Electronic QED coherence in brain microtubules

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Abstract: - In this paper we show in the water confined within the inner hollow of brain microtubules there exist the conditions to allow a spontaneous QED quantum vacuum phase transition towards a macroscopic coherent quantum state, characterized by a phased oscillation between the water molecules states and an auto-generated electromagnetic field associated to a suitable electronic transition in them. As a result, a field of superradiant photons, whose frequency is smaller than the corresponding frequency belonging to a free photon with the same wavelength, is generated. This superradiant field is characterized by an evanescent tail exceeding the microtubules dimension and whose persistence against environmental decoherence is ensured by its own QED coherent behaviour.

Key-Words: - QED coherence, Microtubules, Water, Evanescent Photons.

1 Introduction

The occurrence of macroscopic coherence phenomena in biological systems was firstly conjectured by Frohlich [1] several years ago. He suggested that macroscopic quantum phenomena were able to explain the energy transport without loss in the living organisms and the signal transfer based on collective coherent oscillations associated to a branch of longitudinal electric modes in the frequency range

$$\nu_{coh,F} \sim 10^{11} - 10^{12}\, s \qquad (1)$$

called "Frohlich frequency". This could make possible the energy storage in a thin two-dimensional layer beneath the cell membrane, acting as a biological superconducting medium, under dipolar propagating waves without thermal loss [1]. A macroscopic quantum process involving coherent dynamics could be also at the basis of the so-called "biophotons emission", namely the weak emission of photons in the visible range of electromagnetic spectrum by living organisms as firstly suggested by Popp [2] and recently reinterpreted, within the framework of QED coherence in condensed matter and Quantum Vacuum dynamics, by Caligiuri [3].

The possibility to consider the behaviors of typical life processes in terms of QFT principles is also been confirmed by the studies of Umezawa [4] who suggested the presence, in brain's cells, of a spatially distributed system characterized by the full range of quantum mechanical degrees of freedom subjected to quantum phenomena and by those of Davydov [5], who extended some considerations of the Frohlich's model, by proposing the existence of "solitonic excitation states" responsible for the dissipation-free energy waves propagating along α- helices in proteins.

In 1990's Hameroff and Penrose [6,7,8] suggested a primary role of quantum effects in brain functioning and, in particular, in the emergence of consciousness, by considering the dynamics of microtubules (MT) of brain cells, described as a coherent superposition of two-levels quantum states, corresponding to the two conformations of tubulin proteins (α- and β-tubulin), depending on the position of the unpaired charge of $18e$ relative to the pocket.

This model [4] considers the possible occurrence, in the water molecules contained in the MTs inner volume, of superradiance, namely a quantum collective behavior of water molecules and electromagnetic field modes able to convert the perturbative thermal and molecular disordered oscillations into coherent photon modes inside MT, firstly suggested and fully formalized by Preparata et al [9].

Jibu et al [10] then proposed these coherent photons entangle the cytoskeletal protein and the MT quantum sates of a given neuron link to those of other neurons by the tunneling of such coherent photons through biological membranes, in this way trying to propose a possible physical model able to describe human consciousness as arising from the creationannihilation dynamics of a finite number of evanescent coherent photons in brain.

All the above models considered the QED coherence in water as arising from the quantum transitions between rotational energy levels in water molecules and this nevertheless pones, as shown by some authors [11,12], few critical theoretical problems. The first one concerns the value of the wavelength of coherent photons associated to the energy difference of $\Delta E = 4\,meV$ between the two rotational energy eigenstates of water molecule involved in superradiant water model, equal to $\lambda \simeq 310\,\mu m$ (i.e. lying in the infrared range of electromagnetic spectrum), that would be not comparable with the typical length $l \sim 1\,\mu m$ of a moderate sized MT, since $\lambda \gg l$, and so unusable to "manipulate" data inside MTs cavities. The second one is related to the problem of environmental decoherence that, even in a coherent system as that proposed in the Hameroff-Penrose model, would push out of coherence the ensemble by a time $O\left(10^{-6} - 10^{-7}\right)s$, a time scale much shorter than that required for conscious perception, but sufficient to allow a loss-free energy transfer and signal propagation along a moderately long MT ($l \sim 1\,\mu m$) .

In this paper the author shows in water confined within the inner hollow of brain microtubules there exist the conditions to allow a spontaneous QED quantum vacuum phase transition towards a macroscopic coherent quantum state characterized by a phased oscillation between the water molecules states and an auto-generated electromagnetic field associated to a suitable electronic transition in them. This model, already successfully applied to the study of biophotons emission [3], considers electronic transitions rather than rotational energy levels in water molecules and it is able to overcome both the critical points above discussed as well as to explain the origin of superluminal evanescent photons in brain MT [13] that could represent the key to explain some of the most important cognitive functions in human brain

2 A brief outline of QED coherence in condensed matter

According to the framework of QED coherence in condensed matter, originally developed by Preparata [14] and applied to living systems by Preparata, Del Giudice et al. [15-22], under suitable conditions (almost always verified in the condensed matter and living organisms as well) regarding density and temperature of the system, a coherent electromagnetic field, oscillating in tune with all the matter constituents, spontaneously emerges from a self-produced electromagnetic field.

In particular, according to this model, for every ensemble of N elementary components (atoms or molecules) placed in the empty space (namely without any matter or radiation field different than ZPF) there exist a critical value of density $\Theta_{crit} = \left(N/V\right)_{crit}$ and temperature $T_{crit} = T_0$ such that, when $\Theta > \Theta_{crit}$ and $T < T_0$, the system spontaneous "decays" into a more stable state (characterized by lower energy and so strongly favored) in which all the matter components are phase correlated among them by means of the action of an electromagnetic field oscillating in tune with them too, confined within a defined spatial region, called "Coherence Domain" (CD), associated to the wavelength of the tuning electromagnetic field.

More specifically we consider a matter system composed of electrical charged particles (electrons and nuclei) characterized by a discrete energy spectrum $\left\{E_i\right\}$ and indicate with "0" its fundamental state (whose energy is $E_0 = \hbar\omega_0$) and with "k" a generic excited state (with an associated energy $E_k = \hbar\omega_k$). A quantum vacuum fluctuation able to coupled to the systems and excite the state k (from the fundamental one) must then have a wavelength $\lambda = hc/\delta E$ where $\delta E = E_k - E_0$. The probability of this coupling with the excitation of state k is quantified by the "oscillator's strength" for the transition $0 \rightarrow k$, given by [14]

$$f_{0k} = \left(2m_e/3\omega\right)\sum_j \left|\left\langle 0\right|\vec{J}_j\left|k\right\rangle\right|^2 \qquad (2)$$

Where ω is the frequency of the exciting electromagnetic field, m_e the electron mass and $\vec{J}$ the electromagnetic current density operator. For an atom or molecule with n electrons, the total probability of interaction is proportional to n since f must follow the rule

$$\sum_k f_{0k} = n \qquad (3)$$

Within a volume of space $V = \lambda^3$ "covered" by an oscillation of the QV electromagnetic field resonating with them, containing N atomic or molecular species, the total probability P_{tot} that a photon "escapes" from QV, couples with an atom or molecule and puts it in a given excited state is given by

$$P_{tot} = P \cdot N = P\left(N/V\right)V = P\left(N/V\right)\lambda^3 \qquad (4)$$

where P indicates the "Lamb – shift type" probability of coupling for a single atom or molecule, is proportional to the matter density.

Consequently, when density exceeds a particularly high value, almost every ZPF fluctuation couple with the atoms or molecules in the ensemble. This condition starts the "runaway" of the system from the perturbative ground state, in which matter and quantum fluctuations are uncoupled and no tuning electromagnetic field exists, to a coherent state in which, within a CD, a coherent electromagnetic field oscillated in phase with matter determining a macroscopic quantum state in which atoms and molecules lose its individuality to become part of a whole electromagnetic field + matter entangled system.

2.1 The equations of QED coherence in matter

In order to describe the evolution of such a system we consider [14,22], for simplicity, a two-levels matter system described by the matter field $\chi_l\left(\vec{x},t\right)$ with $l = 0,k$ and an electromagnetic field characterized by its vector potential $\vec{A}\left(\vec{x},t\right)$. Neglecting the spatial dependence of both the fields (being slowly varying within the CD) the dynamic equations, describing the time-evolution of the electromagnetic field+ matter interacting ensemble, can be written as

$$\begin{aligned} i\dot{\chi}_0(\tau) &= g\chi_k(\tau)A^*(\tau) \\ i\dot{\chi}_k(\tau) &= g\chi_0(\tau)A(\tau) \\ -\frac{1}{2}\ddot{A}(\tau) + i\dot{A}(\tau) - \mu A(\tau) &= g\chi_0^*(\tau)\chi_k(\tau) \end{aligned} \qquad (5)$$

where

$$g = eJ\left(8\pi/3\right)^{1/2}\left(N/2V\omega_k^3\right)^{1/2} \qquad (6)$$

and

$$\mu = \left(e^2\lambda/\omega_k^2\right)\left(N/V\right) \qquad (7)$$

A being the directional averaged vector potential and $\tau = \omega_k t$. The time – evolution of the system starts from the "perturbative" initial state of QED defined by

$$A(0) \sim N^{-1/2} \to 0,\ \chi_k(0) \sim N^{-1/2} \to 0,\ \chi_0(0) \sim 1 \quad (8)$$

towards the coherent stable state characterized by $A \gg 1$ and $\chi_k \gg 1$. By differentiating the third of (5) and substituting it into the second one, we obtain

$$-\frac{1}{2}\dddot{A}(\tau) + \ddot{A}(\tau) + i\mu\dot{A}(\tau) + gA^2(\tau) = 0 \qquad (9)$$

whose algebraic associated equation is

$$a^3/2 - a^2 - \mu a + g^2 = 0 \qquad (10)$$

Equation (9) describes the short-time behavior of the system [14], it prescribes the "decay" towards the coherent state will occur when the values of parameters μ and g are such to have only one real solution of (10) exists. The other two complex-conjugate solutions then just describes the exponential increase of $A(\tau)$ characterizing the coherent tuning field. It can be shown [14] that this occurs, for a given μ, when

$$g^2 > g_{crit}^2 \qquad (11)$$

where

$$g_{crit}^2 = 8/27 + 2\mu/3 + \left(4/9 + 2\mu^2/3\right)^{3/2} \quad (12)$$

In summary, when condition given by (11) is satisfied, the system will undergo a "phase transition" from the incoherent pertubative ground state (PGS) in which the electromagnetic and matter fields perform Zero – Point very weak uncoupled fluctuations only, towards the coherent ground state (CGS) in which a strong electromagnetic field arises from QV and couples with the oscillations of the matter fields tuning all the matter constituents to oscillate in phase with it and among themselves by means of it. The stability of CGS is ensured because this state is energetically favored and represents the "true" ground state of the electromagnetic field + matter system [14]. It can be shown that the energy gap δE between the CGS and PGS of an ensemble composed by N atoms (or molecules) interacting with ZPF, can be written as

$$\delta E = aN - bN\sqrt{N} \quad (13)$$

in which $a > 0$ and $b > 0$ are two constants of proportionality depending on the system properties. From (13) we see that there exist a definite value of $N = N_{crit}$, a function of a and b, such that, when $N \geq N_{crit}$ (namely just the condition for the runaway of the system towards the coherent ground state) we have

$$\delta E < 0 \quad (14)$$

The very important result given by (14) has remarkable consequences [14-22] among which:

a) the CGS is the "actual" ground state of the system because its energy is lower, of the quantity δE (gap), than the energy of PGS in which we only have the independent Zero-Point fluctuations of electromagnetic and matter components while, in the CGS, the matter constituents oscillates in tune with a non fluctuating "strong" electromagnetic field;

b) the evolution of the system from PGS to CGS can be considered as a real phase transition, corresponding to the release of a quantity of energy δE to the environment, so characterizing the electromagnetic field + matter ensemble as an open system.

The tuning of the electromagnetic field with the matter field determines a rescaling of frequencies of the matter system so that the common oscillation frequency of electromagnetic field and matter field is given by $\omega_{coh} < \omega_{fluc}$, where $\omega_{fluc} = c^2/\lambda_{CD}$ is the frequency of the QV fluctuating electromagnetic field able to excite the level k and whose wavelength λ_{CD} defines the spatial extension of the CD.

The coherent electromagnetic field generated inside a CD shows an evanescent tail at its boundary, determining a superposition between the "inner" electromagnetic fields of the neighbouring coherence domains. This superposition makes it possible the interaction between different CDs giving rise to the coherence among them also known as "supercoherence" so explaining the physical origin of long-range and stable correlation between a very high number of matter components in living organisms.

3 The emergence of electronic QED coherence in brain microtubules

Microtubules are rigid polymers consisting of groups of protofilaments, of average length ranging between $1-50\,\mu m$ [23], cylindrically shaped with an outer and inner diameter respectively of about $25\,nm$ and $15\,nm$ (see Fig. 1). They contain structural subunits, the tubulin heterodimers (of length about $8\,nm$), in turn composed by $\alpha-$ and $\beta-$ tubulin having an high electric dipole moment (about $10^{-26}\,C\cdot m$) [23].

The inner hollow volume of MT can be assumed to be "filled" with (thermally) isolated water [23] that, as we'll show in the following, under the boundary conditions averagely satisfied inside the brain MTs, undergoes a spontaneous quantum phase transition towards a coherent state in which an electromagnetic field oscillates in tune with the water matter field between two energy levels corresponding to an electronic transition of water molecule.

Some fundamentals of the coherent dynamics and thermodynamics of liquid water has been already analyzed in series of papers [17-22], resulting in the occurrence of very peculiar and unthinkable features.

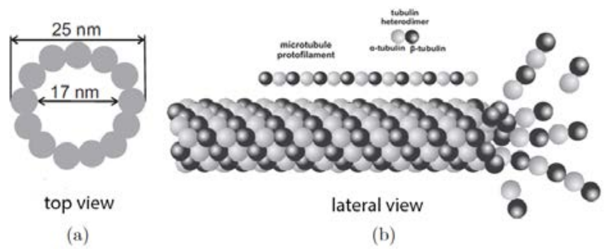

Fig. 1. Schematic view of MT structure and its constituents.

In order the "runaway" from PGS to CGS to spontaneously occur in the water inside MT the condition (11) must be satisfied. In order to verify if this is the case we must obtain an estimate of the value of g_{crit} for our system corresponding to a critical density given by

$$\rho_{crit} = m_{H_2O}\left(N/V\right)_{crit} \quad (15)$$

In the case of water [14] the coupling factor g can be written as

$$g = \left(2\pi/3\right)^{1/2}\left(\omega_p/\omega_0\right)^{1/2} f_{01}^{1/2} \quad (16)$$

where f_{01} is the oscillator strength f_{nk} for the electronic energy transition $0 \leftrightarrow 1$ and ω_p is the plasma frequency given by

$$\omega_p = \left(e/m_e^{1/2}\right)\left(N/V\right)^{1/2} \quad (17)$$

and

$$\mu = -\left(3/2\right)\left(\omega_p/\omega_0\right)^2 \sum_n f_{nk}\,\omega^2 \Big/ \left[\left(E_n - E_k\right)^2 - \omega^2\right] \qquad (18)$$

in which the oscillator strength for the electronic transition $n \leftrightarrow k$ is given by (2). In [14,19-22] the values of g^2, μ and ρ_{crit} related to the first "low-lying" levels of water molecule has been calculated, showing that that smallest value of $\rho_{crit} = 0.310\,g\cdot cm^{-3}$ corresponds to the transition from the ground state to the level at $E = 12.06\,eV$, namely to a $5d$ excited electronic state of water molecule just below the ionization threshold of $12.60\,eV$.

When $\rho \geq \rho_{crit}$ the Quantum Vacuum fluctuations, characterized by a frequency $\omega = \omega_0 = 12.06\,eV$, start to build up coherently with those of the matter field at the same frequency, determining the transition of the system from PGS to CGS. The matter + electromagnetic field system now behaves as a macroscopic quantum system oscillating with a common frequency ω_{coh} and all the other energetic levels will be totally ignored by the system evolution.

If we assume for the brain an average temperature $T \sim 37\,°C$ and a MT cavity volume [23] $V_{MT} \sim 5\cdot 10^{-22}\,m^3$ for a moderately long ($l \sim 10^{-6}\,m$) MT, we can estimate the water density $\rho_{water,MT}$ inside MT as

$$\rho_{water,MT} \sim 0{,}993\,g\cdot cm^{-3} > \rho_{crit} \qquad (19)$$

The (19) demonstrates the existence of the right boundary conditions, inside MT inner volume, required for the occurrence of the a superradiant phase transition of water towards the coherent state.

We further observe the transition energy $\omega_0 = 12.06\,eV$ corresponds to the formation of CDs whose "size" is of order of

$$L_{CD} \simeq 2\pi/\omega_0 \sim 0.1\,\mu m \qquad (20)$$

namely about $1/10$ of the average length of a moderately sized MT and, in particular, of the order of magnitude of the MT dimers ($\sim 8\,nm$).

Equation (20) indicates the superradiant photons belonging to the coherent electromagnetic field oscillating in phase with water molecules inside MT coupled to the electronic transition from the ground state to the energetic level at 12.06 eV, are characterized by a wavelength much shorter than the typical length of MT. This allows the formation of node and antinodes of this field within the inner of MT cavities.

This very important result solves the actual question discussed in [24] regarding the infrared superradiant photons considered in the theoretical models of coherence in MT presented so far.

The coherent dynamics inside CD determines a rescaling of the common oscillation of electromagnetic field and matter to a value $\omega_{coh} \ll \omega_0$, where ω_0 is the field frequency characterizing the perturbative state in which they are out of phase. It has been shown [14,17-22] the "new" value of frequency to be

$$\omega_{coh} = \left|1 - \dot{\phi}\right|\omega_0 \qquad (21)$$

where ϕ is the phase factor ruling the behavior of the vector potential $A(\tau) = A_0 \exp\left[i\phi(\tau)\right]$. In the case of water [14,17-22]

$$\omega_{coh} \sim 10^{-2}\omega_0 \qquad (22)$$

determining an energy gap per molecule $\delta E/N \sim -0.26\,eV$.

3.1 Evanescent electromagnetic field generated by coherence domains

The frequency rescaling given by (21) implies the coherent electromagnetic field generated inside water's CDs is "trapped" within them and cannot radiate outside them, thus preventing their radiative dissolution. This can be seen by considering the Einstein's equation of the photon mass that becomes

$$\begin{aligned} m^2c^4 &= \\ &= \hbar\left(\omega_{coh}^2 - 4\pi^2c^2/\lambda_{CD}^2\right) < \hbar\left(\omega_0^2 - 4\pi^2c^2/\lambda^2\right) = 0 \end{aligned} \qquad (23)$$

The equation (23) also shows, as already discussed by Caligiuri et al. [13], the photons belonging to coherent e.m. field can be considered as evanescent superluminal photons.

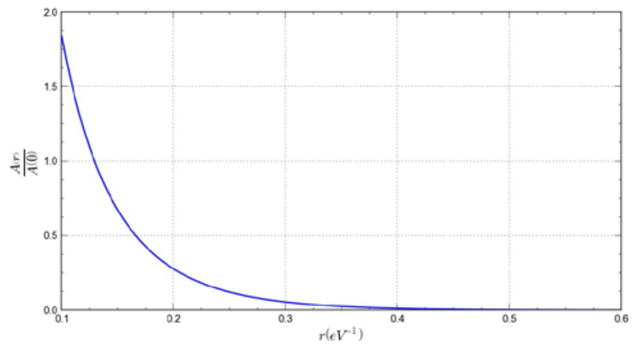

Fig. 2. Tail of coherent e.m. field.

The presence of an evanescent e.m. field associated to the coherent field generated inside CDs can be proved by studying the spatial behavior of eqs. (5). It has been shown [13,14] a spherically symmetric solution of (5) for $A(\vec{x},t)$ is given by

$$\begin{cases} A(\vec{x},t) = A(0)\left(\sin \omega_0 r / \omega_0 r\right) \cdot \exp\left(-i\omega_{coh} t\right),\ r < r_{coh} \\ \left(-\omega_{coh}^2 - \nabla^2\right) A(\vec{x}) = 0,\ r > r_{coh} \end{cases} \quad (24)$$

where r_{coh} is the "radius" of the CD.

By noting that $\nabla^2 A \sim \omega_0^2 A(r)$ we can write

$$\left(d^2/dr^2\right)(r \cdot A) - \left(\omega_0^2 - \omega_{coh}^2\right)(r \cdot A) = 0 \quad (25)$$

whose solution is characterized by an exponential decaying behavior

$$A(r) \sim \exp\left(-r\sqrt{\omega_0^2 - \omega_{coh}^2}\right) \quad (26)$$

showing the presence of an "evanescent" electromagnetic field at the borders of the CD. By imposing the matching, at the CD boundary $r = r_{coh}$, between the exponential solution given by (26) and the first of (24) and recalling that $\omega_0 \gg \omega_{coh}$, we obtain

$$r_{coh} \simeq 3\pi / 4\omega_0 \quad (27)$$

representing a more accurate estimate of the dimension of CD than (20). For water and $\omega_0 = 12.06\, eV$ we have

$$r_{coh} \sim 3.75 \cdot 10^{-8}\, m \quad (28)$$

This result further confirms the cavity inside MT can be though as "filled" with water CDs associated to the coherent dynamics related to the electronic transition from the ground state to the level at $12.06\, eV$. The superradiant "evanescent" field is then given by

$$A(r) \simeq \left(A(0)/\sqrt{2}\right) \times \times\left(\exp\left[-\sqrt{\omega_0^2 - \omega_{coh}^2}\left(r - r_{coh}\right)\right] / \omega_0 r\right) \quad (29)$$

whose profile is shown in Fig. 2.

By comparing the value of r_{coh} given by (28) with the external radius of the transversal section of a typical MT $r_{MT} \sim 1.25 \cdot 10^{-8}\, m$ we obtain

$$r_{coh} > r_{MT} \quad (30)$$

meaning the coherent electromagnetic field resulting from the tuned interaction between matter and electromagnetic field inside the CD has a "tail" extending outside it, under the form of evanescent field, whose spatial extension exceeds the MT boundary and allows the overlapping and interaction of the coherent electromagnetic field belonging to neighborhood CDs.

This interaction could be able to realize the long-range correlation need for the implementation of biological functions. In particular, this tail allows the evanescent electromagnetic field associated to the water CDs inside MT to "cross" the MT wall and interact with the biological structures placed on it and in its neighborhood.

The existence of this "evanescent" electromagnetic field, emerging from the water CDs, then theoretically suggests, on a robust QFT basis, a possible physical mechanism able to explain the tunnelling of superluminal photons, trapped inside water CD, towards the "outside" environment as already shown in a previous paper [13].

4 Stability of coherence domains inside MT against environmental decoherence

As we have seen the transition from PGS to CGS can occur if and only if $\rho > \rho_{crit}$ and $T < T_0$. More specifically, the tuned oscillation between matter and electromagnetic field in the coherent state forbids any thermal fluctuation and is virtually associated with a thermodynamic absolute temperature $T = 0$. The energy gap δE characterizing this state then prevents any energy inflow from the environment.

Nevertheless, if the temperature of the environment increases to a value $T > 0$ (as, for example, occurs for CD placed in a thermal bath at $T \neq 0$), the collisions between the fluctuating environment molecules (thermally excited) and the components of a CD, could transfer to it the energy gap per atom/molecule δE, able to put some of them out of tune with the electromagnetic field, determining the environmental decoherence of the macroscopic quantum state associated to the system. As a consequence, some matter components can be "expelled" from the CD and the formation of an incoherent fraction of matter system at the boundaries of CD.

So, in order to ensure the formation and the persistence of CDs in the water inside brain MT, the fraction of coherent water, at the average brain temperature, has to be sufficiently high.

In order to verify the occurrence of this condition in brain MT, we must consider the fraction of coherent water F_{coh} as a function of absolute temperature T [14,19], namely

$$F_{coh}\left(T\right) = 1 + -\left(64/9\right) Z\left(T\right) \int_0^{3/4} x^2 \exp\left[-\delta E\left(x\right)/T\right] dx \quad (31)$$

where $\delta E\left(x\right)$ is the energy gap of the coherent state expressed as a function of the distance x from the CD centre and $Z\left(T\right)$ is the partition function [14,19] whose expression, in this case, is

$$Z = \left(N/V\right)\left(m \cdot T/2\pi\right)^{1/2}\left(k^2/2\pi\right) \cdot \exp\left(-\delta_0/T\right) \quad (32)$$

being m is the mass of a water molecule and, in the case of water, $k \sim 5 \cdot 10^{-10}\, m$ and $\delta_0 \sim 400\, cm^{-1}$.

From the graph of $F_{coh}\left(T\right)$ for bulk water, represented in the Fig. 3, we deduce that, at a temperature of about $T \sim 310\, K$ corresponding to the average temperature inside brain MT, $F_{coh}\left(T_{brain}\right) \sim 0.2$ namely about less than a half of the corresponding coherent fraction at room temperature, a result seemingly not much satisfactory.

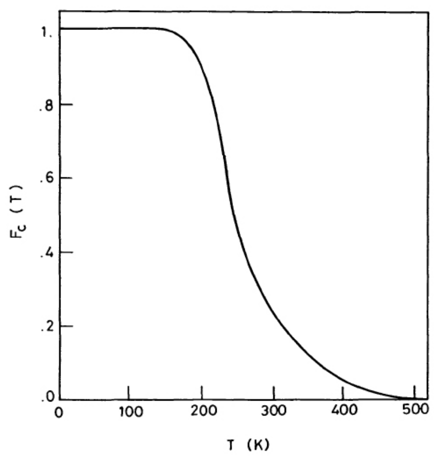

Fig. 3. Coherent fraction in water vs absolute temperature [14,19].

Nevertheless, for the water enclosed within a cavity, as happens in MTs, it has been shown [22] that cavity wall is able to decrease the impact of thermal fluctuations so making the interfacial water substantially thermally isolated and then much more coherent than bulk water.

Since practically all the water contained in a living organisms is always very near to a "wall" [22] (typically less than a fraction of micron from a surface like a membrane or a molecular backbone) we can consider this water as interfacial water and then, for the above considerations, we can assume $F_c \to 1$.

A further confirmation of this assumption results from the experimental evidence that water inside cells resides in a sort of "glassy" state [25] whose coherent general properties has been already investigated [26] showing that, for this water, the coherent fraction is the same of that occurring for $T < 220\, K$ namely, from the Fig. 3, $F_c \sim 1$ able to guarantee the existence and the permanence of an almost fully-coherent state of water inside brain MTs.

In this way we have shown that also the question of environmental decoherence, properly raised by Mavromatos et al [23], can be issued within the framework of QED coherence in water, when we consider the coupling between electromagnetic and matter field occurring at the level of electronic energy transitions.

5 Conclusions

We have shown in the water contained inside the hollow volume of brain MTs there exist the conditions allowing a spontaneous superradiant quantum phase transition toward a energetically favored state, in which the electronic clouds of water molecules coherently oscillate in tune with a self-trapped electromagnetic field within defined space regions (coherent domains).

The model here discussed assumes the coherent state arising from the electronic transition of water molecules from the ground state to the level at energy $E = 12.06\,eV$ so implying the supperradiant photons field, generated inside the coherence domains, to have a wavelength much smaller than the length of a moderately sized MT in brain and an evanescent tail extending beyond the MT's boundary, allowing the overlapping and consequently the interaction of the coherent electromagnetic field belonging to neighborhood CDs. This feature could explain the long-range correlation need for the implementation of biological functions inside the human brain.

Differently from the models of quantum optical coherence in cytoskeletal MT proposed so far, based on the energetic transitions of water molecules associated to rotational energy levels (of the order of few meV), the picture here proposed, instead considering the electronic transition in water molecules, is able to solve some of the most important issues (as, in first place, the too long wavelength of superradiant photon with respect MT size and the too short environmental decoherence time) properly raised by some authors about the actual possibility to consider the superrandiant photons, generated inside MT from water coherent phase transition, in order to explain the occurrence of "ordinary" functions performed by human brain.

Furthermore, as already proposed in previous works [3,13], the above picture could give the required theoretical basis for the elaboration of a quantum model of the more advanced brain functions, including the possibility to consider human brain as a quantum computer capable of hypercomputing abilities.

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