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TO THE 120th ANNIVERSARY OF A.L. CHIZHEVSKY'S BIRTH

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Alexander Leonidovich Chizhevsky (1897–1964) is the founder of heliobiology. This paper is presented as a scientific essay and is dedicated to the memory of Chizhevsky. We briefly discuss an unusual aspect of heliobiology. It is closely related to the question as to whether living organisms are macroscopic quantum objects. There is no scientifically grounded answer to the question, but many scientists are inclined to give a positive answer based on indirect evidence. The project of biophysical experiment using an original device for excitation of the field of vector potential is described in the hope that in future such types of experiments will make it possible to clarify the question.

Keywords Solar-terrestrial relations · Geomagnetic field · Living organism · Biophysics · Magnetobiology · Macroscopic quantum phenomena · Vector potential field

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The prescientific notion of celestial bodies as the primary cause for a number of phenomena in animal and plant life, in lives of people and human societies arose in ancient times. In one form or another, it can be traced throughout the history and prehistory of humanity. In modern times, this notion forms the basis of heliobiology – the research area that examines how solar activity affects living organisms. The founder of heliobiology as a subdiscipline of biophysics is rightfully considered to be our compatriot Alexander Leonidovich Chizhevsky (1897–1964), a great-grandson of legendary Admiral Nakhimov. There is a well-known story about Chizhevsky: when he was a very young man, he noticed a positive correlation between solar activity and battle activity during the First World War. This story and other achievements of Chizhevsky are described in the biography of the scientist and his scientific works (see, e.g., [Chizhevsky, 1973]).

This paper is written as a scientific essay. It is dedicated to the 120th anniversary of A.L. Chizhevsky's birth. To honor the memory of the outstanding scientist, we have chosen one unusual aspect of heliobiology to discuss. It is closely related to the question as to whether living organisms are macroscopic quantum objects.

We should recall that heliobiology intersects with another subdiscipline of biophysics, namely, magnetobiology, whose origins are also lost in antiquity. Notice that there is no connection with Mesmer's theory of animal magnetism in our paper. The fact is that heliobiologists attach particular significance to the effects

that geomagnetic field variations have on living organisms [Vladimirsky, 2009]. First of all, we mean ultralow-frequency (ULF) electromagnetic waves that fill near-Earth space [Troitskaya, Guglielmi, 1967; Guglielmi 1985; Guglielmi, Pokhotelov, 1996; Guglielmi, 2007], as well as geomagnetic storms.

Chizhevsky lived a hard life. In the 1930s, he was unfairly roasted by the biologist M. Zavadovsky, the physicist Ioffe, the lawyer Vyshinsky, and many others. In official decisions, he was called "ignoramus who does not know fundamentals of physics and biology, unscrupulous imitator and infamous plagiarist having outrageous and harmful traits, and, finally, people enemy under the cloak of science". His theory was called senseless and deleterious. Eventually, Chizhevsky was arrested and held prisoner in forced labor camps and exile for many years. He was rehabilitated only in 1962, two years before his death

The hostile and completely absurd attitude of the authorities to Chizhevsky was inspired by the then dominant political ideology, i.e. it had nothing to do with science. It slowed down the advancement of heliobiology for decades to come. Nevertheless, Chizhevsky's ideas proved viable, although unfavorable conditions of their generation did not remain without consequences. Heliobiology is still going through a considerably contradictory stage of development.

We do not aim here at reviewing and analyzing contemporary literature. However, it should be emphasized that articles on magnetobiology and heliobiology are freely published. For example, the very prestigious journal Advances of Physical Sciences published the articles [Ptitsyna et al., 1998; Bingi, Savin, 2003; Grosberg, 2003]. Moreover, in recent years there have appeared specific ways to determine physical mechanisms of the effect of magnetic fields on living organisms [Buchachenko, 2014]. Yet heliobiology still remains an area of purely empirical knowledge. This is largely due to the general problem of scientifically defining life as a natural phenomenon.

Suppose we have prepared in sufficient quantities 60 plus chemical elements represented in the periodic table. What hinders us from making a living organism by some means or other? Perhaps only one thing: we do not know for sure what a living organism is. It radically differs from any other object that is accessible to our senses. But what is the difference? Every living organism consists of cells. It is capable of metabolism, homeostasis, growth, reactivity, adaptability, self-reproduction, variability, and also it has a complex structure, complex behavior, the ability to evolve, and so on and so forth. There are 123 known definitions of life, which take into account these and many other remarkable properties in one combination or another, but none of them satisfies the scientific community. Many naturalists feel that something mysterious still eludes them. However, if to the above listed attributes we add autoreduplication, optical activity, and chiral purity, then something like truth will take shape. Still, if we ourselves try to provide some additional clarity to this issue, we should remember that it has been explored by Isaac Newton, Erwin Schrödinger, and other great minds. The first of these foremost scientific intellects was "diligent, sagacious and faithful, in his expositions of nature", as written in the epitaph on his tomb in Westminster Abbey; and the second wrote a brilliant book "What is Life", which opened the era of modern genetics.

Why do not we ignore the problem of defining a living organism and address specific problems of interpreting reliably established heliobiological laws? But in this case, problems and disappointments also await us. As carriers of the Sun-biosphere interaction relevant literature has repeatedly discussed electric and magnetic fields, radio waves, ultraviolet light, infrasound, aerosols, and, finally, the so-called Z-radiation not yet known to science. As mechanisms of the interaction researchers have unsuccessfully analyzed resonance, parametric, gyroscopic, collective, and exchange effects. By the lack of success we mean that no physical and mathematical model of at least one heliobiological phenomenon has been built yet. In other words, we know facts, but we do not have appropriate theories and hypotheses. The rather unfavorable situation produced an unproductive idea of non-repeatability of biomagnetic experiments and uninterpretability of heliobiophisical observations received some circulation.

Under the circumstances, there are two reasonable research strategies. We can accept the fact that the effect of solar activity on living organisms will not be understood until physics of living organism is established and thus a scientifically grounded definition of life is given. In this case, a heliobiologist has no choice but to assiduously collect facts and refrain from hasty conclusions. Following the second strategy, we can continue to find a key to the understanding of certain aspects of the problem, carefully formulate specific hypotheses capable of experimental verification, do controlled and invariably repeatable experiments, hoping to gain insight into the problem of interest.

To be sure, the choice here is far from being clear. The first path may lead us to the goal, but only if a much more difficult problem is solved. The second strategy is supported by the historical experience of scientific discoveries. Here are just a few examples. In 1911, Kamerlingh Onnes when studying properties of materials at low temperatures discovered superconductivity in mercury. In 1933, Meissner found a phenomenon of expulsion of a magnetic field from a superconductor. In 1935, London brothers explained in general terms the phenomenon of expulsion. The famous London equation has the form

$$\frac{4\pi}{c}\lambda^2 \mathbf{J} + \mathbf{A} = 0 \,. \qquad (1)$$

Here, c is the speed of light, λ is the London penetration depth, $\mathbf{J}$ is the current density, $\mathbf{A}$ is the vector potential such that $\mathbf{B} = \nabla \times \mathbf{A}$, where $\mathbf{B}$ is the magnetic field and $\nabla \cdot \mathbf{A} = 0$ (the London gauge for vector potential). In 1950, Equation (1) provided the key to building the phenomenological Ψ theory of superconductivity [Ginzburg, 2004]. But no one had the key idea about the physical mechanism of superconductivity for 45 years after the discovery by Kamerlingh Onnes. And only in 1956, Leon Cooper discovered the electron pairing mechanism (Cooper effect), which formed the basis of the microscopic theory of superconductivity formulated by Bardin, Cooper, and Schrieffer in 1957.

We hope, and there are good grounds for believing that sooner or later something like that can also happen in heliobiology, but still awhile away from now – not now, anyway. At this point, we have to restrict ourselves to general reflections. In connection with Chizhevsky's anniversary, we choose for this, as mentioned above, a simple question as to whether a living organism is a macroscopic quantum object.

Generally speaking, this question has been examined by Schrödinger in the early 1940s. Recall that Schrödinger was born in Vienna in 1887, received all-round education, and formulated the Schrödinger equation, familiar to every physicist, in 1926. He was awarded the Nobel Prize in 1933 and in the same year he with his family moved to Oxford, leaving Berlin in detestation for the fascist regime. In February 1943 in Dublin, Schrödinger read three lectures under the title "What is life? The physical aspect of the living cell". Note that at that time public activity of Chizhevsy was stopped, and he was in prison. A year later, the lectures were published in monograph form in English [Schrödinger, 1944]. After some varieties of fortune, the monograph was published in Russian due to the active support of Mikhail Aleksandrovich Leontovich [Schrödinger, 1947].

Let us make a short digression and talk about "three great problems" of modern natural science, which have repeatedly been mentioned by Vitaly Lazarevich Ginzburg. Let us give keywords for them: entropy, ψ-function, and reduction [Ginsburg, 2004]. Schrödinger took a lively interest in all the three problems. He, speaking about living organism, emphatically noted: "It feeds on negative entropy" [Schrödinger, 1944]. Schrödinger was not quite satisfied with the Copenhagen interpretation of quantum mechanics (the problem of ψ-function). But both Schrödinger and Ginsburg consider the problem of reduction as the most difficult and the most important of the three. The essence of the problem lies in interpreting manifestations of life in terms of physical laws [Schrödinger, 1947].

The most fundamental laws are laws of quantum mechanics. Natural science assumes that any material object, including a living organism, obeys these laws. From this point of view, our question as to whether life is a macroscopic quantum phenomena seems a little far-fetched. But there is a radical difference between a photon, i.e. an electromagnetic field quantum, and a classical radio signal representing the macroscopic Bose condensate of a huge number of photons. And there is a radical difference between an ordinary piece of metal and a superconductor. This illustrates that we may never get an answer to our question, even if the problem of reduction is solved. However, as inferred from the literature, we have no hope to solve the problem of reduction in the foreseeable future.

How then can we proceed to substantively discuss our problem? The situation seems hopeless. Meanwhile, we undoubtedly classify liquid capable of flowing without friction through narrow slits and capillaries as a macroscopic quantum object. Current flowing in a superconducting metal endlessly, without stopping, we definitely consider as a macroscopic quantum process. Let us compare this with the fact that in Earth there exist cellular organisms that have no less surprising, perhaps even stranger properties absolutely different from properties of objects of inanimate nature. Organisms are capable of reproducing themselves over billions of years, experiencing fantastic metamorphosis. And there is no fundamental reason why the reproduction and metamorphosis processes may stop. This comparison would seem to directly point to the fact that the entire organism is a macroscopic quantum object.

But this is just a general argument. We can call it metaphysical, or, if you like, philosophical. The extensive literature on heliobiology, magnetobiology, and related issues includes many such arguments. Here are

references only to some articles: [Ptitsyna et al., 1998; Anosov, Trukhan, 2003; Bingi, Savin, 2003; Mensky, 2005; Vladimirsky, 2009; Vedral, 2011; Panov, 2013; Farrowa, Vedral, 2015]. Let us also mention the journal NeuroQuantology, which has been published since 2003. In this journal, authors write a lot about quantum consciousness and reasonably believe that the phenomenon of consciousness is not easy to understand in the context of the classical theory, but at the same time they forget that quantum concepts are not entirely comprehensible yet. Sometimes, negligence of authors who talk at length about such a difficult subject astonishes. This stands out in stark contrast to manuscripts by classics of natural science, in which the level of intellectual responsibility is maintained even if the case in hand are extraordinary phenomena (see, e.g., Epilogue of the monograph [Schrödinger, 1947]).

However, in this case, a physicist and biophysicist are interested in answers to fairly specific questions, rather than in general considerations. Since we do not know the equations that govern the behavior of an organism, it is pointless to ask whether they include Planck's constant characteristic of quantum mechanics. Meanwhile, we can constructively discuss, say, the question on experimental observation of manifestations of phase of the ψ function, which presumably describes state of the whole organism as a macroscopic quantum object. We do not know the form of the complex wave function $\psi=|\psi|\exp(i\alpha)$, but we know for a fact that its phase α depends on the magnetic vector potential **A**. If we could detect the organism's response to temporal and/or spatial variations of the field **A**, it would be direct evidence of quantum nature of living organisms. Here, to avoid confusion, it should be noted that the scalar potential of the electromagnetic field also affects phase α of the wave function. However, we limit our discussion to the vector potential for the simple reason that the very field **A** is of particular interest from the point of view of magnetobiology and heliobiology. The total and quite understandable inability to comprehend the nature of living organism does not allow us to think that we are standing on the brink of making discoveries now. Unlike us, the authors of [Anosov, Trukhan, 2003], seem to think otherwise. But we find it difficult to accept this. In our opinion, much is to be done in this direction.

First of all, it is necessary to design an appropriate source of the field **A**. The alternating field excites the electric field $\mathbf{E} = -c^{-1}\partial\mathbf{A}/\partial t$, and this may destroy the integrity of the experiment. Therefore, the source must be static. It is quite clear that in view of the lack of the basic theory, experiments will be carried out by the classical trial-and-error method. Indeed, our hopes and expectations are based only on the same idea as that about the relationship of the superconducting current with the phase of the wave function of Bose-Einstein condensate of Cooper pairs. In this regard, we should rely on physical intuition, and it tells us the choice of the source producing a sharply inhomogeneous field to induce a strong gradient of the phase $\nabla\alpha$ within a biomaterial. It is quite clear that the field **A** should be irrotational since we want to eliminate the disturbing effect of the field **B** on the living organism. In other words, for the same reason for which the source must be static, it must also satisfy the condition $\nabla\times\mathbf{A} = 0$ in the space occupied by the test organism.

One of us (V.F.) has made the appropriate source. It satisfies the three conditions simultaneously. We called it the Φ source. A test sample of the Φ source is shown in Figure 1. The general view of the source explains the origin of its name. We can see a ring made from a soft magnetic material with the

following dimensions: the external diameter is 53 mm, the internal diameter is 40 mm, and the width is 18 mm. The crosspiece 10 mm in diameter is composed of 40 neodymium magnets. By design, the field **B** is entirely inside the ring and crosspiece, whereas the field **A** reverses its direction, when moving in the plane of the figure from one side of the crosspiece to the other. Magnetic field measurements by the F4354/1 tesla ammeter yielded a value of 1030 mT inside the crosspiece. Because of the imperfection of the test sample the magnetic field is slightly scattered into the external space, but the scattered field is nowhere greater than 2 mT.

Laboratory experiments with the Φ source were launched on July 14, 2016. In our quest, we do not expect quick success; we are largely working out techniques. The simplest configuration of the experiment is illustrated in Figure 2. We can see a Petri dish with a colony of single-celled organisms inside. On the lid of the dish is the Φ source. On the reference dish (not shown) is a replica of the Φ source. After a series of experimental sessions, we leant toward the idea that it is reasonable to swap the Φ source with the biomaterial. It is quite clear that in the reference pair the dish and the replica of the Φ source are also interchanged. We also considered other options; in particular we discussed the possibility of putting the Φ source into the Petri dish. The choice of a uniform colony of micro-organisms is dictated by the need to ensure a more or less simple way of comparing the state of the colony exposed in the field of the Φ source with the state of the colony in the reference Petri dish. Our observations have not given an exact result yet, but still there are a fairly large number of test combinations. We are deeply indebted to researchers of the I.D. Papanin Institute for Biology of Inland Waters of the Russian Academy of Sciences for their friendly support and advice in setting up and performing the experiments.

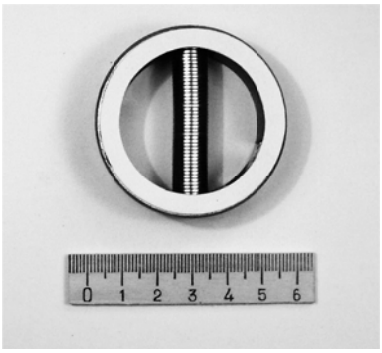

Figure 1. Test sample of the vector potential Φ source for magnetobiological experiments

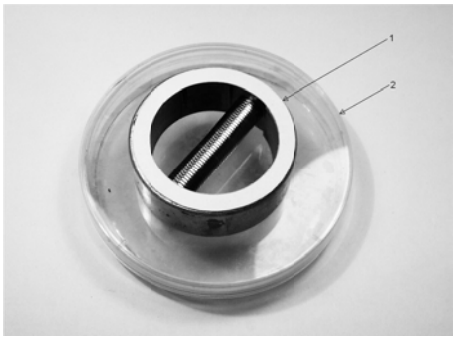

Figure 2. General view of the experimental setup. The relative position of the Φ source (1) and Petri dish (2) with a colony of single-celled organisms

Sooner or later in the laboratory experiments, we must have come up with the idea to improve the source structure, making the field **A** more compact, i.e. removing it from the external space surrounding the experimental setup. For this purpose, it is enough to take a spherical layer, made from a soft magnetic material, and install a crosspiece, composed of neodymium magnets, into it along the diameter. We will not discuss dimensions of the compact source, methods for putting the biomaterial into the source, and other details that are certainly important, but purely technical.

Let us turn attention to the simple question that arises from the idea of the compact source of the field **A**. How will the structure of the electromagnetic field look like if the compact source is converted into a rotator, i.e. the spherical shell is made to rotate about an axis, not necessarily coincident with the axis of the internal crosspiece? The question is interesting because the answer requires a non-trivial solution of the electrodynamic problem.

In conclusion, we should say that the notion of the whole organism as a macroscopic quantum object is only a working hypothesis, but it is quite plausible. Let us emphasize that the founder of heliobiology A.L. Chizhevsky foresaw the emergence of quantum biology, the purpose of which, in his opinion, should include experimental and theoretical studies of living systems in the context of the quantum theory [Chizhevsky, 1974]. We have tried to make a modest contribution to the development of this line of research. In conclusion, we would like to suggest that the real field of the vector potential **A** is the hypothetical Z field about which A.L. Chizhevsky persistently spoke in connection with the reaction of living organisms to solar and geomagnetic activity variations.

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