Quantum Biology

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Quantum biology is the study of how nature employs quantum mechanics in biological processes. In most cases, it is still a question whether quantum mechanics plays a role in biology. In a way it is clear that it already does - every chemical process relies on quantum mechanics [10]. However, in many respects, quantum mechanics is still a concept alien to biology, especially on a scale that can have a physiological impact [18]. Most attempts to find examples of quantum biological phenomena have been fiercely criticized by both physicists and biologists. As Sean Carroll said in his book *he Big Picture: On the Origins of Life, Meaning, and the Universe Itself*, "no theory in the history of science has been more misused and abused by cranks and charlatans - and misunderstood by people struggling in good faith with difficult ideas... than quantum mechanics" [6]. As for myself (and some others), it is still very intriguing whether any biological systems "use quantum mechanics to perform a task that either cannot be done classically, or can do that task more efficiently than even the best classical equivalent?" Or,"do some organisms take advantage of quantum mechanics to gain an advantage over their competitors" [9]?

1 What does it study?

The identification and study of quantum mechanical phenomena in biological systems is an emerging field in the last 10 20 years. People usually regard Erwin Schrödinger as the pioneer with his 1944 book *What is Life?*. Here are the main topics/biological systems studied so far in this area:

- Efficient photosynthesis: This might be the most well-studied subject in quantum biology. Both theoretical and experimental work suggests that the high efficiency (nearly 100%) of energy transport in Fenna-Matthews-Olson (FMO), the photosynthesis apparatus of green-sulphur bacteria living in deep sea (low light condition), could arise from quantum coherent energy transfer ("environmentally assisted quantum transport") [8]. However, even though this might be the area that has most valid evidence in quantum biology, no *in vivo* observations of coherence have been performed yet [9].

- Avian magnetoreception: It was proposed by Klaus Schulten et al in 1978 that the radical-pair mechanism can be a plausible biological chemical-compass for bird navigation [15], and the idea is supported by behavioural experiments. Some recent studies show progress on how the radical-pair mechanism can mediate magnetic-field-sensitive and light-activated chemical reactions in small magnetic field close to Earth's [11]. However, no hosts for radical pairs in the birds' eyes are found yet, or some other candidate radical pair with the right properties to respond to the extremely weak geomagnetic field [9]. And no known biological circuitry can connect the radical pair yield to a neurological signal, only some proposals [14].

- Olfaction and enzyme catalysis: these two processes are believed to involve quantum tunnelling. It is proposed in 1996 that "phonon-assisted inelastic tunnelling of an electron from a donor to an acceptor mediated by the odorant molecule" gives a further level of selectivity to the sense of smell than the traditional believed docking-type mechanism [17], and is supported by recent observation data [5]. As for the enzyme catalysis, strong intrinsic kinetic isotope effects in enzymatic reactions suggests hydrogen tunnelling effect in enzymes [13, 4], but it depends on trivial quantization and discrete energy levels [4]. Both the possible quantum effects in olfaction and enzyme catalysis are semi-classical and do not depend directly on quantum coherence or superposition [9].

- Quantum brain/consciousness: Some scientists believe that our brains utilize quantum mechanics to harness computing power and form consciousness. Most of the hypothesises are proven or almost proven to be invalid or probably unprovable [3], e.g., the Orch-OR theory proposed in the early 1990s by Penrose and Hameroff [2, 12]. One of the newest quantum brain theory is raised by Matthew Fisher from UCSB in 2015. He suspects that nuclear spins of phosphorus atoms could serve as rudimentary "qubits" in the brain — which would essentially enable the brain to function like a quantum computer [7]. With a small group of scientists, he started the experiments of testing this hypothesis recently [16].

2 What techniques/knowledge does it use?

Both theoretical work and laboratory work is developing in this area. However, for the theoretical work, only if the physicists are already famous, can his proposals get attention.
The theoretical work needs wild imaginations (at least how it looks to me..), sharp observation, and of course, solid knowledge in quantum mechanics, physical/theoretical chemistry, material science, quantum infomation and related biological subjects, e.g., neuroscience, molecular biology. Mathematical or statistical modelling is also often used. Besides, a strong heart is very important as few scientists will support the ideas and most people will criticize strongly.
The experimental work is usually done in labs analyzing different physical properties of the compounds or systems interested, e.g, vibrational spectra, nuclear spin, molecule structure, nanoelectronic spectra. The main focus is: how long the coherence time can be in a system and through what ways so that the quantum information can be stored and transported.

3 What are the contributions/applications?

It may reveal how biological systems operate in the most fundamental layer, and help us better understand the conditions for the crossover from classical mechanics to quantum mechanics. It can also give hints to how we can design quantum machines operate in daily environments (i.e., wet, warm and noisy) [1], e.g., more efficient solar cells or photosensors, quantum computers. Along the way we may find some applications in the techniques of studying biological and other systems, e.g, the Posner molecule researched to support quantum brain hypothesis may "provide a platform for liquid-state NMR quantum computation and imaging" [16].

4 Further Reading

Quantum Effects in Biological Systems Workshops (QuEBS) is an annual conference that worth following: http://www.quebs.org/. It is a good source of the newest discoveries and discussions, and names of investigators and labs. (It is a pity that they do not release recordings of talks :(.)
This site provides a good overview of each subtopics and related investigators & projects: http://www.ks.uiuc.edu/Research/quantum_biology/
A lot of quantum physics labs across the world have projects in quantum biology. However, few labs purely focus on it.

5 Personal Comments

The attractive things in this area are:

- Very intriguing and very crazy. It is hard to believe that during these four billion years from first life on earth, nature did not evolve any ways to utilize quantum mechanics in biological systems.
- Quantum mechanism itself is a fascinating area. Quantum biology is very suitable to be a side projects along quantum physics study.

The concerns are:

- The actual work can be very hard and frustrating, but I guess proving something is wrong is also valuable. It would be great if I can try some related work before I going to this area.
- It is closer to chemistry rather than biology, which I'm not sure whether I'm very interested in...
- Some ideas look a bit dangerous - they could be some general nonsense. Need very valid knowledge to judge which are nonsense and which are not.

References

[1] In pursuit of quantum biology with birgitta whaley.

[2] Quantum consciousness | quantum consciousness.

[3] Quantum mind. Page Version ID: 830590131.

[4] R. K. Allemann and N. S. Scrutton. *Quantum Tunnelling in Enzyme-catalysed Reactions*. Royal Society of Chemistry.

[5] J. C. Brookes, F. Hartoutsiou, A. P. Horsfield, and A. M. Stoneham. Could humans recognize odor by phonon assisted tunneling? 98(3):038101.

[6] S. Carroll. *The Big Picture: On the Origins of Life, Meaning, and the Universe Itself*. Dutton, reprint edition edition.

[7] M. P. A. Fisher. Quantum cognition: The possibility of processing with nuclear spins in the brain.

[8] I. Kassal and A. Aspuru-Guzik. Environment-assisted quantum transport in ordered systems. 14(5):053041.

[9] N. Lambert, Y.-N. Chen, Y.-C. Cheng, C.-M. Li, G.-Y. Chen, and F. Nori. Quantum biology. 9(1):10–18.

[10] H. C. Longuet-Higgins. Quantum mechanics and biology. 2(2):207–215.

[11] K. Maeda, K. B. Henbest, F. Cintolesi, I. Kuprov, C. T. Rodgers, P. A. Liddell, D. Gust, C. R. Timmel, and P. J. Hore. Chemical compass model of avian magnetoreception. 453(7193):387–390.

[12] L. K. McKemmish, J. R. Reimers, R. H. McKenzie, A. E. Mark, and N. S. Hush. Penrose-hameroff orchestrated objective-reduction proposal for human consciousness is not biologically feasible. 80(2):021912.

[13] Z. D. Nagel and J. P. Klinman. Tunneling and dynamics in enzymatic hydride transfer. 106(8):3095–3118.

[14] T. Ritz, M. Ahmad, H. Mouritsen, R. Wiltschko, and W. Wiltschko. Photoreceptor-based magnetoreception: optimal design of receptor molecules, cells, and neuronal processing. 7:S135–S146.

[15] K. Schulten, C. E. Swenberg, and A. Weller. A biomagnetic sensory mechanism based on magnetic field modulated coherent electron spin motion. 111(1):1–5.

[16] M. W. Swift, C. G. Van de Walle, and M. P. A. Fisher. Posner molecules: From atomic structure to nuclear spins.

[17] L. Turin. A spectroscopic mechanism for primary olfactory reception. 21(6):773–791.

[18] P. G. Wolynes. Some quantum weirdness in physiology. 106(41):17247–17248.