Are Water Temperature Anomalies Conjugated to Brain Functions in Microtubules?

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ABSTRACT

We considered a system of microtubule(s) (MTs) immersed in a water reservoir in order to investigate its thermodynamic properties and computation (processing) potential. We started with the "double frustration" concept for a single microtubule and next extended our considerations to an MT multi-cluster. We probed the influence of the physical anomalies of water in compressibility and the speed of sound, where acoustic phonons that are conjugated to the stress fluctuations that are produced by changes in symmetry, are possible carriers of information and the cause of 'calculation' enhancement at the physiological temperatures of human brain. We showed that the timing of the internal clock can be as high as 117 GHz and that the long-range coherence should be maintained for about 0.1 ms, which is a reasonable dynamical timescale. We advocated that some 'local', 'intermediate' and 'extended states' of our mind could be in relation to water temperature anomalies. We also suggested that the frustration scheme might introduce a direct link to the evolutionary survival paradigm in the case of the slow or fast computations that are performed by elementary systems able to perform basic calculations that can be identified with 'thinking'.

Key Words: Acoustic phonons, decoherence, geometrical frustration, quantum biology, speed of sound

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Introduction

Rolf Landauer stated that "Information is physical" (Landauer, 1961). Indeed, in all actual cases information is stored and transmitted by means of physical media (Sładkowski and Syska, 2012; Grandpierre *et al.,* 2013; Al-Khalili and McFadden, 2014 and Mohseni *et al.,* 2014 for review) such as sound or electromagnetic waves (light), electrons or spins, to name a few. Whether it is classical or quantum, it is represented by logical bits (like an 'up' or 'down' spin) or qubits (quantum states of the elementary information carriers). The problems are usually coded and executed by classical or quantum computers (e.g., annealing algorithm) that are still using condensed matter physics resources (e.g. Josephson junctions such as in D-wave machines (e.g., Jones, 2013; Byrne, 2015)). Information that is stored is physical even in the case of black holes (Davies, 2004), where it is proportional to the boundary of the event horizon (it's smashed into the point of no return and encoded as a two-dimensional hologram, which is what Hawking claims). All of this, however, concerns 'ordinary' physical matter. But how about the "wet and warm" matter of our brain (Al-Khalili and McFadden, 2014), where quantum information can undergo decoherence, which is the loss of quantum coherence, in a very short time (Tegmark, 1999)? He found that decoherence timescales ~10^{-13} -10^{-20} seconds are typically much shorter than the relevant dynamical timescales (~0.001 – 0.1 s).

Certainly, the time evolution of such a system cannot be unitary since the information is

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not preserved for longer periods of time (than decoherence timescales) and the fundamental quantum mechanical principles do not apply. Moreover, computation using a 'true' quantum computer such as a D-wave (consisted of a square matrix of Josephson junctions) cannot be performed since a time-consuming algorithm (and state) must be constructed and prepared, which itself needs computational power. However, another method has been proposed (Pietruszka and Lipowczan, 2013, 2014) in which the geometrical frustration concept was introduced to do the computations. In this paper, we extend this idea in a broader framework by introducing the anomalous properties of water into our model. To be more precise, we immerse the microtubules that are interacting with 'acoustic phonons' in a water reservoir and take advantage of the temperature anomalies of water at the physiological temperatures of human brain to explain its possible function. [Note that phonon is a "collective excitation" in a periodic, elastic arrangement of atoms or molecules in condensed matter, like solids and some liquids]. In conclusion, we will connect our results with a theory of biological evolution.

Methods

In the forthcoming analysis we will use quantum mechanical approach and statistical physics.

Results

By assuming the MT radius as $r = 6.5 \times 10^{-9}$ m (Pietruszka *et al.,* 2012; Pietruszka, 2013) and the speed of sound in water at a physiological temperature of 37 ^{o}C ($v = 1520$ m/s, see [Chaplin]), we estimated the basic oscillation frequency (ν) mode for the typical size (diameter $d = 2 \times r \approx \lambda$) that is involved in this problem from the relation $v/\lambda = \nu$, where v stands for sound velocity and λ for wavelength. The longitudinal phonon frequency equalled $\nu = 1.17 \times 10^{11}$ Hz = 117 GHz. [Interestingly, this particular value has already been reported in condensed matter physics (e.g., Wen *et al.,* 2009)]. This fact, however, can be further utilised for interacting MTs that are treated as a transmitter-receiver system in a high frequency channel (previously, an "indeterminate long-range interaction" in Pietruszka and Lipowczan, 2014). In particular, such a high oscillation frequency may form an internal clock for an MT-based CPU single core unit or may be connected with the overall transmission band. Hence, the energy that is transferred by a single phonon approximately equals $E = h\times\nu = 1.17 \times 10^{11}$ [1/s] $\times$ 6.62607004 $\times 10^{-34}$ [m^2 kg/s]= 7.75×10^{-23} J = 4.84×10^{-4} eV = 0.484 meV, where h is the Planck's constant. This value seems to be quite reasonable in our problem.

Table 1. Directional coefficients of the linear interpolation in Figure 1 and wave function coefficients as utilised in Eq. (13) by Pietruszka and Lipowczan (2014).

directional	coefficients	amplitudes		probabilities
a_1	8.33E-01	A_1	0.92	8.46E-01
a_2	1.67E-01	A_2	0.38	1.44E-01
sum	1.00E+00			9.91E-01

Next, by taking the water heat capacity for the considered temperature range (Figure 22-1 in Resnick and Halliday, 1999 or the digitised data in the inset in Figure 1), we calculated the internal energy change, where after taking the numerical integral over the temperature, a kink occurred at about the physiological temperature (Figure 1). Then the directional coefficients for both lines (ibid.) were estimated, namely a_1 = 0.833 and a_2 = 0.167 (normalisation: $a_1 = |\alpha_1|/\sqrt{(|\alpha_1|+|\alpha_2|)}$ and $a_2 = |\alpha_2|/\sqrt{(|\alpha_1|+|\alpha_2|)}$, where the original $[\alpha_1] = [\alpha_2]$ = J/K). These values were then compared with the stress/strain energy coefficients that had resulted from the curvature of the actual symmetry that was chosen by the system, which was connected with the probability amplitudes in Eq. (13) by Pietruszka and Lipowczan (2014). It turned out that both coefficients a_1 and a_2 are almost the same (Table 1) as the probability amplitudes (ibid.) and that they fulfil the completeness relation: $|a_1|^2 + |a_2|^2 = 1$. We accepted this remarkable agreement with sheer amazement since such an outcome cannot be accidental. Indeed, it was not. By taking the definition of the Boltzmann probability into account: $P_i \sim \exp(-\beta E_i)$, i = 1, 2, where E_i stands for the energy of a state "i" and $\beta = 1/k_BT$, the energies (E_i) correspond to the thermal excitations in a system. Moreover, one possible explanation is that the acoustic phonons are coupled with (resonate with) the symmetry states of the MTs. Such an explanation seems plausible if we realise that the basic ingredients of our simplistic model are water, the acoustic phonons that are propagating in this medium, the MTs coupled to these phonons and the symmetry (cylindrical or spherical) of the investigated system. What, however, further drew our attention was the high timing of 117 GHz of the internal clock! If such an extremely fast (compared to ~ 4 GHz timing in conventional processors nowadays, A.D. 2016) multi-core (multi MT-core) computer exists, our brain computation capabilities (such as those that are needed for quick pattern recognition) and coherence at macroscopic scales are difficult to overestimate. It turns out that large-scale coherence should be maintained for about 0.99 × 10^{-4} [s] ≈ 0.0001 s = 0.1 ms, which is a reasonable period of time for the relevant dynamical timescales mentioned earlier. [In the latter estimation, we assumed an overall (spherical) brain 'diameter' of about 15 cm].

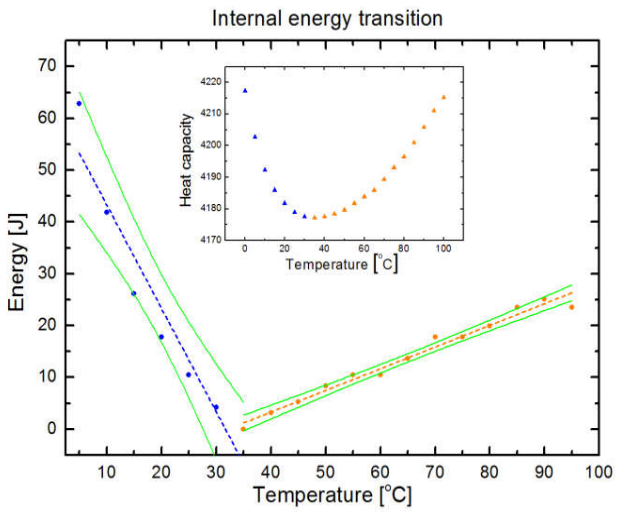

Figure 1. Internal energy of water *versus* temperature. A transition point (a kink) at about physiological temperatures of human brain is clearly visible. Inset: heat capacity of water as a function of temperature (Resnick and Halliday, 1999). Determination coefficients: R^2 = 0.90961 (blue line), R^2 = 0.97483 (red line); confidence level at 95% for both curves.

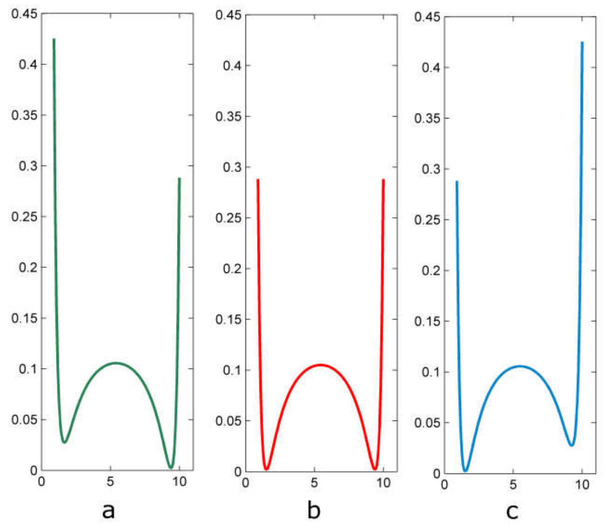

Figure 2. The double well potential (b) symmetric as in Figure 1 (Pietruszka and Lipowczan, 2013), (a) and (c) asymmetric (α = 1.1, β = 1) for both branches (+/-) in Eq. (1), ibid.

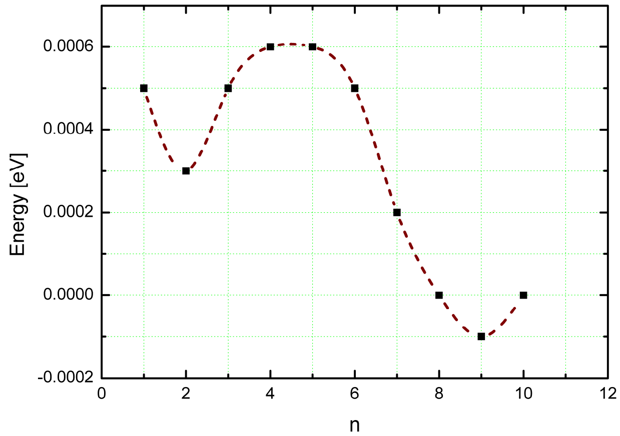

Figure 3. The calculated energy difference between both asymmetric potentials (a and c in Figure 2) as a function of a quantum number "n". The vertical scale in eV established by the estimation performed in the main text (0.484 meV).

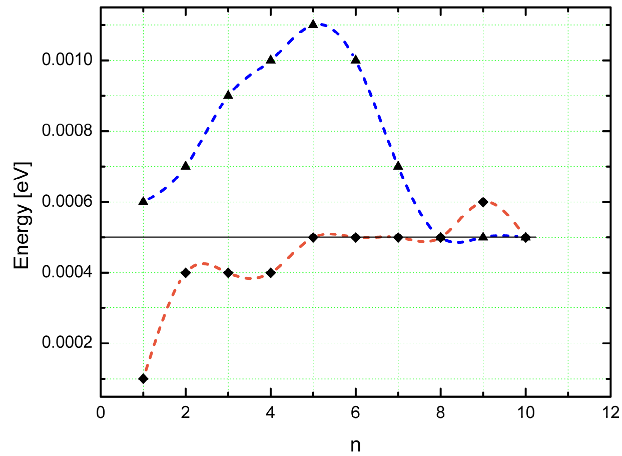

Figure 4. Energy gap between symmetric and asymmetric potentials. The calculated energy gap between the lowest symmetric state and asymmetric one: blue – Figure 2a, and orange – Figure 2c. A solid (black) line designate stabilisation of the value of energy gap for a higher quantum number "n" (the energy converges to the line, which indicates the value of 0.484 meV).

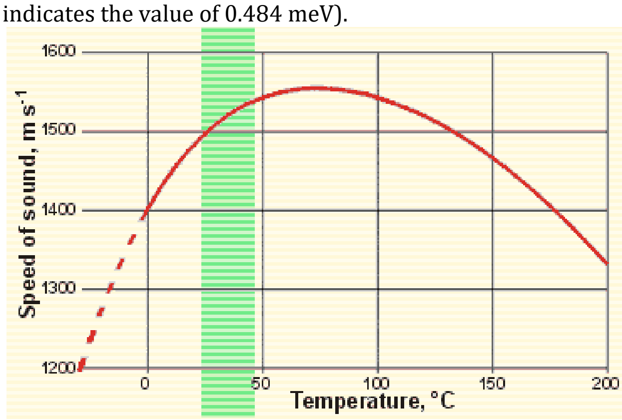

Figure 5. Speed of sound *versus* temperature in water (reproduced after [Chaplin]). The high variability of this magnitude (hatched green area) is corresponding to physiological temperatures of mammalians.

Lastly, we also calculated the energy difference for the symmetric and asymmetric potentials (Figure 2) in order to obtain (*i*) the difference between both the asymmetric potentials (Figure 3) and (*ii*) the asymmetric and the symmetric potential (Figure 4). The condition that the phonon energy can effectively change the system enabled us to estimate the energy scale for the potential.

Discussion

It occurred that our MT multi-cluster (brain), which had a communication channel that was guided by 117 GHz water oscillations (acoustic phonons) that were extremely sensitive to slight changes (± 1°C) in temperature (Figure 5), has an evolutionary advantage over slower, low-temperature individuals. Moreover, water, which was a broadly accessible resource at the earliest stage of evolution (Al-Khalili and McFadden, 2014), may also serve as a basic medium for the information processing or its propagation in the existing world. The first simple organisms may have used water density fluctuations as acoustic phonons in order to couple with the oscillations of simple molecules. As a result, water is a natural candidate for the functions of early life, including information transfer (consider speed of sound / compressibility anomalies that are present within a physiological range of temperatures; note – only longitudinal oscillations are present in bulk water).

Finally, taking into account the propagation speed and attenuation of the acoustic phonons inside a water cluster, one can naively think of the function of the human brain in physical terms (note the highlighted region of high variability in Figure 5) by treating the 'coherent' states of mind in the following ways:

1. 'local states' that occur at the optimum temperature (36.6°C) – the brain functions well,
2. 'intermediate states' at elevated temperatures (at about and slightly above 37°C) – fever (thoughts are 'running'),
3. 'extended states' at (relatively) extremely high temperatures (about 40°C) – protein denature of MTs and brain malfunction (break-down, failure).

Conclusion

Darwinism is the theory of biological evolution, which states that all species of organisms arise and develop through the natural selection of small, inherited variations that increase the individual's ability to compete, survive and reproduce. At least one aspect is covered by our proposal – in order to survive, the reaction capabilities must be high and stable, and hence a relatively high temperature must be maintained. It looks as though, a framework that integrates data from multiple disciplines can help us develop a broader theory than what is possible from any single field alone.

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