Published: November 13, 2018

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Keywords: Chemically Induced Dynamic Polarization (CIDP) of nuclei and electrons, nanobubbles, nuclear magnetic resonance, relaxation time in proteins, nucleotides and cellular structures, metabolism and nuclear "magnetic memory"

RESEARCH ARTICLE

The Role of the Chemically Induced Polarization of Nuclei in Biology

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Abstract

There are many observations, scientific reports, and articles about the sensitivity of people, animals, plants, and bacteria to the Earth's Magnetic Field (EMF) and its perturbations – magnetic storms. There are also undesired effects of artificial sources of the extremely low frequency magnetic fields (ELF-FMs) which have been formally evaluated, however, the mechanisms of such influence on health are not yet understood.

A hypothesis is proposed here that the relatively long-lived chemically induced dynamic polarization of nuclei in bio-molecules named nuclei magnetic memory (NMM) plays an important role in the nonlinear process of transfer and transformation of energy in cellular structures and organisms. Resonant interaction of the polarized nuclei inside and outside the biological molecules, interaction of molecules and nanobubbles with extremely weak static and extremely low frequency magnetic fields (ELF-MFs), dramatically improve a coupling and transfer energy between different levels of structural organization of cells and organisms, resulting in sensitivity of living matter to electromagnetic environments. The external magnetic field's influence is possible in a narrow range of magnetic flux density and probably at multimodal resonance.

STATE OF ART

The importance of the Earth's magnetic field in biosphere[1] is well known. Low-intensity, extremely low-frequency (ELF) magnetic fields (MF) can cause adverse effects on human health[2-4] due to prolonged exposure when residing near high-voltage power lines and other equipment and transport. The typical amplitude of these fields is an order of magnitude smaller than the EMF and MF as it is shown in Fig. 1.

The Earth's magnetic field (EMF) magnitude is from 33 to 65 □T and a typical change in EMF intensity during magnetic storms is not more 100 nT[1-4]. The largest magnetic storm on record is the 'Carrington Event' of August 28th to September 8th, 1859 with a strength of D_{St}≈ -1760 nT[6].

MRI devices which are widely used for diagnostic medical imaging use fields of 1.5 and 3T[5] without detectable side effects as a rule.

Note, that the thermal energy of water is about 2577 J/mol at body temperature whereas the Earth's magnetic field energy is about $3\mu T$/mol and MRI energy density is only about 300mJ/mol . The electric field of the atmosphere (about 100V/m vertical) corresponds to 2*10^{-12} Joules.

There is a **thermal paradox** of observed cellular and organism sensitivity to EMF at such small electromagnetic energy relative to the kinetic energy of molecules.

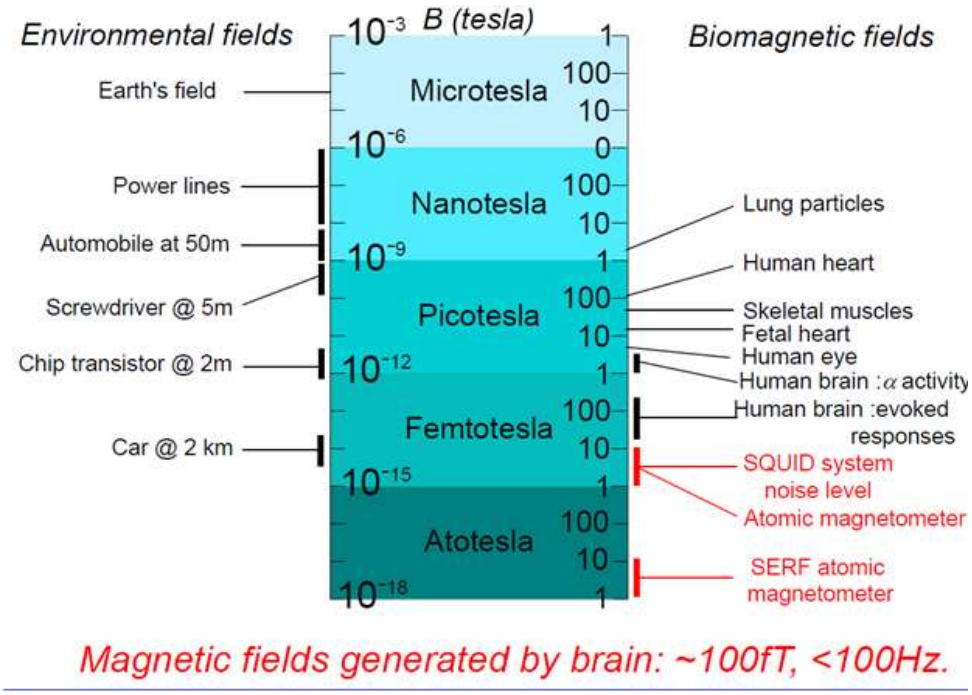

Figure 1. Strength of the environmental and biological magnetic fields[5]

There is a principal difference in sensitivity of single and multicellular organisms to extremely low frequency (ELF-MFs) and static magnetic fields and the absence of such sensitivity of the separate biochemical reactions IN VITRO[7-10].

Many studies have been performed to solve the above problems by looking at the possible mechanism of magneto-biological effects.

Ion cyclotron resonance[10-12], radical-pairs[1,13] and nanobubbles[14,15] were proposed and established as possible mechanisms for interaction of the weak magnetic fields with organisms.

However, none of the above listed mechanisms explain the energy paradox of the difference of IN VIVO and IN VITRO sensitivity.

Many studies describe a broad range of physiological, psychological, and behavioral changes associated with changes in the geomagnetic field[16-20]. Heart rate and circadecadal rhythm variability[16,17] and the high sensitivity of mitochondria to ELF-MFs, increase both its volume and cristae reducing[18] matrix electron-transparence. Cytochemical studies indicate that cells of plant roots exposed to weak magnetic field show Ca^{2+} over-saturation in all organelles and in cytoplasm unlike the control ones[18].

There is also evidence that the MF selectively activates limbic structures of the brain, which are damaged by Alzheimer's disease (AD). The results obtained IN VIVO from animal AD models were used olfactory bulbectomized (OBE) and transgenic Tg (APPswe, PSEN1) mice. The studies showed that a weak MF combined with extremely low frequency could be used as a method for the cleansing of Aβ from the brain[19]. There is a detailed review[20] of possible mechanisms of magnetoreception in a microorganism as magneto-biological effects in bacteria, protists and fungi.

The well-known nuclear magnetic resonance imaging devices use magnetic fields strengths of 1, 1.5 and 3T and there are no detectable side effects as rule[21]. Increasing of the magnetic field strength leads to increased resolution and allows neurochemical analysis IN VIVO and IN VITRO[22-24]. All types of organisms contain molecules which include hydrogen, nitrogen and other elements with nonzero nuclear spin. A summary of their NMR resonance frequency characteristics is shown in Table I[25].

Table I. NMR frequency of biologically important isotopes

Isotope	Spin	Natural Abundance (%)	Human body	NMRI	Earth
				5.8717 T	0.00003 T
			% w/w	MHz	kHz
^{1}H	1/2	99.98	10	250.000	1,27731
^{13}C	1/2	1.108	18	62.860	0.32115
^{14}N	1	99.63	3	18.059	0.09226
^{17}O	5/2	$3.7x10^{-2}$	65	33.892	0.173163
^{23}Na	3/2	100	0.15	66.128	0.33786
^{25}Mg	5/2	10.13	0.05	15.298	0.07816
^{31}P	1/2	100	1.0	101.202	0.51707
^{33}S	3/2	0.76	0.25	19.174	0.09796
^{35}Cl	3/2	75.53	0.117	24.495	0.12515
^{37}Cl	3/2	24.47		20.389	0.10417
^{39}K	3/2	93.1	0.35	11.666	0.05960
^{41}K	3/2	6.88		6.403	0.03271
^{43}Ca	7/2	0.145	1.4	16.820	0.08594
^{53}Cr	3/2	9.55	0.000008	14.130	0.07219
^{55}Mn	5/2	100	0.00003	61.661	0.31504
^{57}Fe	1/2	2.19	0.008	8.078	0.04127
^{63}Cu	3/2	69.09	0.00011	66.262	0.34213
^{65}Cu	3/2	30.91		70.958	0.36254
^{67}Zn	5/2	4.11	0.00285	15.635	0.07988
^{77}Se	1/2	7.58	0.00002	47.669	0.24355
^{127}I	5/2	100	0.00003	50.018	0.25555

- The NMR data in strong magnetic fields is based on NMR Frequency Tables[25]
- The frequency for the 30μJ T magnetic field is estimated by the Larmor *equation*,
- Source is Human Body composition[26]

The chemically induced polarization of nuclei depends on metabolic pathways and has a time of relaxation much longer than for free atoms[27]. Magnetic Resonance Imaging (MRI) devices use a strong static or pulse external magnetic field for nuclei excitation. Medical devices MRI IN VIVO use resonance of hydrogen nuclei only. The modern NMR spectroscopy use fields with strengths of 3, 4, 7 T[24]. The characteristic times of relaxation (Spin -lattice relaxation T1, and Spin-spin relaxation T2) depends on the change of energy due to polarization and are determined by the rotational and translational diffusion of the bonded water molecules[28-31]. Data[31-34] illustrates a strong dependence of the relaxation time of hydrogen nuclei on surrounding conditions and types of tissue and organs.

Table II. Relaxation time T_1 and T_2 for different body tissues under 1.5 T Magnetic Field Strength, in Milliseconds, (page 2595[31])

Tissue	T_1	T_2
Cerebrospinal fluid (CSF)	2400	160
Blood	1200	100
White matter (WM)	780	90
Grey matter (GM)	920	100
Fat	260	80
Bone marrow	400	60
Muscle	870	45
Liver	500	45
Pancreas	600	70

These times in a strong magnetic field of 1.5T would be increased several orders of magnitude at an EMF strength of ≤ 70μT. Therefore, the time of nuclear relaxation is much longer than the characteristic time of most cellular processes[35], respiration, heart rate, and brain waves[36].

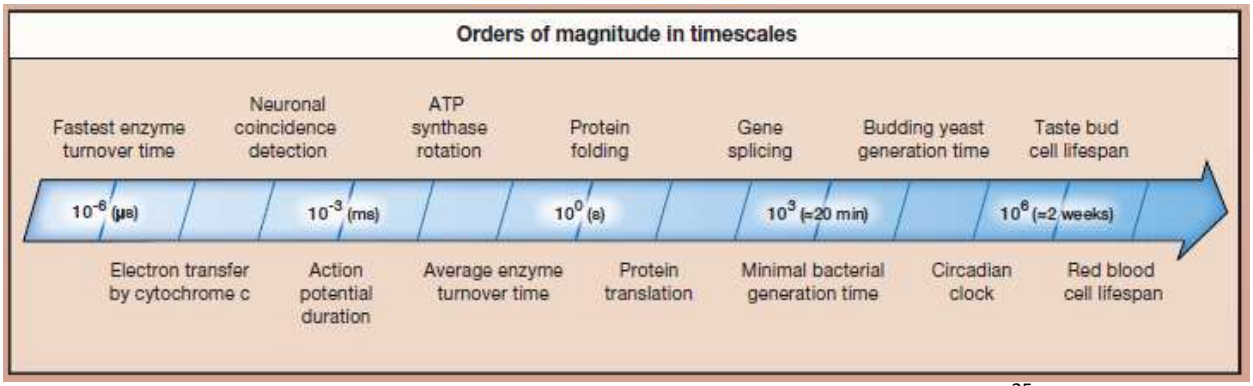

Figure 2. The orders of magnitude in human cellular and bacteria in timescale[35].

A number of research projects have demonstrated that both hypomagnetic[37, 38] (much less of the EMF) as well as hypermagnetic[39-41] conditions leads to undesired health effects.

PROPOSED HYPOTHESIS

Resonance is a necessary and inalienable property of any biological system[42], ensuring its stability and minimal free internal energy[43] at the maximum rate of entropy production in the macrosystem[44,45]. There is necessary resonance between fast photochemical and catalytic (enzymatic)[29,30,46,47] reactions and relatively slow cellular processes which include transport and diffusion metabolites. Resonance is possible in such system due to ion-cyclotron resonance[10-13] as well as nonlinear processes such as discrete breathers[48-50] (modes of oscillation localized in time and/or in space, density of defects or energy resulting in peptide chain oscillations in two- or three-dimensional macro-molecules, skeleton, membranes, etc.). A discrete breather allows a decrease in frequency and an increase in time of relaxation by several orders, however it is

not enough for most of the biological systems. The bifurcations (formation and collapse or destroying of organelles, extracellular vesicles, micro and nanobubbles, proteins, etc)[51-53] provide coupling without limits in the range between different levels of structural organization of any organism.

There is a relatively long time of relaxation in biological structures which promotes a fast recovery of the reaction center due to resonant interaction of polarized nuclei with electrons in accordance with the proposed hypothesis.

Nuclear Magnetic Memory (**NMM**) results from the chemically induced dynamic polarization which also promotes the usage of ion cyclotron resonance for decreasing of the metabolic losses in electron and proton transfer processes.

The discrete breathers in peptide and nucleotides chains, bifurcations, vibrational and electromagnetic oscillations in nanobubbles are the main participant of non-linear energy transfer in the intermediate range of frequencies and relaxation times. There are slower processes of formation and accumulation of the enzymes, hormones, energy- rich active substances (glucose, adenosine 5'-triphosphate, fats, etc) and its release which provide a next level of space temporal coordination and coupling of different levels of organism. These nonlinear processes provide the possibility of semi-independent metabolic optimization on all levels of the structural organization of the brain[54,55].

Effective coupling of all processes in a very large magnitude of timescale provides minimization of the metabolic losses or cost of life and may be described as a kind of resonance, since the minimum internal resistance is inherent in resonant systems. The specificity of living systems is the use of all available degrees of freedom and the continuous conversion of some types of energy into others, such as electromagnetic radiation into chemical energy, chemical energy in mechanical and hydraulic, heat of dissolution to surface energy, etc.

The change of cellular membrane potential of the neurons and muscle fibers cause flows of metabolites through membranes. This change creates a formation of moving boundaries in cytoplasm (nerve impulses or spike), which provide electrophoresis of metabolites from soma to periphery and from dendrites and axons to soma[55,56]. The different types of energy have different times of excitation and relaxation that provide a certain independence of processes and the possibility of simultaneous optimization at different levels of structural organization and at the same time strictly limits their coupling and energy transfer. This means that in biology, resonance requires not only the correspondence or frequency multiplicity, but also the correspondence of the amount or portion of the energy to be transformed. These restrictions may explain the thermal paradox. Weak static and ELF MFs correspond in density energy and frequency to ionic cyclotron resonances and nuclear resonant interactions in biological structures. Portions of the inserted energy may be transformed without significant losses into a discrete breather of the proteins, vibrational energy of nanobubbles, etc. Strong magnetic fields of NMR devices insert energy which cannot be transformed into other kinds of energy which may be accumulated and used by the body, where the inserted energy is about 10% of the thermal kinetic energy of molecules. Correspondingly, the excess of this energy is stored in

polarized nuclei and released by a relaxation emission which is registered by sensors. In reality, the external magnetic field strength of 3T corresponds to an energy density of about 257J/mol or about 10% of thermal energy. This means that an MRI device's magnetic energy cannot be absorbed by the body and allows the measurement and recording of the hydrogen nuclei relaxation processes. The correspondence frequency and energetic capacity of targets may be important in distribution of signals in the nervous system. We do not know of any studies in this field.

Motive forces of the metabolic transport include gradients of the chemical potentials, of the acidity, of the osmotic and oncotic pressures, of the gas partial pressures and electrode (membrane) potentials. These are all possible mechanisms of the metabolic transport (convection, diffusion, electrophoresis, energy dependent or active and energy nondependent transport through membranes, etc.) which have a limited rate and thus determine a density of bioelectricity and created biological magnetic fields.

These limited rates are illustrated by velocity of the chemical wave in biology (Table 1 page 1194[54]).

Table III. Summary of physical parameters of key examples of chemical waves in biology[54]

System	Traveling activity	Estimated diffusion	Wave speed
		$\mu m^2/s$	μm/s
Xenopus extract cell cycle	Cdk1	10	1
Starfish and Xenopus cytokinesis	Rho	~0.03 - 1	~0.2
Drosophila syncytial cell cycles	Cdk1	5	2 - 6
Chemotaxis	Cdc42	~0.1–20	1
Actin waves	Hem1	~0.5	3 - 5
Wound healing	ERK	~1	~0.02
Growing epithelial culture	Mechanical stress	NA	~0.02
Somitogenesis	Notch signaling	NA	~0.02
Blood clotting	Thrombin	~85	~0.6
Eye imaginal disc	Dpp	~0.1–20	~0.001

NA - not applicable

The external magnetic field interacts with bioelectricity or with reaction centers as electrodes, which include excited nuclei. Magnetic energy may change energy of the oscillating nanobubbles, radical pair, and hydrate shields. Inserted energy may be absorbed by electrochemical, electrokinetic, and mechanic processes only, where the maximal density of such transformation depends on the metabolic transport rate and physicochemical properties of proteins. Moreover, the frequency of the excited nuclei depends on the magnetic field strength where excess magnetic flow may break resonant interaction nuclei with other nuclei, peptide chains with a double layer of nanobubbles.

CONCLUSION

This is a proposed hypothesis that all unicellular and multicellular organisms are resonant systems. Organisms use all available types and methods of energy conversion, starting with the optical frequency range and ending with minute, daily, monthly and annual cycles. Correspondingly, this complete hierarchic system needs maximally effective coupling between all levels of organization and continuous mutual transfer of different types of energy in physical and chemical processes. Interaction with external stimuli is strictly limited by spectral resonance and energy density. Such limitations allow the explanation of the thermal paradox.

According to this proposed hypothesis, the long-term chemically induced dynamic polarization of nuclei may play an important role in all types nonlinear processes of transfer and transformation of energy. Chemically induced dynamic nuclei polarization provides the keeping and restoring of the most preferable configuration for the repeated biochemical reactions, which are explored by multi-step processing. The summary rate of these processes determines the cellular capacity of protein machinery and energy consumption. The sub-steps of process include formation of the active complex, transfer of the proton, electronic pair, biotransformation of the reactants, and their release. These cycles need at least two orders of magnitude less time than nuclei relaxation or internal conversion.

There is a decreasing of the necessary energy and time for recycling of reaction centers in nuclei cells, ribosomes, mitochondria, other organelles and cellular membranes. There is promoting to ion cyclotron resonance in ionic pumps and ion exchange centers. There are promoting to discrete breathers in nucleotides and proteins and improvement their interaction with nanobubbles and skeleton (microtubules, for example).

Hierarchic cellular (organism) structure provides a certain independence between the different levels due to spaciotemporal gaps. There are variations of the frequency and relaxation times between different degrees of freedom, delay, or spaciotemporal gap between them, which leads to preferably resonant interactions between external and internal processes. Such interactions are possible under near or equal frequency, times of relaxation, and amplitudes or magnitudes of interacting external and internal processes (likely internal impedance of source and loading). It provides life sensitivity, the maximal density of energy transformation, and corresponds to basic laws of open system thermodynamics.

Magnetic memory of nuclei can play an important role in intermediate processes of energy transfer and conversion. These processes are extremely important in the vital activity of all organisms and their sensitivity to weak magnetic fields which results in sensitivity to magnetic storms and other external influences.

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