Article

On the Temperature and Energy of the Brain Waves
Is there Any Connection with Early Universe?

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ABSTRACT

In this paper new description of the emission of the brain waves is proposed. We consider the brain as the source of electromagnetic waves with frequencies 0.5 to 100 Hz and amplitude 110 to 4μV The spectrum of the brain waves is analyzed with the help of the semi classical model: the probability of the emission of the photons is proportional to the (amplitude)^2 and the frequency of the brain waves is quantized according to formula E= $\hbar\omega$, where E is the brain photon energy in eV, $\hbar$ =Planck constant, $\omega = 2\pi\nu$, ν is the frequency in Hz. As the result the temperature and energy of the brain waves can be calculated, T= 10^{-14} eV. For the photons emitted by brain we propose, following Levy-Leblond and Balibar name *quantons*.

Key Words: brain waves, quantization, temperature, energy, quantons

Introduction

If highly transient neuron assemblies are indeed a key feature of the brain operations that cause consciousness, a critical issue—for scientists especially—is how they might actually be formed. The idea developed in this book is that because we have only one consciousness at any one moment (Arieli, 1995), then the dominant assembly for that moment would have to be so massive that it precluded the formation of any other sufficiently large rivals—the recruitment of, say, 10^7 neurons in less than 250 milliseconds. However, even this large number is simply the response of a group of neurons to a flash of light and does not necessarily entail con-sciousness. The requisite size of an appropriate neuron assembly might be far greater still.

Classical synaptic transmission is perfectly adequate for coordinating the firing of a million or so neurons in a fraction of a second. It is important to remember that neuron firing of an action potential is not linear, with one domino causing the fall of its neighbor one at a time. Yet if the firing of one neuron causes N neighbors to fire, then after S steps, -N^5 neurons will fire in a huge three-dimensional domino effect.

Even if N were as small as 10, only 6 steps would be needed to assemble a million neurons. But suppose that synaptic transmission is not, after all, doing the job. According to the calculations, the spread of activity from the epicenter activated by the flash of light is some 100 to 250 cm/s. This is much faster than a wave of seizure in epilepsy (1 cm/s), yet it is actually much slower than classic synaptic signaling, where an action potential can be propagated down the neuron axon at speeds of up to 10,000 cm/s. Whereas classic synaptic signaling is useful in local cir-cuits of neurons, perhaps a different process is operational in the more gradual recruitment of

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very large, global assemblies that will in turn be necessary for consciousness.

A synapse is a highly specialized point of contact, as different from a mere gap as riverboat stations are from featureless banks facing each other across the water (Levitan and Kaczmarek, 1996). A simpler but less specialized system involves the mere fusion of one dendrite of one cell with that of another, so that electrical current spreads passively, without the need for a participating chemical. These points of fusion are called "gap junctions." Perhaps spread of activation through the agency of gap junctions is what distinguishes the formation of a very large neuronal assembly. In support of this idea, John Jefferys and his colleagues have confirmed that the much-studied oscillations of some 40 Hz are generated as a result of normal synaptic transmission. What is particularly intriguing, however, is that Jefferys has also shown that it is possible for neurons to work collectively at a much faster rate, that there are in addition much faster oscillations of some 200 Hz. This higher-frequency orchestration is mediated not by synapses but by gap junctions (Draguhn, 1998).

Perhaps the very extensive type of neuron assembly that mediates consciousness will be composed of synchronous neuron firing at a frequency far higher than the much-studied 40 Hz. However, because this type of activity depends on coherent gap junction signaling—which is less efficient than classic synaptic transmission—the time taken for large numbers of neurons to be recruited into a synchronous, large-scale assembly will be slower—the good half a second observed. These features—relatively slow-to-form but yet high-frequency coherence once established—might be advantageous in first stabilizing a moment of consciousness, and second in optimizing conditions, a very high-frequency firing, for the signature peptide profile to then be released.

Another alternative to the traditional picture involves a very different mechanism that might operate at a much more minuscule level, beyond the cell itself, and beyond the classic physics of Newton which is successful for describing events in the everyday world, and with it, in principle at least, traditional neuroscience. Just such a vision has captured the imagination of the mathematician Roger Penrose and the anesthetist Stuart Hameroff (2003). Their version of events does not rely on the classic generation of action potentials, but rather on a faster and far more speculative process that is based on quantum theory.

Penrose and Hameroff's speculations about the nature of consciousness begin by noting that in one interpretation of quantum theory, the very act of observation causes a system to be in one type of unpredictable state, a phenomenon they call "subjective reduction It is subjective because it requires an observer. In the brain, however, there is no outside observer, and hence the appropriate conditions might prevail under which quantum events are not downgraded subjectively, but rather occur spontaneously, without anyone watching. This hypothetical phenomenon has been called objective reduction (OR) by Penrose and Hameroff, who believe that the concept of OR could underpin a new type of physics. Because OR would not obey the computable and established rules of either quantum physics or Newtonian physics, they consider that this new physics would be most appropriate for generating consciousness — another incomputable phenomenon.

Quantum theory offers the appropriate time and space scales for assembling millions of neurons in a fraction of a second into a working assembly. This procedure is known as quantum coherence. However, we have seen that classical processes can proceed just as well. Yet here, too, in quantum coherence, there might be a good candidate for a neural correlate of consciousness.

Penrose and Hameroff have speculated that the medium of such orchestration could be the tiny, fluid-filled microtubules, which are present in virtually every cell in the body. Coherence would occur, they suggest, by exciting water molecules buried in a protein, *tubulin* the building block of microtubules. Tubulin can undergo conformational changes in molecular structure. The idea runs that these changes could support wavelike signals propagated in accord with quantum theory comes Penrose and Hameroff speculation: Once the number of neurons is sufficiently large, then in accord with the as yet nonexistent *New Physics*, there would be a spontaneous downgrading of the wave, an OR across large numbers of cells. This OR, a sudden commitment to one type of physical

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state, would somehow correspond to a moment of consciousness in the macro brain.

As it stands, the existence of microtubules and the idea of quantum coherence as a basis for consciousness have not so much been shown to be wrong, but on its own, it has simply been unhelpful for biologists—it is too abstract to be usefully applied to the tangible brain, and it is without experimental motivation.

For Penrose and Hameroff idea to qualify as a successful correlate of consciousness, three basic issues still need to be resolved before biologists can make use of it. *First*, we need a further feature to the scheme whereby the number of requisite coherent neurons can be increased from the tens and hundreds of thousands, to tens and hundreds of millions. *Second*, a means of catering for the role of chemically diverse transmitter systems is needed. Third, we need a reason for discriminating between certain microtubules, such that only those in certain neurons, and not in just any old cell, are appropriate to mediate consciousness at certain times.

One possible way of overcoming these problems lies in a scheme advanced by the neuroscientist Woolf (1975). Woolf's model starts off conventionally enough. Neurons in a certain brain region, the *basal forebrain,* are active and release the transmitter acetylcholine, in the accepted fashion, on to neurons in the cortex. Acetylcholine will, again in the traditional way, act via its normal molecular targets, its receptors, on discrete modules of neurons, stretching some 1 to 2 mm² in the cortex. But now some of the consequences might be unexpected: in addition to its action within local circuitry, Woolf has suggested a chemical-selective and site-selective means whereby the quantum coherence based on microtubule operations could be set in train.

Models such as the one we have just explored, based on Woolf's imaginative exploitation of the known actions of MAP2 and acetylcholine, are at the very least useful in that they cross the traditional disciplines of physics and neuroscience to show how a combination of phenomena, rules, and constraints from each can make a more robust and plausible model.

Note that this hybrid theory is once again dependent on good old-fashioned transmitter signaling. We cannot rule out the possibility that acetylcholine—as a prototype neurochemical—plays an important role in triggering other, nonclassical events as well as at the more macro level of brain function; for example, as a neuromodulator, putting cells on red alert.. All the electrical signals are generated in the same rhythm of oscillations. However, no single cell joins in all the activity all the time, but overall there are sufficient cells to maintain a synchronous activity for very long periods of time. Acetylcholine in this instance has enabled a whole population of cells to become more important than the individual units.

Whatever the eventual mechanisms of attaining a transient coherence in a very large assembly of neurons turn out to be, there is no shortage of candidates even at the moment. The future will no doubt reveal more, along with means for testing which ones really do play a part in formation of assemblies, and hence in the reality of a neural correlate of consciousness that is not just necessary but sufficient.

Classical theory of brain waves

How the brains differ from hearts, livers, and other organs? All organ systems are enormously complicated structures, able to repair themselves and make detailed responses to external control by chemical or electrical input. Yet, only brains yield the amazing phenomenon of consciousness (Nunez, 2010). Complex adaptive systems, for which human brains provide the most prominent examples, are composed of smaller parts interacting both within and across spatial scales. They typically exhibit emergent behavior not obviously predictable from knowledge of the individual parts and have the added capacity to learn from experience and change their global behaviors by means of feedback processes. Other examples include stock markets, ecosystems, and all living systems.

Several general features distinguish human brains from other organs, including the hallmark of richer hierarchical (or multi-scale) interactions. In contrast to simple cognitive "theories Nunez`s papers explicitly acknowledges brains as highly complex adaptive systems, emphasizing the critical

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contribution of cross scale interactions to their dynamic behaviors. In order to minimize communication barriers due to the complicated mathematics, several analog systems from disparate fields are employed. Neuroscientists are typically skeptical of brain analogs, typically for good reason; however, we are *not* claiming that brains are actually just like stretched strings, social systems, quantum structures, resonant cavities, hot plasmas, disordered solids, chaotic fluids, or any other non-neural system.

In many complex systems, as spatial-temporal scales of observation are increased, new phenomena become evident by virtue of synergistic interactions among smaller-scale entities, which serve to explain data, typically in a mathematically aesthetic fashion For example, in the classical thermodynamics of equilibrium systems, it is possible to transition from microscopic molecular scales to macroscopic scales and employ the macroscopic variable temperature to describe the average kinetic energy of microscopic molecular activity. Many complex systems, however, operate in non-equilibrium states, being driven by nonlinear and stochastic interactions. For such systems, classical thermodynamics typically does not apply For example, the description of weather and ocean patterns, which includes important features such as turbulence, rely on semi-phenomenological mesoscopic models, in agreement with molecular theories but not capable of being rigorously derived from them. Phase transitions in magnetic systems and many systems similarly modeled require careful treatment of a continuum of scales near critical points. In general, rather than having a general theory of non-equilibrium nonlinear process, several overlapping approaches are employed, typically geared to classes of systems and often expanding on nonlinear treatments of stochastic systems (Gardiner, 1983). Given this general outline of complex systems, it should not be surprising that human brains support many phenomena arising at different spatial-temporal scales. One can study macroscopic neocortical phenomena such as electroencephalography (EEG) by appealing to a chain of arguments dealing with overlapping microscopic and mesoscopic scales. Such work is detailed in a series of papers presenting a theory of statistical mechanics of neocortical interactions (Ingber & Nunez, 1990). This approach permits us to develop EEG and other models of dynamic processes whose variables and parameters are closely identified with ensembles of synaptic and neuronal interactions. The mathematical formalism supporting this approach has only recently been made possible by developments in mathematical physics since the late 1970s, in the field of nonlinear non-equilibrium statistical mechanics. The origins of this theory are in quantum and gravitational field theory.

EEG allows for accurate identification of distinct sleep stages, depth of anesthesia, seizures and other neurological disorders. It also reveals robust correlations with cognitive processes occurring during mental calculations, working memory and selective attention. Scientists are now so accustomed to these EEG correlations with brain state that they may forget just how remarkable they are. The scalp EEG provides very large-scale and robust measures of neocortical dynamic function. A single electrode yields estimates of synaptic action averaged over tissue masses containing between roughly 100 million and 1 billion neurons. The space averaging of brain potentials resulting from extra-cranial recording is a fortuitous data reduction process forced by current spreading in the head volume conductor. Much more detailed local information may be obtained from intracranial recordings in animals and epileptic patients. However, intracranial electrodes implanted in living brains provide only very sparse spatial coverage, thereby failing to record the "big picture" of brain function. Furthermore, the dynamic behavior of intracranial recordings depends fundamentally on measurement scale, determined mostly by electrode size. Different electrode sizes and locations can result in substantial differences in recorded dynamic behavior, including frequency content and coherence. Thus, in practice, intracranial data provide different information, not more information, than is obtained from the scalp (Nunez and Srinivasan, 2006a).

In practice, intracranial EEG may be uncorrelated or only weakly correlated with cognition and behavior. The information content in such recordings is limited by sparse spatial sampling and scale-dependent dynamics. Furthermore, most intracranial EEG data are recorded in lower mammals;

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extrapolation to humans involves additional issues. Thus, higher brain function in humans is more easily observed at large scales. Scientists interested in higher brain function are fortunate in this respect. The technical and ethical limitations of human intracranial recording force us to emphasize scalp recordings. These extra-cranial recordings provide estimates of synaptic action at the large scales closely related to cognition and behavior. Thus, EEG provides a window on the mind, albeit one that is often clouded by technical and other limitations.

Since the first human recording in the early 1920s the physiological bases for the wide variety of rhythmic EEG activity, a proverbial "spectral zoo," has been somewhat of a mystery. In particular, human alpha rhythms, which are quite robust in wide awake (but relaxed) subjects with closed eyes, may be recorded over nearly all of the upper scalp or cortex and have preferred frequencies near 10 Hz. Given any unknown physical or biological system that produces oscillations at some preferred (or resonant) frequency $f = \omega / 2\pi$, one of the first questions a scientist might ask concerns the origin of the implied underlying time delay x roughly estimated as

$$\tau = \omega^{-1} \qquad (1)$$

The implied physiological time scales for the most robust human EEG rhythms (1 to 15 Hz) are t=10-160 ms. How does this delay range compare with mammalian physiology? Whereas early studies of membrane time constants in mammalian cortex were very short, typically less than 10 ms, more modern studies with improved recording methods report the wide range 20 -100 ms). But apparently in voltage-gated channels, the effective time constant becomes a "dynamical parameter" that depends on both membrane voltage and on time, thus genuine time constants are not really "constant" (Koch, 2004) argues that the voltage response to very brief synaptic inputs is essentially independent of the classically defined time constant, which typically provides *overestimates* of the response time of neurons. In summary, these studies suggest that while synaptic delays (PSP rise and decay times) lie in a general range (within a factor of perhaps five or ten) that might account for dominant EEG frequencies, claims of close agreement between the *details* of observed EEG spectra and dynamic theories

based on membrane time constants are not credible. Model parameters can be chosen to "match" favored EEG data sets, which, in any case, can vary widely between individuals and brain states.

By contrast to these "local" delays at the single neuron level, axonal ("global") delays along the (corticocortical) fibers between anterior and posterior regions are estimated to be roughly in the 30 ms range in humans (Nunez, 1995). Such global delays depend on axon length distribution and axon propagation speed; thus they are expected to be much shorter in smaller mammalian brains if axon diameters (or propagation speed) are unchanged across species. To complicate matters, creation of serial connections between cell assemblies can apparently modify both local (PSP) and global (axon) characteristic delay times. While both local and global delays appear to be in a general range favorable for EEG production, this semi quantitative observation tells us little about the physiological mechanisms responsible for "special frequencies" like the narrow band human alpha rhythms or gamma oscillations (about 40 Hz), the latter recorded mostly from inside the craniums of humans and lower mammals. Neither local theories (based on PSP rise and decay times) nor global theories (based on axon delays) can honestly claim close agreement with EEG data based *only* on predicted EEG spectral properties; the underlying physiological parameters (*e.g.,* time constants and axonal delays) are not known with sufficient accuracy to make such claims credible. While PN Nunez has suggested that the parameters of the global standing wave theory appear to be known more accurately than local parameters, others may disagree. Nevertheless, we *can* agree to search for qualitative and semi quantitative connections between theory and EEG experiments that do not require precise physiological parameter knowledge.

The general idea of standing EEG waves (Nunez, 1974) was based on a very simple idea. Any kind of weakly damped, non-dispersive wave phenomenon propagating in a medium with characteristic speed v can be expected to form standing waves due to wave interference that depends on the system's size and shape (the boundary conditions). Such phenomena occur, for example, in violin and piano strings and many other vibrating systems. Whereas

waves in strings and flutes are reflected from boundaries, waves in closed systems like spherical shells or tori interfere because of periodic boundary conditions causing waves traveling in opposing directions to meet and combine. As a result of this interference, preferred (resonant) frequencies persist in such systems. Examples of standing waves in spherical geometry include the quantum wave function of the hydrogen atom (both radial and tangential waves) and the Schumann resonances of electromagnetic waves in the spherical shell formed by the earth's surface and the bottom of the ionosphere (tangential waves only). The lowest frequency, often dominant in such systems, is the fundamental mode. This fundamental frequency is given for the geometries of a spherical shell of radius R or a one dimensional loop of length $L = 2nR$, perhaps a closed loop of transmission line (Nunez, 1995), by

$$f = \frac{gv}{L} \qquad (2)$$

Here the geometric constant g is either β (spherical shell) or 1 (one dimensional loop). Each cortical hemisphere is topographically essentially a spherical shell. On the other hand, the postulated medium characteristic speed v is the axon propagation speed in the longer systems of corticocortical axons forming in the white matter layer. Since these fibers may be substantially anisotropic with a preferred anterior-posterior orientation, it is unclear whether the shell or loop model is the most appropriate.

The wrinkled surface of each cortical hemisphere can be reshaped or mentally inflated (as with a balloon) to create an equivalent spherical shell with effective radius R related to its surface area by the relation

$$R = \sqrt{\frac{A}{4\pi}} \qquad (3)$$

Thus, cerebral cortex and its white matter system of (mostly) corticocortical fibers is a system somewhat analogous the earth-ionosphere shell. With a brain hemispheric surface area $A \sim 800—1500$ cm² or alternately an anterior-posterior closed cortical loop of $L \sim 50—70$ cm (ellipsoid-like circumference), and a characteristic corticocortical axon propagation speed of $v \sim 600—900$ cm/sec (data reviewed from four independent studies

in (Nunez, 1995), the predicted fundamental cortical frequency predicted by the naive application of Eq (2) is then

$$v = 2 \text{ to } 26 \text{ Hz} \qquad (4)$$

This estimate is "*naive*" because the fundamental mode frequency depends on both the physical shape and material properties of the wave medium (cortex-white matter). These latter properties determine the dispersive nature of the waves; that is, the precise manner in which waves distort when propagating. Such dispersive properties in cortex are expected to depend on the nature and interactions of the synaptic and action potential fields. Furthermore, cortical frequency must depend on at least one additional parameter determined by brain state. Thus, estimates in Eqs. (2) and (4) cannot be expected to represent genuine brain waves, even if the cortex were actually a spherical shell or closed loop; the postulated brain waves are much more likely to be dispersive (if for no other reason than most of Nature's waves are dispersive). Furthermore, the expected neural networks of cognitive processing (believed to be embedded in global synaptic wave fields) would be expected to cloud experimental observations of standing wave phenomenon. One may guess that such networks involve thalamocortical interactions that can generate preferred frequencies in several bands, including alpha and gamma. Thus, our scalp potentials may be viewed as some mixture of interacting global and local activity, both of which underlie and are correlated with various cognitive events.

These general ideas do not, by any stretch of the imagination, constitute a brain theory; rather they simply suggest a hypothesis and related experiments to test for *traveling* and *standing brain waves*. If estimate Eq. (4) had been obtained before the discovery of the human alpha rhythm in the 1920s, it would have provided a plausible, testable prediction. The appropriate experimental question would have been, "*Can brain states be found in which neural network activity is sufficiently suppressed to allow observation of simple standing waves?*" Such imagined experiments would have found the predicted EEG oscillations in the 8-13 Hz band in relaxed subjects (minimal mental load implying minimal network activity) with closed eyes (minimal visual processing).

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If anything, the estimate Eq. (4) is almost *too good,* perhaps raising suspicion by critics that parameter estimates have been fudged to make a good story. But, only two parameters v and L are involved in the crude frequency estimate. Even if the cortical area estimate were off by a factor of two, the frequency estimate Eq. (4) would only change by V2. The axon speed estimate is based on the four independent studies reviewed in (Nunez, 1995). When Nunez first proposed the idea in 1972, corticocortical propagation speeds were poorly known. Axon speeds in (myelinated) peripheral axons and intracortical (non myelinated) axons are roughly ten times faster and ten times slower, respectively, than corticocortical axon speeds. That is, human axon speeds vary over at least three orders of magnitude depending mainly on axon diameter and myelination. Thus, the observed alpha frequency provided a blind prediction of corticocortical axon speed.

The simple standing brain wave model employs *Galilean idealizations* in which many essential properties of genuine brains are deliberately neglected in order to create a simple, useful model. Galileo modeled falling bodies with no air resistance even though he lacked the technology to make the air go away. Similarly, we may lack the technology to fully suppress the brain networks that might eliminate or obscure standing and traveling brain waves, although some anesthesia states may come close to this goal.

The proposed global model is based mostly on the following idea. Scalp potentials (EEG) are generated by synaptic current sources at small scales; each cubic millimeter of cortical tissue contains more than 100 million synapses. In contrast to this small scale activity, EEG data are recorded at macroscopic (centimeter) scales, thereby presenting major problems for network models attempting connections to genuine large scale data. The brain wave model follows the macroscopic dependent variables *action potential and synaptic potential densities,* for example, the number of excitatory synaptic events per square millimeter of cortical surface. All dependent variables are expressed as functions of time and cortical location. The basic approach ignores embedded network activity, although networks have been included (approximately) in more advanced models

(Nunez, 1989). The predicted resonance frequencies for standing waves in cortex are:

$$f_n = \frac{v}{L}\sqrt{n^2 - (\frac{\beta\lambda L}{2\pi})^2} \qquad (5)$$

The symbols and estimated values are:

v: corticocortical propagation speed (600 - 900 cm/sec).

L: effective front-to-back circumference of one cortical hemisphere after inflation to a smooth surface, roughly the shape of a prolate spheroidal shell or rugby ball (50 - 70 cm).

λ: parameter indicating the fall-off in fiber density with cortical distance for the longest corticocortical fiber system (0.1 - 0.3 cm^{-1}).

β: nondimensional parameter controlled by neuromodulators; β increases correspond to increased background excitability of cortex (perhaps from thalamocortical interactions, either chemical or electrical). Wave frequency and damping decrease as β increases. . Does the theoretical *dispersion relation* Eq. (5) have any connection to genuine EEG? Surely nothing so simple can do justice to any complex brain! At best it may enjoy some approximate connections to brains in their more globally dominated states, possibly coma, anesthesia, deep sleep; some generalized epileptic states, and the more globally dominant parts of alpha rhythms. A few experimental predictions rely on this equation, but others follow only from the more general idea of standing and traveling brain waves (Nunez, 2010). Note that this model can provide only relationships not comprehensive explanations of complex physiological processes

In order to distinguish theories of large-scale neocortical dynamics, we have proposed the label *local theory* to indicate mathematical models of cortical or thalamocortical interactions for which corticocortical axon propagation delays are assumed to be zero. The underlying time scales in these theories typically originate from membrane time constants giving rise to PSP rise and decay times. Thalamocortical networks are also "local" from the viewpoint of a surface electrode, which cannot distinguish purely cortical from thalamocortical networks. Finally, these theories are "local" in the sense

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of being independent of global boundary conditions dictated by the size and shape of the cortical-white matter system. By contrast, we adopt the label *global theory* to indicate mathematical models in which delays in the corticocortical fibers forming most of the white matter in humans provide the important underlying time scale for the large scale EEG dynamics recorded by scalp electrodes. Periodic boundary conditions are generally essential to global theories because the cortical-white matter system is topologically close to a spherical shell.

While this picture of distinct local and global models grossly oversimplifies expected genuine dynamic behaviors with substantial cross- scale interactions, it provides a convenient entry point to brain complexity. To facilitate our discussion, string displacement is governed by the basic string equation (Nunez, 2010);

$$\frac{\partial^2 \Phi}{\partial t^2} - v^2 \frac{\partial^2 \Phi}{\partial x^2} + [\omega_o^2 + f(\Phi)]\Phi = 0 \tag{6}$$

For the simple case of homogeneous linear springs attached to a homogeneous linear string of length a and wave speed v, the normal modes of oscillation ω_o are given by

$$\omega_n^2 = \omega_o^2 + (\frac{n\pi v}{a})^2 \tag{7}$$

In this simple limiting case, the natural oscillation frequencies are seen as having distinct local and global contributions given by the first and second terms on the right side of the last equation, respectively. This same dispersion relation occurs for waves in hot plasmas and transmission lines, which might form closed loops more similar to the periodic boundary condition appropriate for neocortical standing waves. If the springs are disconnected, only the global dynamics remains. Or, if the string tension is relaxed, only the local dynamics remains. Next we approach the behavior of the nonlinear system described by the basic string equation, in which local and global effects are integrated.

The quantum model of the brain waves

The structure of the spectrum of the brain waves strongly depends on the state of the brain (Ecless, 1989). The illness of the brain is reflected in the spectrum of the waves. In physics physicist we can invent of the

mathematical models which help in the understanding of the processes. Take as an example *cosmic relic radiation* (CRR). The spectrum of the CRR is well analyzed with the help of the "black body" formula. However nobody imagine that somewhere, 10^{17} s ago the Universe was "black body".
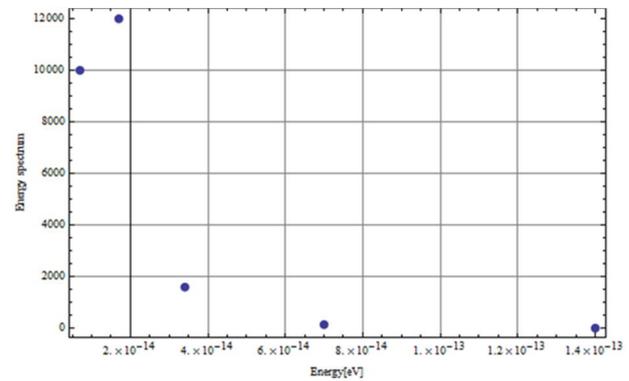

Figure 1. The energies of the photons are the maximum values of energies of waves.

Table 1. Spectrum of brain waves. Frq: Frequencies, Amp: Amplitude, ME; Maximal energies, μV; micro volt, eV; electron volt.

Wave	Frq (Hz)	Max Frq	Amp (μV)	ME (eV)	Amp²
Delta	0,5-4	4	100.0	7x 10^{-15}	10^4
Theta	4-8	8	110.0	1.7 x10^{-14}	1.2x 10^4
Alpha	8-13	13	40.0	3.4 x10^{-14}	1.6 x10^3
Beta	13-30	30	11.0	7 x10^{-14}	1.2x 10^2
Gamma	30-100	100	4.0	1.4 10^{-13}	16.0

In this paper we develop the "black body" formula for the wave emission of the brain source (Marciak-Kozlowska and Kozlowski, 2006). We take as granted the empirical fact. The electrodes measure detects the electromagnetic, very weak waves: *delta, theta, alpha, beta, gamma* (Table 1). The waves have the prescribed frequencies in the range of Hz and amplitudes in the range of μV.

In order to put forward the classical theory of the brain waves, Eq.6, we will quantize the field Φ (x,t). In the model we assume;

A. The brain is the thermal source in local equilibrium with temperature T.

B. The spectrum of the brain waves is quantized according to formula $E = \hbar\omega$ (8) where E is the photon energy in eV, $\hbar$ =Planck constant, $\omega = 2\pi\nu, \nu$ -is the frequency in Hz. In

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Table 1, the frequencies and amplitudes are presented (Tuszyński and Dixon, 2002).

C. The number of photons emitted by brain is proportional to the (amplitude)^2 as for classical waves. The energies of the photons are the maximum values of energies of waves mentioned in Table 1. For the emission of black body brain waves we propose the well know formula for the black body radiation.

In thermodynamics we consider Planck type formula for probability P(E)dE for the emission of the particle (photons as well as particles with m≠0) with energy (E, E+dE)by the source with temperature T is equal to :

$$P(E)dE = BE^2\, e^{(-E/kT)}\, dE \qquad (9)$$

where B= normalization constant, E=total energy of the particle, k = Boltzmann constant=1.3 x 10^{-23} J K^{-1}. K is for Kelvin degree. However in many applications in nuclear and elementary particles physics kT is recalculated in units of energy. To that aim we note that for 1K, kT is equal kK = K x 1.3 10^{-23} J x K^{-1}= 1.3 10^{-23} Joule or kT for 1K is equivalent to 1.3 10^{-23} Joule= 1.3 10^{-23} /(1.6 10^{-19}) eV = 0.8 10^{-4} eV. Eventually we obtain 1K= 0.8 10^{-4} eV, and 1eV= 1.2 10^4 K

$$\frac{dN}{dE} = BE_{max}^2\, e^{\left(-\frac{E_{max}}{T}\right)} \qquad (9)$$

where, B is the normalization constant, T is the temperature of the brain thermal source in eV. The function dN/dE describes the energy spectrum of the emitted brain photons.

In Figure 2, the calculated energy spectrum, formula (9) is presented. In Figure 3, we present the result of the comparison of the calculated and observed spectra of the brain waves. The calculated spectra are normalized to the maximum of the measured spectra. The calculated spectra are for temperature of brain source T= 0.8 10^{-14} eV. The obtained temperature is the temperature for the brain source in the thermal equilibrium. The source in unknown for us reason is thermally isolated (adiabatic well). However in very exceptional cases the spectrum is changed – by the tunneling to the quantum potential well. The temperature 1 eV ≅ 10^4 K then brain wave thermal spectra T=0.8 10^{-14} eV= 0.8 10^{-10} K. The calculated temperature of the brain source is much lower than CRR temperature= 2.7K.
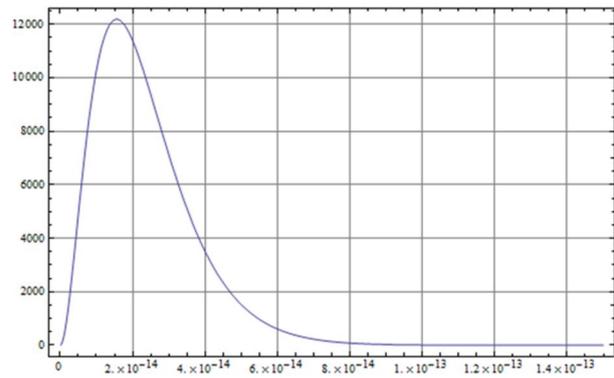

Figure 2. The calculated energy spectrum, from Eq(9).
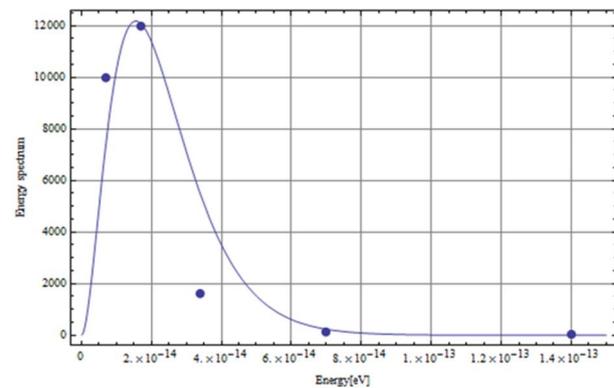

Figure 3. The result of the comparison of the calculated and observed spectra of the brain waves. The calculated spectra are normalized to the maximum of the measured spectra. The calculated spectra are for temperature of brain source T= 0.8 10^{-14} eV.

It must be stressed that we abandon the idea that every physical object is either a wave or a particle. Neither it is possible to say that particles "become" waves in the quantum domain and conversely that waves are "transformed "into particles. It is therefore necessary to acknowledge that we have here a different kind of an entity, one that is specifically quantum. For this reason Levy-Leblond and Balibar developed the name *quanton* (Levy-Leblond and Balibar, 1990). Following that idea the human brain emits *quantons* with energies $E = \hbar\omega$ formula (Eq.8). The brain *quantons* are the quantum objects that follows all quantum laws: tunneling, the superposition and Heisenberg uncertainty rule. For the wave length of the *quantons* is of the order of Earth radius the quantum nature of the brain will be manifested in the Universe scale.

As was shown by (Jibu and Yasue, 1995), the energies that compose the stimuli involved with remote viewing could be extremely small.

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For example, as they suggested an infinitesimal amount of energy is sufficient to create a Goldstone boson. Within macroscopic orders these bosons can be regarded as waves with very low frequencies. The wave motions of aligned electric dipoles would exhibit coherence lengths on the order of about 50 micrometers. According to Jibu and Yasue, no microscopic physical phenomena other than the Goldstone boson could manifest a macroscopic electromagnetic wave within electroencephalographic ranges.

Results

In this paper for the first time the *experimental neuroquantology* is discussed. The electromagnetic waves of the brain are analyzed in the framework of the quantum mechanics. The classical electromagnetic waves emitted by the brain are quantized and the brain pulsations are presented as quanta *quantons* with very small energies of the order of 10^{-15} to 10^{-13} eV. The result of our paper is that the brain is the thermal source with temperature in the range of 10^{-14} eV, *i.e.,* 10^{-10} K. Considering that the human body temperature (and brain!) is the equal to 309K it is hard to imagine that the emission of brain waves is the result of chemical reactions only. It seems that the Hameroff-Penrose suggestion that the consciousness phenomena are linked to the Planck Epoch help in understanding the result obtained in our paper. The brain waves are linked to the very early time in the history of the *Universe*.

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