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LETTERS TO THE EDITORS

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Remembering a random choice kills alternatives

(reply to comment on "21st century: what is life from the perspective of physics?")

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Abstract. **In his comment [*Usp. Fiz. Nauk* 181 449 (2011) (*Phys. Usp.* 54 429 (2011))] on my paper [*Usp. Fiz. Nauk* 180 337 (2010) (*Phys. Usp.* 53 327 (2010))], A V Melkikh raises the question of the initial conditions for the appearance of life on our planet. He suggests that the origin of life is a purposeful process. I believe that life is due to a memorized random selection. It is what is taken as the initial postulate which determines the understanding of how life emerged and evolved on our planet.**

I thank all the readers who have shown an interest in my paper [1]. As regards comments [2], they are based on a misunderstanding resulting from the wrong interpretation of the paradigm of the origin of living matter by my adversary. The fact is that any model is constructed according to an '*if... then...*' scenario. '*If*' is followed by postulates (axioms) introduced into the model, and '*then*' by analytical equations (or computer simulation), and the consequences of solutions to equations or simulations are verified in experiment. No matter how logically sound the model might be, it reflects reality only insofar as it is based on correct postulates (axioms).

The main question facing a researcher who seeks to formulate a hypothesis of the origin of life is whether it was inevitable or just an accident. The answer to this dilemma is of crucial importance. If the researcher chooses **as an axiom** that *the origin of life is a programmed inevitability* (*to be immediately faced with another question*: *Who is the programmer*?), then the language and logical architecture of the model (and more importantly its consequences) will be drastically different from those of **another axiom** according to which *the origin of life is due to memorized random choice and evolution of matter has never had and does not have any purpose* (see Ref. [1]).

From randomness to determinacy (the interpretation of paradox 6). My explanation of paradox 6 [1] is based on the second axiom, which I believe to be more constructive and in line with modern science as opposed to religious beliefs. Here is a well-known analogy to clarify my arguments extracted from the book by H Quastler [3] (as cited by L A Blumenfeld in monograph [4, p. 31]):

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"*Suppose there is a safe box with a lock and a three-digit code to open it. Suppose further that there is a set of digits from 0 to 9 and a random selection device to choose three of them. Let us choose three random digits and enter them as a code to unlock the safe. Up to this moment, any conceivable sequences of three digits have not differed from each other and made no sense whatsoever. The random choice of the triple number needed to open the safe made it meaningful in that this sequence permits the safe to be opened, while any other does not. As is easy to see, this example is not essentially different from that of nucleic acids. In either case, the sensible regularity and new meaningful information are due to remembering a random choice....*"

Therefore, all talk about *a priori* information and theorems for searching and optimizing it (including the No Free Lunch Theorem) makes no sense whatsoever. In the beginning was *random choice*. Importantly, if random choice occurred at the *i*-th step, the random choice region narrows at step $i+1$ and at the following steps randomness gradually passes to determinacy. This inference can be illustrated by the example of the appearance of water on the Earth, which subsequently played the role of a filter selecting chemical compounds to be used at the following stages of evolution. In turn, the compounds thus selected functioned as the filter at the next stages of chemical evolution, and so forth.

Let us explain the mechanism of this recurrent process. Contemporary living organisms contain up to 25 from 83 long-lived elements of the Periodic Table, in addition oxygen and hydrogen (water). Then, fourteen of them account for less than 0.01% of the total weight of an organism. As living organisms are made largely of water and organic substances, hydrogen, oxygen, carbon, and nitrogen are the most important constituents of living matter, making up 99% of its total mass. These leaders among chemical elements are supplemented by several dozen 'outsiders' almost or totally absent in living tissues. An example is many fluorine compounds. What is behind all this?

There is a simple, if incomplete, answer: *living matter emerged and evolved on this planet from what was present in the largest amounts*. Indeed, all the leaders, viz. H, O, N, and C, are very common and widespread over the Earth. They have the smallest atoms and tend to acquire stable electron configurations after binding one, two, three, or four electrons. *Carbon* forms the physicochemical basis of the most important compounds in living nature.

However, what substance is most widespread on the Earth? Evidently, it is not carbon but perovskite $CaTiO_3$, which makes up nearly half of Earth's mass. Earth's mantle almost wholly consists of perovskite [5]. As regards Earth's surface, all the leading elements (H, O, N, and C) present in living organisms are seemingly the most common chemical elements, both in the crust and on the surface. Of special interest is carbon, known to acquire a stable electron configuration after binding four electrons. However, silicon (the nearest neighbour of carbon in the Periodic Table) and its compounds are more widespread over Earth's surface than carbon and carbon-based compounds. Silicon content in Earth's crust is estimated at 27.6–29.5% on a weight basis. Silicon, similar to carbon, tends to bind four electrons and form covalent bonds. Carbon makes up only 0.1% on a crust weight basis. In other words, the hypothesis of the utilization of chemical elements for biological evolution in proportion solely to their occurrence in nature is only partly confirmed.

The controversy is resolved on the assumption that liquid water containing dissolved oxides of certain metals and being either synthesized in Earth's interior or brought from outer space by icy meteorites first appeared on our planet. This solution became the main selection filter and determined subsequent stages of 'choice and rejection' of chemical elements for the synthesis of living matter.

Worthy of note are the specific features of interaction between water and compounds of various chemical elements. On the one hand, silicon binds to oxygen atoms via the bonds between each of its two unpaired electrons and one electron of the oxygen atom. This might have been beneficial for evolution because this triggered the process of superpolymerization and promoted moderate solubility of such compounds in water. On the other hand, silicon Si–Si chains themselves are unstable in the presence of water and sensitive to small molecules having unseparated electron pairs. For example, the hydrocarbon compound methane (CH_4) is resistant to water and sodium hydroxide; to the contrary, silane (SiH_4), a hydrosilicon compound, reacts with water, giving rise to sodium silicate and gaseous hydrogen ($SiH_4 + 2NaOH + H_2O \rightarrow Na_2SiO_3 + 4H_2$). In other words, C and Si compounds behave differently in aqueous environments [6].

By analogy, water affinity of hydrocarbon and fluorocarbon compounds differ by virtue of the specific stereochemistry of perfluorocarbons [7]. In fact, they have a covering of fluorine atoms, all the bonds of which covalently short to internal carbon atoms. Such molecules are inert and strongly hydrophobic, i.e., they are repelled from a water surface [8]. The absolute water nonwettability of fluorine compounds coupled with their chemical inertness appear to be the reasons they were referred to as a group of 'outsiders' at the first stages of prebiological evolution.

With this in mind, a hypothesis offers itself to the effect that, in the early period of evolution, water selected the structural materials for the ensuing creation of life and guarded them against natural temperature cataclysms. The land underwent more prominent sharp falls and rises in temperature than the ocean. Accordingly, terrestrial flora and fauna frequently died to be quickly renewed, while many species of living organisms and their genomes have survived in the sea and the ocean since the onset of biological evolution.

In the course of specific interactions between water and various chemical elements or their compounds, random selection gradually turned into a directed one. It is a trivial statement that life would have never arisen on this planet had it not been for the presence of H_2O molecules, but I read into it more than that. *Namely, water/carbon matter presently called living matter would not have evolved in the absence of water and even the physicochemical conditions for its emergence could not have developed.*

The question is in which Earth sphere or outer space did life originate? *Evidently, carbon-based life could arise anywhere and oftentimes*. By way of example, let us consider a seemingly very unusual sphere for the origin of life, namely, Earth's crust depths. The geological history of the Earth began some 4.6 billion years ago [9]. Outgassing as a result of volcanic activity led to a reduction of Earth's internal pressure, and simultaneously magma periodically altered the acid/alkali composition of Earth's surface toward the prevalence of hydrocarbon constitution. Changes in Earth's relief were an optimal way to create confined spaces and conditions for their filling with water. Hydrocarbons C–H–O, C–H–N, C–H–O–N, and C–H–O–N–P as basic components of all living organisms could be synthesized in Earth's interior, initially in the nonhydrated (primitive) form. Later, some of them were released into the hydrosphere of Earth's surface. The interaction of anhydrous precursors (C_5, C_4N_2, C_2H_2, $C_5H_2N_2$, $C_5H_3N_5$, $C_4H_3N_3$, $C_{10}H_5N_5$, $C_{10}H_5N_3O_2P$) with ocean water and their hydration gave rise to organic substances composing living matter, viz. $C_5 + 5H_2O = C_5H_{10}O_5$ (ribose), $C_4N_2 + 2H_2O = C_4H_4N_2O_2$ (uracil), $C_2H_2 + 4H_2O = C_5H_{10}O_4$ (deoxyribose), $C_5H_2N_2 + 2H_2O = C_5H_6N_2O_2$ (thymine), $C_5H_3N_5 + H_2O = C_5H_5N_5O_2$ (guanine), $C_4H_3N_3 + H_2O = C_4H_5N_3O$ (cytosine), and some others [10–12].

Thus, evolutionary process proceeded in the block-hierarchical mode as described in Ref. [1], with progressively narrowing selection at each successive stage of evolution. *Being* (*randomly selected*) *determined becoming* [13]. As chemical compounds were selected, the conserved ones narrowed the spread of selection of new substances. A deterministic selection trend evolved in the random process. Obviously, with such *block-hierarchical selection*, the time needed for evolution was significantly smaller than with complete random sorting, as was shown in Ref. [1].

New knowledge arises from competition. The second comment from my adversary concerns the mechanism of *knowledge* acquisition in biological systems. This mechanism was only briefly discussed in Ref. [1] because it had been considered at greater length in Ref. [14]. Nevertheless, a few remarks are in order, since I find it difficult to share the adversary's view of this issue.

He appears to be in the grip of a paradigm that the human brain is a large, sophisticated computer. Modern computers operate as symbol-converting units with a rather limited scope of design resources, while the *programmer* has absolute semantic freedom of creativity; hence, the possibility of having software products for solving various problems. One may have the illusion that the greater the hardware and software resources of a computer, the more it resembles an information-processing biological system, such as the human brain. The key word here is *programmer*. It appears as if the notion of *programmer* made my adversary state that "... *an algorithm could only operate when the information to be acquired was known a priori. In this case, however, the information is not new and contains nothing beyond what is already embedded in the system*" [2].

This postulate is wrong because the brain is not a digital information machine but *an analog biochemical processor* that needs neither software nor linguistic support to operate. It works based on quite different principles, one of which is *competition* for finite resources among its constituent elements. In primitive systems, these are largely nutritional (oxygen, glucose, water) and replication resources. As the central nervous system was becoming more complicated in the course of *evolution*, the scope of resources broadened to include information resources (attention, memory, emotions, etc.). A detailed discussion of mechanisms underlying the process of the sophistication of neural systems in different organisms is beyond the limits of these brief notes. A scientific session of the general meeting of the Russian Academy of Sciences (spring 2010) was devoted to brain research (see Refs [15, 16]). Several reports have dealt with the mechanisms of information processing in the brain. Some materials pertinent to this topic can also be found in our reviews "From the dynamics of population autowaves generated by living cells to neuroinformatics" [17], and "Models of neural dynamics in brain information processing — the developments of the 'decade" [18].

Further, A V Melkikh believes that the huge number of neurons in the human brain implies the necessity to sort out many variants if new knowledge is to be obtained. This is just a misunderstanding, since the mechanisms behind the work of *analog biochemical machines* are based on the autowave principles of collective mode interaction rather than on the discrete sorting of all possible combinations of neurons. For example, the activity of the cerebral cortex is described in terms of the neural mass model, in which it is regarded as a large-scale network, with each node comprising many neurons that make up a neuronal cluster (ensemble). The clusters are dynamic structures producing modes. Both the clusters and the modes exist, 'die', break down, and give rise to new structures due to the appearance and disappearance of functional bonds. These mechanisms are fairly well described in the recent review by M I Rabinovich and M K Muezzinoglu, entitled "Nonlinear dynamics of the brain: emotion and cognition" [19].

Finally, there is the last, philosophical, inference. My adversary's viewpoint implies that new knowledge *a priori* pre-exists in the learner. In other words, there is *something* outside the material world that reveals the structure of the world around us, which we call *knowledge*. Such formulation of the problem makes no sense from the standpoint of the natural sciences, since the existence of *knowledge* as an irrational substance outside our consciousness cannot be a subject for scientific research.

The mechanism of block-hierarchical selection operating in biological evolution holds equally well in knowledge acquisition. As more knowledge is accumulated, the systematized body of knowledge gained at preceding stages narrows the spread of probabilities to discover new knowledge. In this way, a deterministic trend evolves in the random process of cognizing Nature. In this scenario, the time to be spent at subsequent stages of science development continuously decreases in comparison with the time that would be needed for comprehensive random sorting. The net result is the accelerated development of science [20, pp. 68–86].

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