

Can Quantum Biology Really Do without New Physics?

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Abstract

Quantum biology is now taken rather seriously. Photosynthesis and avian navigation are two key applications of quantum biology. The basic problem in both cases is posed by the fact that the magnetic interaction energy in Earth's magnetic field is roughly million times smaller than thermal energy. The so called radical-pair mechanism (RPM) was proposed already in the 60's as a possible solution to the problem posed by anomalously large effect in EPR and NMR experiments. According to RPM, a radical pair is accompanied by electron pair, which is in a superposition of spin triplet and singlet states and behaves as quantum coherent system for a time sufficiently long to induce chemical effects. The hyperfine interaction of the members of the electron pair with the nuclei of radicals would amplify the effect. The neutralization of radical pair puts an end to the coherence interaction period. The proposal is that RPM gives rise to chemical compass making possible avian navigation. There is however a problem. RPM has been observed in laboratory only for magnetic fields in the range 1 mT-10 T. Earth's magnetic field is only 2 per cent of the lower bound so that it is quite possible that RPM is not at work. This opens up the door for new quantum physics proposed by TGD based model of quantum biology. In this approach magnetic body acts as intentional agent using biological body as a sensory receptor and motor instrument. Macroscopic quantum coherence is made possible by dark matter realized as a hierarchy of $h_{eff} = n \times h$ phases. In this article RMP is summarized and compared with the TGD based vision. Also the possible connection between avian navigation and circadian clock suggested by the fact that both involve photoreceptor known as cryptochrome and a possible connection with gravitaxis are considered in TGD framework.

1 Introduction

I was recently contacted by a friend with whom we have had several interesting discussions about consciousness and neuroscience. She sent several links related to certain aspects of quantum biology about which I had not been aware and these links inspired this article.

1.1 Background

One of the proposals of quantum biology is a quantum mechanism for the mysterious looking ability of birds and fishes to find back to the place, where they were born. It is believed that navigation involves detection of the inclination of the local magnetic field of Earth but not its direction as in the ordinary ordinary compass. The alternative option states that birds have an analog of compass in their brain. The challenge is to understand what is the mechanism making possible to get the information about magnetic field and how this information is transformed to a chemical signal and eventually to a pattern of nerve pulses. In TGD framework one can challenge the assumption that the magnetic field of Earth is what makes possible the navigation and even what the navigation means.

Quantum biologists try to solve the problem using standard quantum physics. The formidable looking problem is that the energy scale for magnetic energies is extremely small. In the magnetic field of Earth the magnetic interaction cyclotron energy for electron is by factor of order one million below the thermal energy. If one believes of quantum physics in its standard form, one should understand how it is possible to generate a signal making possible non-trivial chemical effects. The proposal that has gained widest

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acceptance is known has as radical-pair mechanism (RPM) [2, 5, 6] and has raised hopes about circumvent this problem.

The answer to the question whether RPM works is very important from the point of view of TGD based explanation for macroscopic quantum effects in living matter since TGD based model involves new quantum physics via the hypothesis that dark matter corresponds to $h_{eff} = n \times h$ phases located at flux tubes of “magnetic body” (MB). If RPM fails, TGD based quantum biology would be the next natural trial (if science proceeded by trying first all options that fail).

I received links to several articles and list them here to help the interested reader. The following list is about phenomena involved.

- *Cryptochrome Mediates Light-Dependent Magnetosensitivity of Drosophila's Circadian Clock* by Yoshii et al [4] (see <http://tinyurl.com/zv1mzp6>). Cryptochrome (CRY) (see <http://tinyurl.com/create.php>) has been proposed to be the photoreceptor being involved with both circadian rhythms and magnetosensitivity. In response to light CRY slows down the circadian clock and eventually leads to an arrhythmic behavior.

The response to magnetic fields in the range around 3 Gauss (6 times the strength of $B_E = .5$ Gauss) was found to be slowing down of the circadian clock. Clock response to magnetic field was present in the presence of blue light but absent in red-light illumination. This suggests that the blue light is necessary for any response at all and that magnetic field affects the response.

This response could be understood as the effect as the activation of CRY by the external field but one can consider also more complex mechanisms. This finding is taken as a support for RPM, which predicts that the response depends on wave-length and strength of magnetic field.

- *Circadian and Geotactic Behaviors: Genetic Pleiotropy in Drosophila Melanogaster* by Clayton [3] (see <http://tinyurl.com/j4vnr8c>) tells about correlation between circadian rhythms and gravitaxis (geotaxis). The following excerpt from the abstract gives some idea about the findings.

Two of these genes, cryptochrome (CRY) and Pigment-dispersing-factor (PDF) are integral to the function of biological clocks. PDF plays a crucial role in maintaining free-running circadian periods. The CRY gene alters blue-light (< 420 nm) phototransduction which affects biological clocks, spatial orientation and taxis relative to gravity, magnetic fields, solar, lunar, and celestial radiation in several species. The CRY gene is involved in phase resetting (entrainment) of the circadian clock by blue light (< 420 nm).

The following articles are about radical-pair mechanism.

- *Chemical magnetoreception in birds: The radical pair mechanism* by Rodgers and Hore [2] (see <http://tinyurl.com/zsg4b95>).

The abstract of the article is too long to be attached here but very informative and honestly tells the situation in the field. Abstract describes the basic problem that RPM must solve: the magnetic interaction energy of electron with the Earth's magnetic field is by 6 orders of magnitude too low. The abstract also mentions that with few exceptions RPM has been observed only in magnetic field intensities 10 Gauss- 10 Tesla. The exception would be avian compass and photosynthesis! The strength of 10 Gauss field is 50 times higher than the strength of Earth's magnetic field of $B_E \sim .5$ Gauss so that it is far from proven that RPM could be behind the avian chemical compass and unreasonable effectiveness of photosynthesis. Quantum biology might require new physics!

- *The Radical Pair Mechanism and the Avian Chemical Compass: Quantum Coherence and Entanglement* by Zhang et al [5] (see <http://tinyurl.com/zvcguuz>).

The abstract gives brief summary of the radical pair mechanism.

We review the spin radical pair mechanism which is a promising explanation of avian navigation. This mechanism is based on the dependence of product yields on 1) the hyperfine interaction involving electron spins and neighboring nuclear spins and 2) the intensity and orientation of the geomagnetic field. This review describes the general scheme of chemical reactions involving radical pairs generated from singlet and triplet precursors; the spin dynamics of the radical pairs; and the magnetic field dependence of product yields caused by the radical pair mechanism. The main part of the review includes a description of the chemical compass in birds. We review: the general properties of the avian compass; the basic scheme of the radical pair mechanism; the reaction kinetics in cryptochrome; quantum coherence and entanglement in the avian compass; and the effects of noise. We believe that the quantum avian compass can play an important role in avian navigation and can also provide the foundation for a new generation of sensitive and selective magnetic-sensing nano-devices.

The basic idea of RPM is that the creation of electron pairs in states, which are quantum coherent superpositions of spin singlet and triplet states of two electrons, have hyperfine magnetic interactions with nuclear spins giving rise to anomalously large EPR and NMR signals. The small mass of electron is essential but still the problem in the case of avian compass and photosynthesis is to understand how quantum coherence time can be long enough for large enough effect to result before the neutralization of the radical pair.

- *The radical-pair mechanism as a paradigm for the emerging science of quantum biology* by Kominis [6] (see <http://tinyurl.com/glegn3u>).

The radical-pair mechanism was introduced in the 1960's to explain anomalously large EPR and NMR signals in chemical reactions of organic molecules. It has evolved to the cornerstone of spin chemistry, the study of the effect electron and nuclear spins have on chemical reactions, with the avian magnetic compass mechanism and the photosynthetic reaction center dynamics being prominent biophysical manifestations of such effects. In recent years the RPM was shown to be an ideal biological system where the conceptual tools of quantum information science can be fruitfully applied. We will here review recent work making the case that the RPM is indeed a major driving force of the emerging field of quantum biology.

The claim RPM as a new paradigm could be motivated by the observation that radical pairs are formed also in the photosynthesis. As already found, the problem is that the magnetic field of Earth is only two percent of the minimal value of the magnetic field needed for RPM according to the laboratory experiments.

It is worth of emphasizing that RPM was introduced as early as 1960's to explain anomalously large EPR and NMR signals in chemical reactions of organic molecules. In TGD I ended up to the hypothesis h_{eff} hypothesis [22] and stronger $h_{eff} = h_{gr}$ hypothesis [23] through the attempt to understand the observation of the pioneers of bio-electromagnetism (see for instance [8, 9, 10] that ELF radiation in EEG frequency range has quantal looking effects on living matter at harmonics of cyclotron frequencies of biologically important ions in endogenous magnetic field $B_{end} = .2$ Gauss, which might correspond to the field strength at the flux tubes of Earth's magnetic field inside organism tuned to give rise to cyclotron frequencies ideal for biology. Cyclotron energies for ions are ridiculously small as compared to thermal energy and large h_{eff} seemed to be the only possible explanation. Could large h_{eff} effects been observed already around 1960's without realizing that new quantum physics is in question?

1.2 Some hints

It seems that several biological phenomena could use the same mechanism - RPM would be this mechanism if standard quantum theory is enough to understand these phenomena.

1. Magneto-sensitivity and circadian clock seem to be related: light-activated photoreceptors - cryptochromes (CRYs) serve also as magnetic sensors and the external magnetic fields slow down circadian rhythm.
2. Also gravitaxis that is the ability to move in direction parallel or opposite to the gradient of local gravitational field could relate to this mechanism. This requires that organism is able to perceive the gradient for the strength of the local gravitational field.

Blue light is necessary for the magnetoreception and the establishment of circadian rhythm with period of order 24 hours. This is an important hint but leaves much open. Is just the presence of blue light enough for establishing to put the circadian clock ticking or does the periodic variant of the amount of blue light give rise to internal clock?

Blue light seems to have health effects. For instance, exposure to blue light at night time could be harmful to health (see <http://tinyurl.com/mggpafe>). In particular, too much blue light at night time could affect the circadian clock and too much blue light could lead to sleep disorders and various negative health effects such as several types of cancer (breast, prostate), diabetes, heart disease, and obesity. It is known that the amount of blue light correlates with melatonin secretion. This would suggest that the periodic variation of the intensity of blue light is what gives rise to internal clock. Of course, there are very probably several cues used by internal clock (for instance, birds are not dead matter behaving as robots!) and the variation of the intensity of blue light could be only one of them.

It has been also found (see <http://tinyurl.com/zv1mxx6>) that the presence of external magnetic fields in the range around 3 Gauss (Earth's magnetic field has nominal value .5 Gauss so that this field is 6 times stronger) tends to increase the period of the circadian clock. This would suggest that the clock in question does not use only the amount of blue light as a cue.

Before continuing it is good to list some abbreviations. Electromagnetic (em), Exclusion Zone (EZ), radical-pairing mechanism (RPM) are standard notions. At least for TGD inspired notions appear in the sequel: Topological Geometro-dynamics (TGD), Strong form of Holography (SH), Zero Energy Ontology (ZEO), Causal Diamond (CD), Magnetic Body (MB), Biological Body (BB).

2 How to understand circadian clock, magneto-sensing and gravitaxis in TGD framework?

That photoreceptors responsible for circadian rhythms are involved with magnetoreception and the presence of blue light is necessary for magnetoreception are the basic challenges for any model. In RPM model this would follow from the assumption that blue light generates radical-pairs interacting with magnetic field but why just RPM should be crucial for photoreception? Why not some "easier" mechanism? Could bio-rhythms be due to some deeper quantum mechanism involving magnetic fields in an essential manner? Of course, RPM could still be involved but with non-standard value of Planck constant if TGD view is correct. Non-standard value of Planck constant could be involved even with the original anomalies associated with EPR and NMR.

I have described briefly what TGD is in the Appendix and recommend it for the reader before continuing.

2.1 Basic problems and basic principles

In Appendix I summarize what TGD and TGD inspired theory of quantum biology and quantum consciousness are. Here I just list the basic ideas relevant to the model considered. The basic elements of

this model are MB following from the many-sheeted view about space-time and distinguishing between TGD and Maxwell's theory and the hierarchy of Planck constants $h_{eff} = n \times h$ possibly satisfying the additional constraint $h_{eff} = h_{gr}$ giving connection with quantum gravity which would allow macroscopic quantum phases in arbitrarily long length scales in TGD Universe.

The key principles and mechanism should be same as in TGD based model of quantum biology.

1. Magnetic body (MB) of living organism has a fractal structure corresponding to body parts labelled by corresponding cyclotron frequency scales. MB serves as an intentional agent receiving sensory data from biological body (BB) and controlling it. BB and MB must communicate and dark photons would make this possible. EEG would be one example of this communication and MB would receive by sensory data from cell membrane as dark generalized Josephson photons and control BB by dark cyclotron photons with the mediary of genome (at least) [12, 16, 15]. EEG would generalize to other frequency ranges and generalized EEG rhythms could emerge in this manner. Dark phases of matter emerge at quantum criticality which is central element of the model. As a matter fact, TGD Universe is in well-defined sense quantum critical.
2. One cannot avoid the following questions. Is the avian navigation an automatic process. Could MB control it? Is conscious intelligence and volition involved so that the mechanism in question would be only a tool. Is the MB in question that of species or does the bird decide whether to follow the flux tubes of the personal MB connecting the bird to where it was born or in the horizontal direction defined by the MB of Earth? One must leave these questions open although the idea that the bird follows the horizontal flux tubes connecting it to the birth place (and assignable to the species?) is very attractive and would not favor the flux tubes of Earth which are not horizontal.
3. Quantum criticality allows several values of Planck constant are possible. The interpretation is in terms of long range as quantum fluctuations and quantum coherence in various length scales would have a universal explanation. Quantum criticality would be a general property of living matter and crucial also now.
4. The most economic assumption is that the mechanism is same as in the case of cell membrane identified as generalized Josephson junction coding nerve pulse sequences and membrane oscillations to EEG and in this manner sending sensory information to MB of the brain. I have indeed proposed long time ago that also biomolecules act as Josephson junctions. In fact, the cell membrane identified as generalize Josephson junction reduces microscopically to an array of generalized Josephson junctions defined by membrane proteins. For generalized Josephson junction Josephson energy $2eV$ for Cooper pair is replaced with its sum with the difference of cyclotron energies at different sides of the cell membrane. Electronic Cooper pairs would be naturally involved but also bosonic ions and Cooper pairs of fermionic ions can be considered for large values of h_{eff} and are indeed in crucial role in TGD based model of cell membrane.

One of the first applications of TGD inspired biology was the explanation of so called Comorosan effect [7, 1] in terms of bio-molecular Josephson junctions [18]. The model assuming generalized Josephson junctions applies in the case of general biomolecules and suggests that there is universal 5 second Josephson time involved. This would require rather large value of h_{eff} (Josephson frequency is inversely proportional to $1/h_{eff}$) since the voltage involved is expected to be rather high in molecular length scales.

5. The basic assumption would be that blue light kicks the photoreceptor CRY to an excited state, which is quantum critical and generates large h_{eff} phases possibly satisfying also the $h_{eff} = h_{gr}$ condition with several values of h_{eff} at the flux tubes. Note that each flux tube carries only one kind of charged particle if it corresponds to a unique value of Planck constant. Dark charged particles are like books on shelves and the situation is just the opposite for the random dense soup of bio-molecules assumed in standard biochemistry.

The basic prediction would be the dependence of the effect on strength of magnetic field as in case of RPM. The slowing down of the rhythm in presence of external B_E could be understood if the cyclotron energy difference in B_E between ground state and excited state changes so that the energy difference becomes smaller and flux tube in question has smaller value of B_{gal} : this could be due to the change of the net charge of the molecule.

One should explain several phenomena using the same model.

1. Navigation involving perception of Earth's magnetic field, which possibly weakens to endogenous magnetic field which is $2/5$ of it inside brain. A constraint to h_{eff} emerges from the condition that cyclotron frequency is in visible-UV range.

If one demands $h_{eff} = h_{gr} = GM_D m/v_0$ one finds that dark mass M_D is of order $10^{-4}M_E$ and that it would correspond to a spherical layer of dark mass at distance of Moon. Skeptic of course begins to talk about Occam's razor. This layer is however natural in the model of dark matter. One could of course just speak about h_{eff} and forget $h_{gr} = h_{eff}$. The important point is that the notions introduced are not ad hoc notions but follow naturally from the very general assumptions of TGD as unification of fundamental interactions (see Appendix).

2. The challenge is to understand circadian rhythm with period about 24 hours. There is some evidence for the importance of the galactic magnetic fields for living matter. One such piece of evidence is the observation that the occurrence of tinnitus seems to appear rhythmically but with respect to galactic time. Galactic magnetic field of strength of about 1 nT could provide explanation. There is also earlier rather mysterious observation that precognition events seem to occur near galactic midday [11]: this observation is of course not taken seriously by skeptics but deserves to be noticed. A possible test for the TGD based model is that the bio-clock actually measures sidereal rather than circadian time.

The galactic cyclotron time for h_{gr} associated with Earth mass M_E is very natural if flux tubes carry Earth's gravitational field - is very near to 12 hours for galactic magnetic field a fraction of nT. Cyclotron frequency would generate the biorhythm in manner analogous to that happening in the case of EEG. Only frequency scale would be much longer.

More precisely, according to the estimate of [22] the cyclotron time of DNA in B_{end} equal to 1 s is scaled up to 11.7 hours in $B_{gal}=.63$ nT. This estimate is obtained by accepting the $h_{eff} = h_{gr} = GMm/v_0$ hypothesis by identifying M as Earth's mass, and by assuming that the parameter $r = v_0/v_{rot,M}$ for Earth has the same value as for Sun. One has $v_0 \simeq 2^{-11}$ for Sun from the Bohr orbit model for the orbits of inner planets originally proposed by Nottale and v_{rot} is the rotational velocity of Sun.

It is needless to emphasize that this estimate involves uncertainties and that the value of B_{gal} assignable to the flux tubes has a distribution, which could be as wide as that for the energies of bio-photons. There are however good hopes of obtaining the circadian (or possibly sidereal) rhythm with natural choice of parameters.

3. The TGD description of gravitaxis should involve the flux tubes carrying gravitational flux of Earth. The same mechanism might be behind ordinary sensing of the gravitational acceleration. A good guess is that this magnetic field has same strength as galactic magnetic field B_{gal} to which Earth's mass would be associated via h_{gr} . The h_{eff} should be correspondingly higher to guarantee that dark cyclotron energy is in visible-UV range. The energy of blue light is good candidate now for exciting the quantum critical state in which this value of h_{eff} is realized.

Gravitaxis would require the detection of the strength of Earth's gravitational field coded into the density of flux tubes parallel to it. The system should be able to detect the density of the flux tubes and this would occur naturally at quantum criticality via reconnections with these flux tubes and involving dark photons with energies in visible-UV range.

4. Two magnetic fields B_{end} and B_{gal} would be involved as also two values of Planck constant but cyclotron energies would be same and in bio-photon energy range. The two MBs should be able to communicate and one can consider the possibility that the spectrum of ionic cyclotron frequencies for $B_{end} = .2$ Gauss in EEG range corresponds to electronic cyclotron frequencies for a spectrum of values of G_{gal} . This assumption would fix the parameters of the model to very high degree. Interestingly, according to TGD based quantum model for hearing [14], the audible frequencies would be coded by the thickness of flux tubes (or equivalently by the value of the magnetic field) and galactic flux tubes would give rise to a similar coding. Could hearing actually use the flux tubes of B_{gal} ?

If so, the ranges for audible frequencies and for bio-photon energies measured as number of octaves would be same. The range of frequencies audible for humans is about 10 octaves beginning from 20 Hz. Hence the spectrum of bio-photons should extend from say 1 eV to 10 keV. Dark IR photons are also predicted as a Josephson radiation from cell membrane with energies of photons of order $2eV \sim .1$ eV (Coulomb energy of Cooper pair assignable to cell membrane Josephson junction and roughly twice the thermal energy $E_{th} = 3T/2 \simeq .5$ eV at physiological temperature 330 K). I do not know whether IR energies are excluded as bio-photon energies and therefore whether the range of bio-photon frequencies could actually begin from .1 eV. If so, bio-photon energies would extend up to 1 keV.

It is important to notice that the MB involved with navigation could be Earth's MB or galactic MB if its flux tubes correspond to personal MB of the organism connecting it to its birth place. It is quite possible that both MBs are involved. One can imagine endless variety of models and the proposed model can be defended by the fact that it is based on the same mechanism as the quantum model for communications between BB and MB giving as special case the model of cell membrane.

2.2 Could circadian rhythms be analogous to EEG rhythms in TGD Universe?

In TGD Universe it is natural to think that the circadian rhythms and in fact all biorhythms - are basically analogous to EEG rhythms.

1. In TGD EEG frequencies would correspond basically to cyclotron frequencies in and endogenous magnetic field of .2 Gauss which is 2/5:th of Earth's magnetic field carrying dark particles (in TGD sense) having non-standard value $h_{eff} = n \times$.
2. The energies of cyclotron photons, which would be extremely small and much below thermal energy for the ordinary value of Planck constant, are scaled up by factor n by $E = h_{eff} \times f$ formula and can have non-trivial biological effects.
3. A further proposal is that the formula $h_{eff} = h_{gr} = GMm/v_0$ holds true - at least for large values of h_{eff} . Here h_{gr} is gravitational Planck constant assignable to magnetic flux tubes mediating gravitational interaction, v_0 is a parameter with dimensions of velocity, m is the mass of the dark charged particle at the flux tubes, and M is some large mass.

This formula guarantees that cyclotron energies proportional to $h_{gr}eB/m$ do not depend on the mass m of the charged particle for given charge. This in turn implies that dark cyclotron energy spectrum is universal. The hypothesis is that the transformation of dark photons to ordinary photons produces ordinary photons identifiable as bio-photons. If so the energies would be in visible-UV range and would dark photons could induce transitions of biomolecules and could serve as a biochemical control tool of the MB. If one accepts $h_{gr} = h_{eff}$ hypothesis for EEG, the value of the mass M should be around $M = M_D \sim 10^{-4}M_E$ for EEG. Using some additional cues given by TGD based view about how planets were condensed around dark matter blobs forming spherical cells or tubes around Sun or actually any astrophysical object, I have proposed a possible identification of M_D as a mass of

spherical shell of dark matter assignable to Earth at the distance of Moon [22, 23]. Here skeptic of course has an excellent opportunity to introduce Occam's razor and I am of course ready to consider also the option that $h_{eff} = h_{gr}$ does not hold true at the flux tubes of B_{end} .

What about the identification of circadian rhythms as cyclotron frequencies?

1. The general idea is that the flux tubes of both Earth's magnetic field and of galactic magnetic field can locally self-organize into complex braided structures serving defining the MBs of organisms, which would therefore be parts of much bigger organism. The flux tubes could connect living systems to each other and for instance, birds and fishes to their birth places.
2. The cyclotron time is much longer than for EEG rhythms and the natural guess is that the flux tubes of interstellar (galactic) magnetic field with field strength varying around the mean value $B_{gal} \sim 1$ nT are involved. The spectrum of cyclotron times would be of correct order of magnitude. $h_{gr} = h_{eff}$ hypothesis essential for the coupling of MB to biochemistry would be satisfied for $M = M_E$ in $h_{gr} = GMm/v_0$ so that one cannot assume that only dark mass contributes to the large mass in h_{gr} .

2.3 Trying to figure out the general mechanism

The details of the mechanism could be fixed by empirical input and using second assumption above as a guideline.

1. To my best understanding the role of RPM for avian chemical compass is speculative. RPM has been indeed observed only for magnetic fields stronger than 10 Gauss. Therefore it can be challenged. Even the notion of chemical compass is speculative.
2. The large cyclotron energies of dark charged particles would solve the problem caused by the extreme smallness of the electronic cyclotron energies - this could be the case even for ions. Radical pairs and electron pairs assigned with them could of course be present also in TGD inspired model. Even pairs of ions and bosonic ions.
3. In TGD context one could assume only spin singlet or triplet Cooper pairs with large value of $h_{eff} = h_{gr}$ in $B_{end} = 0.2$ Gauss. The existence of superconducting phase would require that Cooper pairs assignable to several CRY molecules reside at same flux tube pairs. This would make the process quantum coherent in longer scale.
4. Quantum criticality is needed and could be associated with the emergence of high Tc superconductivity and would correspond to the transversal oscillations of magnetic flux tubes analogous to phonons assumed in ordinary superconductivity and also in RPM. They would lead to a transitions between flux tube pair with shape of flattened square and pair of pairs flux tubes of similar shaped induced by reconnection somewhere along flux tube pair. In transition to superconductivity long flattened square would stabilize. Above transition temperature shorter flattened square shapes would be stable and one would have super-conductivity but in short scale only.
5. Electron pairs would be analogous to Cooper pairs and if there is many of them in the system one would speak of super-conductivity. In TGD inspired quantum biology the electron pairs might be Cooper pairs with members at flux tubes, which are either parallel or antiparallel. Spin singlet and triplet Cooper pairs would correspond to flux tubes with opposite and parallel fluxes. The quantum coherent fluctuation between them assumed in the model does not look possible in TGD framework and is not needed.

6. Spin singlet Cooper pairs would result for closed flux tubes with the shape of flattened square. If one has pairs of this kind of flux tubes in parallel and close enough to each other, the second member of the Cooper pair could hop to second flux tube of the other flux tube pair so that members of the pair would be at flux tubes with parallel magnetic fields and form triplet. This kind of hopping could give rise to the coherent quantum transitions between spin singlet and triplets and the ratio of singlets and triplets would be different from one in the final state and depend on the value of magnetic field and cause a chemical effect. This assumption need not be necessary for the model to work. The control by MB could be much more direct and take place at bio-photon energies.
7. Dark photons are somehow emitted and go to the flux tubes of B_{gal} in the case of circadian rhythm and gravitaxis. In the case of avian navigation the flux tubes could be those of B_{end} (B_E could be equal to B_{end} inside brain) or those of B_{gal} .

The model of cell membrane as generalized Josephson junction with membrane proteins (channels and pumps) suggests a model in which the emission of dark photons could be generalized Josephson radiation with energy determined as difference of cyclotron energies plus ordinary Josephson energy. Dark Josephson photons going to the flux tubes of Earth equal to $B_{end} = 2B_E/5$ inside organism. from Blackman's experiments. This would give rise to magneto-detection of B_E . The mechanism would be exactly like the mechanism communicating sensory data to MB from cell membrane and allowing MB to control cell via genome using dark cyclotron photons. One can however consider also the replacement of B_{end} with B_{gal} .

One can imagine also the analog of RPM mechanism. In this case the dark electron pairs would fluctuate quantum coherently between spin singlet and triplet state and also interact with nuclear spins of the radical pair. The fusion of radical pair to a neutral state would destroy the quantum coherence. By a generalization of Uncertainty Principle cyclotron time would define the natural time scale and would be much longer than the time scale of coherence for RPM model. Maybe this could allow to test h_{eff} hypothesis.

2.4 More concrete model for the mechanism of magnetoreception and circadian rhythms

It is could to list some basic facts first.

1. Photopigment CRY must be excited by blue light needed to perceive magnetic field.
2. CRY interacts with magnetic field to establish the biorhythm.
3. External magnetic fields around 3 Gauss in presence of blue light slowed down the speed of the circadian clock.

What is the mechanism giving rise to the circadian clock? The naive guess is that circadian rhythm corresponds to the periodic variation of the sensitivity to the external magnetic field determined by the amount of solar light. This certainly serves as a cue for the behavior and affects directly neuronal level but need not give rise to the fundamental biorhythm.

The simplest model does not explain why the circadian clock slows down (leading eventually to the loss of circadian rhythm) in external magnetic fields B_{ext} not too far from 3 Gauss- about 6 times the value of Earth's magnetic field? Hence it seems that the amount of blue light alone is not behind the clock mechanism but something more delicate is involved. The cyclotron frequencies assignable to weak external magnetic field (say B_{gal} whose flux tubes mediate gravitational interaction) as primary sources of circadian rhythms and controlled by B_{ext} somehow are suggested by the TGD inspired model of EEG.

The following picture suggests itself in TGD framework, where MB containing dark matter as large $h_{eff} = h_{gr}$ phases of ordinary matter controls biochemistry in quantum coherent manner in scales of even entire organism.

1. Basic entities are CRY molecule and its MB carrying some internal magnetic field B_{end} (to be not confused with $B_{end} \simeq .2$ Gauss) and having large h_{eff} . MB of galactic magnetic field B_{gal} : this in order to obtain cyclotron frequencies of order 24 hours for protons and ions. Magnetic flux tubes of galactic MB carrying cyclotron Bose-Einstein condensates for electrons, protons, ions each of them with $h_{eff} = h_{gr}$ proportional to the mass of charged particle in question. Different charged particles at their own flux tubes like books in the shelves of library.
2. Photons of blue light excite CRY. Excited CRY gradually returns to the ground state. This should lead to emission of dark cyclotron photons with cyclotron frequency of magnetic field involved for some charged particles at flux tubes? Transformation to dark cyclotron photons increasing \hbar to $\hbar_{eff} = n \times \hbar$ takes place only at quantum criticality for the emitted photons. This might select the transitions corresponding to blue light.
3. The two MBs should interact by dark radiation at cyclotron frequencies. The excitations of CRY molecule by blue light would decay to ground state and emit dark photons with energy of blue light but with the cyclotron frequency for protons/ions of order 24 hours. Magnetic field with the strength not too far from 1 nT, the strength of galactic magnetic field seems to be the most natural possibility.
4. CRY's MB must reconnect with that of galactic MB. Reconnection makes possible resonant interaction at multiples of cyclotron frequency. Large h_{eff} and biophoton hypothesis require that the energies involved are in visible-UV range. Blue light is in this range.
5. The resonant interaction would give rise to the perception of Earth's MB and make possible navigation: bird would fly to in the direction, where it perceives the flux tubes of Earth's MB.
6. Circadian rhythm would correspond to the galactic cyclotron frequency which would be same for all charged particles with the same charge by $h_{gr} = h_{eff}$ hypothesis implying that dark cyclotron photons have universal energy spectrum in the range of biophoton energies.

Why the external magnetic field with strength of order 3 Gauss has the slowing down effect? CRY should be able to couple to magnetic fields of this order of magnitude. The coupling should reduce the frequency of the emitted dark photons. It would seem that the frequency of dark photons emitted by CRY is reduced. This requires that the energy difference for its excited and ground states is reduced. If the ground state and excited state have different the difference of total energies contains the difference of cyclotron frequencies proportional to charge difference and magnetic field. If this difference is negative, its magnitude increases with B_{ext} so that the frequency of emitted photons reduced. Hence the CRY couples to flux tubes with weaker galactic magnetic field. This slows down the clock.

One can of course adopt a conservative attitude and consider a minimal modification of RPM by assuming quantum criticality and by replacing the Planck constant with $h_{eff} = n \times h$ with $n \geq 50$. The excitation of CRY molecule responsible for the phenomena described could indeed involve generation of radical pair in presence of blue light. The decay of RPM to neutral pair could produce photons transforming to dark photons at flux tubes? If so, the decoherence produced by the decay of RP would be compensated by coherence at the level of dark matter: negentropy maximization principle (NMP) [13] would suggest this.

2.5 Gravitaxis and $h_{eff} = h_{gr}$ hypothesis

Gravitaxis might relate to the basic hypothesis about dark matter in TGD Universe as large h_{eff} phases: one would have $h_{eff} = h_{gr} = GMm/v_0$, v_0 is velocity parameter, m is some large mass, now presumably Earth's mass. This hypothesis is originally due to Nottale and plays key role in TGD inspired quantum biology.

What sensing a gradient in gravitational field could mean from the point of view of this hypothesis?

1. The simplest model assumes that the flux tubes along with gravitational interaction is mediated, are magnetic flux tubes with vanishing Kähler magnetic field but non-vanishing electromagnetic and Z^0 magnetic fields. These flux tubes would be vacuum extremals in absence of volume term in action. The volume term is proportional to cosmological constant and induced by the twistor lift of TGD [24]. The flux tubes carrying magnetic monopole flux would be assigned to non-gravitational interactions: this distinction looks natural but does not seem to be necessary.
2. The density of the gravitational magnetic flux tubes must correlate with the average intensity of gravitational field at GRT limit of TGD. At fundamental level of many-sheeted space-time the detection of gravitational field strength would reduce to the detection of the density of these flux tubes. This detection would reduce to the same mechanism which makes possible magneto-sensitivity making possible avian navigation, biological clocks, and basic step of photosynthesis.

The overall conclusion is that TGD based quantum biology neatly unifies the description of several phenomena suggesting quantum biology in terms of magnetic body and dark matter as large h_{eff} phases. TGD based model is also needed since RPM proposal predicts effect which is at most 2 per cent of that needed to explain the observations.

3 Appendix: What TGD is?

Since the purpose is to see the representations through TGD lense it is polite to first to tell to the reader what TGD is. The reader interested in details can find them for instance in [21].

3.1 Why TGD?

The first question is “Why TGD?”. The attempt to answer this question requires overall view about the recent state of theoretical physics.

Obviously standard physics plagued by some problems. These problems are deeply rooted in basic philosophical - one might even say ideological - assumptions which boil down to -isms like reductionism, materialism, determinism, and locality.

Thermodynamics, special relativity, and general relativity involve also postulates, which can be questioned. In thermodynamics second law in its recent form and the assumption about fixed arrow of thermodynamical time can be questions since it is hard to understand biological evolution in this framework. Clearly, the relationship between the geometric time of physics and experienced time is poorly understood. In general relativity the beautiful symmetries of special relativity are in principle lost and by Noether’s theorem this means also the loss of classical conservation laws, even the definitions of energy and momentum are in principle lost. In quantum physics the basic problem is that the non-determinism of quantum measurement theory is in conflict with the determinism of Schrödinger equation.

Standard model is believed to summarize the recent understanding of physics. The attempts to extrapolate physics beyond standard model are based on naive length scale reductionism and have products Grand Unified Theories (GUTs), supersymmetric gauge theories (SUSYs). The attempts to include gravitation under same theoretical umbrella with electroweak and strong interactions has led to super-string models and M-theory. These programs have not been successful, and the recent dead end culminating in the landscape problem of super string theories and M-theory could have its origins in the basic ontological assumptions about the nature of space-time and quantum.

3.2 TGD and GRT

The new view about space-time as 4-D surface in certain fixed 8-D space-time is the starting point motivated by the above mentioned energy problem of general relativity and means in certain sense fusion of the basic ideas of special and general relativities.

The higher-dimensional space-time is 8-D $H = M^4 \times CP_2$: empty Minkowski space M^4 of special relativity with points replaced by 4-D CP_2 (complex projective space of 4 real dimensions). The symmetries of special relativity are preserved but lifted to the level of H so that classical conserved quantities like energy exist. CP_2 in turns codes in its geometry the standard model symmetries and quantum numbers and its spinor connection codes for classical electroweak gauge fields. Their projections to space-time surface are dynamical. Also classical color fields can be understood. These geometrized fields are expressible only in terms of four CP_2 coordinates and cannot as such directly correspond to those of standard model. How standard model emerges as a limit of TGD will be discussed below.

Rather recently [24] I have discussed twistor lift of TGD replacing space-times with the twistor spaces and H with the product of twistor spaces of M^4 and CP_2 , which are unique as 4-D spaces in the sense that they have twistor spaces with Kähler structure making possible to lift the Kähler action to 6-D one. The theory dimensionally reduced to a 4-D theory containing cosmological constant and gravitational constant as additional constants besides CP_2 radius and Kähler coupling strength.

3.3 TGD and string models

TGD can be also seen as a generalization of hadronic string model or of superstring models by replacing strings with 3-D surfaces and 10-D space-time with 8-D $M^4 \times CP_2$. 3-space as we experience it corresponds to a large 3-surface to which smaller 3-surfaces are glued by wormhole contacts. These smaller 3-surfaces we would interpret as physical objects with shape and size and when they are really small, we call them elementary particles. We would directly see this extremely complex space-time geometry. This geometry has fractal hierarchical structure: 3-surfaces glued to larger 3-surfaces glued to....

As a matter of fact, string world sheets and what I call partonic 2-surfaces in 4-D space-time regarded as space-time surface turn out to be fundamental objects of also TGD forced by very general principles such as well-definedness of em charge and strong form of holography (SH) implied by strong form of general coordinate invariance [17]. SH states that information given at these 2-surfaces allows to deduce information about quantum states and classical dynamics: effective 2-dimensionality in the sense of information theory would be in question.

3.4 TGD based ontology

TGD forces to dramatically generalize the ontology of standard model and GRT.

1. The new view about space-time differs radically from that of GRT. Space-time surfaces are topologically non-trivial in all scales. They have typically finite size and obey size scale hierarchy. One can glue space-time sheets to larger space-time sheets to get a fractal scale hierarchy with sheets glued to larger sheets by wormhole contacts and having interpretation as correlates for physical objects.

Second key difference is that space-time surfaces can have also regions with Euclidian signature of the induced metric - time and space are geometrically in the same role. Wormhole contacts are this kind of regions and serve as building bricks of elementary particles and are identifiable as lines of generalized scattering diagrams.

2. A new view about classical fields emerges distinguishing TGD from Maxwell's theory. One can say that each physical object has field identity - field body consisting of space-time sheets. The notion of magnetic body (MB) turns out to be central in TGD inspired biology and adds MB to the pair organism-environment as a third member. The communications from BB involve classical radiation fields: EEG is one example of this communication from the brain to the MB of brain. The size scale of MB is typically considerably larger than that of BB: even of order Earth size scale or even larger. MB makes possible remote mental interactions and could be behind the morphic fields of Sheldrake.

3. How TGD relates to GRT and standard model? The basic idea is that the sheets of many-sheeted space-time obeying extremely simple physics (only 4 analogs of field variables plus SH realized by preferred extremal property implying effective 2-dimensionality of dynamics) are lumped together and identified as GRT space-time differing slightly from flat M^4 .

The deviation comes in the following manner. The deviations of the induced metric for space-time sheets from M^4 metric (empty space metric) are summed up to give GRT gravitational field as deviation from M^4 metric. Induced gauge potentials known once space-time surface is known are summed up in the same manner to give the gauge potentials of standard model. This because test particle experiences the sums of various induced fields associated with space-time sheets. Ordinary linear superposition is replaced at fundamental level with the set theoretic union for space-time sheets.

4. The hierarchy of Planck constants $h_{eff} = n \times h$ was originally motivated by certain strange findings in neuroscience about effects of ELF em fields on vertebrate brain [20, 19]. First it was postulated that dark matter corresponds to phases of ordinary matter with $h_{eff} = n \times h$ having certain special kind of space-time surfaces (singular n -sheeted covering spaces) as correlates. Later it turned that these phases are actually predicted by basic TGD: in TGD framework Planck constants is for single space-time sheet h and only effectively $h_{eff} = n \times h$ but at QFT limit one can say that $h_{eff} = n \times h$ is strictly true.

Later the view about dark matter as evolved and according to the recent view dark matter would emerge at quantum criticality (perhaps even at ordinary criticality) and would be a correlate for long range quantum fluctuations and long range quantum coherence. Various quantal length scales are indeed typically scaled up by n . This suggests that biosystems are quantum coherent and quantum critical because MB contains dark matter.

MB containing dark matter would serve as intentional agent receiving sensory data from BB and controlling BB. EEG and its generalizations to various frequency ranges based on dark photons would be the tool for this. The dark cyclotron photons assignable to given charged particle would have very specific value of h_{eff} guaranteeing that cyclotron energy scale does not depend on particle mass and would be in the range of biophoton energies (visible and UV). Biophotons would result in the phase transition $h_{eff} \rightarrow h$. Also dark photons in IR range (Josephson photons assignable to cell membranes) are predicted.

Biochemistry would not be enough to understand the biology. MB and its “motor actions” would be crucial for understanding bio-catalysis, in particular the miraculous property of biomolecules to find each other in the molecular crowd.

5. Zero energy ontology (ZEO) is a further new piece of TGD ontology. In standard ontology the state of system at fixed value of time characterize the time evolution of the system. Classically the state is typically characterized by particle positions and velocities and by values of say Maxwellian fields and their time derivatives. Field equations in principle allow to deduce the time evolution from these.

In ZEO one introduces causal diamond (CD). CD is intersection of future and past directed light-cones (Penrose diagram) with points replaced by CP_2 . CDs are assumed to form a fractal scale hierarchy. CD has two light-like boundaries: “future” and “past” boundary. Light-likeness means that 3-D M^4 projection of given boundary correspond to a sphere expanding with light-velocity.

Physical states are replaced with zero energy states analogous to physical events consisting of initial and final states. Initial/final state can be assigned to 3-D intersections of space-time surfaces with the “future”/“past” boundary of CD. ZEO is consistent with the crossing symmetry of quantum field theories and with the conservation laws. It is however extremely flexible since any zero energy state is in principle achievable by a sequence of quantum jumps. The analog of ordinary positive energy can be assigned with either “future” or “past” boundary and the arrow of time is different

for these states. ZEO leads to a quantum measurement theory allowing to circumvent the basic problem of standard quantum measurement theory due to the non-determinism of state function reduction contra determinism of unitary time evolution.

6. p-Adic and adelic physics are further new ontological elements of TGD. p-Adic numbers are generalizations of real numbers, and there are infinite number of p-adic number fields for each prime $p = 2, 3, 5, \dots$. I ended up with p-adic physics almost accidentally by playing with p-adic generalization of thermodynamics and finding that p-adic thermodynamics can reproduce elementary particle masses with minimal assumptions and thus replaced Higgs mechanism with more fundamental theory. The properties of p-adic number led soon to the proposal that p-adic number fields are correlates for cognition and imagination. Much later this led to the unification of real physics and various p-adic physics in terms of adelic physics fusing all these number fields to a bigger structure.

Why p-adic physics is so nice that one can talk about p-adic imbedding space and space-time surfaces as kind of cognitive representations of real space-time surfaces. In particular, SH allows to assign p-adic space-time surface to given set of string world sheets and partonic 2-surfaces as preferred extremal but no necessary to real one. All imaginations cannot be realized!

Also p-adic generalization of Shannon entropy makes sense but it can be negative. One can say that entanglement carries negative p-adic entropy - positive negentropy - although real entropy is non-negative. The interpretation is in terms of conscious information naturally assignable to cognition.

3.5 TGD, quantum measurement theory, and consciousness

TGD inspired theory of consciousness can be seen as quantum measurement theory in ZEO. Observer as an outsider becomes a part of physical system. Observer does not cause state function reductions but as a conscious entity is a sequence of state functions on same boundary of CD - generalized Zeno effect.

1. The maximization of negentropy gain in state function reduction becomes the basic variational principle of consciousness theory consistent with second law which applies at the level of ensembles and is closely related to the growth of real entanglement entropy. I refer to this principle as Negentropy Maximization Principle (NMP).
2. In ZEO state function reduction can take place to either boundary of CD. In a sequence of reductions to a fixed boundary the boundary itself remains fixed as also the states at it - possibly entangled with those at the opposite boundary. This boundary is referred to as "passive". The second - "active" - boundary drifts farther away from the passive boundary and the states at it change. Each step can be regarded as time localization localizing the active boundary of CD.

Self corresponds to this sequence of state function reductions. The permanent part of self - "soul" - corresponds to the unchanging part of self and changing part corresponds to consciousness determined by sensory input. In particular, the experience about flow of time corresponds to the drift of the active boundary of CD farther away. Self is a generalized Zeno effect.

3. Eventually NMP forces the first reduction to the opposite boundary to occur. This is the counterpart of the usual large and non-deterministic quantum jump assignable to quantum measurement. Self dies and re-incarnates as time reversed self since the CD starts to increase in size in opposite time direction. This prediction has rather radical implications.

Some of the implications deserve to be noticed.

1. One ends up with a new view about time. Geometric time as fourth space-time coordinate (or time coordinate as distance between the tips of CD) is not same as subjective time defined by a sequence of state function reductions. The consciousness experience associated with each reduction has the

changing components with contents coming from the active boundary so that subjective time is mapped to discrete clock time.

2. Selves having hierarchy of CDs as imbedding space correlate form a hierarchy. Subself is assumed to be experienced as mental image and subselves as kind of average sub-subself so that self is not drowned to microscopic information. Subconscious corresponds to conscious sub-sub-... -selves. We are ourselves mental images of some higher level self and the hierarchy continues ad infinitum with entire Universe at the top.

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