Abstract

The one-day workshop “Quantum Transport in Light-Harvesting Bio-Nanostructures” has been hosted at the Physics Department of Florence University on the 11th of March, 2013. It provided both experimental and theoretical lectures by the main international leaders of research areas such as quantum transport phenomena, ultra-fast spectroscopy, natural and artificial light-harvesting complexes, quantum effects in biological photosynthetic systems, solar energy and information technologies. The goal was to spread the ideas on the new strategically important and rapidly developing research area of Quantum Biology to the scientific community in Florence.

Keywords: quantum transport, photosynthesis, quantum biology, solar energy

1. Introduction on Quantum Biology

Nowadays, the alarming trends in global energy demand and the finite nature of conventional oil and natural gas reserves are unavoidably leading to the urgency of finding and timely developing new green energy systems.

According to the EU-US joint statement in the Lisbon Summit in November 2010, the EU-US Energy Council will be focused on “Green Growth” by enhancing cooperation on the development and deployment of clean energy technologies and facilitating participation by qualified researchers. In this context, a better understanding of natural photosynthesis could lead to the realization of new “Nature-inspired” devices. Indeed, one of the main obstacle is the difficulty to produce solar cells with good efficiency, for instance single-junction (semiconductor) silicon devices are now approaching their theoretical limiting efficiency of around 30%.
Around 6 years ago fascinating experiments, based on ultra-fast spectroscopy techniques, have shown that electronic excitation energy transfer in light-harvesting complexes, involved in one step of bacterial photosynthesis, has to be described by quantum physics, while classical mechanics does not allow one to well explain the experimental data. In these biological systems, the efficiency of transferring sunlight energy to molecular reaction centres is extremely high (nearly 100%). Speed is the key - the transfer of solar energy takes place almost instantaneously and very robustly, so little energy is wasted as heat. This triggered also several theoretical studies on how Nature exploits quantum coherence and environmental noise to implement such transport mechanisms. In particular, the presence of quantum effects seems to play a crucial role in this remarkably efficient, fast and robust electron energy transfer. Therefore, these experimental and theoretical investigations have led to a new, challenging, exciting, still young but very rapidly developing research field, i.e. Quantum Biology. It is expected to allow us to have a deeper understanding of the role of quantum physics in biological structures, whose practical implementations might be crucial, in the 21st century, for novel and more efficient and powerful renewable energy nanotechnologies based on quantum phenomena.

2. Scientific Motivation

The internationally leading theoretical group on quantum physics of Prof. M.B. Plenio, earlier at Imperial College London (UK) and later at Ulm University (Germany), was strongly involved with a leading role in this vibrant and cross-disciplinary field of research on “Quantum Effects in Biology”, since its inception in 2008. One of its main research activities was the analysis of quantum phenomena in photosynthesis and, particularly, in the analytical and numerical investigation of theoretical models describing energy/information transport in biological complexes and in quantum complex networks, providing several important contributions in explaining the basic key mechanisms underlying noise-assisted energy transport in biological photosynthesis. The organizer of this workshop was closely involved in
this activity while working for several years in this group, before moving recently (as MIUR-FIRB PI) to Florence University (Prof. Inguscio’s group). The main goal of his FIRB project (www.qubiot.com) is, indeed, to transfer the knowledge and expertise, previously acquired abroad, to lunch this very exciting and rising field of quantum biology in Italy (where this research area is not running yet), linking, for the first time, completely different research fields as biology, atomic physics, quantum optics, chemistry, quantum information, and spectroscopy, e.g. crosswise applying different tools and approaches. Therefore, this workshop was especially motivated by this aim, and in particular the idea was to provide, mainly for the local scientific community in Florence, an open access and broad audience workshop based on mostly introductory lectures on this topic, from both the theoretical and experimental side, by the main international leaders of this new research field.

3. The Workshop

The invited speakers came from six different EU countries for this one-day workshop on quantum biology that was financially supported by Dr. Caruso’s FIRB-MIUR grant. Actually, it was the first event of a week being dense of quite important scientific events in Florence, as the national CNR-INO Symposium and the QSTAR Research Center kick-off meeting.

Structure of the workshop:

- Experimental observations on quantum coherence in photosynthesis in 2008
- Crystal structures and theoretical modeling
- Principles of noise-assisted transport phenomena
- Role of environmental vibrational modes
- Experimental evidence of coherence in charge separation
- Theory of non-linear ultra-fast spectroscopy
- Experiments on single light-harvesting molecules
• Discussions on open problems in quantum biology
In particular, the meeting started with a lecture on the beginning of this new field around 6 years ago, by means of some fascinating experiments on 2D ultra-fast non-linear electronic spectroscopy on biological systems and polymers, where they observed the first strong evidence of the presence of quantum coherence, in the form of quantum beatings, in this energy transport dynamics. Later, it was showed how such experimental optical results could be matched with the crystallography structure data to build up theoretical models on light-harvesting dynamics. Concepts of noise-assisted transport were, then, discussed as a first example of the beneficial interaction between electronic and vibrational degrees of freedom in biological systems. Indeed, the non-trivial spectral structures of the environmental fluctuations and particularly discrete vibrational modes seem to be responsible for the generation and sustenance of both oscillatory energy transport and electronic coherence on timescales that are comparable to excitation energy transport. Hence, they showed experimental evidences on the role of quantum coherence in
understanding the mechanisms of charge separation in presence of highly disordered energy landscape. On top of that, an introduction on the theoretical description of non-linear spectroscopy and the connection with modern problems of biophysics and quantum mechanics was also provided. Finally, more recent experiments on such quantum coherence but explored at the level of individual light-harvesting complexes were discussed.

**Figure:** Green Sulphur Bacteria are prototypes of light-harvesting systems and probably progenitors of life on Earth. They are found living also at the bottom of the Pacific Ocean where there is no sun-light and such pigment-protein complexes absorb about one photon every 24 hrs (thermal light) and then the generated electronic excitation is transferred to a reaction center (where the electron energy is converted into chemical one) with the very remarkable efficiency of 99% in about 5 ps.

### 4. Outcomes and outlook

This workshops attracted a lot of attention and interest by the local community and also other scientists coming from different parts of Italy (around 80 participants) and triggered several interesting and stimulating discussions and possible future collaborations, especially thanks to the participation of the most eminent experts in the field. The list of invited speakers, more details on the program, the talk abstracts, and related scientific references are available at the workshop webpage [http://lens.unifi.it/index.php?include=meetings&active=main&id=58](http://lens.unifi.it/index.php?include=meetings&active=main&id=58).

Finally, it represented also a very good and successful test for organizing, in the future, in Florence the official international conference (QuEBS) on the topic, hosted so far by very prestigious institutions, as Harvard, MIT, and UC Berkeley.