New Results about Microtubules as Quantum Systems

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Abstract

The latest news in quantum biology is the observation by the group led by Anirban Bandyopadhyay about detection of quantum vibration in microtubule scale - their lengths vary up to 50 μm. If this observation can be replicated, one can speak about breakthrough in quantum consciousness.

The findings reported in an earlier talk of Banduopadhyay give support for the general TGD inspired view about topological quantum computation (TQC) and allow for a rather detailed model in the case of microtubules. The idea is that flux tubes form a 2-D coordinate grid consisting of parallel flux tubes in two different directions. Crossing points would be associated with tubulins and the conformational state of tubulin could define a bit coding whether the braid strands defining coordinate lines are braided or not (swap or not). In this manner any bit pattern at microtubule defines a particular TQC program. If also conformations are quantum superposed, one would have "quantum-quantum computation". It however seems that conformation change is irreversible chemical reaction so that this option is not feasible.

The TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks rather natural. Coordinate grids can be fixed on basis of the experimental findings and there are 8 of them. The interpretation is in terms of different resolutions. The grids for A and B type lattices are related by 2π twist for the second end of the basic 13-unit for microtubule. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only in phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence, which is a strong objection against Penrose-Hameroff model.

TGD suggests also a generalization of the very notion of TQC to 2-braid TQC with 2-D string world sheets becoming knotted in 4-D space-time. Now qubits (or their generalizations) could correspond to states of flux tubes defining braid strands as Penrose and Hameroff seem to suggest and the emergence of MTs could be seen as an evolutionary leap due to the emergence of a new abstraction level in cognitive processing.

1 Introduction

The latest news in quantum biology is the claim about corroboration of the Penrose Hameroff Orch OR theory (http://www.kurzweilai.net/discovery-of-quantum-vibrations-in-microtubules-inside-brain-) [J1]. In my humble opinion the news suffers from rather heavy hyping. If the observation by the

group led by Anirban Bandyopadhyay about detection of quantum vibration in microtubule scale (their lengths vary up to 50 μm) can be replicated, one can speak about a breakthrough in quantum consciousness. The results do not however prove Orch OR, which involves poorly defined vision about quantum gravitational description of state function reduction, so that most predictions are just order of magnitude estimates relying on Uncertainty Principle.

The biological half of the theory relies on microtubules and for this side of the theory the claimed finding would of course be a victory. Indeed, there is a meeting in Amsterdam devoted to Orch OR theory of consciousness motivated by this finding (`http://www.brakkegrond.nl/programma/1253/Penrose_Bandyopadhyay_Hameroff/Lezing_Microtubuli_het_grote_debat_over_het_bewustzijn/#eng`). Unfortunately, I could not find any article about the findings of Bandyopadhyay online. I managed however to find two years old Youtube talk of Bandyopahdyay summarizing earlier experimental results supporting the vision about microtubules as macroscopic quantum systems (`https://www.youtube.com/watch?v=VQngptkPYE8`) [J3] to be discussed below. The talk describes in informal manner results, most of which can be found also in the articles [J11, J12, J14].

The findings reported in the talk give support for the general TGD inspired view about TQC and allow rather detailed model in the case of microtubules. The idea is that flux tubes form a 2-D coordinate grid consisting of parallel flux tubes in two different directions: the guess that they could consist of helical Fibonacci flux tubes and their mirror images is not however convincing. Crossing points would be associated with tubulins and the conformational state of tubulin could define a bit coding whether the braid strands defining coordinate lines are braided or not (swap or not). In this manner any bit pattern at microtubule defines a particular TQC program. If also conformations are quantum superposed, one has "quantum-quantum computation" . It however seems that conformation change is irreversible chemical reaction [J6] so that this option is not feasible.

The TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks more plausible to me. Coordinate grids can be fixed on the basis of the experimental findings and there are 8 of them. The interpretation is in terms of different resolutions. The grids for A and B type lattices are related by 2π twist for the second end of the basic 13-unit for microtubule. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only in phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence, which isa strong objection against the Penrose-Hameroff model.

This would fit very nicely with the general vision about frequencies as passwords inducing not only directed attention but activities in target - also TQCs! The increase of Planck constant could be associated with the phase transition to A-phase making possible high T_c dark super-conductivity for which evidence is observed! One can even deduce estimates for $h_{eff}/h = n$ if one requires that AC photons have energy above thermal threshold: $n = h_eff/h = f_{visible}/f_AC$ would be the estimate. For biophoton energies one would obtain something like $n \simeq 10^8 - 10^9$, which pops up in different contexts in TGD framework.

This picture generalizes in the fractal universe of TGD. One can form layers of 2-D coordinate grids and connect them by vertical flux tubes to obtain 3-D grid defining TQC. The brain is known to have grid-like architecture and neurons could by quantum computation produce bit/qubit defining swap or not/superposition of swap and not-swap for a larger scale TQC. One would have fractal of TQCs. One can even think 4-D grids in Euclidian spacetime regions (predicted in TGD Universe) with 6 bits defining the swaps at each crossing point: could this have something to do with the genetic code?

A further idea is that 1-braid TQC generalizes in a natural manner to 2-braid TQC in TGD framework (for 2-braids see [K5]). The knotting occurs for string world sheets defining the orbits of braid strands - say magnetic flux tubes idealized to strings. In the case of microtubules this option suggests itself strongly. The emergence of MTs could have meant emergence of 2-braid TQC and the increase of abstraction level in the information processing. Note that 2-braiding is possible only if string worlds sheets "live" in 4-D space-time: for super strings "living" in higher-D space-time this is not possible.

2 Theoretical ideas

The theoretical ideas of three models relevant to the experiments of Bandyopahdyay will be discussed first. The theories are the Penrose-Hameroff theory, Bandyopahdyay's theory and TGD.

2.1 Penrose-Hameroff theory

Approximately two decades ago Penrose and Hameroff proposed a model that they called Orchestrated Objective Reduction (Orch OR) [J17]. Besides the highly speculative quantum gravity related ideas, the model assumes that microtubules are quantum coherent systems essential for consciousness. For the importance of microtubules one can find a lot of qualitative support. A I believe that microtubules are important for consciousness and I have developed ideas about the role of microtubules [K8]. Personally, however, I find it difficult to believe in the reduction of consciousness to microtubular level, but see microtubules as one particular layer in the hierarchy of conscious entities. Personally, I would prefer fractality over the naive length scale reductionism.

Many objections [J6] against the biological feasibility of Orch OR (`http://en.wikipedia.org/wiki/Orchestrated_objective_reduction`) [J17] have been raised. For the latest response of the authors to the criticism see [J16]. There are two basic challenges: one should formulate precisely what Orch OR really means and be able to identify the qubit.

1. The basic vision about quantum superposition of space-time geometries gives rise to consciousness as something analogous to quantum computation. State function reduction would thus reduce to a mechanism rather than being something irreducible. Most quantum physicists would disagree about this. The quantum superposed geometries would be protein conformations. Since there is no theory of quantum gravity, the proposal boils down to the ad hoc estimate for the time τ for Orch OR to take place claimed to be $\tau = \hbar/E_G$, where E_G is the difference of gravitational energies for the superposed geometries. The estimates favor nuclear scale 5 fm and one needs a coupling between nano-scale physics of electrons and physics nuclei and London forces are suggested to be responsible for this coupling. It deserved to be mentioned that the gravitational energy for a blog of water with radius around 10^{-4} meters - the size scale of large neuron - is about Planck mass so that gravitation and biology might relate. In my own proposal involving large gravitational Planck constant assigned to space-time sheets mediating gravitational interaction, Planck mass might serve as a threshold above which large values of Planck constant would emerge [K11, K9].

2. Concerning the identification of qubit there is a long list of suggestions. The superposition of tubulin conformations was one of the first proposals. Reimers [J6], who has criticized heavily Orch-OR proposal, reports that irreversible chemical reaction is responsible for selecting conformation so that quantum superpositions would not make sense. Conformational switching could however be involved with classical computational aspects of biological information processing and Hameroff has proposed before Orch OR that microtubules could act as classical cellular automatons.

   Also other proposals for qubit have been made. Quantum fluctuations generating London force between electric dipoles could somehow give rise to qubits. Also magnetic dipoles, nuclear spin, AC current flow, and synergistic modes have been mentioned. Also the identification of qubit as a helical conduction pathway has been proposed ("Oscillating London force dipoles in resonance rings in helical pathways through microtubule lattices"). It is difficult to imagine what the two superposed states defining qubit would be. For instance, could qubit correspond to electron current running in two different directions and is quantum superposition possible at criticality for a phase transition inducing the change of the current direction? For this option the information storage capacity of microtubule would be rather modest. In also difficult to see the claimed connection with topological quantum computation since braiding gives rise to entanglement between states at the ends of the braids.

Orch OR proposal involves several interesting ideas probably relevant for quantum consciousness.

1. Aromatic rings have probably some deep role in quantum consciousness. For instance, most psychoactive biomolecules and also DNA and three aminoacids contain them. Hameroff and

Penrose trace this role to London force between aromatic rings and quantum fluctuations making them qubits. I am unable to imagine what the exact proposal is. In any case, what is known is that electrons at aromatic rings are delocalized.

Comment: My own humble proposal is that electrons could be further delocalised at magnetic flux tubes in longer scales and make cyclotron BE condensates of dark electrons or their Cooper pairs possible. They would make possible the coupling between receptor-information molecule complex and magnetic bodies at various levels of hierarchy. Hierarchy of Planck constants and negentropic entanglement suggests the existence of a new kind of state consisting of electrons (that is fermions) but analogous to Bose-Einstein condensate.

2. The idea about insulation provided by hydrophobic pockets of proteins against fluctuations destroing quantum coherence is nice and it would be natural to put aromatic rings into these pockets.

3. The needed long value of Orch OR decoherence time τ (originally assumed to correspond to 40 Hz thalamocortical resonance frequency) is one of the problems of Orc OR and the recent discovery of EEG like oscillations in kHz range [J9] is claimed to make the situation more tolerable.

   Comment: Fractal hierarchy of EEGs mediating communications between parts of biological body and corresponding magnetic body is basic prediction of TGD and the observation seems to provide evidence for this prediction.

4. Reimers et al challenges [J7] also Fröhlic Bose-Einstein condensation [J13] and claims that according to his own simulations the resulting state is extremely incoherent [J7]. There are however models which give Bose-Einstein condensation [J2] and the in [J3] the experimental findings about assembly of microtubules are interpreted as Fröhlic condensation. The frequency inducing the condensation would be however 3 orders of magnitude lower than predicted by Fröhlich.

There is a further puzzling result (`http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2114131/pdf/jc10231067.pdf`) [J5] in conflict with the assumption of Orch OR that brain microtubules are dominantly so-called A-type tubules. Brain microtubules re-assembled in vitro form lattices of type B and for them the lattice must have surface discontinuities. This makes sense for microtubules which are partially fused together as in the structures consisting of cylinder whose surface is formed by 9 units consisting of 3 microtubules glued together along their sides. This would not allow Fibonacci helices proposed by Penrose and Hameroff to serve as conducting pathways defining the analogs of braid strands in their model for microtubule as topological quantum computer (TQC) unless one is ready to give up helical symmetry. One way out of the difficulty would be that vitro results do not hold in vivo but Kikkawa et al has shown that all in vivo microtubules have lattice of type B (`http://jcb.rupress.org/content/127/6/1965.abstract`) [J8].

The above mentioned article concludes that only the lattice B is realized in nature. This lattice does not possess helical symmetry. After each full turn along sequence α or β tubulin sequence there is a shift as the figure 2 of the article demonstrates: this discontinuity is called seam in the article. Furthermore, these helices can be said to have periodicity 5. The helix-like curve satisfies the condition $z = 4a\phi/2\pi$ and the n^{th} tubulins along vertical is located at $z(n) = na$, a the size of the tubulin. For $\phi = 2\pi$ one has $\Delta z = a$ rather $\Delta z = 0$ as figure 2 of the article shows. This discontinuity could have some important biological meaning.

Hameroff, Nip, Porter, and Tuszynski have an article about microtubules as topological quantum computation written in 2002 [J10]. They do not give any justification for why the conduction pathways should correspond to Fibonacci numbers but the article by Hameroff represents evidence that the important certain amino-acids crucial for consciousness inside tubulin molecules are located along the Fibonacci conduction pathways (`http://www.quantumconsciousness.org/biosystemselsevier.htm`) [J10].

2011 Hameroff and Penrose considered the possibility that microtubules could perform topological quantum computation. The proposal of Penrose and Hameroff (`http://www.quantumconsciousness.org/biosystemselsevier.htm`) [J10] assumes realization of braiding in terms of helical braids strands assignable to A-type microtubules (which according to experimeters do not exist in brain and - as it seems - in living matter in general). In the simplest realization the strands are parallel to each other

and have horizontal periodicity characterized by 13 tubules. Also Fibonacci pathways with horizontal periodicity of 3, 5, and 8 are Fibonacci pathways. The strands with different periodicities can intersect and can therefore be braided. One can also construct left- and right handed variants of the strands and left- and right-handed strands intersect periodically with a period of 13. The experimentsdiscussed in bneuntvideo however suggest a different kind of braidings.

In the intersection points braiding (swap) operation could be realized meaning that first strand goes either over or below the second one. Gupta and Hameroff suggests that MAPs are responsible for this kind of swap and thus define the fundamental quantum gates for TQC (`https://sbs.arizona.edu/project/consciousness/report_poster_detail.php?abs=1435`) [J15]. Of course, also more complex gates can be imagined but swap is enough to build universal TQC. Official biology assigns to MAP many other functions associated with MAPs but also this function can be imagined. Penrose and Hameroff have also consider the possibility that topological qubits are represented in terms of quantum superpositions of helical pathways with 13-periodicity characterized by the gap between neighboring pathways.

2.2 The identification of Bandyopadhyay for conduction pathways

In his Youtube talk Anirban Bandyopadhyay (`https://www.youtube.com/watch?v=VQngptkPYE8`) [J3] discussed an identification of conduction pathways different from that of Penrose and Hameroff. In [J14] Gosh, Sahu, and Bandyopadhyay argue for evidence for massive global synchronization in brain and claim that experimental findings support the Penrose-Hameroff theory. In the article "Atomic water channel controlling remarkable properties of a single brain microtubule: correlating single protein to its supramolecular assembly" [J11] it is reported that ordered water inside microtubule is necessary for the conduction inside microtubule. According to the same article the tubulins inside microtubule has same energy levels in chemical energy range as isolated tubulins which suggests that the mechanism binding tubulins to form MT is not chemical. In the article "Multi-level memory-switching properties of a single brain microtubule" [J12] it is reported that the hysteresis curve for current along MT as function of voltage is ideal square curve meaning that there is no dissipation involved with the change of the current direction. This would make MT as an ideal memory device. Whether Penrose/HAmeroff have in mind the use of current direction as qubit remains unclear. In video talk Bandyopadhyay refers also to these results.

I consider only the general proposal discussed in video lecture here: the Youtube representation gives concrete illustrations of conduction pathways.

1. It is assumed that there are two kinds of hexagonal tubulin lattices labelled as A and B. As found there is strong evidence that A-type tubules do not exist stably. For both types the tubulin dimers defining dipoles are nearly axial and define candidates for conduction paths with winding periodicity of 13 tubulin dimers. For B type one has rows made of α or β type tubulins along with α and β have effective periodicity of five if one accepts discontinuity at after 2π rotation. One might think that this dictates the choice of the candidates for the conduction paths to consist of sequences of $\alpha - \beta$ dimers: for these sequences are along the microtubule. If hops occur between α and β this assumption is natural. The proposed pathways are however more general and - as it seems to me - based on rather ad hoc mathematical rule.

2. The notion of helical conduction pathway is the starting point. For B-type tubules this notion must be modified. Presumably the criterion for what it is to be a helical pathway is that they are straight-lines connecting nearest neighbors to each other- this is natural if conduction is identified as hopping between neighboring tubulin molecules. The position of each pathway represented by a value of discrete dynamical variable replacing spin as representation of qubit -essentially the angle $\phi = n \times 2\pi/13$ is in question. There are 13 different values for ϕ. For A-type conducting pathways the condition that one has $\alpha - \beta$ sequence very probably gives the the claimed pathways with periodicity 13. One can ask whether the pathways of type A are obtained by twisting the pathways of type B at the second end by 2π and whether living systems could be able to perform this twist to achieve phase transition between two states of the microtubule.

3. Instead of single pathway one considers groups of parallel pathways consisting of translates of a fixed pathway with a fixed gap $\Delta\Phi_{gap} = n_{gap}2\pi/13$ along the circumference of microtubule.

I failed to understand the motivation for this: maybe the idea is that the additional degree of freedom makes possible the analog of spin degree of freedom as angular position of the pathway. One could also consider the possibility that the translates of a pathway define a braid: this braid would be however trivial since the pathways are parallel. If I have understood correctly, topological qubits would be represented as quantum superpositions of helical conduction pathways with same gap $\Delta\phi = n_{gap} \times 2\pi/13$ between neighboring pathways. This is not what TGD suggests.

4. By $n = 13$ modulo arithmetics it can that the series of pathways with $n = kn_{gap}\ mod\ 13$, $k = 1, 2, ...$ generates additional gaps. One says that the decomposition occurs. The addition of translated parallel pathways can also lead to a pair of pathways with $n_{gap} = 0$ or $n_{gap} = 1$ in which case pathways overlap or touch. This is not allowed. What this means physically is unclear to me. One could also avoid touching simply by allowing only the translates to be such that $kn_{gap} \leq 13$ holds true: even weaker condition can guarantee this.

Consider first what one obtains for A-type microtubules.

1. The construction rule gives for $n_{gap} \in 1, 2, 3, 4, 6, 12$ many secondary gaps, in particular $n_{gap,new} = 1$ so that "don't touch" rule is violated. For $n_{gap} in \{5, 7, 8, 9, 10, 11, 13\}$ only 1 or one secondary gap or no secondary gap is obtained. The decompositions of primary gaps are

$$5 \to (5,3)\ ,\quad 7 \to (7,6)\ ,\quad 8 \to (8,5)\ ,\quad 9 \to (9,4)\ ,\quad 10 \to (10,3)\ ,\quad 11 \to (11,2)\ ,\quad 13 \to 13\ .$$

2. One can form from these collections of parallel pathways more complex collections as unions. Only unions for which "don't touch" rule is satisfied. This leaves for A-type microtubules 4 groups of pathways characterized by four values of n_{gap} each. The 4 groups of 4 of n_{gap} values which can co-exist without breaking teh basic rule are

$$\begin{array}{cccc} (8, & 5, & 10, & 13) \\ (7, & 9, & 11, & 13) \\ (5, & 7, & 10, & 13) \\ (5, & 7, & 9, & 13) \end{array} \tag{2.1}$$

Here only the generating gaps are listed. For instance, the $(8, 5, 10, 13)$ decomposes to $(8, 5, 3, 10, 13)$.

3. There is a problem: these parallel pathways do not have intersections and therefore cannot form braids unless also their mirror images are allowed or one introduces additional group of pathways, which could be called transversal.

4. One does not obtain Fibonacci conduction pathways with periodicities 3, 5, 8 for A-types microtubules suggested by Penrose and Hameroff. One could argue that since the periodicity as winding number is a topological characteristics, the correct identification should give all winding numbers or at least those which are Fibonacci numbers in case A-type microtubules.

What about B-type microtubules?

1. For B-type microtubules one obtains 4 pathways, one of them parallel to the microtubule and the remaining three with periodicity 7. Only the gaps 2,3,4 are allowed by the "don't touch" rule. 2 and 3 do not decompose and 4 decomposes to (4,2) so that 2 and 4 can co-exist.

2. For the axial pathway X there is no restriction to the values of n_{gap} unless one just assumes $n_{gap} = 2$ as in the illustration of slides. It is argued that together A and B-type pathways cover the entire series. I failed to understand what this means: in any case, the primary gap number $n_{gap} = 12$ is missing and I find difficult to understand what complementarity could mean.

3. The 3 pathways 2,3,4 are parallel and cannot intersect each other but they can intersect the axial pathways called X so that braiding is possible. For X type pathways conduction would take place along sequence of $\alpha - \beta$ pairs.

4. For A-option one obtains only periodicity 13 and for B option periodicity 7 for primary gaps 2,3,4 and periodicity 1 for the line parallel to microtubule with periodicity 1.

Bandyopahyay emphasizes that A-type pathways are ideal for TQC whereas B-type pathways are ideal for communications. I did not understand the argument. Certainly this requires that a phase transition from B to A can take place.

The transitions reported to occur as the microtubule is excited at certain resonance frequencies, would in this picture correspond to transitions between different groups rather than excitation of single pathway. The number of resonance frequencies is reported to be 8. If there are n pathways all possible transitions would give $n(n+1)/2$ resonance frequencies: this number cannot be equal to 8 unless some frequencies are degenerate. It would seem that more plausible interpretation is in terms of excitation of a physical state assignable to given pathway or group of its parallel translates rather than between groups of them.

2.3 Microtubules from TGD point of view

In TGD framework microtubules are especially interesting from the point of view of TQC - not only for 1-braids but also for their generalization 2-braids. Indeed, MTs might represent an evolutionary step in which 1-braid TQCs were extended to 2-braid TQCs.

2.3.1 What does one mean with TQC?

I ended up with my own proposal about TGD Universe as topological quantum computer (TQC) around 2002 [K13] with inspiration coming from New Scientist article [C1] - at the same time Hameroff has proposed the idea about conducting pathways as braids. By looking at old blog articles I learned that I have developed the vision about DNA as TQC during 2007 [K2, K12].

The proposal is that the braiding of magnetic flux tubes associated with the magnetic bodies of biomolecules - and probably also much larger structures - makes possible TQC like activities basic aspect of living systems. For instance, braids connecting DNA and nuclear and cellular membranes could make possible automatic construction of memories as space-like braidings of magnetic flux tubes induced by time like braiding generated by the liquid flow around cell and nuclear membrane [K2]. Also microtubules could be connected to axons by flux tubes and similar mechanism could be at work. A universal representation of memories could be in question and couple microtubules directly to the neural activities.

It is essential that the second of each braid is free to move so that temporal braiding patterns are generated and induce spatial braiding patterns (dance metaphor helps to visualize this [K2]). Second essential point is that the qubits reside at the ends of braid strands. This is why the statement of Penrose and Hameroff that conduction pathway defines a qubit in some manner - say in terms of current direction - does not make sense in standard TQC paradigm. In the following I shall propose that the statement can be made to make sense if one considers generalization of TQC involving 2-braids instead of 1-braids so that 2-D objects get "knotted" instead of 1-D objects [K5].

The braiding induced by say 2-D flow of lipids would still be passive generation of memories but one could consider also genuine quantum computation like activities in which the braiding defining the TQC program is constructed in a controlled manner. For instance, one could associate to microtubular surface highly regular "pre-braidings" involving crossings of magnetic flux tubes for which basic braiding operation (swap) between neighboring braid strands could be controlled by the tubulin molecule associated with the crossing. Swap could be determined by the tubulin conformation in the crossing defining a classical bit so that classical computer program expressible as cylindrical surface decorated with bits would code TQC program. In this manner coupling of the events at cell membrane to microtubular quantum cognition would be achieved.

What one exactly means with topological quantum computation (TQC) is not at all obvious and one can consider several variants of it in TGD framework.

1. Zero energy ontology (ZEO) leads to the notion of unitary U-matrix having as its rows M-matrices which are "square roots" of density matrices which are products of hermitian matrix and unitary S-matrix. These matrices define time-like entanglement coefficients between the positive and negative energy states at the opposite boundaries of causal diamond (CD). For braid strands along light-like 3-surfaces defining string ends one obtains entanglement between

fermions at the ends of strands. Since the entanglement matrix is unitary it defines density matrix which is sum over projection operator acting as identity matrices and state function reduction yields a negentropically entangled state carrying information. One can pose additional conditions on space-time like negentropic entanglement and ends up with a highly unique form of entanglement coefficients from the condition that any splitting of the system to two parts defines negentropic entanglement [K6].

2. In absence of degeneracy giving rise to negentropic entanglement one would have ordinary entanglement and ordinary quantum measurement theory applies. The outcome of TQC would be statistically determined from state function reductions for large enough number of sub-CDs of given CD. It would be coded by quantum classical correspondence (QCC) to the parameters characterizing classical fields inside CD (frequencies, wave numbers,...). EEG patterns would be one particular representation of this kind.

3. Interaction free quantum measurement in principle allows to measure the quantum state without changing it (in the ideal situation, see Elitzur-Weizman bomb testing proposal [B1]). One could therefore imagine a non-halting TQC and extraction of the information without halting it at all. Negentropic entanglement is stable under state function reduction by NMP [K6]: it can increase or it can be transferred but it cannot be reduced. Interaction free quantum measurement could make possible the reading the outcome of TQC without halting TQC. TQC would represent "Akashic records" and by NMP Universe would be building increasing library of Akashic records. This might provide a general mechanism of term memory.

4. Also a generalization of ordinary 1-braid TQC to 2-braid TQC is suggestive. 1-D braid strands define braiding of orbits of point like particles in 3-D space space-time - say light-like 3-surface. In TGD framework the 1-D braid strands correspond to the boundaries of 2-D string world sheets and the evolution of string world sheets corresponds to 2-braid in space-time. One obtains a generalization of 1-braid TQC to 2-braid TQC in which knotting occurs for 2-D string world sheets of 4-D space-time rather than 1-D strings of 3-D space.

   Qubits at the ends of time-like braid strand are replaced with quantum states at space-like braid strands defining ends of string world sheet and TQC corresponds to a time evolution in which the 2-knotting of braid strands changes. The first basic operation is what Alexander the Great did for the knot - the breaking of 1-knot temporarily. What happens is following: if braid strand A goes over B before the moment of breaking, it goes below B after it. This is however not the only possible operation: also reconnection - basic operation for magnetic flux tubes - can take place: the braids strands AB and CD are replaced with AD and CB. These operations define standard vertices in closed string model. The sequence of these operations defines 2-braiding and one can assign to it a generalization of 1-braid TQC to 2-braid TQC. 2-braid TQC is not possible in super string models since strings are imbedding in space-time having dimension higher than $D = 4$.

   The quantum states of braids strand would define qudits. In TGD qupits representable as superposition of p^N states, p prime, are of special interest in TGD framework.

2.3.2 Could MTs lead from 1-braid TQCs to 2-braid TQCs?

What can one say about the situation concerning microtubules in TGD framework? Since I am not a professional biologist, I can imagine rather freely.

Consider first TQC in the standard sense, that is for 1-braids.

1. The obvious question concerns the nature of the braid strands (conduction pathways in the terminology of Penrose and Hameroff) and here standard physics cannot provide much insight. A natural TGD based identification would be in terms of magnetic flux tubes carrying dark electrons or even better, their Cooper pairs forming currents running along the microtubule. This would predict that microtubules act as super-conductor like systems. The basic aspect of this kind of system is resistance which does not depend on the length of the wire since the resistance is determined by what happens at the ends of the wire where electron current enters or leaves the wire - now flux tube. For ordinary superconductors the resistance involves term

which does not depend on temperature. Also now one might expect that the resistance has similar behavior.

The states of Bose-Einstein condensate at the braid strand cannot defined the qubits in ordinary 1-braid TQC for which the states reside at the ends of braid matter. The flux tubes should have ends - at least effectively. The ends should carry quantum numbers defining the qubits. The effective end would correspond to wormhole throat of a wormhole contact at which the magnetic flux flows to another space-time sheet. Quite generally, the flux tubes would be closed structures: for instance, elementary particles correspond to two-sheeted flux tubes having two wormhole contacts as "ends".

2. Maybe the tubulin at the crossing point could induce swap or not depending on its state. Tubulin dimers possess two different configurations and the original proposal of Hameroff was that these configurations correspond to two values of bit. The bit represented as a tubulin conformation would tell whether the left-handed strand runs above or below the right-handed strand at the crossing. The braiding would have representation as a 2-dimensional cylinder with points representing classical bits determining the TQC program. Classical computing and quantum computing would couple together. If tubulin conformations could form quantum superpositions, one would have "quantum-quantum-computation". According to [J6], the process inducing the change of tubulin conformation is chemical irreversible process so that this option does not seem to be possible.

3. The swap at the crossing point for certain value of time would be determined by the state of the tubulin at the crossing at particular moment. At each moment the braiding pattern for braids connecting microtubule ends would determine the TQC program in terms of unitary entanglement matrices. What is important is that unitary matrix between the states at the ends of braid gives rise to negentropic entanglement with entanglement probabilities forming a matrix proportional to unit matrix. The negentropic entanglement alone could be in principle source of conscious information obtained by interaction free quantum measurement. These states would define what I have called "Akashic records" responsible for memory storage as quantum invariants.

What is new that a generalization of TQC based on 2-braids defined by string world sheets can be imagined. The idealization of time evolutions of magnetic flux tubes can be idealized as string world sheets so that magnetic flux tubes would become key players also in 2-braid TQC. The transition from DNA as TQC to MT as TQC could correspond to the replacement of 1-braids with 2-braids. The quantum states of 2-braid TQC would corresponding unhalting 1-braid TQCs. This would represent a step leading to a higher abstraction level and could play a fundamental role in evolution in accordance with the role of emergence of microtubules in ontogeny.

1. The states of braid strands could define qubits for TQC based on 2-braids defined by string world sheets assignable to time evolutions of flux tubes idealized as strings.

   The spin direction of cyclotron Bose-Einstein condensate defines one candidate for qubit. The direction of DC current along braid strand could also define qubit. If the system is ideal Josephson junction then a constant voltage should however gived rise to an oscillating current. The presence of resistances at the ends of the flux tubes is expected to give rise to the standard form of Ohm's law in average sense.

2. The hysteresis curve for the micro tubular current I as function of voltage V between the ends of microtubule is reported to be square [J12] so that the phase transition changing the current direction could be quantum phase transition at criticality and make possible qubits as superpositions of both current directions near criticality for the current flip. TQC would halt when the voltage is changed so that it is not in the critical region anymore.

3. For magnetic flux tubes the vertex changing swap for 1-braid corresponds to reconnection, which would therefore find a new application in TGD inspired biology. I have earlier proposed that the ATP-ADP transformation generates reconnection but failed to realize that the interpretation could be in terms of 2-braid TQC. Energy metabolism as a continual occurrence ADP$\rightarrow$ATP and its reversal could be also a direct signature of 2-braid TQC. The spatio-temporal pattern of ADP$\leftrightarrow$ ATP transformations would reveal the TQC program code.

4. The change of the conformation of tubulin molecule would induce a swap. The reconnection of flux tubes -perhaps also induced by a change in the conformation of tubulin molecule - is also possible. The TQC program for 2-braids would be coded by the temporal history of changes of tubulin conformations represented in terms of bits. Chemistry would be used to write TQC programs. 2-braid TQC could be seen as sequence of 1-braid TQCs, which need not halt.

Admittedly, the model involves several new physics elements, which skeptic with Occam's razor could use to debunk the approach: dark matter hierarchy represented as hierarchy of effective Planck constants, the motion of magnetic body implied by the TGD based geometrization of classical fields and new view about space-time, and the notion of negentropic entanglement and Negentropy Maximization Principle [K6] defining the variational principle of TGD inspired theory of consciousness. These new elements are not however ad hoc assumptions but basic pillars of quantum TGD.

2.3.3 Identification of conduction pathways

Consider next the detailed identification of the conduction pathways assumed to correspond to a grid formed by flux tubes.

The interpretation of Bandyopadhyay has some problematic aspects. The proposed parallel strands do not intersect and cannot therefore define braid. The transitions to which the resonance frequencies are assigned, are not identified. No comment is represented concerning the problem that A-type microtubules have not been observed experimentally. From these problematic aspects it takes some time to end up with TGD based vision about the situation.

1. In TGD framework it is natural to regard the pathways of A-type microtubules as obtained by 2π twist for the "upper" end of B-type pathways which are of type X and possess the primary gap numbers allowed for A-type groups: recall that this gives 4 groups of four primary gaps. The pathways obtained from the transversal pathways of B-type microtubules by 2π twist define an excellent candidate for the complementary pathways needed to obtain crossings and braiding.

   What looks like a problem is that the twist for the 3 groups of 7-periodic pathways would produce two 7-periodic pathways per 13-unit, which corresponds to 14 rather than 13 tubulins rather per basic unit. The only explanation is that the discontinuity disappears and implies that there one has 13 tubulins per single structural unit of Q-type tubule.

2. If one excludes the decomposable pathways with $n_{gap} = 4$, the twists of 2 and 3 groups would define transverse pathways for A-type microtubules. Altogether 8 different coordinate grids formed by the pathways - now magnetic flux tubes - would be obtained. The 8 resonance frequencies would correspond to the phase transitions $A \leftrightarrow B$ induced by $\pm 2\pi$ twist for the "upper" end of the basic unit.

3. In TGD framework the most natural explanation for why A type tubules are ideal for TQC is that they correspond to a large value of h_{eff}, and the phase transition increases the value of h_{eff} and makes superconductivity and TQC possible for A type tubules. Unitary S-matrix characterizing TQC defines entanglement probabilities which are identical so that negentropic entanglement is in question. Negentropic entanglement is very closely related to large value of $h_{eff}/b = n$: n corresponds to the number of entangled states in the simplest situation.

4. One can estimate the value of h_{eff} if the AC radiation inducing the phase transition corresponds to dark photons with energy which is above thermal energy. For the energy $E \simeq 2$ eV of visible photons this would give for 8 MHz frequency $n = h_{eff}/h \simeq 6 \times 10^7$. For IR frequencies above thermal threshold which corresponds to the energy $E \simeq .05eV$ assignable to resting potential, one would have $n = h_{eff}/h = 10^5 - 10^6$.

   Corresponding p-adic length scales giving estimates for the length scales of flux tubes would scale like $n^{1/2}$. For B-type microtubules the p-adic length scale would be naturally 5×4 nm corresponding to 5-periodicity and 4 nm length diameter for single tubulin. For A-type microtubules corresponding scale would be by factor 10^3 longer for IR frequencies: upper bound would give 20 μm. The length of microtubules obtained in experiments ranges from 2μ to 25 μm so that the estimate seems to make sense.

2.3.4 Could frequency hierarchy correspond to a p-adic hierarchy of magnetic flux tubes?

The hierarchy of frequency scales kHz, MHz, and GHz could correspond to cyclotron frequencies for electron and perhaps also proton. In particular, the crucial role of water in making conductivity possible [J11] suggests that protonic cyclotron B-E condensate is important in the water core of MT at least but possibly also in longer length scales.

1. TGD allows magnetic monopole fluxes for flux tubes: in this case the cross section of the flux tube would be closed 2-D surface (sphere) rather than disk, and no current rotating around the tube would be needed to create the magnetic flux. This kind of flux tubes could explain the presence of magnetic fields in cosmic scales: in Maxwellian cosmology they are impossible in early cosmology because the needed currents are impossible. This kind of fluxes might be associated with super-conductors and even permanent magnets. The unit of magnetic flux $\Phi = \int eBdS$ is $h/2$ for a disk cross section. For spherical cross section of monopole flux tube the flux is $\Phi = \oint eBdS$ and unit is $2h$ that is 4 times larger. This could serve as a test for whether one has monopole flux or standard flux.

2. I have proposed that constant endogenous magnetic field $B_{end} = .2$ Gauss$= .2 \times 10^{-4}$ Tesla could explain the effects of ELF radiation to vertebrate brain [J4] as resulting from cyclotron transitions of large h_{eff} B-E condensate. The cyclotron transitions could also be replaed with phase transitions scaling the value of p-adic prime and thus the value of the magnetic field: this option implies that all particles make the same transition simultaneously. The model yields essentially the same predictions as the earlier model. The phase transition scales down the radius of the flux tube characterized by p-adic length scale $L(k) \simeq 2^{(k-151)/2} \times L(151)$, $L(151) \simeq 10$ nm by a power of two: the increase in cyclotron energy due to the reduction of flux tube radius is in good approximation $ne(B_f - B_i)/m = neB_f(1-2^k) \simeq neB_f$, where B_f is the field strength for the compressed magnetic flux tube.

3. For electron in endogenous magnetic field of .2 Gauss cyclotron frequency is $f_e \simeq .5$ MHz: for proton one has $f_p meq 300$ Hz (note that the ratio of cyclotron frequencies of electron and proton is given by the mass ratio $m_p/me \simeq 1843 \sim 2^{11}$) . The reported resonance frequency is $f \simeq 8$ MHz, which is 2^4 times higher than f_e. This suggests that the irradiation induces p-adic phase transition of flux tubes contracting them by a factor 1/2 and increasing field strength by a factor 4. This would mean that the p-adic length scale is reduced from $L(k)$ to $L(k-4)$. The possibility of this interpretation yields support for the p-adic length scale hypothesis.

4. Purely number theoretic considerations predict that in biologically interesting length scale range ranging from 10 nm to 2.5 μm there are four p-adic length scales which correspond to Gaussian Mersenne primes $M_{G,n} = (1+i)^n - 1$, $n = 151, 157, 163, 167$. One could speak of a number theoretic miracle. It is easy to see that the transition induced by 8 MHz radiation could correspond to the transition $k = 167 \to 163$ for electron. This gives strong support for the fundamental role of the miracle Mersenne scales.

   B_{end} corresponds to magnetic length of $L_B = \sqrt{\hbar/eB} = 5.7$ μm not far from the p-adic length scale $L(169)$ is $L(169) \simeq 5.1$ μm. L_B would give flux quantum $h/2$. The problem is that this scale is by a factor 2 longer than the Mersenne scale $L(167)$. Situation changes if the flux is monopole flux for flux tube with spherical rather than disk-like cross section. By previous argument the flux quantization would be obtained for a sphere with radius given by the p-adic length scale $L(167)$. One would obtain Mersenne scale and the transition $L(k) \to L(k-4)$ would correspond to $k = 167 \to k = 163$. Proton cyclotron frequency would be scaled up in this transition to 4.8 kHz and it would be natural to identify frequencies in kHz frequencies as harmonics of f_p.

5. The scaling $k \to k - 11$ would transform $f_e = .5$ MHz to $f_e = 1$ GHz. The p-adic scale would become $k = 156$. $k = 157$ would have been more attractive outcome. $L(156) \simeq 57.6$ nm looks too large to be radius for a magnetic flux tube assignable to the MT strand of thickness of order 4 nm. I would more naturally correspond to the length scale defined by a strand of 13 tubulins.

6. Microtubule strand corresponds to length scale 4 nm which suggests that p-adic length scale $L(149)$ assignable to lipid layer of cell membrane characterizes the flux tubes defining the coordinate grid at MT surface. GHz frequency is assigned with the order water in the interior of MT $L(145) \simeq 1.25$ nm seems to be a good candidate for the corresponding p-adic length scale. $f_p = 1.35$ GHz frequency is obtained if flux the transition is $k = 167 \to 145$.

7. An attractive possibility is that the flux tubes in the interior of MT contain dark proton sequences [K7] defining the dark nuclei with single dark proton with large value of Planck constant h_{eff} with size scale of single DNA codon. The amazing prediction of the model of dark nucleon is that the counterparts for the DNA, RNA, amino-acids and even tRNA are obtained and vertebrate genetic code can be realized as a natural correspondence between these states [K4, K7]. One can imagine the possibility that the dark genetic codes inside MT and connected by radial magnetic flux tubes to the codons at the braid strands at the surface of MT.

2.3.5 About B-type lattice

Some TGD- and computer science inspired comments on B-type lattice are in order.

1. B-type lattice is discontinuous along vertical line. There is a horizontal pair of α and β tubulin monomers at discontinuity and here α (β) tubulins have 3 instead of 2 nearest neighbour β (α) tubulins. Could the possible flux tubes connecting microtubule to the axonal membrane and making possible to receive sensory input begin here? The flux tube pair parallel to this line brings in mind DNA double strand. The α- or β-sequences with vertical 5-periodicity would be discontinuous after full turn: the shift in vertical direction would be 5 tubulin units but single turn of the helical path would correspond to a vertical shift of 4 tubulin units only.

2. The discontinuity suggests that the tubulin consists of pieces of 13-units maybe defining a sequences of 13 binary digits as code words - kind of bytes - in turn defining the classical computer code giving rise to TQC code.

3. A second interesting aspect is the 7-periodicity of transversal pathways in axial direction. One of the TGD inspired models for genetic code [K3] interprets 64 genetic codons as a subset of 127 element space consisting of $2^7 - 1$ elements identified as a subset set of mutually consistent logical statements of 7-bit algebra so that the negation of the statement cannot belong to the set.

   Statements would be analogous to axioms of mathematical system being identically true. One statement is non-realizable: in case of set theoretic realization it would be naturally empty set. If statements are realized as spin excitations of ferromagnet then absence of spin excitations would correspond to the non-realizable statement. One could also argue that only communicable statements are possible. Communication of the state could be defined as radiation generated by the transition from the ground state to a multiply excited state. If there is no change (ground state goes to ground state), the statement is not communicable. Could 7-bit sequences be restricted by the condition that they represent identically true statements? This condition would make possible error correction mechanism analogous to parity bit.

2.3.6 Could DNA sequences code for TQC programs?

One also ends up with a rather crazy idea about possible interpretation of genetic code.

1. If one piles up 2-D TQC:s one obtains 3-D 1-braid TQC. In crossings one must have 3 bits to specify whether to swap or not since there are three planes for TQC and 3 pairs of crossing strands (12,13,23).

2. For 2-braid TQC one obtaisn 6 bits at each crossing of 3-D grid. The first bit tells whether reconnection occurs and second tells which of the resulting crossing strands goes over the other. One can imagine even a concrete realization. DNA strand which is a coil with radius of 10 nm could be accompanied by a flux tube and there would be for each codon to flux tubes crossing this flux tubes so that 6 bits would be needed to characterized the 2-braid locally. DNA as TQC model suggests that second flux tube connects DNA codons to a helical flux tube at lipid layer of nuclear or cell membrane. Second strand could connect it to similar tube at cell membrane.

3. Just for fun one can imagine also a second, even more science fictive realization. If one further piles 3D TQC:s in 4-D one obtains 4-D one making sense in zero energy ontology because failure of strict non-determinism is basic element of TGD. Single crossing would in 4-D would involve crossings of four lines in orthogonal dimensions. TGD predicts also space-time regions with Euclidian signature in all scales (lines of generalised Feynman diagrams). I have proposed that any system corresponds to an Euclidian space-time sheet having its size and shape and behaving like quantum system. In these regions the fourth piling might really make sense!

   This would make 6 crossing pairs corresponding to 6 planes in which particular TQC takes place - for which one must tell whether to swap or not (12,13,14,23,24,34). This makes 6 bits. DNA codons correspond to 6 bits! Could codons define crossing points of magnetic flux tubes arriving from 4 coordinate directions- perhaps at Euclidian space-time sheets? Could the planes correspond to 3 components of magnetic field and 3 components electric field. Magnetic flux tubes and electric flux tubes in 3 directions? In Euclidian regions magnetic and electric do not differ intrinsically. It is however difficult to concretize this proposal.

In the following I try to understand the observations reported by Anirban Bandyopadhyay (`https://www.youtube.com/watch?v=VQngptkPYE8`) in TGD framework.

3 The obervations of the group of Anirban Bandyopadhyay from TGD point of view

The observations of Anirban Bandyopadhyay are briefly summarized by Massimon Pregnolato at `http://www.quantumbionet.org/admin/files/MassimoPregnolato-RitaPizzi2011.pdf`. At this stage one can of course several models for the findings and in the following one option is selected.

1. The most plausible model is based on the notion of coordinate grid formed by longitudinal and transversal magnetic flux tubes whose crossing points are the points at which swap occurs or does not occur depending on the state of tubulin dimer. The grids associated with A and B tubules are obtained by a 2π twist for the upper end of the tubulin.

2. There is a large number of options for grids and they are identified on basis of the experimental findings. Transversal coordinate lines would correspond to the 7-periodic parallel lines with either gap 2 or 3 (gap 4 lines decompose to gap 4 and gap 2 lines) and longitudinal coordinate lines to one of 4 line groups involving four gaps so that 8 coordinate grids are obtained and related by a 2π twist for A and B tubules respectively. Gaps could characterize measurement resolution.

3. For A-type microtubule one can consider also Fibonacci grids constructed from helical curves and their mirror images with periodicities 3,5,8,13 and arbitrary gaps but it seems that it is difficult to interpreted the resonance frequencies and understand their number for this option.

3.1 Fröhlich B-E condensation or something else?

Excitation at the resonance frequencies cause microtubules to assemble extremely rapidly. This is proposed to be due to Fröhlich condensation. The resonance frequency of AC stimulation leading to a rapid generation of microtubules in the length scale range $[.2 - 22.5]$ μm is around 8 MHz. There is correlation between resonance frequencies and lengths of microtubules and qubit sets that are possible.

Comment: The identification as formation of Fröhlich B-E condensate can be criticized. The frequency at which this would take place was predicted by Fröhlich to be around GHz rather than in MHz range.

In TGD framework AC stimulation could generate flux tube grid or activate existing magnetic flux tube grid forming a braid like structure serving as a template for the formation of microtubule around it. If the formation of grid corresponds to quantum criticality, the resonance frequencies could also generate phase transitions between A and B type states of the microtubuli. AC signal could also generate contacts to these flux tubes making possible supra currents. The formation of microtubules is known to proceed by the formation of vertical nucleotide polymers which are then glued together horizontally: flux tube could serve as a template for the formation of the nucleotide polymer. The

magnetic fields at flux tubes can be accompanied by helical electric fields (in this case both magnetic and electric fields are helical) and these fields could be responsible for the polarization of microtubule and induce the growth of microtubules in such a manner that the polarized alpha-beta tubulin always attaches in the same manner to the growing polymer. Fröhlich condensation would be a consequence of generation of flux tube coordinate grids defining microtubule skeleton- growth of the magnetic body would precede that of biological body.

The length of the tubule increases with resonance frequency which suggests that single tubulin dimer is added to the polymer during each cycle. MHz range and formation time around few seconds. This would mean something like 10^6 giving MT with length of order 10^{-4} meters. The order of magnitude is correct.

3.2 8 resonance frequencies in AC stimulation and 8 distinct interference patterns

Microtubules are reported to have 8 resonance peaks for AC stimulation (kilohertz to 10 megahertz), which appear to correlate with various helical conductance pathways around the geometric microtubule lattice. The explanation is proposed in terms of current pathways which are identified topological qubits.

Comment: To me this terminology looks strange and confusing. Why not to speak about braid strands or specify what topological qubit means if one is speaking about TQC? I am unable to understand why groups of parallel pathways are considered as topological qubits (TQs). The idea about parallel translates might however make sense.

As already explained, the notion of coordinate grid in the sense discussed is consistent with the findings. The resonance frequencies could correspond to phase transitions changing A-type coordinate grids to B-type or vice versa. Coordinate grid would define the basic architecture of TQC.

The second claim is that there are altogeher eight distinct quantum interference patterns from a single microtubule, each correlating with one of the 8 resonance frequencies and pathways. According to the interpretation discussed in the talk 4 sets of four pathways representing quantum TQ each can exist simultaneously for type A microtubules claimed to be ideal for quantum computation. Lattices of type B exhibit 4 different pathways and are claimed to be ideal for communications. The lattices A and B are complementary in the sense that together they allow all possible pathways (this is not quite true: $n_{gap} = 12$ is lacking). The set of possible pathways depends on the length of MT.

Comment: Also this would conform with the TGD inspired model in which one has 8 coordinate grids for tubules of B and their deformations by twist to A type tubules. The 8 interference patterns would correspond to different coordinate grids. What coordinate grids are physically allowed coordinate grids are depends the length of the microtubule.

3.3 Observations about conductivity

There are also several observations about conductivity suggesting quantum coherence.

1. In assembled microtubules AC excitation at the resonant frequencies causes electronic conductance to become lossless, or 'ballistic', essentially quantum conductance, presumably along these helical quantum channels. Resonance in the range of kilohertz demonstrates microtubule decoherence times of at least 0.1 millisecond. Does this mean that AC signals at resonance frequencies are able to create these channels or groups of them?

   Or does this mean, that the resonance signal transforms the microtubule to A (or B) type lattice which is highly conducting or even super-conducting (via magnetic flux tubes). The claim that A type lattice does not exist in vivo reduex to the statement that it does not exist stably in vivo. The AC signal at resonance frequency induces the twist taking lattice B into lattice A in which TQC is possible.

2. There are three frequency scales corresponding to kHz Hz, MHz and GHz ranges. The natural identification for these rather low frequency scales is in terms of cyclotron frequencies of dark electrons and possibly also various ions at magnetic flux tubes. The simplest identification would be in terms of three ranges for the strengths of magnetic field. I have proposed that .2 Gauss magnetic field define endogenous magnetic field explaining the effects of ELF em radiation on brain in terms of cyclotron transitions of biologically important ions, in particular Calcium ions

for which cyclotron frequency would be 15 Hz (later an alternative explanation making essentially the same predictions has emerged). For electron the cyclotron frequency would .5 MHz so that for 16 times strong field would correspond to cyclotron frequency of 8 MHz appearing as resonance frequency. GHz frequency would require a magnetic field of .04 Tesla.

3. It is stated that the system cannot be classified as insulator, semiconductor, or conductor. The reason would be that the two bands involved do not overlap as in conductors, are not completely separate with large gap as in insulators, nor separate with a small gap. Instead the bands touch each other in pointwise manner.

   Comment: Stimulus with the resonance frequency could regenerate the flux tubes or bridges to the flux tubes allowing the transfer of electrons to them. The ballistic resistance temperature independent resistance would be due to a very long free path or due to super-conductivity at the magnetic flux tubes - the latter is the TGD inspired hypothesis. This kind of behavior could result if the electrons can leak to the flux tube only if they have same momentum as the Cooper Bose-Einstein condensate at the flux tube. Resonance condition would mean that the magnitude of the wave vector of electron is quantized in magnitude: this would also support the proposed interpretation.

4. It is claimed that conductance does not depend on microtubule length, is temperature independent, and has discrete values. Also ohmic dissipation is claimed to be negligible.

   Comment: The interpretation could be in terms of superconducting current pathways defined by magnetic flux tubes looks natural as already found.

The observation that water is necessary for MT conductivity [J11] suggests that the presence of water is essential for large h_{eff}. One of the many possibilities is that the flux tubes (which are closed) return through the interior of MT containing the ordered water. Also dark variants of genes realized as dark proton sequences dark nuclei could be involved.

3.4 Ferroelectric hysteresis

What is interpreted as ferroelectric hysteresis is claimed to demonstrate memory capacity in microtubules [J12]. Current viz. voltage over the microtubule exhibits square hysteresis. Suddenly all-in one jump changing the direction of current at critical voltage. This is analog of ferromagnetic or ferroelectric behavior but in completely quantal manner.

One can ask whether the quantum superpositions of two current directions might represent qubit. If so, the information processing capacity of microtubule would be rather modest unless one consideres seriously 2-braid TQC. (recall however that in neuroscience single neuron is assumed to represent bit).

It is not at all obvious that ferroelectric hysteresis is in question and TGD suggests different interpretation for the hysteresis curve. The current as function of voltage could reflect quantum coherent current in Bose-Einstein condensate of electronic Cooper pairs with all Cooper pairs having the same momentum. Macroscopic quantum coherence would make the state stable against perturbations defined by the external voltage and only when the voltage exceeds critical magnitude the state would change its momentum to opposite values instantaneously. If the interpretation as cyclotron BE-condensate is correct one would have Cooper pairs with spin 1 in same state and effectively only single particle representing memory.

The assumption of Bose-Einstein condensate might be unnecessary strong: negentropic entanglement might be enough. Dark electrons are negentropically entangled and the entanglement stores potentially conscious information. The degeneracy of the ground state essential for achieving stable enough entanglement also in standard approach to TQC. The negentropic entanglement would not be in spin degrees of freedom but in those labeling sheets of the covering of M^4 and CP_2 defined by the space-time sheet of electron. Anti-symmetry in these exotic degrees of freedom would make electrons bosons if seen from the perspective of standard physics and allow them to effectively B-E condense to the same state with respect to standard quantum numbers. Note that this proposal resembles somewhat the proposal of Hameroff and Penrose for topological qubits in terms of parallel current pathways with same gap. In this case the negentropic entanglement could perhaps stabilize the state in the sense that NMP [K6] would not allow the quantum jump leading to opposite direction of electron current to take place.

3.5 Dynamical instability of MTs

MTs are dynamic instable and the length of MT changes in jumps. The conjecture of the talk is that some kind of language is involved. On basis of few second time scales one can wonder whether the correspondence with language production could be rather direct. Could regions of type A contain the information communicated in speech, say the information needed to form words or sentences? If microtubules of type B are indeed responsible for communications, one can ask whether $A \to B$ phase transitions generate the signal in turn inducing the nerve pulse patterns correlating with internal speech. The connection with language could be realized also at gene level [K3].

I have proposed that microtubule acts as quantum antenna [K8] emitting radiation with frequencies $f_n = nc/L$, where L is the length of MT. The variation of the length of microtubule would predict frequency modulation of the radiation coding for potentially conscious information. The model for nerve pulse and EEG makes similar prediction [K10, K1]. Josephson frequency for cell membrane as Josephson junction is proportional to membrane voltage and the variations of membrane voltages due to oscillations and nerve pulse activity are coded to EEG via frequency modulation. Even ordinary speech involves frequency modulation as is clear by listening recorded speech with abnormally slow speed. If microtubules talk, the most natural language would be based on frequency modulation.

The system seems to be critical, maybe it is quantum critical in TGD sense. At quantum criticality the dynamics involves a large number of length scales. In TGD framework quantum criticality would mean that the hierarchy of Planck constants is involved such that given length scales is proportional to the effective value of Planck constant. Maybe different lengths for flux tubes correspond to values of effective Planck constant $h_{eff} = nh$.

4 Conclusion

The important conclusion suggested by the experiments is that microtubules - in particular, brain microtubules - are macroscopic quantum systems. Already this would be enormously important conclusion. To my personal opinion, the interpretation in the talk is not convincing at the level of details and TGD inspired modification of the proposal in terms of flux tube coordinate grids making possible TQC architectures with tubulin dimers defining bits defining in turn TQC program looks more plausible to me. A natural generalization of of 1-braid TQC to 2-braid TQC is also highly suggestive in TGD framework and could be seen as evolutionary step assignable to the emergence of microtubules. The interpretation based in Fibonacci conduction paths fails to predict correctly the number of resonances. An attractive interpretation for the resonance frequencies is in terms of phase transitions between A and B type lattices. If A type lattices can be generated only in h_{eff} increasing phase transitions induced by AC stimulus at resonance frequencies, one could understand their experimental absence and why super-conductivity like state is generated.

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