Entanglement Between Bio-Photons and Tubulins in Brain: Implications for Memory Storage and Information Processing

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ABSTRACT

Entanglement is an integral part of the quantum information processing and quantum computations that have been proposed to take place in the brain. Microtubules and photons are agents that have been mainly discussed as related factors in quantum computations of the brain. In the present article, we report the dynamical behaviour of entanglement between Tubulin states and bio-photons and their implication for the previously proposed memory storage in Microtubules. We had used Von-Neumann entropy to quantify entanglement and we showed that the degree of such entanglements depend on coupling constant (λ), detuning (Δ) and number of bio-photons. The entanglement between bio-photon and tubulin in human brain is controlled by coupling constant in different parts of brain.

Key Words: Bio-photon, tubulin, microtubule, entanglement, 'Orch OR' model

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1. Introduction

Discovery of the ultra-weak photon emission (UPE) dates back to 1920's when a former Soviet Union's cell biologist named Gurwitsch reported photon emissions from biological objects (Gurwitsch, 1923). This phenomenon is also referred to as mitogenic radiation, dark luminescence, low level chemo luminescence and bio-photons (Grass *et al.,* 2004). Chemical reactions in the cell such as oxidation, which produce free radicals, are considered as the main cause of bio-photon emission. It is hypothesized that emissions are duo to exited free radicals which emit bio-photons during their de-excitation. This mechanism is supported by many experimental evidences like augmentation of bio-photon emissions by reducing tissue's antioxidants (Ursini *et al.,* 1989) or increased bio-photon emissions after addition of reactive oxygen species (ROS) (Boveris *et al.,* 1980). Even in rat's brain tissue UPE is correlated with cerebral energy metabolism and oxidative stress (Kobayashi *et al.,* 1999).

On the other hand, several lines of evidence had showed that the living creatures can communicate through ultra-weak photon emissions. A brief list of these evidences is presented in Table 1.

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Reference, Year	Finding
Gurwitsch and Gurwitsch, 1959	Bio-photonic communication between onion roots and mitosis induction with bio-photons
Albrecht-Buehler, 1992	*Tissue cells arrange themselves based on the pattern of tissue cells on the other side of a glass.*
Shen et al., 1994	*Pig's neutrophil granulocytes induce degranulation in each other with bio-photons*
Musumeci et al., 1999	*Two group of yeast cells affect each other's growth positively with bio-photons*
Jaffe, 2005	*Germinating Fucus-zygotes probably direct their growth with bio-photon emissions produced by their living substrate*
Fels, 2009	*Paramecium caudatum populations affect each other's growth with bio-photon emissions*

Considering these reports, it sounds that free radical's de-excitation couldn't be the final explanation for emission of bio-photons. In addition to the mentioned bio-photonic communications, associative learning based on photon detection in a unicellular organism was reported by Armus et al (2010). In which *Paramecium caudatum*'s ability to associate attractive stimuli to illumination contrast in its environment (photon detection) was reported. Therefore, photon detection and memory storage structures should exist in paramecium.

Thus we assume an explanation that can account for subcellular memory and photonic interactions is needed. In order to gather the mentioned observations under a framework, it is possible to use some concepts of the Orchestrated Objective Reduction (Orch-OR) model for consciousness (Hameroff and Penrose, 1996). Based on this model, human brain contains many quantum subsystems. Information between these sub-systems is processed and communicated with the help of quantum mechanics and its most important property, entanglement. Besides, theory holds that cognition could be achieved in sub cellular scale i.e. in microtubules (MTs). Moreover, some scholars proposed that the memory can also be stored in microtubules (Hameroff *et al.,* 2010). Computer simulations (Craddock *et al.,* 2012) suggested that this memory formation can be mediated through phosphorylation of MTs by CAMKll protein.

However, if memories are stored in microtubules or if MTs are involved in information processing, the informational content of MTs remains isolated within MTs. Microtubules should be able to retain the information alongside its transition. One should come up with a satisfactory explanation that can integrate the concepts of unicellular learning, photonic communication and possible informational interaction between MTs. It is therefore the main aim of the present work to see whether an acceptable formulated physics can be used to integrate these concepts or not. We will use entanglement with the help of Hamiltonian and von Neumann entropy to address this question in more detail.

2. The Model Hamiltonian

The model of two-level quantum systems can be exerted into tubulins. Ground state $|g\rangle$ and excited state $|e\rangle$ are modeled by tubulin dimer (Mavromatos and Nanopoulos, 1998, Tuszyński and Dixon, 2001; Mavromatos *et al.,* 2002, Rahnama *et al.,* 2011). As compare with two-level quantum systems we can introduce Pauli operators for tubulin states, $\hat{\sigma}_+$, $\hat{\sigma}_-$ and $\hat{\sigma}_z$, where $\hat{\sigma}_+ = |e\rangle\langle g|$ makes a transition to the excited state, the operator $\hat{\sigma}_- = |g\rangle\langle e| = \hat{\sigma}_+^\dagger$ takes it into ground state and $\hat{\sigma}_z = |e\rangle\langle e| - |g\rangle\langle g|$ is fluctuation operator. It was reported by Wang et al (2011) that bio-photons in the brain are in the visible region of electromagnetic spectrum. On the other hand, the frequencies of transitions between tubulin states are the order of THz (Tuszyński and Dixon, 2001). Therefore, bio-photons of brain can make a transition between tubulin states and thus, we can use the model of interaction between two-level systems (tubulins) and one-mode quantized electromagnetic field (bio-photons) for this interactions.

Hamiltonian of this interacting system in the rotating wave approximation (Scully, 1997) is:

$$H = H_{Tubulin} + H_{Biophoton} + H_{Interaction}$$
$$= \frac{1}{2}\hbar\omega_0 \hat{\sigma}_z + \hbar\omega \hat{a}^\dagger \hat{a} + \hbar\lambda(\hat{\sigma}_+ \hat{a} + \hat{\sigma}_- \hat{a}^\dagger) \quad (2.1)$$

Where $H_{Tubulin}$ represents the Hamiltonian of tubulin, $H_{Biophoton}$ is the bio-photon Hamiltonian operator and $H_{Interaction}$ is the Hamiltonian operator for the interaction between tubulin and bio-photons. Here, ω_0 and

ω are frequencies of tubulin transitions and bio-photons, respectively. $\Delta = \omega_0 - \omega$ is detuning of frequency and $\hat{a}\,(\hat{a}^\dagger)$ is bio-photon annihilation (creation) operator.

In Hamiltonian (2.1), λ is a factor that represents coupling between tubulin and bio-photon states and $\lambda = \frac{dg}{\hbar}$, where d is the tubulin dipole moment and

$$g \approx \frac{1}{2}\sqrt{\frac{\hbar\omega}{\varepsilon V}}$$

(Mavromatos *et al.,* 2002). Based on this coupling, we expected that Entanglement between tubulin and bio-photonic states depends on λ.

Quantum state of tubulin at time t and quantum state of electromagnetic field are represented by $|tubulin\rangle = C_g(t)|g\rangle + C_e(t)|e\rangle$ and $|biophoton\rangle = \sum_{n=0}^{\infty} C_n|n\rangle$, respectively. $|C_n|^2$ is the probability of detection of bio-photon and $|n\rangle$ is its number state known as Fock states. Total state of system is $|\psi(t)\rangle = |tubulin\rangle \otimes |biophoton\rangle$. All coefficients in total state are obtained by solving Schrödinger's equation of this state $i\hbar \, {}^{d}\!/_{dt} |\psi(t)\rangle = H_{Interaction}|\psi(t)\rangle$. Assuming that, the tubulin is in the excited state $|e\rangle$ at the time $t = 0$, the total state determined by (Scully, 1997).

$$|\psi(t)\rangle = \sum_n [C_{g,n+1}(t)|g,n+1\rangle + C_{e,n}(t)|e,n\rangle] \quad (2.2)$$

Where

$$C_{e,n}(t) = C_n[\cos(\frac{\Omega_n t}{2}) - \frac{i\Delta}{\Omega_n}\sin(\frac{\Omega_n t}{2})]e^{i\Delta t/2} \quad (2.3)$$

$$C_{g,n+1}(t) = -C_n \frac{2i\lambda\sqrt{n+1}}{\Omega_n}\sin(\frac{\Omega_n t}{2})e^{-i\Delta t/2} \quad (2.4)$$

and $\Omega_n^2 = \Delta^2 + 4\lambda^2(n+1)$

3. Dynamics of the von Neumann entropy

We want to quantify the entanglement for information processing and communicating through the tubulins. Although there are a number of measures to quantify entanglement (Vedral *et al.,* 1997), we use the von Neumann entropy which maybe directly related to information theories (Wei *et al.,* 2003). For a bipartite system containing parts A and B, the von Neumann measure of entanglement is defined as,

$$\begin{aligned} S_{AB} &= -Tr[\rho_A \log_2 \rho_A] \\ &= -Tr[\rho_B \log_2 \rho_B] = S_{BA}, \end{aligned} \quad (3.1)$$

Where the reduced density matrices are

$$\rho_{A(B)} = -Tr_{B(A)}[\rho_{AB}] \quad (3.2)$$

In Eq.(3.2), the total density operator (matrix) is defined as $\rho_{AB} = |\psi_{AB}\rangle\langle\psi_{AB}|$, with $|\psi_{AB}\rangle$ being the state of the combined system. If the state of the composite is not a stationary one, from the definition of ρ_{AB}, it is clear that the degree of entanglement evolves with time. By following these procedures for total state of bio-photon-tubulin system, the evolution of entanglement is determined as:

$$\begin{aligned} S(t) = -\{&|C_n|^2(\cos^2(\tfrac{\Omega_n t}{2}) + (\frac{\Delta}{\Omega_n})^2\sin^2(\tfrac{\Omega_n t}{2})) \times Log_2[|C_n|^2(\cos^2(\tfrac{\Omega_n t}{2}) + (\frac{\Delta}{\Omega_n})^2\sin^2(\tfrac{\Omega_n t}{2}))] \\ &+ 4(n+1)|C_n|^2(\frac{\lambda}{\Omega_n})^2\sin^2(\tfrac{\Omega_n t}{2}) \times Log_2[4(n+1)|C_n|^2(\frac{\lambda}{\Omega_n})^2\sin^2(\tfrac{\Omega_n t}{2})]\} \end{aligned} \quad (3.3)$$

4. Results and Conclusion

In this section, we present the time variation of von Neumann entropy, Eq. (3.3), as the degree of bio-photon and tubulin entanglement. To this end, we assume that initially the system is prepared in a separable (*unentangled*) state $|\Psi(0)\rangle = |n\rangle \times |e\rangle$. This defines a state in which the tubulin is described by $|e\rangle$ and (n) photons are present. The time evolution of the bio-photon and tubulin entanglement is then computed *via* the procedure described at the end of the previous section. This procedure and a glance at the Hamiltonian of Eq. (2.1) indicate that the dynamics of entanglement between bio-photon and tubulin strongly depends upon the coupling factor λ and the detuning, $\Delta = \omega_o - \omega$ and number of photons (n).

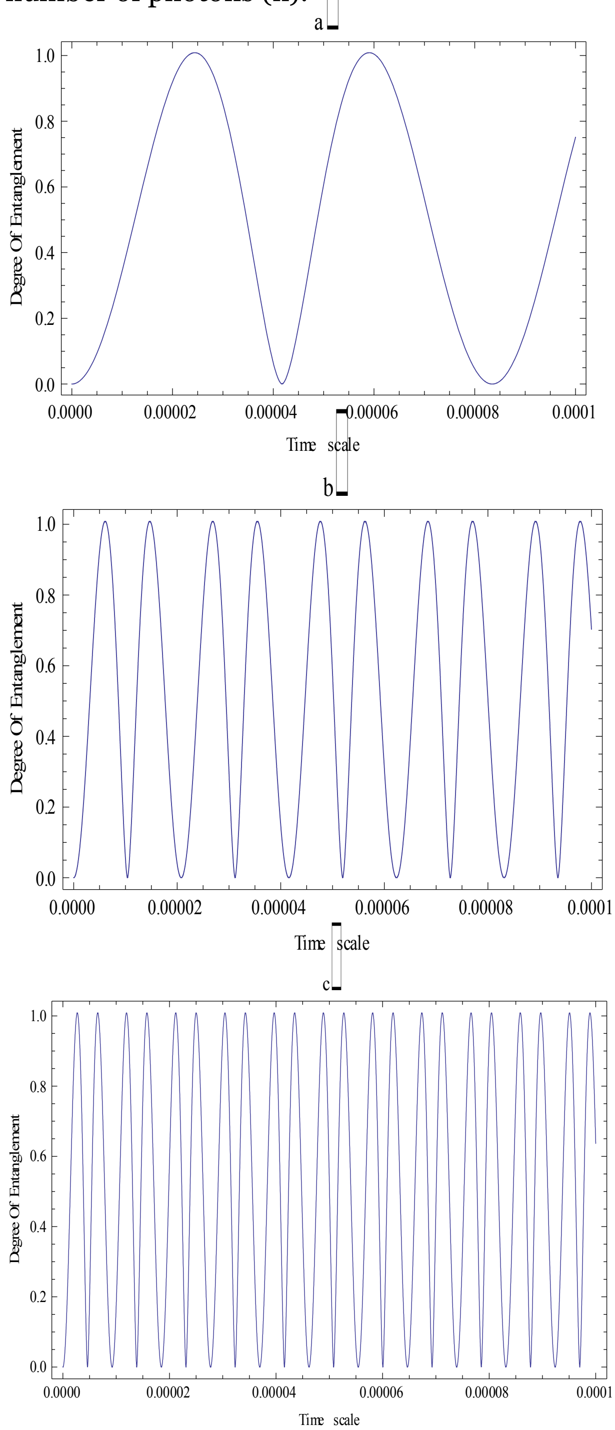

Figure 1. Degree of entanglement versus time at $\Delta = 0$, $\lambda = 100$ and (a) $n = 10$, (b) $n = 20$, (c) $n = 30$.

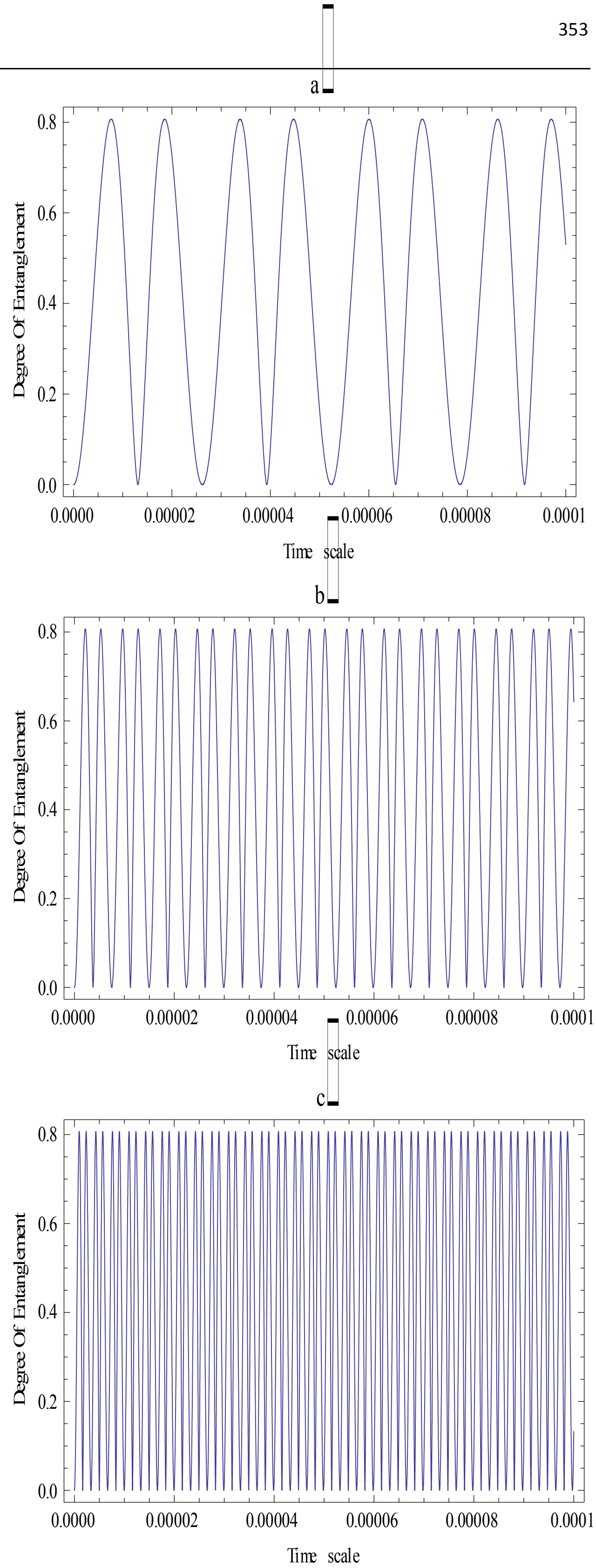

Figure 2. Degree of entanglement versus time at $\Delta = 0.1$, $n = 10$ and (a) $\lambda = 100$, (b) $\lambda = 150$, (c) $\lambda = 200$.

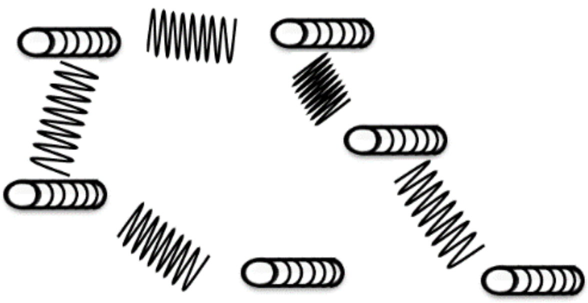

Figure 3. A schematic representation that depicts the possible interactions between UPEs and Microtubules. These interactions can be regarded as an information transmission mechanism.

In Figure 1 we illustrate the behavior of entanglement versus time. Increasing in the number of bio-photons reduce the period of entanglement. Figure 2 also shows that reduction in the period of entanglement is a result of increasing in value of λ .

Moreover, it is observed from Figure 1 and Figure 2 that as the detuning is decreased the bio-photon and tubulin states become more entangled. Results of this research shows that processing and communicating of information through tubulins are strongly affected by coupling factor λ and detuning Δ and number of bio-photons.

Particularly, these results have multiple implications. First, our result can be an alternative explanation for the increase of UPE caused by visual imagination (Dotta *et al.,* 2012) and the correlation between UPEs and EEG (Van Wijk *et al.,* 2008 and Rahnama *et al.,* 2011). We assume that our proposed entanglement -if exists- can be the cause of the increased UPE due to *information transfer* in the brain.

Second, Entanglement between photons and tubulins can also be the mechanism in which hypothetical stored information in tubulins can be transmitted throughout the biological systems (from paramecium to human brain). However, we believe further investigations are absolutely necessary to approve the proposed relationships in these phenomena.

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