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Procedia Computer Science 7 (2011) 92–95

Procedia Computer Science

The European Future Technologies Conference and Exhibition 2011

Quantum Effects in Biology and Their Applications to Light Harvesting and Sensing

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Abstract

This session introduced the novel area of quantum effects in biological systems: it presented its seminal experimental discoveries and theoretical ideas, namely regarding photosynthetic systems and olfactory recognition, and discussed their potential applications to the development of artificial devices for more efficient light harvesting and finer sensing.

Keywords: Quantum coherence in biological systems; light harvesting; sensing

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1. Introduction

The recent discoveries of long-lived quantum coherence in excitonic transport in photosynthetic complexes, first at cryogenic [1] and more recently at ambient temperatures [2], provided evidence for the surprising presence of coherent quantum dynamics in systems that a priori would be considered too hot, too noisy and too large to exhibit any quantum effects. This is turn led to the counterintuitive idea of noise- or environment-assisted quantum coherence [3], a particular regime where the coupling to the environment can actually improve the efficiency of the energy transfer. These results open up the challenge to, on the one hand, formulate in a quantitative form a possible link between quantum coherence and biological function and, on the other hand, engineering controllable artificial nanostructures for efficient light harvesting or precision sensing that rely on quantum mechanical features.

The above discoveries have also brought a unified and more general view to the study of quantum effects in biology, as there are other systems and functions where quantum coherence could again play a significant role. One such system is the avian magnetic compass. Migratory birds have the surprising capacity to be sensitive to the Earth's magnetic field, both to its direction and to its very low intensity (below 100 μT). Although the origin of the avian magnetic compass sensor remains an open problem, the hypothesis with strongest support from evidences is that this mechanism derives from the quantum spin dynamics of transient photoinduced radical pairs [4]. Is that the case? And if so, could we reproduce this behaviour in an artificial system, and could we control it to achieve ultra-fine magnetic sensing? Another challenging open problem, also investigated in this context, is olfaction: the physical mechanisms underpinning odour detection are still not clear. Although the odorant shape and size play a relevant role, experiments

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1877-0509/$ – see front matter © Selection and peer-review under responsibility of FET11 conference organizers and published by Elsevier B.V.
doi:10.1016/j.procs.2011.12.028

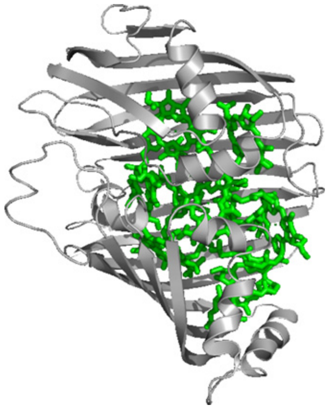

Fig. 1. Representation of the Fenna-Matthew-Olson photosynthetic complex.

show them as insufficient to discriminate different odours [5,6]. A hypothesis currently under investigation is that the smell of a molecule depends on its vibrational spectroscopic properties and that olfaction relies on quantum tunneling (or more precisely, inelastic electron tunneling spectroscopy) to detect them [5,6]. Again, could this be the case? And how are these ideas being explored to develop more efficient and sensitive artificial noses?

2. The session

The session on *Quantum effects in biology and their applications to light harvesting and sensing*, organized by H. Briegel (University of Innsbruck), S. Huelga (University of Ulm), Y. Omar (Technical University of Lisbon & IT) and M. Rasetti (ISI), was constituted by invited communications by Greg Engel (University of Chicago), Martin Plenio (University of Ulm) and Luca Turin (BSRC Fleming, Athens) and a final discussion panel.

In ground-breaking experiments, ultrafast nonlinear spectroscopy has been used recently to probe energy transfer dynamics in the Fenna-Matthew-Olson (FMO) and other photosynthetic aggregates [1,2]. The FMO complex (see Fig. 1) is an example of a pigment-protein complex, which realizes a network through which electronic excitations on individual pigments can migrate via dipole-dipole mediated coupling. These experiments have provided evidence for the existence of wave-like excitation energy transport between multiple pigments through the presence of beating signals between different exciton states. These beatings have been observed to persist on timescales up to around 1 ps, which is a significant fraction of the typical transport time in FMO. Thanks to these discoveries, there is now considerable interest in exploring the possibility of assigning a functional role to quantum coherence in the remarkably efficient excitation energy transfer in FMO and other pigment-protein complexes. Theoretical investigations of the role of pure dephasing noise in EET have uncovered that noise has the ability to enhance both the rate and yield of EET when compared to perfectly quantum coherent evolution [3]. In an oversimplified argument the presence of noise assisted transport might be conjectured from the existence of noise-induced transitions between exciton eigenstates states, which cause energetic relaxation towards the reaction centre. However, this approach suffices to suggest the existence of EET as a noise-assisted processes but it is less transparent in showing how DAT actually works, when it does not exist or is inefficient and how it might be controlled or exploited in artificial nanostructures. Recent work provides a fresh look at the problem by aiming at clearly identifying the mechanisms that are underlying noise assisted transport [3,4]. Identifying and spelling out these mechanisms clearly does provide additional value even if the individual contributions might have been known in some context. Such classifications pave the way towards tailored experimental tests of individual contributions. Furthermore a clear understanding of these fundamental mechanisms will allow for the optimization of network architectures in order to utilize quantum coherence and noise optimally in artificial nanostructures. In his lecture Greg Engel described the ground-breaking experiments on coherence in exciton-energy transport in pigment-protein complexes [1,2] while Martin Plenio outlined the theoretical developments of [3,7] and demonstrated possible applications of these principles ranging from biology to man-made nanostrutures.

In his address, Luca Turin introduced the problem of molecular recognition by the olfactory system. Two theories exist to explain this phenomenon: one based simply on the shape of the odorant molecule, with the recognition

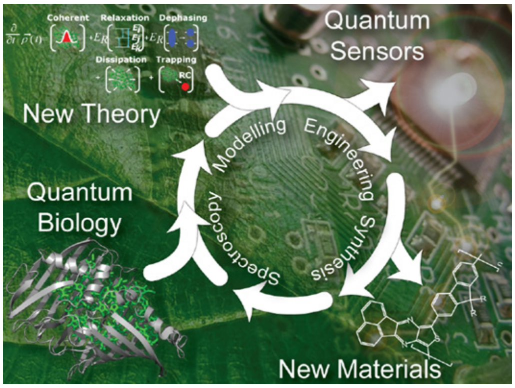

Fig. 2. The study of quantum effects in biology inspires new applications, which in turn may contribute to deepen our understanding of biological functions and systems at a fundamental level.

happening via a *lock and key* ligand binding, and one defended by the speaker himself where — besides the binding with the receptor's site — there the vibrational energy modes of the odorant must be compatible with the energy levels on the receptor, so electrons can travel through the molecule via inelastic electron tunneling, triggering the signal transduction pathway. Luca Turin then reported on experiments recently realized [6] where Drosophila melanogaster can distinguish different (isotopic) odorants with the same shape and can be trained to avoid them selectively. Furthermore, they have found that flies trained to avoid a deuterated compound exhibit selective aversion to an unrelated molecule with a vibrational mode in the energy range of the carbon–deuterium stretch, which support the existence of a molecular vibration-sensing component to olfactory reception. Further research is needed to clarify the odor recognition mechanism in humans, but these results shed light on the fundamental aspects of this biological mechanism and open novel prospects for the non-trivial challenge of developing fine and reliable artificial odor sensors, currently still outperformed by dogs.

3. Outlook

The study of quantum effects in biological systems is an emergent and truly multidisciplinary area, at the interface between physics, chemistry, biology and engineering. This novel field is challenging the supposed fragility of quantum coherence in complex and noisy systems, stemming new ideas of noise-assisted transport of quantum states and quantum information. Furthermore, it is offering us a new insight and understanding at the most fundamental level of the important process of photosynthesis, opening the prospect of applications to the design and fabrication of more efficient light harvesting and solar energy devices (see Fig. 2). And the suspected role of quantum physics in avian magnetoreception and odor recognition is motivating research on finer magnetic sensing and the development of an artificial nose. Finally, further to these ideas, there is also ongoing research on the role of quantum coherence in energy [8] and charge [9] transport in proteins and in the selectivity filter of potassium channels [10].

Acknowledgements

The authors would like to thank Greg Engel for providing the figures illustrating this article. YO acknowledges support from CEMAPRE, as well as from Fundação para a Ciência e a Tecnologia (Portugal) through the programs POCTI/POCI/PTDC and the project PTDC/EEA-TEL/103402/2008 QuantPrivTel, which was partially funded by FEDER (EU). MB Plenio is supported by an Alexander von Humboldt Professorship.

References

[1] G.S. Engel, et al., Nature 446 (2007) 782.
[2] G. Panitchayangkoon, et al., Proc. Nac. Acad. Sciences 107 (2010) 12766;
E. Collini, et al., Nature 463 (2010) 644.

[3] M. Mosheni, et al., J. Chem. Phys. 129 (2008) 174106;
M.B. Plenio, S.F. Huelga, New J. Phys. 10 (2008) 113019.

[4] T. Ritz, et al., Biophys. J. 78 (2000) 707–718;
K. Maeda, et al., Nature 453 (2008) 387–390;
R. Wiltschko, J. Royal Soc. Interf. 7 (2010) S163–S177.

[5] J.C. Brookes, et al., Phys. Rev. Lett. 98 (2007) 038101.

[6] M.I. Franco, et al., Proc. Nac. Acad. Sciences 108 (2011) 3797–3802.

[7] F. Caruso, et al., J. Chem. Phys. 131 (2009) 105106;
P. Rebentrost, et al., New J. Phys. 11 (2009) 033003;
A.W. Chin, et al., New J. Phys. 12 (2010) 065002;
A. Ishizaki, et al., Phys. Chem. Chem. Phys. 12 (2010) 7319.

[8] V. Atanasov, Y. Omar, New J. Phys. 12 (2010) 055003.

[9] J. Lin, et al., Science 310 (2005) 1311–1313.

[10] A. Vaziri, M. Plenio, New J. Phys. 12 (2010) 085001.