Quantum biology

LIFE ON THE EDGE

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Summary and review of the above book

INTRODUCTION: This book is important in trying to bring a serious discussion of quantum biology to a lay audience. The continuing need to bring quantum biology into the mainstream is indicated by the sceptical tone of some of the book’s reviewers and the still sparse start-class article provided on Wikipedia. The main drive of the book is to indicate that quantum coherence is widespread in biological systems, and provides a vital means of increasing energy efficiency, without which life might not exist at all. The emphasis of the book can at times seem unbalanced with the pole position given to the avian compass and also a good deal of space devoted to rather speculative ideas about coherence in genes. In contrast, photosynthesis which appears to dominate the academic literature is played down to some extent. As in many books, things go less well where there is an attempt to discuss the implications for consciousness. The criticism of Penrose based ideas fails to note, either the strong similarities between molecules in photosynthetic quantum-coherent systems and those found in the cytoskeletons of neurons, or the resemblance of chloroplasts and mitochondria that are both closely connected to the their respective cytoskeletons. This allows the consciousness chapter to end by supporting an EM field theory of consciousness which may have some connection to synchrony, but does not provide any reason why the EM field could actually generate consciousness.

THE QUANTUM ENGINE

Starting from an apparently off-beat discovery of quantum coherence in low-temperature photosynthetic microbes in 2007, quantum coherence is emerging as a general principle of biological systems. The 2007 discovery of quantum coherence in microbes at low temperatures quickly extended to organisms at room temperatures and to multicellular plants. In this book, the authors extend the discussion to animal life, including quantum tunnelling in enzymes and the quantum entanglement based avian compass in European robins. It becomes apparent that rather then being an occasional oddity, quantum coherence has a
general role in raising the efficiency of biological processing, and it may even allow for energy efficiency above the limit proposed by Carnot.

**QUANTUM BIOLOGY & PHOTOSYNTHESIS**

In photosynthesis, the cytoskeleton, which is a cell’s support structure, and also the transporter of biomolecules within the cell, is connected to the chloroplasts that are central to the process of photosynthesis. The chloroplasts contain structures known as thylakoids that are filled with chlorophyll molecules. The surface of the thylakoids has antennae formed by chromophore light-harvesting molecules, of which chlorophyll is the best example. These have the function of capturing light.

The chloroplasts of photosynthetic organisms are filled with chlorophyll pigment molecules that convert light photons into excitons that then pass amongst the chlorophyll molecules on their way into the organism’s reaction centre. The excitons are wave-like superpositions that can explore different possible paths. Coherence or ‘quantum beating’ is detected during this transfer process, and the quantum walk with its choice of numerous paths makes this energy transfer more efficient than the classical random walk.

The chlorophyll molecule is made up of pentagonal arrays of carbon and nitrogen atoms enclosing a magnesium atom with a long tail of carbon, oxygen and hydrogen atoms. The magnesium atom’s outermost electron can be easily displaced to leave a positively charged ‘hole’. The positively charged ‘hole’ and, the now displaced, and negatively charged electron together comprise an ‘exciton’. This can be viewed as a positive and negative charge acting together as an energy store. However, the opposite charges of the exciton are attracted to one another, and if they combine their energy becomes lost as heat. A plant has to transfer the energy very rapidly to a photosynthetic reaction centre, in order to prevent random wandering of the energy amongst the numerous chlorophyll molecules, which would result in substantial heat loss. In a manner similar to the transfer of energy within enzymes, energy is transferred from one chlorophyll molecule to another. This is possible because of the tight packing of the molecules.

Studies of these photosynthetic systems have shown a 600 femtosecond oscillation symptomatic of quantum coherence, otherwise referred to as a ‘quantum beat’. This means the exciton is not following a single random route through the chlorophyll molecule, but is instead using the multiple routes allowed by quantum superposition. These multiple choices of route allow the selection of the quickest most energy-efficient route. This search strategy is sometimes called the ‘quantum walk’, as opposed to the less efficient classical ‘random walk’. Quantum coherent energy transfer was initially discovered in photosynthetic bacteria at low
temperatures, but later studies showed the process at room temperature and in plants as well as bacteria and algae.

**Reaction centre**

The reaction centre is the destination for the excitons involved in photosynthetic energy transfer. In the reaction centre, the energy of the excitons is converted into chemical energy used by plants and bacteria. Photosynthetic reaction centres are equipped with a pair of chlorophyll molecules known as a special pair because they are embedded in different environments, and vibrating at slightly different frequencies. The special pair structure is ideally tuned to inhibit the use of wasteful energy routes when delivering energy to an acceptor molecule, and may allow energy efficiency above the limit proposed by Carnot.

Electrons in the reaction centre are captured by the NADPH molecule, and this is involved in the manufacture of ATP, in a process similar to that found in mitochondria in animal cells. NADPH feeds electrons into a chain of enzymes that pumps protons out of the chloroplast membrane; the subsequent backward flow of the protons is used to produce ATP, thus providing the energy needs of the plant.

The process is very similar in both animals and plants demonstrating important similarities between apparently very different types of organism, with both using processes governed by quantum rules. It is apparent that the processing of both animals and plants evolved from the processing of bacteria and algae.

**Molecular vibration**

Recent quantum biology has thrown light on how life deals with molecular vibration or so-called noise. Molecular vibration or noise is seen to support rather than disrupt the quantum walk. Two types of molecular noise are used to support coherence; in the first place, there is low-level white noise spread across all frequencies, and derived from the jostling of all the molecules in a living cell. The second type of noise is more energetic, but limited to a small number of frequencies; this derives from the vibration of larger structures such as the chlorophyll molecules along with their associated protein scaffolding. The bends and twists of the protein scaffolding are sources of vibration, particularly at certain frequencies. These more restricted vibrations have been indicated to correct quantum coherence when white or lower frequency noise threatened to produce decoherence. These two types of vibration are seen as driving quantum coherence within cells. Some research suggests that there is a ‘Goldilocks’ zone between aimless wandering of energy in a very cool environment, and retarded transport in a very hot environment, with the temperature inside photosynthetic organisms lying in the Goldilock’s zone.
Breathing or respiration in animals involves a complex molecular process inside an organelle called the mitochondria, which appear to have evolved from bacteria that were originally independent organisms. The intricacy of the processing in mitochondria reflects the fact that they were once independent organisms. In terms of chemical complexity, respiration as performed by mitochondria is second only to photosynthesis.

Carbohydrates are broken down by the body to yield sugars such as glucose that are carried by the blood stream to the individual cells. Oxygen is also delivered to the cells by the blood stream. Within the cell, electrons in the outer orbits of carbon atoms are transferred to the NADH molecule. The electrons are passed along a chain of enzymes called the respiratory chain. At each step, the electrons drop to a lower-energy state, and the difference in energy drives enzymes that pump protons out of the mitochondria, and thus create a proton gradient between the outside and the inside of the mitochondria. The energy of this drives another enzyme called ATPase which in turn makes the ATP biomolecule, the basic energy producer of cells. Respiration is essentially the transfer of electrons through a series of enzymes.

Each electron transfer in this process is across a gap of several tens of angstroms. This was previously thought to be too much for conventional electrical transfer, but it is possible with quantum tunnelling where an electron that is not energetic enough to get over the top of a barrier is nevertheless able to tunnel through the barrier. Proton as well as electron tunnelling is thought to be important in the activity of enzymes. Enzymes are not static, but vibrate, and this may serve to bring particles close enough together to allow quantum tunnelling. Enzymes are vital to life in allowing biological processes to take place quickly enough to support life, and this means that the existence of life is in fact dependent on quantum tunnelling.

The European robin and some other creatures navigate by means of magnetoreception, which is the ability to detect the Earth’s magnetic field. This is very weak, and for an organism to detect it, the magnetic field must drive a chemical reaction in the organism’s body.
Free radicals and entanglement

When bonds between atoms are formed by sharing electrons, these electrons are quantum entangled, and also in what is known as a spin-singlet state. A spin-singlet state means that the electrons spin in opposite direction, so that their spin cancels out. The bond between the atoms can be broken, in such a way that there are lone electrons in the outer shells of the separated atoms. Such atoms are referred to as free radicals. However, despite the loss of the atomic bond, the entanglement of the singlet pair of electrons can persist. But although entangled, they may not remain just as a singlet pair, and it is possible for them to become a superposition of the singlet and the triplet state.

Triplet state: In the triplet state, the lone electrons of the outer shell can spin in the same direction leaving them with a net spin that can become aligned with the Earth’s magnetic field. Radical pairs are unstable so a very small effect such as that of the Earth’s magnetic field can decide the difference between a singlet and a triplet state.

Cryptochrome

The European robin’s ability to sense the magnetic field is triggered by a small amount of light at the blue end of the spectrum that enters a protein called cryptochrome in the bird’s eye. The first step is the absorption of a photon of blue light by a pigment molecule within the
cryptochrome protein. This leaves an electron vacancy after the energy of that photon has ejected an electron.

This vacancy can be filled by an electron donated from an entangled pair of electrons in an amino acid called tryptophan that exists within cryptochrome. However, the donated electron remains entangled with its partner, and this pair can form a superposition of singlet and triplet states in a chemical system that is very sensitive to the strength and angle of the magnetic field. This sensitivity to the direction of the bird's flight governs the outcome of a chemical reaction within the bird, which in turn drives its choice of flight direction in relation to the Earth's magnetic field.

Unlike the familiar compass that distinguishes between north and south, the robin's internal compass is an 'inclination compass' that distinguishes between the nearest pole and the equator. This means that the bird is able to distinguish the inclination of magnetic field lines, which are close to vertical near the pole, but move towards being parallel to the planet's surface as they approach the equator; this is called an inclination compass measuring the angle between the field lines and the Earth's surface to give the relative position between the pole and the equator.

**CONSCIOUSNESS**

As in many books, the weakest chapter is the one that attempts to discuss consciousness. After a somewhat padded section at the beginning of the chapter, the authors have a go at what everyone in consciousness studies does, which is to refute Penrose. What is curious here is the failure to note the similarity between the molecules involved in photosynthetic quantum coherence and those present in the cytoskeleton of neurons, nor the similarity between chloroplasts in plants and mitochondria in animals, both of which are closely connected to the cytoskeleton.

Unusually for a mainstream theorist, the author is interested in Bernroider's work on quantum features in ion channels, a study which has been the target of aggressive but uninformed attacks by the usual braying chorus claiming to detect pseudo-science. However, the author is prepared to accept the principle that quantum processes could operate in the
Bernroider and Summhammer's (2012) simulation of an ion passing through a voltage-gated channel showed that the ion was delocalized, meaning it behaves as a wave rather than a particle, during this process; moreover, this ion waves oscillates at a high frequency that transfers energy to the surrounding proteins. This transfer of energy cools the ion itself, and this helps to preserve its quantum state. The degree of cooling may determine whether sodium or potassium ions are transferred, which in turn determines the polarization of the neural membrane.

The authors attempt to link Bernroider to McFadden's EM field theory of consciousness. While there are claims for an EM role in producing synchrony in consciousness-related brain processing that is another matter from actually producing consciousness. It is not apparent how the EM field in the brain is somehow physically distinct from the apparently unconscious EM field in the rest of the universe, or how a boundary presumably arises between the brain's conscious EM field and the unconscious field outside.

What is more notable is the strong connection between the neural membrane where Bernroider has observed quantum coherence in ion channels and the cytoskeleton within the neuron, with its strong resemblances to the quantum coherent structures found in photosynthesis.