha-rhythm sources exist in the frontal and precentral region.

The calcarine fissure may be the most likely source creating such configurations of MEG and EEG foci. Its raster slope could be the source of the frontal EEG focus evoked by physical induction. The similar orientation of single generators (towards the precentral and frontal regions) is facilitated by position of parietal-occipital sulcus over which small amplitude foci are detected from the parietal MEG leads.

How can this line of thought be harmonized with the known regularity of phase relations between occipital and frontal EEG leads? A study of the dynamics of isopotential maps was carried out to answer this question.

Studied were isopotential maps drawn at 5 ms intervals (instant mapping) of a 16-channel EEG in the alpha-rhythm band. The example of mapping one spindle of the alpha-rhythm oscillation on a high time resolution EEG demonstrates that the spatial configuration of EEG field basically repeated its pattern on the two neighboring maps without any leap-like changes. It was changing most smoothly in occipital regions. The pattern of isopotential lines and configuration of foci were repeated on maps of the first 50 ms and the second 50 ms of the oscillation (only polarity changed while the field topography remained identical). In contrast to the frontal, the occipital foci did not change their position although polarity changed in both. There was also observed the regular motion of the zero isopotential line. Passing through TPA it was slightly bent down, got broken in the middle (25 ms) and turned (50 ms) as if rotated clockwise (in the right hemisphere). The same motion repeated in 50 ms.

Detected regularities in phase and topographic correlations of foci for one alpha-rhythm oscillation may be attributed to the joint action of the differently oriented dipole-like generators in TPA synchronously activated in groups with regular phase delay.

Dynamic examination of color isopotential maps with 'Pericolor-2000' computer revealed at least one focus of alpha activity in TPA of each hemisphere in 8 subjects. Each focus was formed by rotation of the zero isopotential line around one of its points on TPA which could be observed visually as circular motion of spiral waves and slight migration of their rotation center.

The presented radial or spiral scanning has its rotation center which may point out to the original source of alpha-rhythm generation on EEG in contrast to merely describing a single circular EEG wave process which makes identification of its start unrealistic. Locating centers of radial scanning in TPA may support the hypothesis that the scanning mechanism participates in the regular distribution of excitation cycles in the remote isolated cortex sensory parts. The process involves the sensory flux quantization in the alpha-rhythm frequency. Thus, positions of MEG and EEG alpha-rhythm extremums in the spatial and time mapping may be attributed to function of the most powerful differently oriented sources of the rhythm in the region of calcarine fissures of the both hemispheres, and of tangential sources in TPA and parietal-occipital sulcus in case of several EEG fragments.

SPONTANEOUS MAGNETIC ACTIVITY OF SICK BRAIN

MEG of spontaneous magnetic activity was recorded from subjects suffering from some diseases of the nervous system.

The first MEG from a patient suffering from psychomotor epilepsy was recorded by D. Cohen in 1972. A few seconds after the beginning of extended hyperventilation high amplitude delta-waves appeared on MEG. The simultaneously recorded EEG showed mixed delta- and theta-activity in three leads.

Studies of MEGs and EEGs of ten patients suffering from various neurological problems (brain tumor, depression, migraine, behavioral disorders, generalized epilepsy with bilateral synchronous 3 Hz peak-wave complexes of EEG) indicated that the following types of activity were shown on MEG better than on EEG: single slow waves related to tumor; alpha-activity in patients with diffused delta-rhythm; harmonic components of the 3 Hz peak-wave complexes.

Examination of 80 patients suffering from a wide range of brain diseases such as generalized and focal epilepsy many of which appeared to be secondary to the identified brain pathologies (cicatrices, atrophies, tumors, angiomas, calcifications, etc.) revealed increased magnetic activity in the frequency bands where it is normally low (0.5-8 Hz and 13-22 Hz). Strong correlation between pathology and signal amplitude variability was traced.

There was detected a limited region on the head over which the "peak-wave" complex was recorded. This could be attributed to possible orientation of the current evoking the detectable MF.

Since it was discovered that the peak component is reflected on MEG stronger than the wave component the authors were inclined to assume that the "peak-wave" complex is elicited by different sources.

Examination of 15 patients treated for focal epilepsy (frontotemporal, rolandic, dextrooccipital, anterotemporal) indicated that MEGs could be successfully used in all cases of the Jackson epilepsy to localize pathologic activity even when it was missing from EEG or no abnormality was detected with the X-ray tomograph scanning. The authors [84] detected the spike activity on MEG which was missing from the EEG.

Spike discharges were traced on MEG and EEG at slow waves. Shifting the MEG sensor at a distance of 3 cm allowed to distinquish areas of epileptic discharges and delta-activity. Theta-activity on MEG which was missing from the EEG was detected in a patient with dextrotemporal glioma two weeks after the operation.

Comparison of traditional techniques used to search for epileptic foci (EEG, computer tomography, etc.) with MEG-research indicated that the accuracy of the latter is related to focus location.

Attributing this regularity to distortions related to nonsphericity of the scull the authors [84] used the "local sphericity" technique and reduced the magnetic mapping error. They used a four-channel magnetometer and the system of optical homing of sensor to the MEG lead point to detect a "border"bet-ween the activity related to the damaged brain area (delta-and theta-waves) and the epileptic focus proper (spikes, peaked waves, etc.).

Examination of 8 focal epilepsy cases with the new system confirmed that MEG shows a multifocus pattern which cannot be traced on EEG. Therefore, the authors found more similarity between tomographic test and MEG in terms of focus localization than with EEG.

We studied MEGs of two groups of patients. Group 1 consisted of patients of both sexes aged 16-29 years old with preliminary diagnosis of "generalized epilepsy" (2 subjects) and 'focal epilepsy' (3 subjects). Group 2 consisted of 8 children aged 10-15 years old with epileptic syndrome of perinatal genesis. In the course of the tests all patients were under the care of medical doctors (the Burdenko Institute of Neurosurgery of the USSR Academy of Sciences, Psychiatric Clinic of the Moscow First Medical Institute, Department of Clinical Psychoneuro-logy of the Moscow Institute of Scientific Research in Pediatrics and Infant Surgery of the RSFSR Ministry of Health) [48].

The study may be exemplified by the following case.

One of the patients, A.I., 20 years old, suffered from recurrent weakness and numbness of the left arm (Jacksonian epilepsy). EEG recorded from parietotemporal leads from the both sides showed easily recognizable paroxysmal "peak-slow wave" complexes having 3 s frequency and

300 mcV amplitude. Peak-wave complexes on MEG were averaged in 50 points above the right and 25 points above the left hemisphere in the parietal region using the "peak-slow wave" complex on EEG in C4—T4 and C3—T3 leads as a starting signal for the right and left hemisphere correspondingly. Measurements ofMF amplitudes of 50, 100 and 200 ms time components were used to draw MEG maps for each component. Two pairs ofextremums with opposite polarity were detected for the 50 ms component in the right hemisphere indicating entry and exit points of lines of force and consequently the direction of the two dipole sources which were believed to be oriented towards the vertex. The two dipoles for the 100 ms component were oriented in the opposite direction although their location was the same. Only two extremums of opposite polarity were detected above the left hemisphere in points identically symmetrical to the points in the right hemisphere. The MF amplitude in these points was found to be two times less than in the symmetrical points above the right temple. RC test showed that foci in the right and left hemisphere functioned independently. Symmetric sources in the two hemispheres were localized in the region of the posterior central gyrus at the 3.2 and 3.1 cm depth under the scalp in the right and left hemisphere correspondingly. The 100 ms components source was localized in the point 3.0 cm behind and 2.2 cm above the right external acoustic canal at the 4.7. cm depth beneath the scalp.

Limited areas (not coinciding with the alpha-rhythm foci) of maximal theta-waves activity on MEG were detected on the head surface of all patients in group 1. The picture of the cortex sources distribution responsible for the maximal contribution into the MEG signal was drawn by selecting the most information intensive technique of signal processing in each individual case.

The epileptic syndrome in all children (group 2) was described by polymorphic paroxysms without specific modifications of the personality. The case histories contained evidence of perinatal problems. No evidence of focal neurological symptoms, considerable arrest of static-motor and psycho-speech development was detected. The neuropsychologic examination performed by E. Simernitskaya and T. Osipenko according to the general method adapted to infants involving evaluation of praxis, gnosis, speech, memory and thinking aimed at defining topics of interhemispheric disfunctions and deficiency of interhemispheric interaction. The study of obtained MEG amplitude maps revealed prevalence of the high amplitude delta- and theta-activity in the region of temporal lobes of the brain on the right side in 5 cases and on the left in 2 cases. Similar but less pronounced modifications were traced as a rule in the other hemisphere symmetrically to the main source. Apparently, the both sources should be regarded as mirror-type foci. In 3 cases symmetrical patterns of the right and left hemisphere coincided with accuracy of up to 3 mm. The coincidence could be also traced in the foci topics and quantity.

MEG tests were performed on another case, patient N.G., at the interval of several months when full remission has been accomplished. The second MEG map showed leveling of the main source although the symmetrical source has become more visible against the new background. The topical classification of fine symptoms of the brain disfunctions detected with the neuropsy-chological method corresponded to MEG localization in all patients. Keeping in mind that all examinations of this group were performed with dual blind verification, coincidence of localization results obtained by various researchers and by different methods supports the combined use ofneuropsychological examination and magnetographic mapping to correlate disfunction and precise localization of the damaged area.

Thus, MEG is a promising technique of clinical research offering considerable potential not only for tumoral and epilepsy cases but also for parkinsonism, alcoholic and narcotic poisoning.

EVOKED MAGNETIC ACTIVITY OF THE BRAIN

Evoked magnetic field (EMF) is presently the most popular means used to detect sources of brain activity as it reflects response of certain structures of the brain to an adequate stimulus registered as MF modification. There were applied sensory stimuli widely used in electrophysiology such as visual, auditory and tactile. EMF was recorded simultaneously with evoked electric potential (EP). EMF to light Hash was first detected by D. Cohen (1975). Response to a more complex visual stimulus was recorded by Brenner *et al*, 1975 [90]; Reite *et al*, 1978 [135] and Williamson *et al*, 1981 [147] and others.

Establishment of the laboratory on neuromagnetism as a result of cooperative effort by members of the departments of physics and psychology of the New York V University is a good example interdisciplinary research in the field of biomagnetism. Workers of the laboratory, among which S. Williamson appears to be

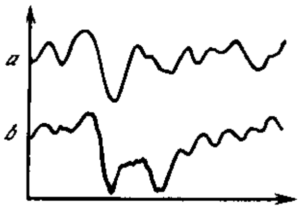

Fig. 27. Evoked magnetic response (*a*) and simultaneously recorded evoked potential (b), lead 0

one of the active, began to publish original reports in 1975 and reviews in 1977. Tests appears to be were staged in an unshielded room with a gradiometric system of SQUIDs in a city lab. There were primarily analyzed visually and sensormotorly evoked magnetic fields [132].

It was found that EMF is described by a much more correct localization around areas of the brain corresponding to the stimulus than the EP localization. While EMFs in visual regions of the both hemispheres were in the opposite phase, EP modifications were in phase (Fig. 27).

EMF amplitude appears to be still increasing with the stimuli intensity growth when EP amplitude ceases to grow.

EMF latency is a constant value describing properties of the visual system. It is unrelated to the stimulus duration. In contrast to EP, EMF does not fall with the stimulus increase. In some subjects there was detected certain difference between EMF of different hemispheres which could not be traced in the course of EP registration.

Since 1980 researchers [143] began to present information on EMF studies on maps showing distribution of the detected MF amplitudes and vectors. These maps may be used for easy localization of the electric source in the brain. Dipole's depth may be calculated by dividing the distance between the two maximal values of EMF of the opposite polarity by 2. The depth of the dipole may be estimated by drawing the zero EMF line on the scull dividing EMFs of different polarity.

Visual EMF mapping supported the conclusion that the electric source of the primary components of responses is located in the visual cortex fissure. As it is believed that cortex of the cerebral hemispheres has columnar structure and modern magnetometers can measure only the tangential currents relative to the scull's surface, the signal may be elicited, as it logically stems from the above, only above the fissure. It is assumed that the dipole is located at the 2.1 cm depth. Therefore, the spatial potential of magnetometry is quite important to evaluation of sensory functions of the cerebral cortex.

The first report on auditory EMF registration was published in 1978 in the USA [135]. It was detected above the Sylvian fissure by repeating sound clicks at 0.25 s intervals and summing up 512 realizations. The average auditory EMF amplitude was 0.4 pT. There was developed a source model comprised of the two vertically oriented current dipoles located on the both sides of the longitudinal fissure 3 cm deep inside the temporal lobes.

Hari *et al*. [117] detected auditory EMF to the I Hz 800 ms monoaural stimulation with a plastic tube. Responses were elicited in the beginning and end of the stimulation [77].

Danish researchers [107] also applied the same sound lasting 500 ms. Maximal amplitudes for the EMF were 0.5 pT for 100 ms latency and 0.3 pT for 180 ms latency.

Subsequently there were published many reports on the detailed study of auditory EMF aimed at drawing a tonotopic map of the human cerebral cortex.

There was even detected the auditory EMF from the 7.5 month human embryo still in the womb [89].

Somatic EMF elicited by weak electric stimulation of various parts of human extremities were first studied in the laboratory of neuromagnetism of the New York University. EMFs were localized close to the Rolandic fissure in the hemisphere opposite to the stimulated finger. It was reported that the current dipole activated by the little finger stimulation is located 2 cm above the dipole activated by stimulation of the thumb.

It appears that the EMF method may produce maps of the somatosensory projection zones featuring better resolution than the EP registration related to the same stimulation localization.

Many reports presented to the Fifth Biomagnetic Conference were dedicated to source detection of EMRs to auditory, visual and electric stimulation of separate human nerves. There was also considered the part played by fissures in localizing sources of EMR because SQUID is capable of measuring only horizontal (tangential) currents and the cerebral cortex has a columnar structure.

MAGNETIC ACTIVITY OF THE NERVOUS SYSTEM OF ANIMALS

The ideology which had dominated the previous biomagnetic conference was visibly shattered by the report from J. Beatty's laboratory (University of California, USA) on recording MEG of rats following creation of an epileptogenous focus [81] This type of data nourish the hope that neurophysiologic analysis of neuromagnetic data will be used more extensively in tests on animals with anesthesia in realization of conditioned reflexaction.

MF from the giant axon of a large lobster has been detected. The signal was averaged 100-fold in the 0.1 Hz-5 kHz band at signal-to-hoise ratio 15. There was also reported detection of MF from Purkinje fibers of the heart of the dog with signal-to-noise ratio 10, and from an isolated papillary muscle of the heart of the rabbit [84].

The study of MF and electric field of a small strip from auricle of the frog suspended in a vessel with electrolite revealed that: 1. MFs were evoked by axial intracellular currents; 2. Actual correlation between the detected electric fields and MF was fully in line with the theory; 3. Joint study of electric potentials distribution on electrodes and evaluation of currents by their magnetic effect is a reliable method of studying dynamics of conductivity.

The biomagnetic method was also used to perform quantitative evaluation of the number and sizes of axons regenerating in the point of the median nerve cutting in monkeys [84]. The method has several advantages such as no need to damage cellular membranes; the obtained results are not related to distance between tissue and electrode or to electric conductivity of the adjoining tissues; the hazard of electrochemical action in the point of contact between electrode and tissue is eliminated.

There was initiated the biomagnetic research of cooperative behavior of small sections of the brain tissue. This research provides the bridge between tests on a limited number of individual neurons and analysis of MEG from an intact organism. Studied were components of EP and EMF to electric stimulation of dorsal surface of cerebellum of the turtle with a manipulator used to change orientation of the preparation in the salt solution relative the magnetic pick up coil.

It was assumed that the fast component of EMF (2-3 ms) was elicited by direct activation of the Purkinje fibers and the late component was related to the post-synaptic potentials. Simultaneous registration of EMF and EP response to cerebellar peduncle stimulation partially allowed to single out the component currents making contributions into the EMF which, according to the authors, reflects the antidrome action potential as well as synaptic currents.

The other part of the above test was designed to perform magnetic registration of proliferating depression (PD) caused by the theta-stimulation of the dorsal surface of cerebellum. Duration of the detected magnetic signal with 10 pT amplitude was 0.5-1 min while duration of the electric signal was 2-5 min. Perhaps, the both methods reflected action of different sources causing PD.

Another similar experiment involved study of the hippocam-pal slice from the guinea pig [86]. The intercellular resistance to currents along the neurons' length estimated from the magnetic signal amplitude was 5 Ohm/m.

Simultaneous extracellular magnetic and electric measurements allow to independently estimate distribution of extracellular voltage and intercellular current. Integration of the obtained results into appropriate mathematic models makes it possible to describe the time behavior of the transmembrane potential and to estimate the effective specific axial resistance during the action of potential proliferation.

The study of MEGs and electrocorticograms of anesthetized rats obtained from the epileptic focus created by a penicillin injection [81] revealed that MEGs showed oscillations similar in their structure to the epileptic discharge although the late components had a different morphology. An epileptiform seisure caused a slow MEG shift from the median line similar to long electric shifts obtained from the focus with the nonpolarized electrodes.

The more detailed tests involved triggering epileptic action by penicillin injection into medial crust of the left and right cingulum convolution of the anesthetized rat. The authors drew a MEG map using a nonmagnetic stereotaxic apparatus to rotate the test animal around the longitudinal axis. The map was instrumental in evaluating the spatial-time model of cellular currents and detecting the penicillin focus of intercellular currents oriented perpendicular to the cortex surface i.e. along the axis of most of the pyramid neurons. Owing to such orientation of pyramid neurons MF polarity for each of the four components of the spike in the left and right foci was opposite. This was in agreement with the reverse orientation of the pyramid cells in the right and left medial cortex.

Therefore, MEG provides more information to the study of extracellular currents in the penicillin focus and aids localization of the primary cell depolarization and hyperpolarization areas as well as direction and magnitude of intercellular currents.

This study confirmed the adequacy of the single current di-pole model for an epileptic focus as well as the MEG measurement feasibility with the cylindric system of coordinates.

The spherical system of coordinates was used for the rabbit head in the course of verifying the hypothesis on suppression of MF evoked by the radially oriented current dipole implanted in the brain [86].

Since simulations on animals may be used to study short-latent specific responses, research of somatosensory induced magnetic field in monkeys and cats was performed.

A conclusion can be made on the basis of this research that neuromagnetometry of animals may provide experimental substantiation of MEG neurogenesis as well as of a new unique method of noninvasive study of cell population physiology.

It is quite interesting to consider in this context an assumption that MF of stimulated nerve can promote myelinizaition of the nerve fiber. This assumption is also supported by high sensitivity of neuroglia to external MF in adult animals [59], lack of the coil effect in the glial cell culture, and increased response of embrio and young organisms passing through myelinization to the impact of external increased or attenuated MF [59].

It may be concluded on the basis of these studies that an adequately strong external MF can change orientation of the dipole created by various sensory stimuli. This assumption is supported by the data changing under MF of the visual EP in the man and rabbit, and comato-sensory EP in the rat [66]. We have recorded MEG and EEG of the man and used the data to draw the alpha-band field map [18]. Spontaneous MEG was analysed with the spectral method based on the fast Fourier transform. The results of the analysis produced a wider spectrum in the low frequency delta-band as compared to EEG. These results and due account of external noise may hold much promise for identification of the slow wave pathological activity. MEG mapping was performed with the covariance analysis which did confirm the dipole structure of the alpha-rhythm source (Fig. 28).

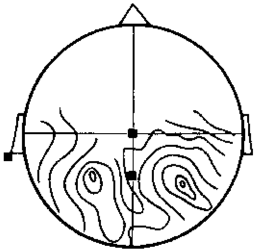

Fig 28. Distribution of MF isolines of MEG in the alpha band confirming the dipole structure of source

It would be also interesting to study magnetoretionogram reflecting the impact of external MF as it may cause visual reaction (magnetophosphene) in man. At the same time important role could be played in the process by magnetic properties of rhodopsin. Magnetic properties of biological objects and their oermanent MF will be discussed in the following chapters.

Chapter 4

MAGNETIC FIELDS EVOKED BY DIRECT CURRENTS

So far we have been considering the significance of alternating MF of biological objects (primarily of man). This is the area showing sizable competition between magnetography and electrography. However, discussion of properties of MF evoked by direct currents shows that competition between them reduces. Magnetometry offers itself as a unique technique for the evaluation of magnetic properties of biological objects and natural or artificial inclusions.

We have already made a reference to permanent MF discussing MF of fishes, cross-striated muscles and eye. This indicator may inform the researcher about the action of direct or low frequency (below 0.1 Hz) skin currents and the functioning of skeletal and smooth muscles. The last refers primarily to muscles of the stomach. The damage potential may be one of the sources of permanent MF in biological objects. Perhaps, it was a source of MF in a wounded fish [67]. Other sources may involve the chicken embryo development and the related permanent MF [84].

Quite unexpectedly magnetic measurements revealed that permanent magnetic field was elicited in the abdominal cavity in man following a drink of cold water. Its magnitude reached 200 pT and then slowly faded away over an hour [95]. One hour after taking meals MF gradients in the human abdomen reached 75 pT/cm and contained a number of varying components. Following a continuous interval in eating (over 12 hours) MF dropped 3-fold and became permanent in terms of time or oscillated with a 20 s period [138].

It is known that there is a 60-80 mV potential between the mucous and serous membranes of the human stomach [51]. If the stomach mucous membrane is damaged this potential appears to be decreasing in the course of the acid secretion process. An ability to identify this damage by MF modification would constitute a diagnostical method free of the need to swallow unpleasant special pipes. It is also possible to stage a simple experiment by monitoring modifications of MF related to the secretion process triggered by pharmacologic means or by administering aspirin. It would be also interesting to check MF modification related to the intestine smooth muscles with the view to study intestine disfunctions [143].

It should be recalled that electrogastrography has been the most extensively used method in the studies of electric activity of human stomach. The technique involves administering an active electrode through the mouth into stomach. A passive electrode is fixed on an external part of the body. In these circumstances motion of the electrode inside the stomach generates considerable interference into the recorded signal. Coating of the electrode by food having sizable dielectric constant, such as fat, may cause the recording to discontinue. All efforts to record human stomach potentials working from the body surface are hampered by signal interference generated by electrochemical activity on the body - pick up electrode border, induction elicited by other organs such as signals evoked by intestine contraction and by electrocardiac activity. Electrical potentials generated by a ventricle are distributed across the body through the volume conductor and may be recorded from the chest surface and arms. It is hoped that improvement of the magnetogastrographic technique will permit to conduct selective recording of currents elicited in the gastrointestinal tract.

While the study of gastromagnetism was triggered by MCG research myomagnetism was initiated as a consequence of magnetomyography i.e. the noninvasive method to detect bioelectrical action of cross-striated muscles based on measurement of MF evoked by the direct and alternating currents generated in the course of muscle contraction.

The first ever MMG was produced by study of human skeletal muscles in the elbow area during the hand compression [98, 99]. The detected signal had both permanent and alternating MF components. The spectral analysis of MMG showed a 40 Hz peak in measurements above the elbow and a 80 Hz peak in measurements from the palm. The MMG amplitude was about 20 pT. The amplitude of MMG recorded from the forearm was about 2 pT [97]. Barbaner et aL [84] described MMG recorded in a wide - up to 400 Hz - band from the elbow. MMG signals were recorded in these frequencies as well. In all cases the MMG signal disappeared in the absense of contraction of the corresponding muscles.

MMG recorded from the human right leg was described by Cogg *et al.* [85]. Experiments were conducted with the first order SQUID gradiometer. The pick-up coil diameter was 4.4 cm. The system's bandwidth was 4 kHz and the background noise level was $1 \cdot 10^{-13}$ T Hz$^{-1/2}$. The human crus was used as an object of MMG waveform study. The pick up coil axis was positioned almost perpendicularly to the skin surface over the musculus ti-bialis anterior. Wave averaging was used to produce clearly dis-cernable waves. The averaging procedure was triggerred by the present MMG signal amplitude. As the crus MMG base line drift is small the triggering procedure applied guaranteed reliable averaging of 32 initial recordings. The form of MMG wave was found to be almost symmetrical. The impulse duration at one half peak height was 4 s. Asymmetric MMG wave is produced by rotating the crus 45^{o} around its axis. Although the frequency spectrum of the crus MMG is similar to the one reported by Cohen *et al*. [99] the crus MMG impulse duration was 4 s. The depth of the MMG signal source under the skin was estimated by evaluating correlation between amplitude of the MMG impulse and distance between skin surface and the dewar bottom end, measuring 1 cm.

Preliminary studies of the action potentials taken from implanted electrodes indicated that duration of potentials elicited by one motor unit of the musculus tibialis anterior was 2-19 s. Since the largest MMG amplitude was detected over the upper musculus tibialis and duration of the corresponding MMG impulse was 10-20 s, the authors conclude that the source of MMG in this case is a motor unit of the upper musculus tibialis.

Motions are performed, apart from extremities, by other organs of the body. If they elicit biological currents or contain magnetic particles, motion of a particular organ may be detected with the magnetometric method. For example, electrooculogram (EOG) involves the use of skin surface electrodes to record potentials elicited by eye movements. Magnetooculogram (MOG) is related to the magnetic component evoked by the eye muscles action currents. The MOG amplitude was found to reach 10-12 pT [30]. Karp *et al*. [121] reported that similarly to EOG, magnetooculogram is affected by variations in illumination. Modification of the MOG permanent component related to eye adaptation to various light conditions may measure 5 pT in several minutes.

Apart from MOG, the eye area may provide recording ofmag-netoretinogram (MRG) measured in decimal parts of pT in response to exposing retina to light [85]. Ophthalmologists may greatly profit from the use of these methods in their clinical research. At the same time allowance should be made to possible artefacts created by MF of the eye. Possible interference from MF of other organs should be taken into account in the course of every biomagnetic research.

D. Cohen *et al*. (1980) was the first to describe MF evoked by currents generated in extremities. It was detected that long muscular fibers in legs and arms generate a sizable (up to 3 mA) current flowing along extremities [101].

MF of arms is attributed to action of muscles since it was absent in patients suffering from arms paralysis. Sizable damages of skin (scars, burns) did not affect the magnetic fields distribution. A short massage of arms was enough to elicit currents generating these magnetic fields. No MF created by these currents was detected in areas devoid of any muscles (women's breast, for example).

D. Grimes *et al*. [85] performed research with the view to assess the part played by ion currents in tissue regeneration. They studied stationary MF evoked in the crus area of healthy subjects and its variation versus position of the extremity and time, as well as relation to the extent of muscular contraction or relaxation. The subject in the state of relaxation laid on his back, his legs resting on a horizontal platform. Its height was adjustable to assure maximal proximity of the subjects's legs to the pick-up coil. Adjustment of the subject's position set conditions for detecting MF from the front, rear and lateral surfaces of the leg. The used method of data gathering and averaging produced the root mean square noise level of 1.10^{-12} T in the 0 to 40 Hz frequency range.

In spite of the measurements' variability in different subjects the maximal field readings were detected in the area located approximately one third of the tibia length below the dia-physis i.e. at the point of maximal area of the muscle section. There was also reported a subject producing signals of reverse polarity. When the subject relaxed the reading of the detected signal increased during approximately one hour. The type of signals usually detected by authors of the above research easily harmonizes with the availability of the two oppositely oriented and spatially separated currents flowing parallel and nonparallel with muscular fibers.

A special 2D-gradiometer capable of evaluating both the volume and orientation of currents was used to study superficial direct currents in the human skin [101].

It was detected that pressing a finger against a hair on the surface on a man's head causes the 2D-gradiometer to detect currents having identical distribution pattern in all the inspected males. The pattern remained unchanged following various impacts on man, local heating included. Eliciting the 10-25 pT/cm gradient MF these direct currents flow on the headskin and center from all sides in the vertex area. They were not detected on the forehead, ba!d spot, pubic region and under arm pits but were well pronounced on the hairy surface of the chest. Direction of these currents coinsided with orientation of hair follicles. It is practically unfeasible to detect this phenomenon relying only on the difference of potentials.

Therefore, perhaps, this is the evidence of emerging dermo-magnetism related to studies of MF of the skin. This thrust of research may be quite perspective for the skin is the first organ to encounter the impact of the environment.

Chapter 5

MAGNETIC INCLUSIONS AND MAGNETIC PROPERTIES OF BIOLOGICAL OBJECTS

It was detected that pressing a finger against a hair on the and flesh are diamagnetic. It is known thatdiamagnetism of certain bacteria may increase 4% following their death [82]. Savostin [41, 59] intended to explore the mechanism of the external MF impact on finding the matter with magnetic susceptibility in biological objects. Research performed during the recent decade resulted in finding natural magnetite [36, 127, 128]. This line of research was dramatically expanded in the course of osteomagnetism study of vertebral animals. This study is well exemplified by the research performed by R. Baker *et al* [79] who used an astatic magnetometer to evaluate magnetic susceptibility of different human organs in response to the 0.2 T MF impact. The basic results are presented in Table 5.

It may be seen from the table that magnetic properties of the human sinuses are different from magnetic properties of other organs. It should be also noted that magnetic properties of the pineal organ are quite different from those of the other areas of the brain tissue although the authors did not give much importance to that. It is known as well that proceeding from the neu-rophysiologic data Semm *et al* [141] attributed to the pineal organ a magnetic reception function.

R. Baker *et al* [80] also conducted the histologic study of the same samples. High iron concentration was detected only in

Table 5
Remaining Induced Magnetization of Human Tissues Represented in Electromangetic Units (EMU)

Tissue	Part of the body	Number of persons	Number of tests	Average remaining magnetization (range) EMU X 10^ per 1 g of tissue
Soft	Brain	2	5	-0.004(-0.007-0.003)
tissues	Olfactory lobe	1	1	0.008
	Optic chiasm	1	1	0.009
	Dura mater (vertex)	3	4	0.215(-1.790-0.900)
	Dura mater (sphenoid)	3	5	1.540(-0.10-6.520)
	Pineal organ	4	4	2.360(-0.234-8.380)
Bones	Rid	1	1	0.780
	Skull	1	1	1.150
	Turbinated bone	1	1	2.050
	Sphenoid	1	1	0.190
Walls	Sinus of sphenoid +ethmoid fragments	2	4	16.110(5.810-24.000)
	Sinus of sphenoid	4	7	13.000(3.020-31.580)

the sphenoid bone (ethmoid of the hearing complex). Iron concentrations were shaped as 2 mem thick layers located 5 mem below the bone surface making both the external and internal sinus wall. No magnetite was detected in the ischemia victim (this data was not included into the table). The authors maintained that the artefact magnetic contamination of the material could not take place.

Among the various implied physical and chemical mechanisms of biological action of ordinary magnetic fields such as induction created by electromotive force, modification of the cellular membrane permeability, etc. or specific fields such as optical pumping, cyclotrone effect, Josephson effect, etc. today more and more priority is given to the magnetite hypothesis of magnetic reception (MHMR). As a matter of fact, MHMR has not yet been discussed in Soviet publications.

Development of this hypothesis is closely related to advances of supersensitive magnetometry based on SQUIDs and the proofs of the biogenic origin of magnetite as well as to dramatic expansion of the number of objects of magnetobiologic research.

Table 6

Development Stage of Magnetite Hypothesis of Magnetic Reception

N	Year	Author	Result
1	1945	Ising G.	Was the first to propose the ferromagnetic hypothisis of magnetic reception
2	1963	Lowenstam H.	Detected magnetite inthe"teeth" of chiton mollusks
3	1975	Blakemore R.	Discovered magnetotactic bacteria
4	1978	Gold et al.	Found magnetite in bees
5	1979	Walkott et al.	Found magnetite in pigeons
6	1981	Zoeger et al.	Found magnetite in dolphins
7	1981	Kirshvink J.	Found magnetite in man (?)
8	1982	Jones etal.	Found magnetite in butterflies
9	1983	Baker et al.	Found magnetite in human nasal bones
10	1985	52 authors	Overview "Biogenic magnetite and magnetic reception"

These three areas of scientific research have been developing primarily in reseatch centers abroad.

Table 6 presents the main stages of MHMR development. Incidentally, many of the referred authors tend to classify their area of research as biomagnetism notwithstanding the fact that this term has been already "engaged". They appear to be inspired by the fact that MF of the order of 0.4 T is evoked at the magne-tosome end in magnetotactic bacteria. In our view this area of research should be rather referred to as biogenic ferromagnetism. This is essentially the field of magnetoecology targeting out of MF biotropic factors primarily the yector and orientation of biological objects.

The biogenic ferromagnetism has advanced so dramatically that there have been discovered new bacteria types and a new organella (a magnetosome in some bacteria).

It may be seen from Table 6 that spectacular progress has been made in the field of MHMR during 40 years of its development.

It would seem quite logical that this area of research should organically join the mainstream of the modern research of biomagnetism and provide a reliable link between biomagnetism and magnetobiology.

So far, the search for the natural magnetite has been mainly the concern of geologists and zoologists while biomagnetism continues to be the hobby of physicists and clinic physicians. The general report on biomagnetism by Kirshvink was presented during the workshop in Italy [85] but the subject was not yet included in the program of the conferences.

At the same time conferences on biomagnetism did discuss the problems ofpneumomagnetism which, to put it straight, were artificially involved into the modern biomagnetism. It might have happened because D. Cohen [91] while studying MCG accidentally discovered artificial magnetic inclusions in lungs of some subjects. Thus, pneumomagnetism which will be further discussed below has joined the family of modern biomagnetism despite the fact that the true "relative" (the search for natural magnetite inclusions) remains quite neglected and the problem of magnetic transport of medicines [52] similar to matters of pneumomagnetism are overlooked in the course of discussions at biomagnetic conferences.

To be consistent one should separate the study of artificial magnetic inclusions in biological objects from biomagnetism (since it is not a magnetism of biologic origin) and classify it into pneumomagnetism, vasomagnetism (magnetic transport of medicines via the blood channel) and gastromagnetism (dealing with magnetic inclusions in the digestive tract). In the last case it might be possible to determine whether a person used the food contained in a tin or in another packing [95].

Natural magnetic inclusions in the human nasal bone are covered by several hypotheses [80].

I .Sinus bones are an element of iron depot. A case of anemic subject indicates that the material is absent when the subject develops deficit of iron.

2. Magnetic deviations are related to perception of external magnetic fields.

3. Magnetic material is related to growth and regeneration of bones.

These hypotheses do not contradict one another and their substantiation requires further research.

It should be also mentioned that liver is the principal local depot of iron in man. Various diseases may cause the iron concentration to raise or fall. Introduction into clinical practice and regular use of SQUID for diagnostical purposes is instrumental in quantitative evaluation of liver iron deficit or excess. This method features sizable advantages over other techniques. So, hepatomagnetism has every reason to become a promising magnetometric method.

Natural magnetic inclusions were also detected in human adrenal glands [123, 128]. Nevertheless, this report remained aside of the flow of information (coming as a magnetic boom) on magnetite contents in the skull bones. The use of magnetometric method in tests of pigeon brain section initially exposed to MF was instrumental in detecting natural magnetic materials between dura mater and the skull. These data supported the idea that pigeons use information on the geomagnetic field to orient themselves in space. There was also proposed the idea on possible iron accumulation in the pigeon's head from blood erythro-cites [124].

It would be appropriate in this context to recall some incomplete data on geomagnetism. It was known as far back as in 1930's that deoxygenated hemoglobin's magnetic susceptibility falls by 7%. V. Karmilov writes in his review that patients suffering from cancer show certain modification of blood magnetic properties. A. Chizhevsky [68] offered theoretical substantiation of possible magnetic interaction of rotating erythrocites. M. Muroyama [129] reported that a strong enough permanent external MF does not affect erythrocites in a healthy human subject but tends to orient erythrocites of a patient suffering from sickle-cell anemia. Having studied the human blood erythrocites behavior in external MF a group of Soviet physicists concluded that magnetic susceptibility of a living cell is the function of its physiologic state and that studies of this parameter are particularly important to designing new methods of medical diagnosis.*

Similar conclusions were also made by other researchers following examination of the same biological object [36, 70, 130].

Magnetic susceptibility is best studied in bacteria because in some bacteria species there were detected magnetic inclusions [87] and specific organellas-magnetosomes [128]. Some features of these bacteria and organellas are presented in Table 7 quoted from a publication by Denham *et al* [104]. As a rule bacteria have a linear chain of 20 cubiccal particles rich in iron with side measuring to the order of 50 nanometers. Together with Kalmijn he noted that bacteria contained a permanent magnetic dipole. And finally, using the Mossbauer spectroscopy Frankel and Blakemore reported that iron granules were composed of magnetite (F3O4) often referred to as black iron ore. Each granule was coated with membrane or shell. Blakemore and his colleagues named them magnetosomes. They account for about 2% of dry weight of bacteria and contain 10 to 100 times more iron than nonmagnetotactic bacteria [128].

The magnetosome chain is large enough to have a substantial magnetic moment which may explain appropriate orientation of bacteria from the point of physics. For example, dead bacteria maintain their orientation along magnetic power lines. When living bacteria float orientation forces

* Kondorsky E., Shalygin A., XV *All-Union Conference on the Physics of Magnetic Phenomena*, Perm, 1981, p. I, p. 144 (in Russian) [26].

them to move along the magnetic field power lines. Field lines in the northern hemisphere are inclined down in such a way that movement to the North pole amounts to movement in depth. Blakemore maintains that magnetotaxis may orient the bacteria to the bottom and low oxygen sediments where they feel better off.

In order to verify this hypothesis Blakemore *et al*. collected in 1980 bacteria from sediments in New Zealand and Tasmania. This area features the same magnetic inclination as New England, but of opposite polarity. It was established that bacteria were oriented primarily to the south which was again the sign of movement to the bottom. Working independently from Blakemore Kirshvink found the south-oriented bacteria in Australia.

Subsequently, Frankel and Blakemore gathered bacteria at the magnetic equator in Brazil where magnetic power lines go parallel to the Earth's surface. There they found approximately equal quantities of bacteria oriented to the north and south [112].

By now Blakemore *et al.* have determined about a dozen morphologically different bacteria possessing magnetosomes. Some of them, such as *Aquaspirillum magnetotacticum* are the only species existing as a pure bacterial culture. On both ends they have flagellums allowing them to swim in any direction along the field lines. Blakemore et aL also reported that they are sensitive to oxygen and usually swim along the field lines if there is an optimal oxygen concentration. Many researchers presently study bacterial physiology and determine a'mong other things the mechanism responsible for magnetosome formation and the role played by iron in the electron transport.

This approach was quite successful in the field of phyto-magnetism. Discovery of magnetotaxis in green algae was reported by Frankel *et al* [128]. Algae of the genus *Chlamydomonas* were extracted from the polluted coastal lagoon of the Rio de Janeiro river. They were south-oriented and showed the same reaction as bacteria. Passive orientation of the cells was exercised through their magnetic moment which, incidentally, was 10 times higher than in bacteria. However, the researchers did not have enough time to grow an adequate quantity of algae in culture to determine the position of magnetite in cells. Subsequently, similar but north-oriented bacteria were found by Frankel as well. All these discoveries are the first solid evidence of magnetotaxis in eukaryotic organisms. (Bacteria are prokaryotic and have no cell nuclei and certain other intracellular organellas while algae and supreme organisms belong to eukaryotes and have all such elements).

The function of magnetotaxis in algae is yet unclear although it is already known that *Chlamydomonas* may be heterotrophs or autotrophs which implies that they can either absorb all their feed from the aquatic environment or produce a part of it by photosynthesis. Frankel maintained that magnetotactic algae enjoy certain advantages in the process of occupying heterotrophic niches in their environment. Negative phototaxis (migration away from light) was earlier noticed in *Chlamydomonas* [128].

Several researchers found magnetite in other eukaryotes. This is already the field of zoomagnetism. Fuller *et al* reported magnetite discovery in heads of four dolphins. It was found between the dura mater and skull i.e. in the same place as in the head of pigeon. Subsequently, Fuller and Zoger detected magnetite in the same place in the head of the Cuvier whale. (All tests were performed on dead whales which threw themselves ashore and were designated for the Natural History Museum, Los Angeles).

Magnetic particles were also detected in tuna, blue marlin and green turtle. In turtles magnetic paricles penetrated all tissues although in tuna and marlin they were concentrated in the ethmoid cavity involving wall bones and nasal septum. Therefore, it was more or less the same magnetite-containing area as in dolphins or pigeons. Baker *et al* [80] reported detection of magnetite in ethmoid cavity ofrhodents and humans. Kirschvink [124] reported the same localization in monkeys. In all cases researchers noted that magnetic particles were surrounded by nervous tissue pointing out to possible interaction between the particles and the brain.

Detection of MF of the nerve is just one example of cytomagnetism. Kirschvink *et al* observed residual magnetism in two types of tumor in mice: US-8 lymphoma and Lewis lung tumor. Human tissues of the stomach, intestine and kidney carcinoma showed no substantial residual magnetism similarly to tissues of healthy mice.

Many researchers detected that cells of tumors in mice contained approximately five magnetite particles per cell (estimated by their magnetic moment) as compared to less than one particle per thousand cells in human tumors and other tissues. Gabrah and Batkin exposed cultivated tumors to various MFs to evaluate their impact on tumor growth. The Lewis tumor did not react to external MF while US-8 cells showed noticeable response. The impact of MF of the order of mT and 2000 Hz increased the cells' growth dramatically while the impact of the same MF but of 60 Hz considerably inhibited their growth. Today, many researchers are trying to pinpoint location of particles inside the cells as well as to evaluate other possible functions they perform apart from storing iron [128].

It may be seen from Table 7 [104] that presence of mag-netosomes containing almost all magnetite is the principal distinction of magnetotactic bacteria. Discovery of these orga-nellas is an important accomplishment of the modern biomagnetism as it incorporates this lateral biophysical problem into the mainstream of microbiology.

No matter how strong we are carried away by consideration of magnetosomes we should avoid the conclusion that these organellas are the only instrument of response to external MF. Measurement of magnetic susceptibility of nonmag-netotactic bacteria, performed by S. Pavlovich [33] with the Gouy's technique, determined variability of magnetic susceptibility

Table 7

Certain Magnetic Characteristics of Bacteria

Subject	Coercitivity, Oe	Residual coersitivity, Oe	Saturation, Oe	Magnetic saturation, G/cm^3	Residual magnetization.Magnitization saturation	magnetite concentration, %
Magnetotactic bacteria	220	270	1750	0.9	0.47	1
Isolated mag-netosomes	105	140	2000	13	0.42	14
Nonmagneto-tactic bacteria	Nonmagnetic up 1 T					

of microorganisms (which may be attributed to uneven content of dia- and paramagnetic particles or to special chemical composition of the intercellular organellas) and its modification following a 70-days storage of bacteria in the pulsating at 3 min. intervals MF with induction of the order of 500 mcT (Table 8).

According to the data of this table bacteria numbered 6, 7, 10, 12, 13, and 14 possessed the lowest magnetic susceptibility and those numbered 2, 5, and 8 had the highest susceptibility. Thus, bacteria of various types differ in terms of the summary magnetic susceptibility.

Following MF impact the summary magnetic susceptibility dropped 22.6% as against control in Micrococcus lisodicticus and 40% in E. coli R678. At the same time magnetic susceptibility of dry biomass increased according to reliable data 4-19% in Salm. typhimurium, Salm. cholera, E. coli C-85, E. coli C-H2. Bact. subtilis and Proteus vulgaris.

Table 8

Magnetic Susceptibility of Certain Bacteria and Variation after Keeping Bacteria in Magnetic Field [33]

N	Test microbes	Average magnetic susceptibility $x10^{-6}$ e.m.u.		Student index
		Before MF	After MF	
1	E. coli K-12	-0.4543	-0.4338	1.9
2	E. coli P678	-0.3295	-0.4622	15.5
3	E. coli C-85	-0.4160	-.03399	4.1
4	E. coli C-H2	-0.4386	-0.4109	4.2
5	Salm. choleraesues	-0.3907	-0.3385	7.5
6	Salm. enteritidis	-0.4742	-0.4844	1.2
7	Salm. typhimurium	-0.4386	-0.4422	8.5
8	Micrococcus clisodicticus	-0.3390	-0.4157	19.9
9	Micrococcus luteus	-0.4707	-0.4756	0.0
10	Staph. aureus 209	-0.4663	-0.4624	0.3
11	Serratia marcescens	-0.4530	-0.4548	0.0
12	Bac. subtilis	-0.5199	-0.4594	3.0
13	Alcaligenes fecamous	-0.4647	-0.4855	2.4
14	Proteus vulgaris	-0.4965	-0.4101	5.1

Magnetic susceptibility of the other six types of studied bacteria did not change at the impact of MF with specified parameters.

Thus, magnetic susceptibility of cellular matter continuously stored in a weakly pulsating MF tended to increase in over one third of test microbes. Interestingly, the population of magnetosensitive bacteria genera is heterogenous in terms of its magnetic susceptibility and clones featuring high paramagnetism may account for a high percentage of magnetic dissociants. Therefore, magnetic susceptibility may be regarded as an important means of exploring magnetic variability of microorganisms induced by variations of the geomagnetic field.

The use of EPR technique to study dynamics of magnetic properties of yeast was instrumental in detecting signal increment 30 minutes after the onset of its cultivation. Subsequently, the signal intensity changed periodically over 6-7 hours, then sharply dropped and increased again in 8-10 hours. The growth of yeast was usually completed by that time. Interestingly, the dynamics of magnetic properties of yeast basically corresponds to its susceptibility to external MFs [59].

Concluding the present review of the current state-of-the-art of bacteriomagnetism we should stress that presently the main objective is to systematize the dislocated material dedicated to assessment of susceptibility in the course of various research. For example, A. Pavlovich performed a many-year cycle of magnetobiological tests focusing on microorganisms as the main test object. Study of mechanisms responsible for magnetobiological processes and the related research generated the need for biomagnetic research. Being undisputably original and indispensable this approach goes to underline the theoretical significance of this thrust of research.

The practical dimension of this scientific branch envisages the use of biomagnetic data for diagnosis, assessment of variability of macro- and microorganisms, evaluation of magnetic sensitivity of biological objects, identification of the hygienic role of physical factors, etc. The list of its practical uses could be very long because this research is related to functional problems of biology, medicine and biotechnology.

The last area also involves methods to identify artificial magnetic inclusions in biological systems. These methods facilitate better understanding and make more visible as compared with other branches of biomagnetism signal sources detected in the course of studying magnetic inclusions in lungs of humans and animals. This subject was extensively covered in many publications [119]. This research may be performed both with SQUIDs and FMs because the signal is sufficiently large.

These publications clearly show the hygienic thrust of research (evaluation of iron content in lungs of individuals working in contact with iron dust). The countries where such studies have been originally performed began to produce mobile labs in coaches and carry out mass checkups. The use of magnetometry to assess the degree of lungs contamination is more accurate and safer than, for instance, the radiological method.

The study of clearance i.e. evacuation of iron dust artificially administered into lungs indicated, at least according to publications by A. Freedman *et al*. [109], that iron is evacuated from nonsmokers two times faster than from smoking individuals. It was also noted that functions of deep parts of lungs are disturbed only in smokers.

The subjects were first exposed to external MF and then the lung area was sweeped by magnetometer. The resulting maps produced the data on quantity, localization and speed of magnetic dust evacuation from subjects suffering from occupational diseases and from smokers.

For example, tests performed on smokers and nonsmokers revealed that after II months since administering a harmless magnetic powder into lungs 50% of it remained in lungs of smokers and only 10% in nonsmokers. Thus, the technique appears to be instrumental in noninvasive evaluation of lung contamination by ferromagnetic elements.

Removal of these particles usually takes one year. Besides, the new method is more reliable than the radiological and other methods. Owing to its complete safety and relative cheapness it may be used in check ups already now or assist solution of many environmental problems related to pollution of water, air, food, etc. by ferromagnetic particles.

Several researchers from different countries reported the participation of phagocytes in the process of iron evacuation from the lungs.

Phagocytes were found to use such intercellular formations as mitochondria and microtubes. The tests were performed on animals (hamsters and rats). Test results were presented as histologic sections vividly showing correctness of scientific conclusions.

Pneumomagnetism may be regarded as the most advanced area of anthropogenic biomagnetism (in contrast to biogenic biomagnetism) both in terms of extensive use of techniques for evaluation of artificial magnetic inclusions in the lungs, and histochemical research by administering and evacuating magnetic inclusions. Perhaps, researchers working in this particular area could be criticized for lack of coordination between their studies and vaso- and gastromagnetism where similar problems could be faced. Particular interest is invited to magnetic transport of medicines through the blood, respiratory and digestive tracts. So far, only the blood channel has been studied in this sense [52].

Anthropogenic biomagnetism should also master the ability to solve magnetobiological problems i.e. accommodate possible biological influence of external MFs [35, 39, 57, 59, 66, 73].