“What is life?”: Open quantum systems approach

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ABSTRACT

Here we briefly present Schrödinger’s thoughts on biostability

Appendix: What is life? Schrödinger’s views

In his book[1], Schrödinger compared order-stability in biosystems with the state-evolution for non-living system[1]: “When a system that is not alive is isolated or placed in a uniform environment, all motion usually comes to a standstill very soon as a result of various kinds of friction; differences of electric or chemical potential are equalized, substances which tend to form a chemical compound do so, temperature becomes uniform by heat conduction. After that the whole system fades away into a dead, inert lump of matter. A permanent state is reached, in which no observable events occur. The physicist calls this the state of thermodynamical equilibrium, or of maximum entropy’. Practically, a state of this kind is usually reached very rapidly. Theoretically, it is very often not yet an absolute equilibrium, not yet the true maximum of entropy. But then the final approach to‘ equilibrium is very slow.”

See also widely cited paper of Gatenby and Frieden[2]:

“Living systems are distinguished in nature by their ability to maintain stable, ordered states far from equilibrium. This is despite constant buffeting by thermodynamic forces that, if unopposed, will inevitably increase disorder.”

Schrödinger pointed that it seems that biosystems do not follow the laws of classical physics. Their behavior looks strange especially from the thermodynamical viewpoint. They are able (in an unclear way) to violate the *Second Law of Thermodynamics.* In principle, this is not surprising, since biosystems are fundamentally open systems. Schrödinger emphasized that a completely isolated biosystem is simply dead. And he pointed that a biosystem is able to escape following the Second Law of Thermodynamics only via exchange with its environment. But, then he pointed to the main question related to this process: What kind of exchange characterizes stability of a living system? Matter? Energy? Of course, biosystems are continuously performing such exchanges and, in this way, they preserve their material and energy order. But, Schrödinger remarks that the same is done by non-alive systems. So, neither matter nor energy exchange can lead to bio-violation of *Second Law of Thermodynamics* and guarantee stability of biosystems.

Schrödinger tried to resolve the mystery of life by using the approach that is nowadays is known as quantum biophysics (so, he was one of its fathers). He compared quantum physical processes with biological ones; in particular, he compared the role of a physical molecular with gene, as carriers of information. However, he did not succeed in resolution of life’s mystery. Then, in the last part of the book he considered the phenomenon of life from the viewpoint of *entropy exchange between a biosystem S and its environment $\mathscr{E}$*. This was one of the first steps towards information treatment of biological processes. He pointed out that formally the stability and preservation of order within S can be modeled by means of negative entropy. So, S consumes negative entropy from $\mathscr{E}$ and, in this way, it compensates its own entropy increase, and consequently preserve order inside it. But, appealing to such a notion as negative entropy is really speculative, albeit philosophically attractive. As was emphasized in introduction, Schrödinger’s speculations on pecularities of entropy transfer as the basis for preservation of alive-states can be interpreted as the first step towards study of the phenomenon of life from the positions of information theory.

We stress that by trying to explain the basis of order-preserving in living systems, Schrödinger did not have in mind explanation of *homeostasis*: the state of steady internal, physical, and chemical conditions maintained by living systems. (Homeostasis is mathematically described by the feedback loop models with balance equations. Nowadays, with sensors and computing blocks, it is easy to construct a physical system in the state of energy, material, and chemical homeostasis.) In[1], biostability was stability of interconnected regulation mechanisms including processing of mental information by the brain.

Finally, he concluded that with high probability it would be impossible to explain bio-behavior within known laws of physics, neither classical nor quantum. May be new physical laws will be formulated to explain the phenomenon of life. Although quantum information theory is the result of the natural evolution of quantum theory, its creation is often called the second quantum revolution - to highlight the novelty of the applications of the quantum concepts, methodology, and mathematical formalism, to foundations, theory, experiment, and engineering.

References

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2. Gatenby, R. A. & Frieden, R. A. Information theory in living systems, methods, applications, and challenges. *Bull. Math. Biology* **69**(2), 635-57 (2007).