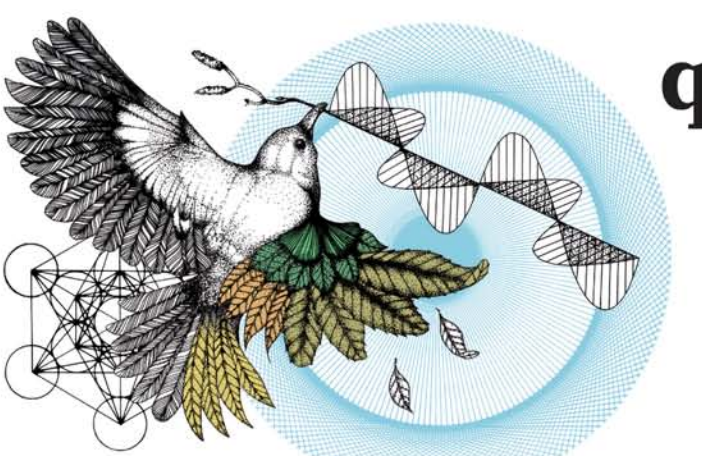


The dawn of quantum biology

The key to practical quantum computing and high-efficiency solar cells may lie in the messy green world outside the physics lab.

by Amirali Zandie*

* Institute of Biochemistry and Biophysics, University of Tehran

Abstract

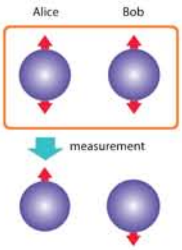
It seems that since the focus of study in biology is on a different scale from **quantum mechanics**, there is no room for non-classical physics in biological study. Moreover, **living systems** like cells are too complex to be investigated by such mechanics in all details, specially with the ever fluctuating and the unstable conditions in living world which is in sharp contrast to fully controlled fundamental physics laboratories. However, recent studies have revealed some exciting processes in living organisms that cannot be explained unless with the help of quantum mechanics. Interestingly, these quantum effects, including **quantum coherence** in long lasting time scale, are among the abstruse phenomena in quantum description.

The quantum coherence effect has been shown by measuring the **light harvesting** efficiency and the coherence time of isolated PSII complexes stimulated by laser pulses. Models based on the resonance effect of **singlet-triplet transition** suggest a magnetic compass based on a **radical-pair** are consistence with the experiments; Orientation of avian migration is affected by the angle of an applied exterior oscillating field with respect to the geomagnetic field

Though the unexpected observation of coherence at room temperature is itself remarkable, its not clear weather the small boost in efficiency of light harvesting as a result of coherence can have evolutionary advantageous.

Recent approval of long range effect of quantum concepts like **quantum entanglement** in distant systems extends the realm of quantum studies into larger worlds. The examples of the most evident of these processes, which are the focus of this paper, are light harvesting in **photosynthesis**, avian use of **magnetoreception** in migration and **olfactory receptors**.

Quantum Entanglement, a Strange Outcome of Quantum Mechanic

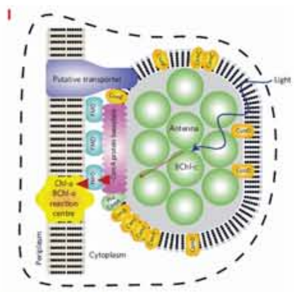


Quantum entanglement is a physical phenomenon that occurs when pairs or groups of particles are generated or interact in ways such that the quantum state of each particle cannot be described independently of the others, even when the particles are separated by a large distance—instead, a quantum state must be described for the system as a whole. Measurements of physical properties such as position, momentum, spin, and polarisation, performed on entangled particles are found to be appropriately correlated. For example, if a pair of particles are generated in such a way that their total spin is known to be zero, and one particle is found to have clockwise spin on a certain axis, the spin of the other particle, measured on the same axis, will be found to be counterclockwise, as to be expected due to their entanglement.

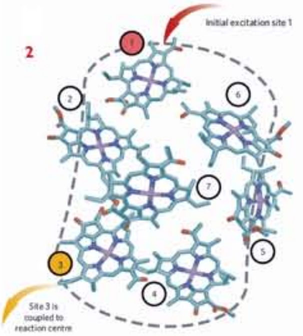
However, this behavior gives rise to paradoxical effects: any measurement of a property of a particle can be seen as acting on that particle (e.g., by collapsing a number of superposed states) and will change the original quantum property by some unknown amount; and in the case of entangled particles, such a measurement will be on the entangled system as a whole. It thus appears that one particle of an entangled pair "knows" what measurement has been performed on the other, and with what outcome, even though there is no known means for such information to be communicated between the particles, which at the time of measurement may be separated by arbitrarily large distances.

Light-harvesting is Aided by Quantum Coherence

1



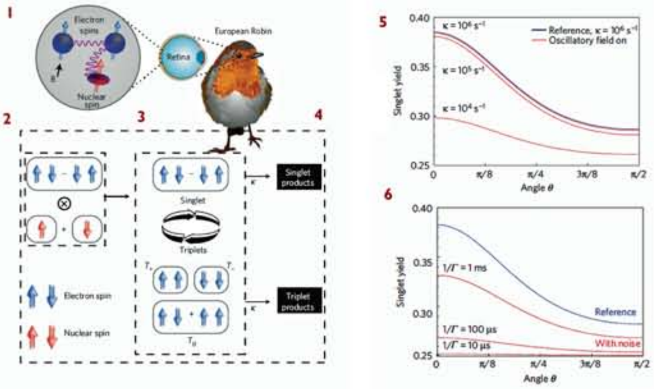
2



The well-studied FMO complex in the light-harvesting apparatus of green-sulphur bacteria exhibits some signatures of quantum coherent energy transfer. Experimental and theoretical works have scrutinized the precise mechanisms and quantumness of the energy transduction through this protein. Research in this field might reveal new quantum mechanical principles for improving the efficiency of energy harvesting in biology.

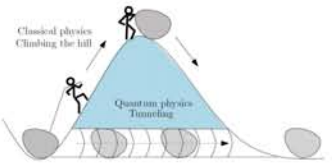
What is remarkable is the observed efficiency of this and other photosynthetic units. Almost every photon (nearly 100%) that is absorbed is successfully transferred to the reaction centre, even though the intermediate electronic excitations are very short-lived (~1 ns). In 2007, Fleming and co-workers demonstrated evidence for quantum coherent energy transfer in the FMO complex, and since then the FMO protein has been one of the main subjects of research in quantum biology.

Spin Correlated States in Radical-pair Model



The standard radical-pair model can be summarized as follows, although the exact details and steps involved can be quite complex: a radical pair is (typically) a pair of bound molecules that each has an unpaired electron. These pairs are created, by a photochemical process, in spin-correlated states; that is, singlets or triplets. The state of these spins then evolves under the combined effect of the Earth's weak magnetic field and internal nuclear hyperfine interactions with the host nuclei. Finally, the rate of charge recombination depends on the spin of the separated charges, directly influencing the reaction products of these radical pairs. These differing reaction products are in principle biologically detectable. Thus, if the relative weights of the singlet and triplet states are sensitive to the angle of the external (geo-magnetic) field, the reaction products will be also, leading to a magnetic compass. The precise nature of the radical pair that might be involved in this mechanism is as yet unknown. The prime suspect is a series of radical-pair reactions that are known to occur within cryptochromes which, because they are resident in the eye, could induce a visual signal by which the host species navigates. Simple models of these kinds of radical pair, using highly anisotropic nuclear spin configurations, are sufficient to show that in principle the radical-pair reaction products are sensitive to the inclination of the external field, and can reproduce the disruptive effect of time-dependent external magnetic fields at radio frequencies.

Possible Role of Tunneling in Olfactory Receptors

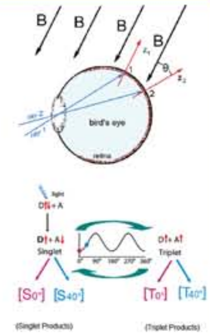


Quantum tunnelling refers to the quantum mechanical phenomenon where a particle tunnels through a barrier that it classically could not surmount. This plays an essential role in several physical phenomena, such as the nuclear fusion that occurs in main sequence stars like the Sun. It has important applications to modern devices such as the tunnel diode, quantum computing, and the scanning tunnelling microscope. The effect was predicted in the early 20th century and its acceptance as a general physical phenomenon came mid-century.

Tunnelling is often explained using the Heisenberg uncertainty principle and the wave–particle duality of matter. Pure quantum mechanical concepts are central to the phenomenon, so quantum tunnelling is one of the novel implications of quantum mechanics.

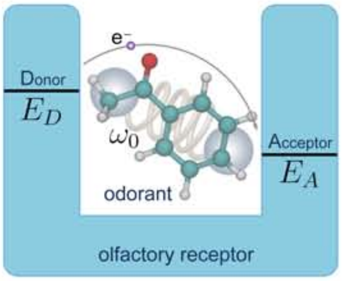
Singlet-triplet Dependent Chemical Reaction Acts as a Compass

"One version of the idea would be that some chemical is synthesized" in the bird's retinal cells when the system is in one state, but not when it's in the other, says Simon Benjamin, a physicist at the University of Oxford, UK. "Its concentration reflects Earth's field orientation." The feasibility of this idea was demonstrated in 2008 in an artificial photochemical reaction, in which magnetic fields affected the lifetime of a radical pair. Benjamin and his co-workers have proposed that the two unpaired electrons, being created by the absorption of a single photon, exist in a state of quantum entanglement: a form of coherence in which the orientation of one spin remains correlated with that of the other, no matter how far apart the radicals move. Entanglement is usually quite delicate at ambient temperatures, but the researchers calculate that it is maintained in the avian compass for at least tens of microseconds — much longer than is currently possible in any artificial molecular system.



Possible Role of Tunneling in Olfactory Receptors

A biological function that might depend on electron tunnelling concerns our sense of smell. Recent experimental data suggest that the traditional models of a docking-type mechanism, based solely on the size and shape of odorant molecules, is inadequate to explain our sensitivity of olfaction. Turin et al. proposed a mechanism in which phononassisted inelastic tunnelling of an electron from a donor to an acceptor mediated by the odorant molecule gives a further level of selectivity to the process. A recent model proposed by Brookes et al. expanded on this idea, and presented evidence that such a mechanism fits the observed features of smell.



References

1. Lambert, Neill, et al. "Quantum biology." Nature Physics 9.1 (2013): 10-18.
2. Stoneham, A. Marshall, et al. "A new type of radical-pair-based model for magnetoreception." Biophysical journal 102.5 (2012): 961-968.
3. Vattay, Gabor, Stuart Kauffman, and Samuli Niiranen. "Quantum biology on the edge of quantum chaos." PloS one 9.3 (2014): e89017.
4. Romero, Elisabet, et al. "Quantum coherence in photosynthesis for efficient solar-energy conversion." Nature physics 10.9 (2014): 676-682.
5. Bordonaro, Michael, and Vasily Ogryzko. "Quantum biology at the cellular level—Elements of the research program." Biosystems 112.1 (2013): 11-30.
6. Solov'yov, Ilia A., Po-Yao Chang, and Klaus Schulten. "Vibrationally assisted electron transfer mechanism of olfaction: myth or reality?." Physical Chemistry Chemical Physics 14.40 (2012): 13861-13871.
7. Wiltschko, Roswitha, and Wolfgang Wiltschko. "Sensing magnetic directions in birds: radical pair processes involving cryptochrome." Biosensors 4.3 (2014): 221-242.
8. http://www.sciencemag.org/