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Comment

Life—Warm, wet and noisy? Comment on "Consciousness in the universe: A review of the 'Orch OR' theory" by Hameroff and Penrose

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One of the most far-reaching questions in the science of living systems is that of the nature of consciousness. While the field of biology has made enormous progress through the application of Newtonian physical principles, significant unanswered questions abound in many facets of biological function, ranging from the inception of life all the way to free will, and potentially further into the metaphysical realm of human capabilities. It is not clear that we presently have the right tools and foundation to address such ethereal concepts. The mystery of life is readily highlighted, in many cases, when one attempts to apply known physical laws, established for non-living matter, to biological systems.

With the development of quantum mechanics over the past century, scientists have been asking whether biology relies upon or attains functions by using quantum physics [1]. This has progressed to the emergence of a field termed 'quantum biology', which is restricted to biological processes that take explicit advantage of quantum mechanisms for higher order function [2,3]. Examples include light harvesting in photosynthesis [4,5], magnetoreception in various species [6], olfaction [7,8], and enzyme function involving long-range electron transfer [9] and proton transfer [10] reactions. The Penrose–Hameroff model of orchestrated objective reduction ("Orch OR") proposes that quantum computation takes place in microtubule assemblies within cerebral neurons, resulting in the phenomenon of human consciousness [11].

Despite this progress, quantum biology remains a difficult and controversial topic. A primary issue is decoherence, a process where the phases of quantum wavefunctions are randomized to reduce quantum phenomena to classical processes. Decoherence arises from dynamic disorder, or "energy noise", and is expected to be extremely rapid in biological environments. For example, the Orch OR theory requires quantum superposition on a time scale that is not currently accepted for biological, or even chemical, systems [12]. Compared to pristine periodic systems at very low temperatures usually studied in physics, biological systems are purported to be "warm, wet and noisy". Does evidence support this assumption?

In light of all that remains to be described regarding the study of life, this brings about the most important question in our opinion: what do we really know about the fundamental nature and properties of the biological environment? The concept of "warm, wet & noisy" is put forth when one imagines the complex components and workings of a biological system to be simply a messy business, incapable of supporting 'delicate' quantum processes. Whether it is

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an acceptance of quantum behavior, or generating a foundation for the study of difficult questions in biology, should we reconsider the premise that living entities are founded on uncorrelated and chaotic machinery? In other words, do we expect incoherence in biology?

On the contrary, it appears that living systems are governed by cycles and correlations, requiring massive cooperation across a large range of time and length scales. At the macroscopic level we see functional periodic changes such as circadian rhythms and seasonal variations, whose regulation cannot be explained by a simple mechanical 'switch' [13]. For example, the dropping of leaves from a tree in autumn is a process that has been in preparation for the entire previous year. In fact, it is a cycle that is tweaked by information gathered from previous years, and changes in global weather gradually influence its timing.

Entrainment of biological oscillators is a compelling example of the management and timing of periodic, seemingly isolated, biological functions [14]. Profoundly, it has been shown that the precise rhythm of the heartbeat can regulate a large number of cycles in the body, and optimal function is achieved in the presence of perfectly coherent beats [15,16]. Thus, statistical mechanics suggests that biomolecules in a biological environment operate in a regime of "correlated randomness". Individual behavior is indeed stochastic, but short- and long-range correlations abound [17].

Living matter can also be shown to be resistant to perturbations that would normally affect isolated components *in vitro*. This has been demonstrated long ago by the injection of picric acid into a single-celled amoeba at concentrations high enough to coagulate isolated protein solutions. Surprisingly, it was found that the proteins within the live organism resist denaturation [18]. Perhaps the landscape of the living system is not so chaotic after all? Instead, we speculate that living matter operates within a very special physicochemical regime, yet to be explicitly defined, from which all of the unexpected and exciting phenomena of life emerge.

In summary, it stands to show that the very way we think about biological systems is not yet consistent or well defined across fields. Addressing difficult questions as far reaching as the nature of consciousness requires multidisciplinary action, advanced experimental techniques, and a foundation incorporating the "special feature" which differentiates living from non-living matter. We should strongly question the premise that life is born out of "warm, wet & noisy" systems. Regardless of whether quantum biology is the new frontier, or another paradigm proves useful, it is clear that one of the next scientific revolutions will involve the evolution of a new framework for unraveling the extraordinary nature of life.

References

[1] Fleming GR, Scholes GD, De Wit A, editors. 22nd Solvay conference on chemistry. 2011. p. 1–366.
[2] Ball P. Nature 2011;474:272–4.
[3] Lambert N, Chen YN, Cheng YC, Li CM, Chen GY, Nori F. Nat Phys 2013;9:10–8.
[4] Engel GS, Calhoun TR, Read EL, Ahn TK, Mancal T, Cheng YC, et al. Nature 2007;446:782–6.
[5] Collini E, Wong CY, Wilk KE, Curmi PMG, Brumer P, Scholes GD. Nature 2010;463:644–69.
[6] Rodgers CT, Hore PJ. Proc Natl Acad Sci USA 2009;106:353–60.
[7] Turin L. Chem Senses 1996;21:773–91.
[8] Brookes JC, Hartoutsiou F, Horsfield AP, Stoneham AM. Phys Rev Lett 2007;98:038101.
[9] Gray HB, Winkler JR. Q Rev Biophys 2003;36:341–72.
[10] Nagel ZD, Klinman JP. Chem Rev 2006;106:3095–118.
[11] Hameroff S, Penrose R. Phys Life Rev 2014;11(1):39–78 [in this issue].
[12] McKemmish LK, Reimers JR, McKenzie RH, Mark AE, Hush NS. Phys Rev E, Stat Nonlinear Soft Matter Phys 2009;80:021912.
[13] McClung CR. Plant Cell 2006;18:792–803.
[14] Glass L. Nature 2001;410:277–84.
[15] Ivanov PC, Nunes Amaral LA, Goldberger AL, Havlin S, Rosenblum MG, Stanley HE, et al. Chaos 2001;11:641–52.
[16] Goldberger AL, Amaral LA, Hausdorff JM, Ivanov P, Peng CK, Stanley HE. Proc Natl Acad Sci USA 2002;99(Suppl 1):2466–72.
[17] Stanley HE, Buldyrev SV, Goldberger AL, Goldberger ZD, Havlin S, Mantegna RN, et al. Physica A 1994;205:214–53.
[18] Pollack H. P Soc Exp Biol Med 1927;25:145.