Quantum Entanglement Oscillations brings Intracellular Communication

Vahideh Tahmoorian Askari Boroojerdi[1,3], Pouya ZakerAbbasi[2]
1.Tabriz University, Tabriz, Iran
2.Amir kabir university of technology, Tehran, Iran
3.Azad university(Islamshahr campus)

Abstract: We investigate the time evolution of quantum entanglement between tubulin dimmers and mitochondrial bio photons in a cellular system. In this model tubulin dimmers and bio photons take the role of qubits and quantum channel. The dynamics of quantum entanglement between these two parties, which is essential in quantum information processing, is discussed. For bio photons in thermal state we show the frequency dependence of the entanglement dynamics.

Keywords – Bio Photon, Entanglement, qubit, tubulin dimmer

I. INTRODUCTION

One of the most surprising elements of quantum mechanics is inseparability, or non-locality. It supposes that all the things are connected provided that they are once interacted with each other. In other words all quantum entities can be affected by their spatially separated relatives[1]. This is the so called quantum entanglement that Schrodinger proposed for the first time. Entanglement is a key feature in quantum mechanics and quantum information theory[2-3]. Recently, quantum mechanics in biological systems have attracted lots of attention. A major interest is toward brain sciences. It is hypothesized that reality comes from the wave function collapse[4-5]. So they believe that classical reality arises from brain cells decoherence. The introduction of quantum coherence in brain cells can probably open up a new window to the brain functionality as a quantum computer. Many functions in biological systems also can be linked to superposition of spatially separated electrons participating in a molecular interaction including antigen-antibody, neuro transmitter- receptor, protein self-assembly and so on[6].

Quantum entanglement in living systems was claimed impossible even by quantum mechanics pioneers[7]. It should be noted that many quantum features are destroyed in a large, warm, wet, noisy environment. Therefore it seems that quantum effects don't survive in the vivo. Frohlich proposed a model of biological systems that supply energy within a certain frequency to prepare longitudinal coherent electric modes[8]. Although he suggested that quantum phenomena is in charge of signal transfer in biological systems, nevertheless Tegmark in his paper in 2000, estimated a microtubule decoherence time scale smaller than what Frohlich proposed[9]. So he refused any quantum mechanical role in the brain. Others[10][11] though, show that ,even with that skepticism, quantum effects have still significant role in brain's functionalities.

Recently experimental demonstrations of wave like transfer of energy in some light absorbing molecules in plants protects the idea of quantum biology[12]. On the other hand it is proved that brain cells mitochondria can emit bio photons[13]. Cognitive processes in the brain for learning and recognizing patterns introduced different mechanisms including neural network. A model of neural network that is composed of interconnected processing units, the so called neuron cells, is proposed in the brain[13-15]. Despite this transport mechanism has been experimentally approved, faster mechanisms are proposed. Neural network models require information to move backward from axon to dendrite. The previous mechanisms that support this requirement were classical. One classical mechanism explains such backward information, by electronic signals that are transferred intracellular through material transport.

Another model is based on Microtubules functionality. Microtubules are composed of 13 arrays of tubulin dimer proteins to form cytoskeletons of the cell which can work as transport channels for communication between remote parts of the cell. Due to the redistribution of electric charges in tubulin dimmers, two different conformations with two different electrical dipole moment directions exist. These two conformations can be taken as a two state system. Different classical mechanisms are proposed based on microtubule signal propagation[16-21]. Recently a new quantum electrodynamics cavity model of microtubule is also developed[10,22].

On the other hand, Bose et al. show that irrespective of the temperature of the field, for a thermal state of a cavity field, the entanglement can arise provided that a subsystem is pure [18]. In this paper the quantum entanglement between cellular bio-photons and tubulin states is investigated. We show that the entanglement between a two-state tubulin dimmer and bio photons oscillates.

This paper is organized as follows; in sec. II we describe our model and write equations. We discuss the results in Sec. III. Finally we conclude in Sec. IV.

II.MODEL AND EQUATIONS

Microtubules are composed of two hydrophobic proteins that each one has one free electron. There are two possible location for this free electron which make two conformations that is called α and β (Fig.1). In this way Tubulin can be viewed as a two-state quantum mechanical system[17][10]. We also take this two state system interact with the thermal reservoir of mitochondrial bio photons. The simplest model proposed to show the light-matter interaction is JCM model. The JCM interaction between the two-state tubulin and bio-photon field that is created in mitochondria, is given by the following Hamiltonian

$$H_{t-b} = g(|\alpha\rangle\langle\beta|a_b + a_b^+|\beta\rangle\langle\alpha|) \quad (1)$$

Where a_b and a_b^+ are the annihilation and creation operators of the field mode, respectively. Here g is the coupling constant corresponding to transition between states.

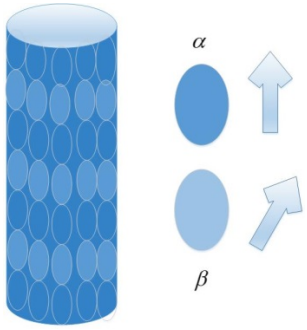


Fig.1 Microtubule structure, with the 20^0difference in dipole moment directions

We take the reservoir in a thermal state. So the bio-photon field in our model is in thermal state $|n\rangle$, the probability distribution though is given by:

$$P_n = \frac{1}{1+\langle n\rangle}\left(\frac{\langle n\rangle}{1+\langle n\rangle}\right)^n, \langle n\rangle = \frac{1}{e^{\beta\hbar\omega}-1} \quad (2)$$

Where $\langle n\rangle$ is the mean bio photon number and $\beta = \frac{1}{KT}$, here K and T are the Boltzmann's constant and temperature.

The tubulin- Bio photon state and density matrix can be written as $|\Psi\rangle = \sum_n b_n|t_n\rangle|b_n\rangle$, $\rho_{t-b} = |\Psi\rangle\langle\Psi| = \sum_n P_n\rho_n$ respectively. Here $|t\rangle$ and $|b\rangle$ are tubulin and bio photon states. Note that energy transfer only effects on the transition between $|\beta,n\rangle$ and $\langle\alpha,n+1|$, therefore

$$\rho_n = \cos^2\left(\frac{\Omega_{n+1}t}{2}\right)|\beta,n\rangle\langle\beta,n| - i\cos\left(\frac{\Omega_{n+1}t}{2}\right)\sin\left(\frac{\Omega_{n+1}t}{2}\right)|\beta,n\rangle\langle\alpha,n+1| + i\cos\left(\frac{\Omega_{n+1}t}{2}\right)\sin\left(\frac{\Omega_{n+1}t}{2}\right)|\alpha,n+1\rangle\langle\beta,n| + \sin^2\left(\frac{\Omega_{n+1}t}{2}\right)|\alpha,n+1\rangle\langle\alpha,n+1|$$

(3)

$$\rho_{t-b}=\begin{bmatrix} P_{n-1}\cos^2(\frac{\Omega_n t}{2}) & 0 & 0 & 0 \\ 0 & P_n\cos^2(\frac{\Omega_{n+1}t}{2}) & -iP_n\cos(\frac{\Omega_{n+1}t}{2})\sin(\frac{\Omega_{n+1}t}{2}) & 0 \\ 0 & iP_n\cos(\frac{\Omega_{n+1}t}{2})\sin(\frac{\Omega_{n+1}t}{2}) & P_n\sin^2(\frac{\Omega_{n+1}t}{2}) & 0 \\ 0 & 0 & 0 & P_{n+1}\sin^2(\frac{\Omega_{n+2}t}{2}) \end{bmatrix}$$

where $\Omega_n = 2g\sqrt{n+1}$ is the Rabi frequency. To show the inseparability of ρ_{t-b} we need the positivity of partial transposed matrix. This condition will reduce to the below expression[18].

$$\Lambda_n = (\cos(\frac{\Omega_{n+1}t}{2})\sin(\frac{\Omega_{n+1}t}{2}))^2 - (\cos(\frac{\Omega_n t}{2})\sin(\frac{\Omega_{n+2}t}{2}))^2 > 0 \quad (4)$$

As this expression shows, inseparability is independent of temperature (via eq. (2) for $\langle n \rangle$). If we assume that this bipartit system is initially in a pure state, then we can use Von Neumann entropy for quantifying the entanglement . By taking the trace over bio photon field states we have,

$$\rho_t = Tr_b\rho_{t-b} = \begin{bmatrix} P_{n-1}\cos^2(\frac{\Omega_n t}{2}) + P_n\cos^2(\frac{\Omega_{n+1}t}{2}) & 0 \\ 0 & P_n\sin^2(\frac{\Omega_{n+1}t}{2}) + P_{n+1}\sin^2(\frac{\Omega_{n+2}t}{2}) \end{bmatrix} \quad (5)$$

Quantum entropy can be calculated by reduced density matrix eigenvalues[19]. Since we assume that the combined system of tubulin- bio photon field is initially in pure state we can use Von Neumann entropy to quantify the entanglement[20][21]. It should also be noted that the higher the entropy, the higher the entanglement is.

III. RESULTS AND DISCUSSION

Now we discuss the entanglement between tubulin and the field of bio photons. Since Rabi oscillations resulting from JCM model is proved experimentally for different coupling constants of different environments and for different initial states[22], we used JCM model to describe the interaction between two-state tubulin and the thermal bath of bio photons. First we take the field of bio photons in a thermal state with the Bose-Einstein distribution (Fig. 2).

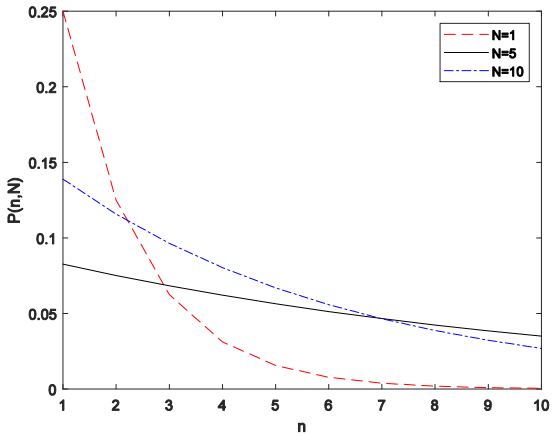


Fig.2 Bose-Einstein distribution for the expected photon number ($\langle n \rangle = N = 1, 5, 10$) in each mode

According to Horodecki et.al[23], the positivity of the partial transposition of a state is a necessity condition of being inseparable. So we use Λ_n parameter as entanglement criteria. One of the main issues in vivo is the hot environment where the coherence is not stable. In Fig. 3 we show that irrespective of the temperature, we can have different time ranges where positivity of the partial transpose of the ρ_{t-b} exists. We also show that where the mixedness of the system raises the oscillations are faster. It is due to the probability distribution of thermal states. It also shows that as the number of bio photons(n) raises, the probability distribution of being in a specified mode is low, therefor time intervals of entanglement witnessing (Λ_n) get closer.

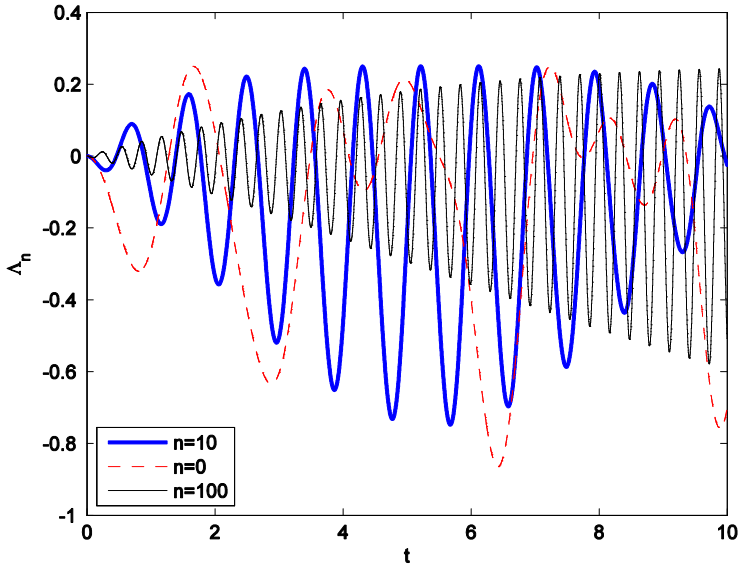
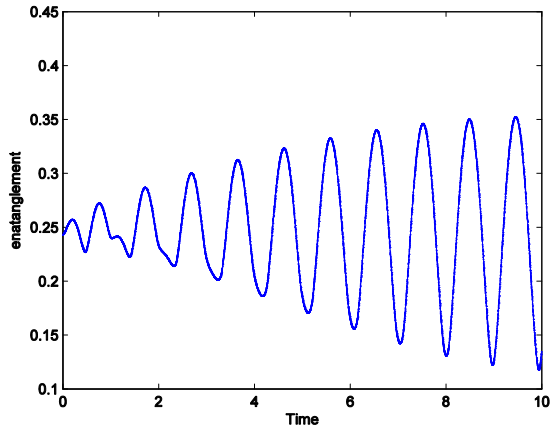
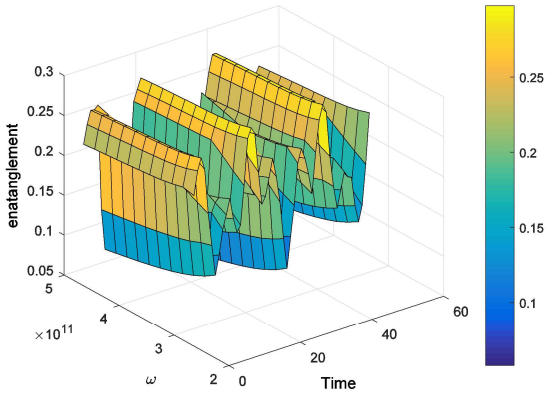


Fig.3 inseparability parameter (Λ_n) versus time for different values of n.

With the exception of $t = 0$, always we can observe the inseparability of the two parts system. Which indicates that as soon as a biophoton is created in the cell it is entangled with tubulin dimmer protein. As the biophoton number increases the probability of being in a specific mode decreases, it means that the mixedness of the field increases, thus the time intervals between entanglement witnessing decreases. Fig.4 displays the degree of entanglement between the tubulin and the biophotons in thermal state. We can see that the entanglement oscillates. Oscillation of entanglement provides the backward information in some time intervals due to exchange of energy between bio photons and tubulin in microtubules. The oscillations also means that the information is not lost but is got back to the system. Which in turn means that the information can get back from axon to dendrite, Fig.4 (a). The degree of entanglement influenced by the frequency of biophotons, we show this in Fig.4 (b). It is obvious that, as the frequency of biophotons increases the probability of being in that frequency increases and in return the degree of entanglement increases (see eq.5).



(a)



(b)

Fig.4 (a) Time evolution of entanglement for $\langle n \rangle = 10$ and n=10, (b) entanglement dynamics with respect to time and biophoton frequency.

IV.CONCLUSION

Dynamics of quantum entanglement between tubulin dimmer and bio photons reservoir is investigated. The oscillations of entanglement in such a quantum cellular system follows the two main goals. One is the backward information transfer from axon to dendrite which was not truly explained by classical mechanisms. The second is the provision for a communication channel in the cell. Since the frequency of biophotons are related to biological processes, we present the frequency dependency of entanglement dynamics as well. It can be shown that microtubuls are also entangled with each other that will make the neural network work as a quantum computer.

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