Conscious Events as Possible Consequence of Topological Frustration in Microtubules

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ABSTRACT
The phenomenon of persistent frustration of pollen tubes led us to recognition of a new form of anharmonic potential, which after a simple transformation may yield a so called ‘double well potential’. Because of possible links with conformational changes taking place in microtubules (MT) of human brain neuronal system, to start with, we have calculated the shift of energy levels of a double well potential with respect to the infinite square double well. We conjecture that the dynamic instability of MTs, which has not been elucidated yet, may be the effect of recently proposed mechanism of geometrical frustration, which can also be utilized in case of tubulin dimers forming parallel protofilament subunits in MTs and for modeling the cognitive brain processes.

Key Words: double well potential, dynamic instability, transition zone, tubulin dimers

Introduction
Biological systems are organized in hierarchical structures, and at a certain level (molecular complexes and proteins) quantum properties may become relevant (Huelga and Plenio, 2013). Some arguments suggest (electron tunneling, proton tunneling in enzymes) that quantum effects in biology are possible at the right length - and time scales. One of the key examples of quantum effects in biology is environment - assisted excitation energy transport (Frenkel exciton) in photosynthesis (Engel et al., 2007).

The development of quantum science revealed that quantum computing may provide performance advantages over classical systems (Feynman, 1982; Deutsch, 1985; Shor, 1997). Quantum computing may be accomplished in many ways, and one of the prominent examples are realizations based on superconducting nanotubes, yet this type of modeling of natural protein based neurobiological microtubules is not free from problems. This is, among others, due to the fact that superconductivity, even the 'high temperature' one, emerges at very low temperatures of liquid helium or nitrogen, well below the temperature of the human brain.

In this short communication we put forward a proposal of a new switching mechanism, based on a concept of vibrations due to symmetry frustration (Pietruszka, 2012; 2013), seemingly able to account for the formation a coherent state ('ring qubit') in neuronal system elements (microtubules). Microtubules are cylindrical hexagonal lattice polymers of the protein tubulin, comprising 15 percent of total brain protein. Microtubules define neuronal architecture, regulate synapses, and are suggested to process...
information via interactive bit-like states of tubulin. Note, that not all living cells contain microtubules, only eukaryotic cell have them.

We introduce our hypothesis as a possible explanation of the well-known dynamic instabilities that are characteristic of MT behavior. It may in particular concern the documented propensity of MT’s to undergo rapid association and disassociation in so termed “microtubule treadmilling” (Philip Linthilhac, private communication), in which one end of the MT is being assembled from subunits while the other end is being disassembled. (This is widely accepted to be the source of the traction force which moves chromosomes from the metaphase plate to the poles during mitosis). If we can successfully attach our concept of symmetry frustration to this most widely accepted behavior then by extension it may be meaningful to make the next intuitive leap to the question of quantum computing and its possible function in a theory of consciousness.

It also seems, at a first glance, that in our approach the low temperature requirement, a condition for superconductivity, does not have to be fulfilled for symmetry - based arguments. There is also a hope that the problem of fast decoherence of the elements responsible for memory encoding and logic operations (e.g. Craddoc et al., 2012) subjected to environmental fluctuations may be avoided for essential reasons (transitions are induced by symmetry changes in MTs).

Results and discussion
Up to now, several analytic forms of the double well potential were considered and the treatment of a double well potential vary in textbooks and papers (Jelic and Marsiglio, 2012, and the references cited therein). Here we propose a new form of a double well potential which arises from our previous calculations based upon pollen tubes oscillations (Pietruszka, 2012). The general form of the original potential, as derived in this paper, is given by

\[ V_n(x) = \pm P \left( \frac{\alpha}{x^n} - \frac{\beta}{x^3} \right) \]  

where \( P \) is a scaling constant (e.g. pressure) and \( \alpha, \beta \) are free parameters, and \( n \) is an integer number. Here we take \( n = 3 \).

Aiming to derive a double well potential we have performed the following transformation of Eq. (1)

\[ V(x) = -V_n(x) + V_n(a - x) + const \]  

where \( V_n(a - x) \) is a mirror image of \( V_n(x) \), \( a \) is a width of the square well (we immerse our potential in the infinite square well of the width \( a \) as in Marsiglio (2008) and Jelic and Marsiglio (2012), which has been chosen between the turning points \( x = 0 \) and \( x = a \)) and \( const \) is a shift to obtain the positive value of the potential. The original potential given by Eq. (1) and its form after transformation is presented in Figure 1.

![Figure 1](image1.png)

It is well known that the eigenstates of the infinite square well alone (without the double well potential) are given by

\[ H_{\text{infinite}} = \frac{\hbar^2}{2m} \frac{d^2}{dx^2} + V(x) \]  

where \( H_{\text{infinite}} \) is the Hamiltonian of the infinite square well, \( \hbar \) is the reduced Planck constant, \( m \) is the mass of the particle, and \( V(x) \) is the potential function. The energy levels for this system are given by

\[ E_n = \frac{n^2 \pi^2 \hbar^2}{2mL^2} \]  

where \( n \) is an integer, \( L \) is the width of the well, and \( E_n \) is the energy level.

The energy levels for the case with nonzero interaction part (lower chart) are given by

\[ E_{\text{interaction}} = E_n + \Delta E \]  

where \( \Delta E \) is the energy shift due to the interaction with the square well potential.
potential is the ground state energies. The double well potential are higher in comparison with eigenvalues in the presence of the double well. It is clearly visible that the energy levels are diagonalized the problem numerically by matrix Kronecker delta function. Further, we solved is the Hamiltonian matrix and δ is the Hamiltonian matrix and δ is the Kronecker delta function. We use the eigenfunctions given by Eq. (3) as trial functions in the first approximation.

To find out the eigenvalues of the energy E we solve the Schrödinger equation

\[ (H_0 + V)\psi = E\psi \]  

and calculate the eigenvalues for the ground state \(H_0\) and the perturbed one \(H_0+ V\).

To solve approximately the eigenvalue problem (the WKB approximation delivers similar solutions, see Jelic and Marsiglio, 2012) we use the usual expansion for the wave function

\[ \psi = \sum_{m=-\infty}^{\infty} c_m \psi_m \]  

By inserting this expression into the Schrödinger equation we obtain

\[ \sum_{m=-\infty}^{\infty} c_m (H_0+ V)\psi_m = E \sum_{m=-\infty}^{\infty} c_m \psi_m \]  

By taking the inner product of Eq. (7) with the bra \(\langle \psi_m | \) vector we arrive at the matrix equation

\[ \sum_{m=-\infty}^{\infty} H_{mn} c_m = E c_n \]  

where

\[ H_{mn} = \langle \psi_n | (H_0 + V) \psi_m \rangle = \delta_{mn} E + \frac{2}{a} \int_0^a dx \sin \left( \frac{n\pi x}{a} \right) V(x) \sin \left( \frac{m\pi x}{a} \right) \]  

is the Hamiltonian matrix and \(\delta_{mn}\) is the Kronecker delta function. Further, we solved the problem numerically by matrix diagonalization and compared the results.

The results are presented in Figure 2. It is clearly visible that the energy levels (eigenvalues) in the presence of the double well potential are higher in comparison with the ground state energies. The double well potential is a consequence of the symmetry frustration (Pietruszka, 2012; Pietruszka et al., 2012), thus, the excited states are present in the frustrated region and absent in the region with the established symmetry. The differences are larger for the lower energy states and monotonically decrease for higher energy levels (Figure 2). This is due to the fact that the double well potential becomes the infinite square well potential at \(x = a\) and \(x = -a\) and does not ‘feel’ the presence of the low energy scale.

We believe, that the presented form of the double well potential, derived for the cases where the symmetry changes, may be used in the context of the possible ‘entangled states’ of tubulins in the MTs present in organic cells, especially in the nervous system of the human brain. Tubulin is a common polar protein found mainly in the cytoskeleton of eukaryotic cells and especially enriched in brain and neural tissue (Mershin et al., 2004, Figure 1). Tubulin dimmers can make transitions between two states recognized as \(\alpha\) and \(\beta\) (Tegmark, 2000; Hameroff and Penrose, 2003; Hameroff, 2007), which is an important fact consistent with our approach (Pietruszka, 2012, Figures 5 and 6). The diameter of ordinary microtubule is about 25 nm, and single tubulin protein is 6.5 nm width and 8 nm high (ibid., Trpisova and Tuszyński, 1997). Similarly carbon nanotubes’ diameters are about 2-16 nm (Cheung et al., 2002), where the quantum processes are undoubtedly present. By assuming a mass of 55 kDa = 91300 x 10^{-27} kg for a single tubuline we may calculate (from the equipartition principle) de Broglie wave length \(\lambda = h/\sqrt{3mkT} = 6 \times 10^{-4}\) nm at 310 K. It seems that some fundamental processes may also emerge at quantum/classical borderline in the case of tubulin protofilaments.

The double well potential given by Eq. (2) is similar to that obtained by Tripsowa and Tuszyński (1997, Figure 2a), however, our potential is due to the symmetry change in the considered region (Pietruszka et al., 2012, 2013). The tubulin protein dimer can undergo similar instability (Mitchison and Kirschner, 1984; Hameroff and Penrose, 2003, Figure 3 and 4, Wei and Lintilhac, 2007) as it was suggested in the case of pollen tube (Pietruszka et al., 2012). Depending on parameters in Eqs (1) and (2), a symmetric or asymmetric potential can be obtained, like as in Tripsowa and Tuszyński (1997, Fig. 2).
The ‘entangled state’ of the tubulin was widely examined by Penrose (1989; 1997) and Hameroff and Penrose (2003), who suggested that MTs operate as a quantum computer. They have constructed a theory in which human consciousness is the result of quantum gravity effects in microtubules, which they dubbed Orch-OR (orchestrated object reduction). This approach was disproved by Tegmark (2000) due to decoherence time where the time scale of neuron firing and excitations in microtubules is slower than the decoherence time by a factor of at least $10^{10}$. In contrast, in our situation (the symmetry frustration scheme) the coherent state can be maintained according to the oscillation period of conformational changes. As long as the region with undefined symmetry (‘transition zone’, see Pietruszka et al., 2012) exists the coherent state is preserved and this determines the decoherence time of the system. Interestingly, the self-collapse corresponding to the objective reduction (OR) also in our scenario occurs abruptly. We may also associate the sequence of pre-reduction, coherent superposition phase (‘quantum computing’) and self-collapse with a discrete conscious event. The transitions between the states are present both in classical (Pietruszka, 2012, Figure 5) and quantum regimes, Figure 2. However, in the case of pollen tubes the classical transitions between the two states of symmetry seem possible, while in microtubules the collective (coherent) state may emerge due to the increasing number of tubulins which form a ring of 13 (Hameroff and Penrose, 2003, Figure 7). This number (13) of tubulins gives $2^{13} = 10^{3.91}$ possible quantum states. Tubulins may interact locally (nearest neighbor interaction) and the ‘entangled state’ can be extended on the tubulins forming the single ring. In consequence, since the character of interaction is unknown, we may propose the following symbolical description, where the ‘entangled state’ (entanglement represents correlations that cannot be shared by third parties, Horodecki et al., 2007) of a single ring takes the form

$$\psi_i = \alpha_i \otimes \alpha_2 \otimes \cdots \otimes \alpha_m |\alpha_i \rangle$$  \hspace{1cm} (10)

Here $m$ is equal 12 or 13 depending on the number of filaments in MT and

$$a_i |\alpha_i \rangle = b_1 |\alpha_i \rangle + b_2 |\alpha_i \rangle$$  \hspace{1cm} (11)

is a quantum coherent superposition state of a single tubulin dimer (Hameroff and Penrose, 2003, Figure 4); $|\alpha_i \rangle$ and $|\alpha_i \rangle$ are two states at a given site $i$ in a single quantum event.

In turn, the ‘computation’ conducted in a single ring can be transmitted along the MT as a solitary wave (action potential, e.g., Maśka and Pietruszka, 1995) due to (classical) strain/stress propagation. This view is in accord with the statement (Tripsowa and Tuszyński, 1997) that the stored energy released in the hydrolysis of GTP has a form of conformational states of the tubulin dimmers and is propagated along MT. The conformational changes of the tubulin after the hydrolysis may cause a mechanical strain that destabilizes MTs.

**Conclusion**

In conclusion, the promising mechanism sketched in this paper supposedly allows not only the energy transfer along MT but, what is even more important, the transmission of quantum information (Lloyd, 1997) encoded in the 12 (13) tubulins forming a ‘ring qubit’. Had the ladder of energy states involve higher accessible states (Figure 2), the more complicated processes (‘calculations’) can be conducted.

The model for computation we have presented here is quite general and can be used in many areas of human scientific activity; however the problem of consciousness seemed for us the most appealing target, since the notion that the instability behaviors of microtubules may be also interpreted in terms of symmetry frustration is intriguing.
References


