Re: Could Photosynthesis Breakthrough Yield Solar Power Advance?

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- *From*: "Berkeley Brett" <RoyalOui@xxxxxxxxx>
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News and Views

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Biophysics: Quantum path to photosynthesis

by Roseanne J. Sension*

Knowing how plants and bacteria harvest light for photosynthesis so efficiently could provide a clean solution to mankind's energy requirements. The secret, it seems, may be the coherent application of quantum principles.

The Sun bombards Earth with a steady stream of energy about 1017 joules per second, on average [ref 1]. If we could convert this energy efficiently to a chemically useful form, our reliance on fossil fuels and nuclear power and so our production of climate−change agents and hazardous waste materials could be substantially reduced. But how can we achieve such efficiency?

Of course, the photosynthesizing organisms on Earth already have the answer. In higher plants and certain bacterial systems, the initial steps of natural photosynthesis harness light energy with an efficiency of 95% or more values that we can only aspire to with artificial photocells. Elsewhere in this issue, Engel et al. [ref 2] (page 782) take a close look at how nature, in the form of the green sulphur bacterium Chlorobium tepidum, manages to transfer and trap light's energy so effectively. The key might be a clever quantum computation built into the photosynthetic algorithm.

Photosynthesis is initiated by the excitation, through incident light, of electrons in pigment molecules chromophores such as chlorophyll. This electronic excitation moves downhill from energy level to energy level through the chromophores before being trapped in a reaction centre, where its remaining energy is used to initiate the production of energy−rich carbohydrates. In natural light−harvesting systems, chlorophyll pigments are arranged together in an 'antenna', sometimes with elegant symmetry and sometimes with apparent randomness, but always with a precise structure that is supplied by a protein scaffold (Fig. 1). Many studies indicate [refs 3, 4, 5, 6] that this strictly defined structure, together with the close proximity of the chromophores, is essential for the strong absorption of light, fast downhill energy transfer and efficient trapping of the electron excitation in a reaction centre, all of which are characteristic of natural photosynthesis.

[Image occurs here]

But where does quantum mechanics, let alone quantum computing, fit in here? The mechanism of energy transfer through chromophore complexes has generally been assumed to involve incoherent hopping that is, seemingly uncoordinated movement in a 'random walk' with a general downhill direction either between individual chromophores, or between modestly delocalized energy states spanning several chromophores. The energy transfer is determined by quantum−mechanical states and their overlaps, to be sure, but there is nothing inherently 'quantum' or wave−like in the process itself.

Engel et al. [ref 2], however, performed two−dimensional Fourier transform spectroscopy of the bacteriochlorophyll FennaMatthewsOlsen antenna complex, and discovered regular variations in the intensity of their signal. These 'quantum beats', which persist for hundreds of femtoseconds, are characteristic of coherent coupling between different electronic states. In other words, the electronic excitation that transfers the energy downhill does not simply hop incoherently from state to state, but samples two or more states simultaneously. The data also suggest that the protein scaffold might itself be structured to dampen fluctuations that would induce decoherence of the electronic excitation.

Coherent energy transfer allows the 'wave−like' sampling of the energy landscape to establish the easiest route for the electronic excitation to the reaction complex much faster than the semi−classical hopping mechanism allows indeed, it does so almost instantaneously. The process is analogous to Grover's algorithm in quantum computing, which has been proved to provide the fastest possible search of an unsorted information database [ref 7].

Although the data were acquired at low temperature (77 kelvin), the observation of electronic coherences in such a complex system is remarkable. Assuming that the effect is general that similar coherences occur in many different natural light−harvesting systems, and are observed at non−cryogenic temperatures we may find that nature, through its evolutionary algorithm, has settled on an inherently quantum−mechanical process for the critical mechanism of efficient light harvesting. This is an interesting lesson to be considered when designing artificial systems for this purpose.

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