QUANTUM PHYSICS AND BIOLOGY – A SEARCH FOR COMMON GROUND

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In quantum physics and chemistry we usually assume that physical phenomena are fundamentally described by quantum mechanics. We also assume that an understanding of biology on the molecular level requires analysis of the microscopic physical and chemical phenomena responsible for biological form and function. Yet quantum mechanical phenomena usually appear to be unrelated, even irrelevant, to biology. To scientists for whom classical kinetics and energetics generally suffice, the signature quantum effects such as the coherent wave behavior of particles and entanglement due to non-local correlations often seem quite counterintuitive.

This apparent separation between quantum dynamics and the (assumed) classical dynamics of biological systems raises profound questions for both physical science and biology. Such questions become prominent as novel experimental methods probe biological phenomena on extremely short time scales and reveal unexpected quantum mechanical features. The motivation for my Wiko project was to define and study these questions and their ramifications. Looking back on the project, I should say first that it was a great pleasure to work on these topics in a Focus Group on Quantum Biology together with my fellow Fellow Atac Imamoglu and two of our Life Sciences Fellows, Akihito Ishizaki and Alipasha Vaziri.

Before I came to Berlin, my work in Quantum Biology addressed the relevance of quantum dynamics to electronic energy transfer in the early stages of photosynthesis. I focused on the extent to which quantum effects are mechanistic components of the relevant molecular processes and was able to uncover questions about the relevance of observable quantum dynamics to biological function. These studies were primarily concerned with reconciling experimental observations with modern quantum dynamical theories. In my year at Wiko, my interests broadened and diversified in several respects. On the one hand, I began to analyze two broad issues of quantum photosynthesis: first, the use of quantum phenomena in biology as paradigms of open quantum systems; and second, the relevance of such quantum phenomena to evolution. At the same time, prompted by readings and discussion with other Fellows, I also considered whether there might be other biological phenomena in which quantum mechanics plays a significant dynamical or functional role and what the underlying requirements might be.

The First Initiative: Open Quantum Systems

Any critical manifestation of quantum dynamical behavior in biological function raises questions about both the quantum physics of complex systems and the differences between quantum and classical behavior. Biological systems have revealed examples of so-called open quantum systems in which non-trivial quantum effects can be preserved for significantly long times, despite interactions with an environment that would normally remove all dynamic quantum features. Whereas in quantum physics we usually make a sharp distinction between the quantum system and its environment, this distinction is blurred in open quantum systems: the system and its environment are often intercalated or overlapping. The question how such an open quantum system can maintain signature quantum dynamical features is an inversion of the more traditional question of how quantum behavior is lost when zooming out from atoms and molecules to biological units. The study of open quantum systems in biology has provided new insight into the boundary between quantum and classical behavior.

The Second Initiative: Large-Scale Questions that Address Quantum Effects in Evolution

In this area I formulated two questions: How has photosynthetic machinery evolved to be so efficient? And can we use studies of natural genetic variation and experimental evolution to investigate quantum processes in photosynthesis? I arrived at these questions after extensive discussion with my biology colleagues at Wiko, in particular with my peer Fellows Jack Werren and Sonia Sultan. Thinking about these issues and discussing them with my Wiko colleagues has introduced me to a new area that I think is enriched by different disciplinary perspectives on the roles of "how" and "why" questions in scientific enquiry.

I also became interested in bird navigation and neuronal communication. Both of these areas might involve quantum coherent dynamics. Atac Imamoglu and I discussed how to probe the quantum effects in the way birds sense the earth's magnetic field and use it to navigate. Alipasha Vaziri and I discussed the dynamics of ion channel transport and neuronal stimuli. Inevitably we came to consider the relationship between physical function and mental function. This led to fascinating interdisciplinary discussions with other Fellows and Wiko associates, most notably (to me) with Wiko Advisory Board member and Art Historian David Freedberg, when he visited in late May.

To explore these topics in our Focus Group, Atac Imamoglu and I convened a two-day seminar in early May on "Quantum Coherent Effects in Biology". Our goal was to bring together quantum physicists, chemical physicists, and evolutionary biologists, in order to discuss both the nature and role of quantum mechanical effects in biological systems. The primary emphasis of this meeting was quantum coherence in photosynthesis; a secondary emphasis was the role of coherent electron-spin dynamics in avian navigation. We also had lively discussions devoted to the more general question of when and where quantum effects may be seen in biology and what conditions would be required for this. Some of the seminar participants are now working on a joint manuscript summarizing our discussions of photosynthesis. In addition to this manuscript, Atac Imamoglu, Akihito Ishizaki, and I have begun work on a paper describing a quantum measurement interpretation of the common light-induced biological processes.

My primary goal as a Fellow at Wiko was to study the overlap between quantum physics and biology and to explore the opportunities that this might create for new understanding in each of these areas. Although my time at Wiko was relatively short (only five and a half months) it was highly stimulating in all respects: my interests in quantum biology grew and matured, I learned from and with the other Fellows, and I thoroughly enjoyed the musical and artistic side of Wiko. The lively intellectual environment of the Fellows' community at Wiko is highly conducive to pursuing new, potentially significant ideas, to exploring potential links between seemingly disparate fields, and to thinking more deeply about our academic and artistic disciplines.

No less important to me was my stay in Berlin, which offered me many artistic and intellectual riches. Some of these were anticipated while others were unexpected: all revealed a Berlin of great cultural heritage that is also characterized by a vibrant contemporary life. I was particularly moved by the thoughtful analysis and remembrance of the past that is evident in so many places. Walking through the city, observing and listening to its voices, seeing how different neighborhoods have changed, understanding how the past is being addressed to inform both the present and the future: these months have made me appreciate my links to Germany in a deeper sense than before. I would like to thank the entire Wiko staff for making this wonderful opportunity possible.