What are entanglement batteries and quantum batteries?

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Contents

Abstract

Quantum information science is a rapidly developing field. My latest surprise was caused by a popular article telling about the article of Ray Ganardi et al with the title "Second Law of Entanglement Manipulation with Entanglement Battery". I also learned of quantum batteries as a new extremely fast way to store energy. What do these notions mean and what could be their TGD counterparts? In this article, I will consder this question from the TGD point of view.

1 Introduction

Quantum information science is a rapidly developing field. My latest surprise was caused by a popular article in Sciencedaily (see this. The article told about the article of Ray Ganardi et al with the title "Second Law of Entanglement Manipulation with Entanglement Battery" [**?**] (see this). I also learned of quantum batteries as a new extremely fast way to store energy this). What do these notions mean and what could be their TGD counterparts?

The key idea of quantum information science leading to these notions is to take thermodynamics as a "role model" for quantum information science by replacing energy with information.

Consider first thermodynamics.

1. In thermodynamics, Carnot's law relates to a thermodynamic system in a heat bath and gives an upper bound for the fraction of heat energy which can be transformed to work, which is ordered energy. A cylinder containing a hot case and expanding is a basic example of this kind of situation.

2. The heat bath serves as a source of thermal energy, which can be partially transformed to work. This operation is the reversal for the dissipation occurring spontaneously by the second law. The presence of the heat bath would be required by the second law. Carnot's law gives an expression for the maximal efficiency in terms of the ratio of the difference of the temperatures of the system and heat bath and the temperature of the heat bath.

3. The heat bath as a source of thermal energy can be replaced with a source of some other kind of energy. Battery is the basic example of this kind of energy source. In biology cell membranes and proteins serve as batteries providing metabolic energy.

In quantum information theory energy is replaced by entanglement to which one can assign information. Assume that entanglement manipulation involves only local operations and classical communications.

1. Is reversible entanglement manipulation by a third system possible? This would be analogous to the manipulation of the system in a heat bath or in presence of a battery so that the system could do work and be returned to its original state reversibly.

2. Reversible entanglement manipulation is not possible for a mere pair of entangled systems. But what happens if one adds a third system as an analog of heat bath or battery but carrying entanglement instead of energy? One can call this system an entanglement battery. Is reversible entanglement manipulation possible now? Does the analog of Carnot law make sense?

   It turns out that in this case the entanglement manipulation can be a reversible process for the pair of entangled systems but the third system loses entanglement and therefore information so that the analog of the second law is true.

2 TGD counterpart for entanglement - and quantum batteries

If good to start by listing the basic new ideas of TGD [L17, L18] relevant for the understanding of entanglement and quantum batteries.

2.1 Basic ides of TGD relevant to the quantum information theory

TGD involves two complementary views of reality.

1. The view of physics as geometry, combined with the condition that Poincare invariance of the special relativity is not lost, leads to a new view about space-time differing rather dramatically from the Einsteinian view.

   Space-time is a surface in $H = M^4 \times CP_2$ Holography = holomorphy principle (H-H) characterizing its dynamics has deep implications: for instance, classical theory is exactly solvable and the space-time surface are minimal surfaces, analogous to Bohr orbits of particles identified as 3-surfaces, irrespective of the classical action as long as it is general coordinate invariant and depends only on the induced geometry [L15, L19, L23, L12].

2. The view of physics as number theory leads to a vision about what cognition is but makes also very powerful predictions about ordinary physics. As a matter of fact, most quantitative predictions follow from the number theoretic vision [L9, L5, L3, L7, L11].

The TGD view of quantum physics involves several new elements.

1. The hierarchy of effective Planck constants $h_{eff} = nh_0$ with the estimate $h = (7!)^2 h_0$, where h_0 is the miminal value of $h_{eff} = nh_0$ [L19]. This makes possible equantum coherence in arbitrarily long scales. This also leads to p-adic physics as correlate for cognition.

2. Zero energy ontology (ZEO) [L4, L13] predicts that the counterpart for a sequence of repeated quantum measurements of the same observables does not change the system unaffected but a flow of consciousness, a conscious entity, self. In these "small" state function reductions (SSFRs), the system's internal state changes. The corresponding observables relate to the classical non-determinism associated with the space-time surfaces if H-H is true and are assigned with cognition. These observables have no counterpart in standard physics.

3. In ZEO, the TGD counterparts of quantum measurements of physical observables correspond to "big" state function reductions (BSFRs). The arrow of geometric time changes in BSFR [L14]. The change of the arrow of time can be regarded as death or falling asleep: this in a universal sense. Consciousness is not lost but corresponds to a self with an opposite arrow of geometric time. The classical signals sent during this period do not reach the brain in the future so that we do not remember anything about the deep sleep state.

What implications the TGD view of physics and consciousness might have concerning quantum information science, in particular the notion of entanglement battery?

1. The number theoretic view of TGD brings in the p-adic physics of cognition in which a hierarchy of Planck constants [K1, K2, K3, K4, K5] and hierarchy of p-adic length scales are in a central role [L9].

   Recent work [L15, L19, L22] has led to a generalization of p-adic number fields to function fields related to p-adic number fields by a morphism. In this view p-adic physics could be seen as a convenient description of the non-determinism of real number based physics rather than a fundamental notion. Prime p corresponds to a prime near power of a small prime defining a degree of a polynomial. This generalization makes it possible to understand the p-adic length scale hypothesis stating that p-adic primes new powers of 2 (and also 3) seem to be physically of special importance.

2. Cognitive information is associated with cognitive entanglement and cognitive state function reductions reduce this entanglement. This kind of entanglement is not possible in standard quantum theory. It relates to the slight non-determinism of the classical time evolution assuming H-H. Space-time surfaces as fundamental objects are like slightly non-deterministic Bohr orbits for particles as 3-surfaces. This non-determinism naturally corresponds to p-adic non-determinism.

   Transfer of cognitive information would mean transfer of mental images. One can say that in the simplest situation the entangled pair of systems would be like a student whereas the entanglement manipulator would be in the role of a teacher, and the entanglement battery would be like a text book. The learning would mean generation of entanglement between the members of the pair (or a more general system) defining the student. Quantum teleportation could make possible the transfer of entanglement for a subsystem.

3. The number theoretical counterpart of the second law is Negentropy Maximization Principle (NMP) [L13] states that the number theoretical complexity of the space-time surfaces is bound to increase. By H-H principle, space-time surfaces are roots for a pair of polynomials of generalized complex coordinates of H and their algebraic complexity unavoidably increases in the sequence of quantum jumps. This gives rise to evolution.

4. One particular measure for the number theoretical complexity is given by the effective Planck constant h_{eff}, which could correspond to the dimension of an algebraic extension of rationals. The degree of the polynomial defining the extension provides an alternative measure and it is not possible to make strong conclusions at this stage. The larger the value of h_{eff}, the larger the maximal entanglement entropy and the potential cognitive information content.

5. p-Adic entanglement negentropy can be positive and by NMP tends to be so [L13]. Negentropic entanglement serves as a correlate for conscious cognitive information associated with p-adic physics characterizing the classical non-determinism. One can assign to it p-adic entanglement negentropy as a generalization of Shannon entropy. In the number theoretic evolution maximal entanglement negentropy increases. This tendency, coded by NMP, is

mathematically analogous to the increase of entropy but states just the opposite. This can be understood: the p-adic negentropy is associated with the entanglement whereas the ordinary entropy is associated with information of a third system about either entangled system.

6. p-Adic entanglement negentropy and real entanglement entropy are closely related but p-adic entanglement negentropy can be larger than the latter and by NMP tends to be so. Jeremy England [I1] has observed that evolution and increase of entropy are closely related. This looks paradoxical. In the TGD framework which can be however understood since the increase of p-adic negentropy in evolution implies the increase of real entropy [L1].

7. The energy scale of a quantum system as a function of h_{eff} increases. Therefore the increase of h_{eff} and of maximal cognitive information requires energy feed having an interpretation as metabolic energy. Biosystems need a metabolic energy feed to stay cognitively conscious.

2.2 The theorem of Ganardi et al and the TGD view of living systems

The theorem of Ganardi et al allows to have a new perspective on the TGD view of living and conscious systems.

1. In TGD inspired theory of consciousness and quantum biology, sensory perception and cognition could be seen as construction of standardized mental images [L2] and conscious communications could be seen as a transfer of standardized mental images. TGD inspired biology and neuroscience involve a concrete proposal for the mechanism involved. The theorem of Ganardi et al justifies the intuitive picture concerning conscious information transfer.

2. Entangled subsystem pairs of a biological system, such as the two DNA strands, the brain consisting of two hemispheres, and the magnetic bodies of the left and right hemisphere, define conscious information packets. By the theorem of Ganardi et al, the entanglement can be transferred by quantum teleportation involving local operations and classical communications between two conscious systems. The entangled subsystem pairs would define cognitive mental images so that one could talk about a telepathic transfer of mental images.

   Note that in TGD classical physics dictated by H-H is an exact part of quantum physics so that classical communications are very natural.

3. H-H implies that the basic geometric objects are space-time surfaces analogous to Bohr orbits for particles identified as 3-surfaces and replace 3-surfaces in ZEO as fundamental objects. The Bohr orbits are slightly non-deterministic due to the weak non-determinism associated with classical time evolution. This also implies non-determinism in fermionic degrees of freedom [L21, L20]: H-H allows to solve exactly also the Dirac equation for the induced spinors to be distinguished from the Dirac equation for in H.

4. The cognitive entanglement could be in discrete degrees of freedom associated with a single space-time surface or between these degrees of freedom associated with separate space-time surfaces. For ordinary 2-D minimal surfaces the seats of non-determinism correspond to frames at which the surface can branch in several ways. In the 4-D case, these degrees of freedom would correspond to 3-surfaces as loci of classical non-determinism. These loci would define memories at the fundamental level [L16]. Also the entanglement between two disjoint space-time surfaces can be considered as well as the entanglement between 3-D light-like partonic orbits.

One can pose several questions in this framework.

1. Does the generalized Carnot's law give an upper bound of information transferred from the entanglement battery to the entangled pair of systems in terms of the p-adic temperature as the cognitive analog of temperature having a spectrum quantized as $T_p = 1/n$?

   Does the $T_p \to 0$ limit correspond to an optimal situation in which the entanglement battery is a pure system and an ideal source of entanglement provided it has a large degeneracy of states.

2. The failure of the strict classical dynamics predicts large degeneracy of states due to the possibility of a large number of non-deterministic time evolutions. This non-determinism would correspond mathematically to the non-determinism of p-adic differential equations. This alone does not give rise to entanglement however.

3. One can however regard the discrete set of loci as subsystems which can have time like-entanglement so that the non-determinism gives rise to a cognitive entanglement battery.

2.3 Quantum batteries

Quantum batteries (see this) are highly entangled quantum coherent systems. This makes possible their loading using collective quantum transitions in which the component systems experience quantum transition simultaneously. This can make the loading of quantum batteries extremely fast (see this).

In TGD, this kind of collective quantum transitions, analogous to phase transitions, are a basic element in the model of conscious information transfer and TGD suggests a concrete model for these phase transitions. Genetic code, having a universal realization in TGD, would play a key role in this mechanism.

1. Genetic codons correspond at fundamental level correspond to entangled dark proton triplets and chemical representation is only a secondary representation [L6, L10, L8]. Dark codons in turn entangle further to form dark genes. The communications between dark genes with 3N dark protons occur by sending entangled dark 3N-photons analogous to Bose-Einstein condensates.

2. The communication occurs by 3N-resonance involving simultaneous absorption of 3N-photons changing the state of the dark gene represented by 3N dark protons.

3. The frequencies involved are cyclotron frequencies for dark protons and the modulation of the frequency scale represents the message transformed to a sequence of 3N-pulses. Also partial multi resonance is possible if the modulation is not the same for all dark protons. The communications to the magnetic/field body (such as EEG) and control of biomatter by the field body would be based on this mechanism.

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