Life from the standpoint of quantum physics

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Abstract. Experiments on biological systems revealed limitations of quantum mechanics to explain the processes that are observed in living matter. In this paper we give an analysis from the position of quantum physics of three processes in biological systems (1) transmutation of chemical elements in living systems; (2) description of a virus (bacteriophage T2) behavior; (3) the difference in properties of a living and a dead plant under high pressure (Macovschi’s experiment).

1. Introduction

Recent experiments on biological systems highlighted limitations of quantum mechanics to explain the processes that are observed in living matter. According to quantum mechanics, a biomolecule is a quantum system, therefore, its behavior and the processes in biological systems at the molecular and atomic level should obey the probabilistic laws of quantum mechanics. It follows from the probabilistic approach that it is possible to tell only with a certain probability whether a chemical reaction is to occur. A simple example from biochemistry demonstrates the problems with this approach. Chemical processes in biological systems, as opposed to inanimate chemical systems, occur with the help of enzymes rather than via random collisions. An enzyme is a complex protein that folds to form an active site; the three-dimensional shape of an enzyme is determined by the pattern of hydrogen bonds between amino acid components. A molecule binds to the enzyme permitting a reaction to occur. The enzyme must fold to a strictly defined shape that matches the shape of the molecule for the reaction to take place. Even if the probability of each step in this process is high and the error is small, this error must accumulate over time. Thus, if we take the probability of each step in the folding process to be as high as 0.95, the probability of ten links to form a particular shape is \(0.95^{10} \approx 0.6\). Any change in the pattern of hydrogen bonding (the shape of an enzyme) inactivates the enzyme. Conversely, in real systems the same processes repeat over again from generation to generation, and we observe a surprising stability of living organisms. A recent study of the mutation rate in \textit{Escherichia coli}, showed that a single gene that encodes an average-sized protein is estimated to suffer a mutation once in about \(10^6\) bacterial cell generations \cite{1}. This indicates the high accuracy with which DNA sequences are maintained from one generation to the next. Screening of the genome sequences of different organisms revealed that the tendency for stability, rather than for the generation of variation, influences how information is encoded in the genome \cite{2}. Processes that we observe in biological systems do not exhibit any molecular chaos. On the contrary, they work as well-tuned mechanisms.

A high degree of determinism manifested by a living system suggests that we should search for deterministic interpretation of quantum formalism. For large molecules, even if all observable values do not change with time, wave function can be determined only approximately due to complexity of the
problem. It is impossible to calculate the behavior of a biomolecule using the technique of the fundamental quantum mechanics alone without bringing in the heuristic models of enzymatic reactions and concepts of chemical bond. It is important to note, that introduction of new controlling potentials in quantum mechanics does not remove the probabilistic essence of the approach and does not solve the problem of determinism. Below we will give three examples of processes in biological systems. These examples are from different areas of biophysics but they can be combined by a common feature: they reveal the unique behavior of the living matter and cannot be adequately described by the laws of modern physics.

2. Transmutation
According to nuclear physics transmutation processes must run at high temperatures, however, in 1960s Kervran conducted a series of experiments in which he observed transmutation of chemical elements in the biological systems at normal temperatures. In one of the experiments he studied the reaction

\[ {K}^{39} + {p}^1 = {Ca}^{40} \]  

(1)

in the process of growing seeds. (the system contained hydrogen atoms). Kervran examined the amount of potassium and calcium in 840 seeds and compared it to the amount of potassium and calcium in the resulting sprouts. He found that the sprouts have 0.033 g less potassium that the original seeds. At the same time, the amount of calcium in sprouts increased by 0.032 g compared to the seeds. That is, transmutation of potassium into calcium occurred within the biological system in the process of sprouting.

Kervran claimed that in the absence of vital elements, biological systems are capable of conducting a transmutation process of chemical elements at low temperatures. Thus, in another experiment he suggested that in case of carbon deficit the following reaction can take place

\[ {c}^{12} + {o}^{16} + {n}^1 + {p}^1 + {c}^{14} = {c}^{12} + {o}^{16} \]  

(2)

where nucleus of one of the nitrogen atoms give a proton and a neutron to another. In this reaction, one nitrogen atom becomes carbon and the other becomes oxygen.

In 2003, Vysotski and Kornilova [3] described an experiment, in which they synthesized isotope \( {Fe}^{57} \) in a microbiological culture at a low temperature. They studied the following reaction

\[ {Mn}^{55} + {d}^1 = {Fe}^{57} \]  

(3)

The bacterial culture was placed in four dishes with different nutrient mediums. Two of the dishes contained a sugar-salt nutrient medium on the basis of light water \( {H}_2{O} \), one with \( {MnSO}_4 \) and one without, the third dish contained the sugar-salt nutrient medium on the basis of heavy water (\( D_2{O} \)) without \( {MnSO}_4 \). The fourth dish contained the nutrient medium on the basis of heavy water \( D_2{O} \) with \( {MnSO}_4 \) added to it. The latter dish had the necessary conditions for the transmutation reaction to occur.

Vysotski and Kornilova used the Mossbauer method for identification of the isotope \( {Fe}^{57} \). All ingredients were checked for presence of the isotope \( {Fe}^{57} \) prior to the experiment. It is important to note that the isotope \( {Fe}^{57} \) is rare in nature (it is found only in 2.2% of natural iron). Analysis of the four dishes demonstrated that the isotope \( {Fe}^{57} \) was only present in the fourth dish. Note that this transmutation reaction did not require high temperature or any external sources of energy.

It is obvious that Vysotski and Kornilova’s, as well as Kervran’s, experiments cannot be explained by the known laws of quantum physics. Kervran suggested that the rules of physics cannot be directly
applied to the biological systems, because all physics laws were obtained based on experiments with inanimate objects.

In our view these experiments provide an additional argument for the introduction of ‘nonlocal hidden variables’ like a physical field in quantum physics. Such approach would allow us to give the causal (deterministic) description of quantum phenomena.

3. “Intelligent” behaviour of the bacteriophage from the physics standpoint.

Below we will present an example of a virus behavior that, like the examples in the previous section, is impossible to explain by the known laws of quantum physics. A virus is a microscopic particle that consists of several biomolecules. The viruses that infect bacteria are known as bacteriophages. We will consider one of them, bacteriophage T2. Phage T2 is hundred times smaller in size than the microbe cell and looks like a tadpole. A ‘head’ (a protective protein shell) contains DNA (some types of bacteriophages contain RNA only). A ‘tail’ is a protein tube. By six legs, the phage attaches to the surface of the much larger bacterium. Once attached, the bacteriophage injects DNA into the bacterium. The DNA instructs the bacterium to produce masses of new viruses.

Note, that viruses are generally not considered to be true living organisms because they do not use any external energy (food, radiation), and cannot reproduce without getting inside some living cell.

The following is an approximate list of the bacteriophage’s functions.

a) Detecting (done at a range of several phage’s own lengths) and turning the tail towards the bacterium.

b) Attaching to the surface of the bacteria and penetrating it with the tail.

c) Injecting genetic material into the bacterium. (The contraction of phage’s ‘head’, the simultaneous cooperative shift of its protein subunits with respect to each other occur, which makes the tail become shorter and thicker).

From the physics standpoint, the “intelligent” behaviour of the dumb bacteriophage must be caused by some physical phenomenon of interaction. Thus some researchers suggest that:

a) detecting and turning towards the bacterium is done by electrostatic forces. (However, this explanation is not very convincing because the abilities of electrostatic forces are limited (there are only two sighs of a charge + and –), at the same time the variety of phages in the micro world is enormous and every phage parasitizes on its own type of bacteria).

b) attaching to the surface of a bacterium occurs due to Van der Waals forces. These forces appear as a result of a change in the configuration of electrons and nuclei.

c) injecting of genetic material, partially occur due to the pressure difference (DNA is packed tightly inside the protein shell of a phage; as a result of that DNA has elastic energy and exerts pressure on the walls of the protein shell). Interaction of DNA and protein, that is explained to be due to the formation of spatial correlations of electric charges, also plays an important role in the process.

This reasoning, however, cannot explain the tremendous stability of the molecular machine, as well as the coherence and the high degree of determinism of bimolecular behavior. For example, if one assumes that the interactions between biomolecules are due to the complex spatial correlations alone, then how to explain the stability observed in the functioning of a bacteriophages. at the temperature around 300K?

It is reasonable to suggest that there are unknown forces that control the behaviour of a biomolecule. These unknown forces must act in the entire volume of a living organism or a virus and at any direction and define the tremendous coherence and a high degree of determinism of biomolecules behaviour. Therefore, one may consider the existence of a new physical field.

From our point of view many paradoxes can be understood if we assume that all quantum objects have their “continuations” in the physical vacuum, which are structures composed of elements of nonmolecular nature. The existence of the structures directly follows from the casual approach to quantum mechanics [4] Obviously, the more complicated a quantum object (atom → molecule→ biomolecule, etc.) is, the more complex is the structure that accompanies it in the physical vacuum. These structures hold information necessary to control bioprocesses.
It is worth noting the difference between a filed and a structures. In physics, a field is defined (has a known value) in each point in space that is a field in most case has a property of continuity. A spatial structure, on the other hand, is a system composed of elements (items) of arbitrary nature and has a definite shape. Here lies a significant difference between structures and the physical field. It is important to note that in order for a structures to be stable and at the same time dynamic there must exist some kind of interaction and processes which control the coherent behavior of the distant elements of the structure.

4. Change of water properties in living organisms. Experiments by E. Macovschi

The ability of a living system to change the properties of intracellular water was demonstrated in the experiments by Romanian biochemist Eugene Macovschi (1906-1985) and his group. In this experiment, a living plant tissue was exposed to 200 ATMs hydrostatic pressure. Under this pressure it released some amount of water and remained alive. In the case of a dead tissue, after being exposed to 200 ATMs it released all the water it contained. Once the biological water was released from both living and dead biological systems, it immediately regained the properties of ordinary water. It is important to note that the water was taken from the same plant tissue under the same boundary conditions, which makes this experiment unique. According to contemporary biochemistry, living and dead matter consists of the same substances and are not qualitatively different. However, Machovski’s experiment showed that two forms of matter, living and dead, are fundamentally different.

Recently there is a great interest in the unusual properties of interfacial water demonstrated by Gerald Pollock and his group. They showed that a water layer of tens of microns that formed on the surface of a hydrophilic gel, the so called EZ water, has properties significantly different than normal water. For example, it is more structured. However, the properties of EZ water could not explain the effect observed in Macovschi’s experiment because it would be the same on the surfaces of both the living and the dead plant.

Using quantum electrodynamics (QED) approach, G. Preparata and E. Del Giudice [5,6] proved theoretically that water at a room temperature and normal pressure must organize itself in Coherence Domains. In such a domain, all molecules are in a coherent state described by the same wave function. According to Preparata, the quantum energy level is lower within the coherence domain compared to the energy level of the rest non-coherent water, which provides stability of the domain to the energy fluctuations. One can conclude from the Macovschi’s experiment that the living tissue either structured the coherence domains, which allowed it to sustain the high pressure, or created the condition favorable for the formation of more coherence domains within it. When the plant died the water structure broke. It means that a living system can change the quantum properties of water. However, modern physics does not provide the mechanism with which a living organism can affect water at the quantum level.

5. ‘Self-organization’ in animate matter

The term ‘self-organization’ appeared for the first time in the scientific language in the beginning of the 1970s as a collective term for numerous natural phenomena. Self-organization, as implied by its name, occurs without direct influence from outside. If a system does not evolve to equilibrium due to an external energy or mass influxes, stable structures can form spontaneously in such system. Self-organization in physical and chemical processes originates, as a rule, in open non-linear systems. A typical example of regular structures formed spontaneously from chaos are Bénard cells, which are formed as a result of fluid convection in the gravitational field. Note, that in non-living systems, the self-organization of higher ordered structures from more simple ones, or even from chaos, does not contradict the second law of thermodynamics because self-organization takes place only in open systems.

A complex organism developing from an embryo is an example of a self-organizing structure. In the process of growth, the organism “consumes” energy and matter supplied from outside, owing to which it is not only conserved but develops into a higher level of organization. In this sense the organism is like a self-organizing structure of inanimate matter that develops in an open system. However, this is the only similarity between the animate and inanimate structures. Development of an organism follows certain laws remaining valid through generations, unlike the spontaneous development of structures of the inanimate matter. Schrödinger was probably the first who drew attention to this problem. He wrote
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[7]: ‘The living organism seems to be a macroscopic system which in part of its behaviour approaches to that purely mechanical (as contrasted with thermodynamical) conduct to which all systems tend, as the temperature approaches the absolute zero and the molecular disorder is removed.’

E. Schrödinger distinguished two principles of the process of ordering in the inanimate and animate nature: (1) The order that forms in open systems which are in a strongly non-equilibratory state (‘the order from disorder’), and (2) the order that evolves from another state of order (‘the order from order’). The second principle is executed in the development of living organisms. From the thermodynamics point of view, it takes place under quasi-equilibratory external conditions.

Another interesting feature of the process of ordering in the animate nature is that it can develop without the external energy or mass influxes. It can be observed, for example, in the process of meiosis (reductive division). In meiosis the double chromosome set of the parent cell simply separates into two single sets, one of which goes to each of the daughter cells, the gametes. However, before being separated, any two ‘homologous’ chromosomes come into closer contact with each other, during which they sometimes exchange their genes. The process is called ‘crossing-over’. There is a noteworthy feature of the process: in crossing-over neither energy nor matter are consumed from outside, but, on the contrary, mass is released in the process. Note that this process occurred on a molecular level, that is a quantum system. There is no random or chaotic behaviour in this process, on the contrary the biological system works as an ideally tuned mechanism.

In the same book Schrodinger had addressed the problems, which quantum physics faces in its attempt to apply the probabilistic description to biological quantum systems. He wrote: ‘A single group of atoms existing only in one copy produces orderly events, marvellously tuned in with each other and with the environment according to most subtle laws... we are here obviously faced with events whose regular and lawful unfolding is guided by a ‘mechanism’ entirely different from the ‘probability mechanism’ of physics.’ He made two important statements:

1. The organism’s activity cannot be reduced to the manifestation of known laws of physics. In fact, any law of physics manifests itself only for a large number of occurrences, i.e. as a statistical or probabilistic law. (The probabilistic laws of quantum mechanics in its modern form rule out replication.)

2. The laws that underlie the development of an organism resemble most closely the deterministic laws of classical mechanics at the absolute zero where any disorder and friction disappear.

The causal interpretation of quantum formalism, which is proposed in work [4] provides a way to the deterministic description of a biological quantum systems. As was said above, the causal interpretation requires the introduction of ‘nonlocal hidden variables’ like a physical field, which reflects motions of the physical vacuum. In this context, a very promising model is the model of the physical vacuum that in its properties is similar to a superfluid medium (for example superfluid He-3).

6. Conclusion. The problems with the description of a living nature using the probabilistic laws of quantum mechanics give an argument in favor of the causal interpretation of quantum formalisms. In our view, to come closer to understanding of the laws of the self-organization in the animate nature it is necessary to go beyond the molecular level in the investigations and to take into consideration the properties of the physical vacuum.

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