On the Photonic Cellular Interaction and the Electric Activity of Neurons in the Human Brain

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Abstract. The subject of Ultraweak Photon Emission (UPE) by biological systems is very fascinating, and both evidence of its effects and applications are growing rapidly due to improvements in experimental techniques. Since the relevant equipment should be ultra-sensitive with high quantum efficiencies and very low noise levels, the subject of UPE is still hotly debated and some of the interpretations need stronger empirical evidence to be accepted at face value. In this paper we first review different types of interactions between light and living systems based on recent publications. We then discuss the feasibility of UPE production in the human brain. The subject of UPE in the brain is still in early stages of development and needs more accurate experimental methods for proper analysis. In this work we also discuss a possible role of mitochondria in the production of UPE in the neurons of the brain and the plausibility of their effects on microtubules (MTs). MTs have been implicated as playing an important role in the signal and information processing taking place in the mammalian (especially human) brain. Finally, we provide a short discussion about the feasible effects of MTs on electric neural activity in the human brain.

1. Electromagnetic Radiation and Living Systems

The relation of *biological systems* and *electromagnetic radiation* can be discussed from different points of view. Some of the interesting interactions are as follows:

- *Efficient excitation energy transfer of light by photosynthetic system*

    Recently published experimental data in photosynthesis have provided support for the hypothesis that the system uses some nearly100% efficient excitation energy transfer of light (which means almost without dissipation), and it is suggested that quantum coherence plays an important role in this mechanism [65]. This subject has attracted the attention of representing physics and chemistry, especially quantum information theorists who aim to find

out how quantum coherence makes the system so efficient. These inquiries resulted in the subject of *quantum biology* becoming a very popular topic in recent years.

• *Response of mammalian cells to near-infrared light*

In a series of studies spanning a period of some 25 years G Albrecht-Buehler (AB) demonstrated that living cells somehow have a molecular analogue of an *eye* which can process light information and react in an *intelligent* manner [66–68]. In his studies microtubular structures especially *centrioles* have been identified as the main candidates for light information processors [68]. He further showed that electromagnetic signals are the triggers for cell repositioning in physical space. It is still largely a mystery how the reception of electromagnetic radiation is accomplished by the centriole. Another mystery related to these observations is the original electromagnetic radiation emitted by a living cell [69]. Using pulsating infra-red signals scattered off plastic beads AB mimicked the effects of the presence of another living cell in the neighbourhood. The question that still remains unanswered and which we address here is the source of infra-red radiation speculated by AB to originate in the mitochondria and later on demonstrated to be correct using quantum mechanical arguments [69].

• *Production of light by living systems*

Photon emission by biological systems can be produced by different mechanisms. In general, light emission can be classified into three groups: (1)Induced light emission, (2)Spontaneous light emission and (3)Black-Body radiation. Here, we discuss a subclass of the second group which is called *Ultraweak Photon Emission* (UPE). All living cells of plants, animals and humans continuously and spontaneously emit ultraweak photons (ultraweak electromagnetic waves) in the optical range of the spectrum, which is associated with their physiological states and can be measured with specific experimental techniques [57]. In different literature sources the UPE is referred to by different names such as ultraweak emission, biophotons, ultraweak bioluminescence, self-bioluminescent emission, photoluminescence, delayed luminescence, ultraweak luminescence, spontaneous chemiluminescence, ultraweak glow, biochemiluminescence, metabolic chemiluminescence, dark photobiochemistry and bioluminescence.

• *Transmission of light by living systems*

Recently, Sun et al. [70] demonstrated that a single neuron can conduct photon signals. Moreover, Wang et al. [71] presented an experimental proof of the existence of spontaneous and visible light induced UPE form freshly isolated rats whole eye, lens, vitreous humor and retina [71].

• *Bio-communication*

There is growing experimental evidence that cells and tissues may interact over distances even when chemically isolated, most likely via electromagnetic fields [51]. Stemming from the pioneering experiments of Gurwitsch in 1920s [52], some researchers confirmed that cellular interactions can be mediated by electromagnetic fields e.g. see [53–56].

Overwhelming majority of the experiments focused on the study of electromagnetic cellular interactions examined in the optical region. For the review of the historical and recent theories and experiments on electromagnetic cellular interactions see [51].

2. UPE emission inside neurons

There are experimental indications that ROS and RNS are responsible for UPE production in living systems [42,43] and are also necessary for synaptic processes and normal brain functions. Numerous findings have provided evidence of fundamental signal roles of ROS and RNS in cellular processes under physiological conditions. Free radicals and their derivatives act as signaling molecules in cerebral circulation and are necessary for molecular signaling processes in the brain such as synaptic plasticity, neurotransmitter release, hippocampal long-term potentiation, memory formation, etc. [57–63]. Recently Bókkon et al. put forward a molecular hypothesis about biophysical picture representation (intrinsic biophysical virtual visual reality) which states that external photonic signals from an object are converted into electrical signals within the retina and are conveyed to V1 and transformed into regulated UPE via redox processes inside V1 neurons [42,43]. Accordingly, spike-related retinotopic electrical signals - along classical axonal-dendritic pathways can produce synchronized biophotonic signals by redox processes within synchronized retinotopic V1 neurons. In this model, small groups of retinotopic visual neurons can function as visual pixels appropriate to the topological distribution of photonic signals on the retina. As a result, we can get an inherent biophysical picture of the object generated by UPE in early retinotopic V1 during visual perception and imagery [43,44]. This novel biophysical hypothesis may revive the Kosslyns depictive theory [45] and the *homunculus* (mind's eye) hypothesis [46]. Now the question arises how can this hypothesis be supported experimentally? It should be noted that visual circuits that are normally involved in the detection of visual perception features are also responsible for the generation of the phosphene light perception [43,48]. Recently Wang et al. presented [49] the first experimental evidence for the existence of spontaneous and visible light induced UPE from in vitro freshly isolated rats whole eye, lens, vitreous humor and retina. In addition, recently, Dotta and Persinger [50] measured significant increases in biophoton emission from near the right hemisphere but not the left for most volunteers when they imagined a white light in a dark room compared to simply casual thinking. These results support the above biophysical picture representation notion [42,43] and also indicate a more essential role of right hemisphere in visual imagery.

3. Toward coherent states in biological systems?

Biological systems operate within the framework of irreversible thermodynamics and nonlinear kinetic theory of open systems, both of which are based on the principles of non-equilibrium statistical mechanics. The search for physically-based fundamental models in biology that can provide a conceptual bridge between the chemical organization of living organisms and the phenomenal states of life and experience has generated a vigorous and so far unresolved debate [1,2]. Recently published experimental evidence has provided support for the hypothesis that biological systems use some type of quantum coherence in their functions. The nearly 100% efficient excitation energy transfer in photosynthesis is an excellent example [3]. Quantum coherence is a plausible mechanism responsible for the efficiency and co-ordination exhibited by biological systems.

The hypothesis invoking long-range coherence in biological systems was proposed by H. Fröhlich [4–6] and followed by detailed investigations by Tuszynski *et al.* [7–21], Pokorný [22–24], Mesquita *et al.* [25–28] and others for over three decades. The possible role played by coherent states manifested outside low temperature physics has attracted considerable interest in both the physics and biology communities. The original Fröhlich model was very general and did not limit

the mechanism of biological coherence to any particular cellular structure. In his model, when the energy supply exceeds a critical level, the dipolar ensemble of biologically relevant molecules populates a steady state of non-linear vibrations characterized by a high degree of structural and functional order [51]. This (electrically polarized) ordered state expresses itself in terms of long-range phase correlations, which are physically similar to such phenomena as superconductivity and superfluidity, where the behaviour of particles is collective and inseparable.

3.1. The Wu-Austin Hamiltonian

There are different approaches possible to be adopted in the analysis of the coherent state generation in biological systems based on Fröhlich coherent states as described in the works of Mesquita et al. [25–27]. The Wu-Austin Hamiltonian [29–31] is the basis of a quantum mechanical approach to Fröhlich coherent states. Bolterauer and Ludwig [72] investigated the thermodynamics of Wu and Austin system quantum mechanically and have shown that even without pumping their Hamiltonian can give rise to Bose condensation. However, the Wu-Austin Hamiltonian has the unphysical property of having no finite ground state. Turcu [32] have obtained a master equation for Fröhlich rate equations. The main aim of his work was to show that there is a rich family of Hamiltonians, modeling differently the pump and the thermal bath, from which the same Fröhlich-like rate equations can be obtained. We believe that the system of neuronal MTs is a good candidate for being described by one of these Hamiltonians. MTs are composed of tubulins which can be considered as biological electric dipoles. Pokorny provided a detailed analysis of the coherent states in MTs. He experimentally observed resonance effects in MTs in the 10 MHz range [22–24].

3.2. Criticism on Coherent states in living systems

Recently, Reimers et al. [2] have shown that a very fragile Fröhlich coherent state may occur at sufficiently high temperatures and concluded that there is no possibility for the existence of Fröhlich coherent states in biological systems. Also they provided several diagrams in terms of effective temperature which was defined by the authors as $T_{eff} = \frac{T_s}{T}$, where T_s is the temperature of system and T is the temperature of the thermal bath. Physically, the parameter is wrong because a temperature ratio is a unitless quantity not a quantity with the unit of temperature. They have used the effective temperature parameter for the Wu-Austin Hamiltonian [29–31] and considered it in the high temperature limit. Their diagrams are mostly based on the effective temperature parameter and hence are, in our opinion, not acceptable due to the self-contradictory arguments used in their derivations. For more details see [73]. In fact, the criticism raised by Reimers et al. [2, 37] is mainly directed against the so-called Orch OR model which was proposed by Penrose and Hameroff to introduce a physical basis for consciousness. In some formulations of the OrchOR model, a manifestation of quantum coherence involved Fröhlich coherent states in MTs [33–35]. MTs are highly ordered in the neurons of the brain and can indeed be regarded as providing support for Fröhlich coherent states. In this context, the conclusions of our discussion above also apply to MTs. Therefore, we believe that it is still hypothetically possible to generate Fröhlich coherent states in MTs. However, another issue that arises when considering quantum states for MTs is the rapid *decoherence* problem. The question is how it is possible for MTs to be in a coherent state while the environment is relatively hot, wet and noisy? According to decoherence theories, sufficiently strong interactions with the environment cause decoherence, which destroys quantum effects [36]. For macroscopic particles there are two main *natural* ways of experiencing this decoherence: First, decoherence due to collisions with other particles and second the thermal emission of radiation due to the internal heat of an object [38, 41]. Tegmark [39] has calculated decoherence times for MTs based on

the scattering between MTs and environmental particles. Hagan *et al.* [40] have shown that Tegmark used wrong assumptions for his investigation of MTs. Another main objection to the estimate in equation (7) is that Tegmarks formula yields decoherence times that increase with temperature contrary to well-established physical laws and the behavior of quantum coherent states. In view of these (and other) problems in Tegmarks estimates, Hagan *et al.* [40] assert that the values of quantities in Tegmarks relation are incorrect and thus the decoherence time should be approximately 10^{10} times larger leading to a ms range of values for typical decoherence times. According to Hagan *et al.*, MTs in neurons could possibly avoid decoherence via several mechanisms for quantum processing to occur there. Tegmark introduced a function for the decoherence rate [47] which is composed of two parts: one for short wavelengths and the other for long wavelengths. Every scattering calculation based on the Coulomb interaction and Tegmarks decoherence rate function leads to decoherence times that are proportional to temperature according to relations such as $\tau_{dec} \propto \sqrt{T}$, $\tau_{dec} \propto \sqrt{T^2}$, $\tau_{dec} \propto \sqrt{T^3}$, etc. Therefore, it can be expected that subsequent calculations based on these criteria are flawed in the high-temperature limit, i.e. as temperature approaches infinity, decoherence time increases too, and if temperature approaches absolute zero, decoherence time approaches zero, a very unphysical conclusion.

4. Microtubules and centrioles

MTs are biological hollow cylinders with a 17-nm inner diameter and a 25-nm outer diameter (see Figure1), composed of units called tubulin dimers, each of which has the dimensions $4nm \times 8nm \times 6nm$ [57]. MTs have been implicated as playing an important role in the signal and information processing taking place in the mammalian, and especially human brain. Earlier, MTs have been considered as optical cavities [74] with quantum properties [75].
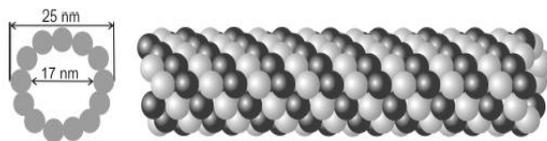

Figure 1. Microtubule (MT) is a biological hollow cylinder

It is worth stressing here that centrioles and cilia, which are complex microtubular structures, are involved in photoreceptor functions in single cell organisms and primitive visual systems. Cilia are also found in all retinal rod and cone cells. The dimensions of centrioles and cilia are comparable to the wavelengths of visible and infrared light (see Figure 2) [57]. Albrecht-Buehler has demonstrated that living cells possess a spatial orientation mechanism located in the centriole. This is based on an intricate arrangement of MT filaments in two sets of nine triplets, each of which is perpendicular to the other. This arrangement provides the cell with a primitive *eye* that allows it to locate the position of other cells within two to three degrees of angular accuracy in the azimuthal plane and the same accuracy with respect to the axis perpendicular to it [66].

5. Mitochondria and Microtubules

Both mitochondria and microtubules can form dynamic networks in neurons. Moreover, the refractive index of both mitochondria and microtubules is higher than the surrounding cytoplasm, whose consequence is that mitochondria and microtubules can act as optical waveguides, i.e. electromagnetic radiation (UPE) can propagate within their network [44, 64].
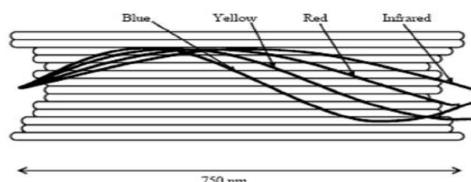
Figure 2. The dimensions of centrioles and cilia are comparable to the wavelengths of visible and infrared light

Regulated UPE (from mitochondrial radicals and excited molecules) can induce polymerization of microtubules. Then, according to the quality of absorbed UPE from mitochondria, microtubules can transport mitochondria in accordance with information processes in cells and neurons. There can be a mutual cross-talk/regulation between mitochondria and microtubules by redox and free radical processes [44].
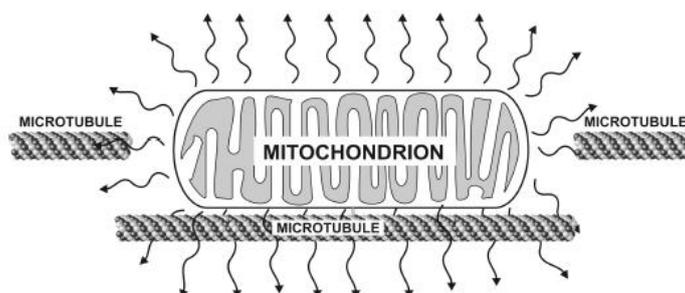
Figure 3. The light production by mitochondria can interact with MTs

6. MTs dynamics and Electric Neural Activity of Neurons

Electrodynamic interactions between various cytoskeletal structures, with MTs playing a central role, and ion channels crucially regulate the neural information-processing mechanism. These interactions involve long-range ionic wave propagation along microtubule networks (MTNs) and actin filaments (AFs), and exhibit subcellular control of ionic channel activity. Hence, they have an impact on the computational capabilities of the entire neural function. Cytoskeletal biopolymers, most importantly AFs and MTs, constitute the basis for wave propagation, and interact with membrane components, leading to a modulation of synaptic connections and membrane ion channels. Association of MTs with AFs in neuronal filopodia guides MT growth and affects neurite initiation [57]. Electric signaling by AFs and MTs may play active roles in coincidence detection and storage of spatiotemporal patterns of inputs, and signaling within the cytoskeleton may be particularly critical to information storage over time scales longer than LTP times. The initial route to the MT network could be through the AFs concentrated in the spines. Inputs to arbitrary sites in the neuron can be transmitted from the neuronal membrane to AFs in spines via scaffolding proteins and signal transduction molecules. Electric signals can then be transmitted, utilizing AF cross-linker proteins to MTs, and subsequently through microtubule associated proteins (MAPs) and signal transduction molecules to other MTs in the network [57].

7. Conclusion

It has been shown that the intensity of UPE is in direct correlation with neural activity, cerebral energy metabolism, EEG (Electroencephalography) activity, cerebral blood flow and oxidative processes [76, 77]. From a theoretical point of view, the interaction of mitochondrial UPE and MTs can take the MTs into coherent states. The synchronous and coherent vibrations of billions of electric dipoles of biomolecules cannot be ignored in the EEG diagrams. MTs are particularly numerous in the brain where they form highly ordered bundles and are the best candidate for long range coherence and large synchrony [57]. In addition to electrical and chemical signals propagating in the neurons of the brain, signal propagation may take place in the form of UPE too. We believe that the role of UPE in the brain merits special attention (see [57]).

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