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Unlocking nature's quantum engineering for efficient solar energy

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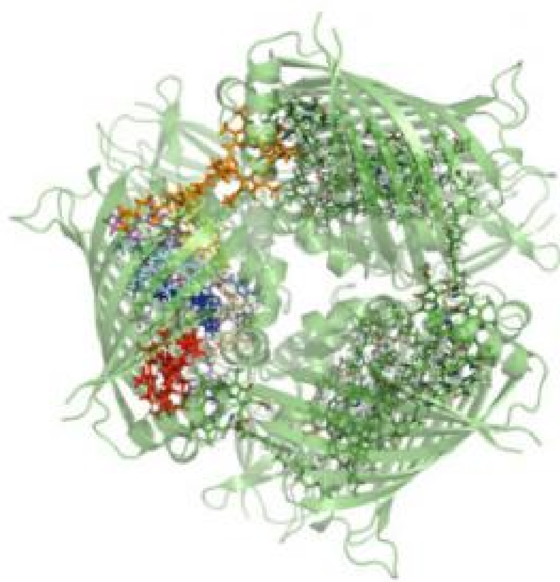

(Phys.org)—Quantum scale photosynthesis in biological systems which inhabit extreme environments could hold key to new designs for solar energy and nanoscale devices. Certain biological systems living in low light environments have unique protein structures for photosynthesis that use quantum dynamics to convert 100% of absorbed light into electrical charge, displaying astonishing efficiency that could lead to new understanding of renewable solar energy, suggests research published today in the journal *Nature Physics*.

The research resolves an important mystery in the newly-emerging field of quantum biology – the origins and longevity of the quantum, wave-like properties that transport energy during the early stages of photosynthesis, phenomena unexpectedly observed in molecular complexes extracted from a variety of plants, algae and bacteria.

In photosynthesis, light photons absorbed by pigments such as chlorophyll create excited molecular states, excitons, that carry energy as quantum waves through networks of pigments held in place by protein structures – or pigment-protein complexes (PPCs) – to each PPC's reaction centre, where the exciton's energy is used to release electrons needed for photosynthetic chemistry. Preventing the trapping or dissipation of excitons during this journey is a key problem in both nature and man-made solar cells.

Research from Cambridge's Cavendish Laboratory studying light-harvesting proteins in Green Sulpher Bacteria – which can survive at depths of over 2,000 metres below the surface of the ocean – has found a mechanism in PPCs that helps protect energy from dissipating while travelling through the structure by actually reversing the flow of part of the escaped energy – by reenergising it back to exciton level through molecular vibrations.

These PPCs, in this case the bacteria's Fenna-Matthews-Olson complex, ensure that every photon absorbed makes it to the structure's reaction centre – crucial for an organism's survival in the planet's most inhospitable environments, where little light penetrates.

"Once the detailed structure of the protein vibrations was included in our simulations, we found that the energy of the excitons does not just continually decrease as they are funnelled towards their final position – something you might expect in the complex thermal conditions found in biological systems," said Dr Alex Chin, from Cambridge's Winton

Programme for the Physics of Sustainability, who conducted the research with Prof. Martin Plenio, Prof. Susana Huelga, Dr Felipe Caycedo-Soler and Robert Rosenbach from the Institute of Theoretical Physics at Universität Ulm in Germany and Dr Javier Prior from the University of Cartagena.

"In fact, our research suggests that these natural PPCs can achieve 'hot and fast' energy transfer – energy flows that prevent complete cooling to the temperature of their surroundings – which has been proposed as a way of improving solar cell efficiency beyond limits currently imposed by thermodynamics."

The researchers contend that the exceptional light-harvesting capacity of these protein systems is down to intricate processes of energy transport that fall outside 'classical' physics, depending strongly on tropes of quantum physics – primarily that of 'quantum coherence'.

Quantum coherence in photosynthesis involves energy, in the form of the particle-like excitons, moving through the molecular structure using multiple channels simultaneously. This quantum coherence is usually very fragile and quickly destroyed by random fluctuations of surrounding proteins – so the observation of long-lasting coherence in PPCs came as a complete surprise to many researchers.

"Quantum coherence appears to increase the speed of energy flow across molecules and preventing it from getting stuck in local traps or defects," said Chin, adding that "Our results provide a microscopic basis for understanding how the coherence, central to these theories, is maintained in PPCs. The resulting insights provide several promising clues as to what efficiency advantages quantum coherence might provide to these systems".

"Some of the key issues in current solar cell technologies appear to have been elegantly and rigorously solved by the molecular architecture of these PPCs – namely the rapid, lossless transfer of excitons to reaction centres."

As Chin points also out, stabilising 'quantum coherence', particularly at ambient temperatures – something the researchers have begun to explore – is an important goal for future quantum-based technologies, from advanced solar cells to quantum computers and nanotechnology.

"These biological systems can direct a quantum process, in this case energy transport, in astoundingly subtle and controlled ways – showing remarkable resistance to the aggressive, random background noise of biology and extreme environments.

"This new understanding of how to maintain coherence in excitons, and even regenerate it through molecular vibrations, provides a fascinating glimpse into the intricate design solutions – seemingly including quantum engineering – that nature has produced through evolution, and which could provide the inspiration for new types of room temperature quantum devices."

More information: 'The role of non-equilibrium vibrational structures in electronic coherence and recoherence in pigment–protein complexes' www.nature.com/nphys/journal/v … /full/nphys2515.html

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