Matter-antimatter asymmetry, baryo-genesis, lepto-genesis, and TGD

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Abstract

The generation of matter-antimatter asymmetry remains still poorly understood. Same is true about the generation of matter. In TGD framework the generation of matter can be explained in terms of cosmic strings carrying dark energy identified as Kähler magnetic energy [K5]. Their decay to ordinary and dark matter would be the analog for the decay of the inflaton field to matter and matter-antimatter asymmetry would be generated in this process. The details of the process have not been considered hitherto.

The attempt to see whether the counterparts for the visions about lepto-genesis from right-handed inert neutrinos, baryo-genesis from leptons, and generation of antimatter asymmetry claimed to be possible in standard model framework, could make sense in TGD led to a much more detailed vision about how the primordial cosmic strings carrying only right handed neutrinos could decay to ordinary matter. It also turned out that the "official" version of TGD for which quarks and leptons correspond to different chiralities of imbedding space spinors is enough to achieve also matter antimatter asymmetry.

Contents

1 Introduction

The generation of matter-antimatter asymmetry is still poorly understood. There exists a multitude of models but no convincing one. In TGD framework the generation of matter-antimatter asymmetry can be explained in terms of cosmic strings carrying dark energy identified as Kähler magnetic energy [K5]. Their decay to ordinary and dark matter would be the analog for the decay of the inflaton field to matter and the asymmetry would be generated in this process. The details of the process have not been considered hitherto.

The stimulus for constructing a general model for this process came from attempt to understand the notion of sphaleron [B4] claimed to allow a non-perturbative description for a separate non-conservation of baryon and lepton numbers in standard model. The separate non-conservation of B and L would make possible models of baryo-genesis and even lepto-genesis assuming that in the primordial situation only right-handed inert neutrinos are present. To my opinion these models however fail mathematically because they equate the non-conservation of axial fermion numbers - which is on a mathematically sound basis - with the non-conservation of fermion numbers. This kind of assumption is unjustified and to my opinion is misuse of the attribute "non-perturbative".

The basic vision about lepto-genesis followed by baryo-genesis is however very attractive. This even more so because right-handed neutrino is in a completely unique role in TGD Universe. The obvious question therefore is whether this vision could make sense also in TGD framework. It would be wonderful if cosmic strings - infinitely thin Kähler magnetic flux tubes carrying magnetic monopole field, which later develop finite sized and expanding M^4 projection - carrying only right-handed neutrinos were the fundamental objects from which matter would have emerged in a manner analogous to the decay of vacuum expectations of instanton fields [K5]. Even better, Kähler magnetic energy has interpretation as dark energy and magnetic tension gives rise to the negative "pressure" inducing accelerated expansion of the Universe.

The basic question is whether B and L are conserved separately or not. In TGD Universe one can consider two options depending on the answer to this question. For option I - the "official" version of TGD - quarks and leptons correspond to opposite 8-D chiralities of the induced spinor fields and B and L are conserved separately. For option II [K1] only leptonic spinor fields would be fundamental, and the idea is that quarks could be fractionally charged leptons. This option could lead to genuine baryo-genesis, and in the simplest model baryons would be generated from 3-leptons as 3-sheeted structures for which fractionization of color hyper-charge occurs. Leptonic imbedding space spinors moving in triality zero color partial waves would be replaced with triality ± 1 partial waves assigned with quarks. Whether this replacement is on a mathematically sound basis, is far from obvious since induced spinor fields at space-time level would couple to induced spinor fields with leptonic couplings.

In any case, one can check whether leptogenesis, baryogenesis, and matter antimatter asymmetry are possible for either of both of these options. It turns out that for both option I and II one can construct simple model in terms for the generation of quarks from leptons via emission of lepto-quarks analogous to gauge bosons but differing from their counterparts in GUTs. Option II allows also genuine baryogenesis from leptons. The conclusion is that the "official" version of TGD predicting separate conservation of B and L allows an elegant vision about the generation of matter from cosmic strings containing only right-handed neutrinos in the initial states.

2 Background

A brief summary about conditions for the generation of matter-antimatter asymmetry and some of existing theories explaining it is in order.

2.1 Basic conditions for the generation of matter-antimatter asymmetry by baryon number generating interaction

The basic conditions for the generation of matter-antimatter asymmetry by baryon number generating interaction [B1] were deduced by Saharov and are following.

1. Baryon number non-conservation.
2. C breaking and CP breaking. Matter-antimatter asymmetry requires these symmetry breakings.
3. Thermal non-equilibrium which naturally corresponds to a phase transition. In a typical cosmological situation the reactions responsible for preserving thermal equilibrium become slower that the rate for the cosmological expansion so that the particles participating the reactions decouple from each other and from thermal equilibrium. Otherwise these reactions destroy matter-antimatter asymmetry.

Also scenarios in which baryon number and lepton number are conserved are possible - TGD in its standard form allows one such option [K5]. The basic idea is that the universe decomposes into regions dominated by matter or antimatter. If slight matter-antimatter asymmetries - necessarily of opposite sign - are generated in region and its environment, the annihilation of particles and antiparticles leads to a situation in which there is only matter or antimatter present in both regions. If cosmic strings correspond are carriers of dark energy decaying to dark matter, they correspond naturally to the regions, where the asymmetry is generated. These cosmic strings could correspond "big" cosmic strings (magnetic flux tubes) going through large voids or the strings containing galaxies like pearls in necklace along them [K2] [L1]. Cosmic strings would serve as seats of antimatter whereas the surrounding regions would contain matter. What is lacking is a more detailed view about how cosmic strings burn to ordinary and dark matter and the identification of an exact mechanism for the generation of matter-antimatter asymmetry.

2.2 Generation of matter-antimatter asymmetry in GUTs and standard model

Most of models for the generation of matter anti-matter asymmetry rely on GUT philosophy and give up the assumption about separate conservation of B and L so that these these theories are also theories of baryo-genesis (for the theories of baryo-genesis see the article by Riotto [B10]). For GUTs the non-conservation is present at the level of action but there is also a proposal that standard model could accommodate the non-conservation non-perturbatively.

1. In a typical model B and L are not conserved separately. Only B-L is conserved (the convention is that proton has B=1, and electron L=1). B and L are defined as vectorial fermion numbers. Axial B and L are not conserved for massive fermions and Higgs mechanism leads to the massivation of a theory which is originally massless.

2. In GUTs one arranges quarks and leptons of given generation into same multiplet. This implies that B and L are not conserved separately whereas B-L is. The exchanges of lepto-quarks (gauge bosons) assumed to have mass of order 10^{-4} Planck masses (of order CP_2 mass) induce proton decay. No proton decays have been observed yet and this has led to a fine-tuning of the parameters of these theories to avoid too fast proton decay.

Some theoreticians believe that even standard model could allow to understand baryo-genesis and generation of matter-antimatter asymmetry. Instanton [B3] and sphaleron [B4] (see also the introductory article about sphalerons [B8] and conference slides [B9] about instantons/sphalerons and possible new physics within standard model)are the key notions of this approach. Perturbative approach to standard model predicts that both vectorial and axial quark and lepton numbers are separately conserved for massless fermions. The non-conservation of B and L is claimed to have a non-perturbative origin. The picture is roughly following.

1. Axial fermion numbers are not conserved for massive fermions even when the mass results from Higgs mechanism. Non-conservation is due to the fact that axial gauge symmetries are not genuine symmetries quantum mechanically because the integration measure for the path integral is not invariant under the axial gauge symmetries for which left and right handed fermions have opposite gauge charges.

2. By using refined topological arguments one can express the divergence $D_\mu A^\mu$ for the axial fermion current in terms of so called instanton density for the gauge field [B2]. Each fermion family gives a similar contribution to the divergence. One can calculate the changes of axial fermion numbers for an instanton connecting two states as the integral of instanton density reducing to the difference of so called Chern-Simons charges for final and initial field configurations.

   A numerical study of the situation using lattice gauge theories is possible [B6] and provides information about rates for the appearance of instantons. Axial B-L is still conserved because the divergence of axial current is same for all fermions. Anomaly argument does not however force the non-conservation vectorial B and L (briefly B and L) and perturbatively they are conserved: here the weakness of the standard model approach obviously lies.

3. As noticed, the notion of instantons is crucial for the approach. Instantons are solutions of pure YM field equations (without Higgs field) in 4-D Euclidian 4-sphere S^4 or Euclidian space

E^4: the Wick rotation to M^4 is of course mathematically and physically questionable step. Instantons connected two field configuration characterized by different Chern-Simons charges. The change of the Chern-Simons charge is integer valued. One can say that instantons transform two topologically non-equivalent vacua to each other. The proposed interpretation is that instanton tranforms incoming Dirac sea so that filled vacancy representing fermion with definite handedness becomes superposition of a hole and filled vacancy (fermions of opposite handedness). This would lead to the non-conservation of axial fermion numbers. It is important to stress again that the fermion numbers are axial - not vectorial- and that fermion number non-conservation does not follow from the presence of instantons alone.

4. The notion of sphalerons is a related concept. Sphalerons are static but unstable solutions of YM equations in Euclidian space E^4 in presence of Higgs field and are interpreted as a signature for the phase transition leading to generation of baryons from leptons. Since in Euclidian metric time and space do not differ in any manner, one can interpret one of the spatial directions as time direction so that the situation becomes dynamical. Since there is a change of the sign of the Higgs vacuum expectation between diametrically opposite points of sphere S^3 at infinity, there is also a change of Higgs vacuum expectation in time direction. With a sufficient amount of good will one can say that sphaleron connects to in-equivalent local Higgs vacua. Sphaleron is hoped to give a simplified description of the situation, which might have something to do with reality.

5. The vision about non-perturbative breaking of baryon conservation has inspired models for the generation of matter-antimatter asymmetry and for how originally purely leptonic state generates baryons.

These models can be however criticized for sloppy mathematics.

1. The additional assumption that the change of the axial fermion number equals to the change of the vectorial fermion number is highly questionable and actually forces non-conservation of B and L by hand. To me this assumption looks like a misuse of the attribute "non-perturbative". This assumption can hold true only if one assumes that the fermionic handedness correlates with the sign of ΔQ_{C-S}. The instanton region would contain only left or right handed fermions depending on the sign of the integer characterizing instanton.

2. It is difficult to imagine what the non-conservation of (vectorial) B and L could mean in terms of particle reactions. Why not to be happy with what good mathematics gives: B and L are conserved and only axial fermion numbers fail to do so? This is perfectly natural since axial fermion numbers are opposite for right and left handed fermions. If this is accepted, baryogenesis and related generation of matter-antimatter asymmetry are impossible in standard model framework.

3. Also the allowance of anomalies in path integral measure is questionable. For instance, in super string models the basic condition selecting the various candidates is that anomalies are absent.

The idea that leptons could transform to baryons in or without presence of instantons and at the same time generate matter-antimatter asymmetry is very attractive, and one one can wonder whether one could find a more coherent theoretical framework allowing this. The most ambitious models based on a small modification of it assume the existence of inert right-handed neutrinos (for which there is some cosmological support). They would have been the only particles present during the primordial phase and would have have generated leptons, which in turn have generated baryons by instantons. This idea is especially interesting from TGD point of view since right-handed neutrinos are in completely exceptional role in TGD Universe and the phase consisting of them possesses 4-D generalization of conformal SUSY (much large symmetry algebra than ordinary super-conformal algebra of M^4) so that the generation of matter from right handed neutrinos would have interpretation as breaking of this gigantic super-conformal symmetry.

3 Could TGD allow matter-antimatter asymmetry and baryo-genesis?

What makes the idea about non-conservation of B attractive is that TGD allows two variants.

1. For Option I quarks and leptons correspond to different chiralities of H spinors. Chirality is now not M^4 chirality (handedness) but 8-D H-chirality. B and L are separately conserved and proton is stable against decays predicted by GUTs.

   A possible but rather weak objection is following. The naive expectation is that various bosons come in two varieties. Vector bosons in 8-D sense would couple to 8-D vector currents and thus have same coupling to both quarks and leptons. Axial bosons in 8-D sense would couple to 8-D axial currents and have opposite couplings to quarks and leptons. Axial and vectorial bosons can of course mix but one would expect more bosons than observed (W bosons are vectorial in 8-D sense, photon and Z^0 couple are mixtures of axial and vector bosons, and gluons in TGD framework couple vectorially (also leptons are predicted to have colored excitations).

2. For Option II only leptons appear as fundamental fermions. Leptons instead of quarks are favored by the supersymmetry (actually super-conformal symmetry) generated by right-handed neutrinos. In fractional quantum Hall effect (FQHE) charge fractionization takes place and this inspires the question whether quarks inside hadrons could be leptons with fractional charge. I considered this alternative already around 2005 as a side product of work with hyper-finite factors of type II_1 [K1].

   Charge fractionization would result from the replacement $Q_L \rightarrow Q_L - 1/3$ for antileptons. Lepton number would the only conserved quantity and quarks and baryons could result by a phase transition in which leptons would somehow transform to quarks or to baryons.

   This raises several questions. What charge fractionization means? What lepto-quarks could be? What is this phase transition?

3.1 Could the option assuming only leptonic spinors make sense?

The stability of proton supports Option I but since only lower bounds for proton lifetime can be deduced experimentally, one must be ready to consider also Option II.

1. One cannot deny the attractiveness of the idea that quarks could be fractionally charged variants of leptons. For this option the process leading to the generation of baryons would not break any conservation laws and the mathematically highly questionable anomalous path integral would not be needed. In fact, path integral over gauge fields is replaced with functional integral over 3-surfaces in TGD framework.

2. Right-handed neutrino behaves like inert neutrino and in TGD ν_R has a unique role. The reason is that the conservation of electric charge forces to assume that all fermions except purely right-handed neutrino are localized at 2-D surfaces, "string world sheets". Pure right-handed neutrino is delocalized at entire space-time sheets - which could be identifiable magnetic flux tubes assignable to elementary particles. ν_R can give rise to a SUSY, which is however not the $\mathcal{N} = 1$ SUSY considered usually - almost excluded at LHC at TeV energy scale. The reason is that 8-D spinors cannot be Majorana spinors [B5]. Right-handed neutrino obeys also maximal super-conformal symmetry extending 2-D conformal symmetry to $D = 4$ [K7] so that the generation of matter could be seen as a symmetry breaking.

3. One can indeed imagine a scenario in which right handed neutrinos mix with left-handed neutrinos localized at string world sheets. The weak interactions of left handed neutrinos (or actually mixtures of right and left handed neutrinos) would generate other leptons. Leptonic phase could in turn generate fractionally charged quarks (or baryons) and hadronization would lead to generation of baryons and other hadrons.

   This vision can be coupled with the earlier proposal for how matter-antimatter asymmetry is generated. Right handed neutrinos could reside at magnetic flux tubes representing cosmic strings and the process leading to generation of leptons and quarks would take place here.

3.2 What it could be to be a fractionally charged lepton?

For option I quark-like and leptonic spinors appear at both space-time level and imbedding space level.

1. At space-time level one has second quantized induced spinor fields satisfying modified Dirac equation. The condition that modes have well-defined electromagnetic charge together with the fact that classical W fields are present and mix different em charges implies that this condition can be satisfied only if the induced spinor fields are localized at 2-D surfaces - string world sheets. Right-handed neutrino is an exception and delocalized into entire space-time sheet. The functional integral over preferred extremals gives rise to a perturbative expansion in terms of fermionic propagators when one expresses the spinor modes as functionals of space-time sheet of preferred extremal [K7].

2. Imbedding space spinors identified as leptonic and quark spinors differ in one aspect only. Their coupling to CP_2 Kähler gauge potentials is $n = -1$ for quarks and $n = 3$ for leptons. Imbedding space spinors can be assigned to the center of mass degrees of partonic 2-surfaces (or possibly the position of the tip of CD associated with fermion). Spinor modes represent the ground states for the representations of the symplectic algebra of $\Delta M^4_\pm \times CP_2$ and also for the representations of Kac-Moody algebra associated with isometries and deforming on the light-like orbits of partonic 2-surfaces at which the signature of the induced metric changes from Minkowskian to Euclidian.

   For leptons the spinor harmonics correspond to triality zero ($t = 0$) color partial waves in CP_2. For quarks the spinor harmonics correspond to $t = \pm 1$ color partial waves. These modes do not correspond directly to the physical quarks and leptons. States with correct correlation between electro-weak and color quantum numbers are obtained by allowing the action of the colored generators of the symplectic algebra on the physical states. The state construction is represented in [K3].

At the space-time level, where the fundamental spinorial dynamics takes place, the coupling of fermions to the Kähler gauge potential must be unique. If only single fermionic chirality is present, it must be either $n = 3$ or $n = -1$ and $n = 3$ is favored by the possible SUSY generated by right-handed neutrino.

What about imbedding space level? How could the above picture of option I change if one assumes that only leptonic spinors are present at the space-time level?

1. For Option I it is natural to assume that the induced space-time spinors correspond to imbedding space spinors with the same chirality and same value of n. Could one loosen this correspondence? Could imbedding space spinors, which are not second quantized, and are assigned to cm degrees of freedom, be associated with imbedding space spinor having both $n = -1$ and $n = 3$ for fermions.

   (a) Are these two state basis orthogonal? Certainly not as CP_2 spinors. As vacua for WCW spinor fields this could be the case if there is some topological distinction between the 3-surfaces assignable with these state basis. The idea about fractionization of charges (color hyper-charge) suggests that for quark states the space-time surface are 3-valued maps of CP_2 to M^4 analogous to Riemann surface of $z^{1/3}$ so that a color hyper-charge rotation of 2π in CP_2 (say at homologically non-trivial geodesic sphere of CP_2 defining coordinates of the partonic 2-surface) does not lead to the original point and only the rotation by 6π does this. This would be an analog for spin fractionization. This could justify the use of quark spinor harmonics for the imbedding space spinors.

   (b) Could the two state basis be non-orthogonal and provide alternative state basis? Many-quark states can correspond to many-lepton states only if the differences $N_q - N_{\overline{q}}$ of numbers of quarks and antiquarks is a multiple of 3 so that the many-fermion state has triality $t = 0$. Color confinement is consistent with this condition and implies it. This option does not look attractive and will not be assumed in the sequel.

2. A serious problem is caused by the $n = -1$ coupling of the induced leptonic spinor fields. Internal consistency could quite well force the imbedding space spinors to have the same coupling.

3.3 How leptons could transform directly to baryons for Option II?

If the direct transformation of leptons to quarks identified as fractionally charged leptons is possible, it must be non-perturbative in the sense that it involves several leptons and quarks simultaneously in order to satisfy the conservation of color and em charge. Since the resulting many quark state must have a vanishing triality, the number of quarks and therefore also leptons must be a multiple of 3. The simplest situation corresponds to a transformation of 3 leptons to 3 quarks forming a color singlet - perhaps identifiable as baryon.

The geometric view about color spin fractionization suggests that three leptonic space-time sheets defining 1-fold coverings of CP_2 fuse to from a 3-fold covering of CP_2 (so that M^4 coordinates are 3-valued as functions of CP_2 coordinates). The proposed explanation for the effective hierarchy of Planck constants $\hbar_{eff} = n\hbar$ is in terms of n-furcations of 3-surface: the recent case might correspond $n = 3$. Each sheet of the covering would carry lepton number 1. These 3-quark states would be only a special case of more general states containing $n = 1, 2$ or 3 quarks at the 3-sheeted structure.

In the process transforming 3 anti-leptons to baryon - say proton - one unit of em charge must be carried away and W^+ boson could do this. In the reverse process proton would decay to 3 leptons and W^- boson. $W^\pm$ boson must be virtual and absorbed by another particle so that weak interactions are also involved. The probability for this process must be very low, probably much lower than beta decay rate (I do not know whether possible decays of baryon to leptons and W boson have been studied). This means that the coupling for the fusion vertex must be very small.

If this picture is correct, the key non-perturbative element would be a phase transition changing the effective value of $\hbar$ to $3\hbar$. These phase transitions for large values of n are essential in the TGD inspired model of living matter. There is also a proposal that gravitons possess a very large value of $\hbar$ and decay to bursts of ordinary gravitons. This could explain the failure to observe gravitational waves [K4]. This mechanism forces to consider a geometric description of proton as a 3-sheeted structure presumably assignable to the magnetic body of proton.

It is too early to say whether this picture is consistent with the existing view about hadrons in which quarks space-time sheets are assumed to be connected by Kähler-magnetically charged color flux tubes. Also the question whether quarks understood as 3-sheeted structures containing only single quark could be allowed remains open. In any case, many-quark states must have triality zero so that quark number must be a multiple of 3.

3.4 Generation of matter-antimatter asymmetry without breaking the separate conservation of B and L

Cosmic strings dominate the TGD inspired cosmology [K6] during the primordial period after which a phase transition leading to radiation dominated cosmology takes place. The transformation of neutrinos to leptons inside cosmic strings which in turn decays to quarks and lepto-quarks which partially leak out from the system is an attractive mechanism for the generation of matter-antimatter asymmetry.

The mechanism to be discussed conserves B and L and thus works for option I. It works also for option II, if it makes sense to speak about quarks rather than only color singlet bound states of quarks formed as 3-sheeted structures with quark number 3, and treat quarks as independent objects. Many-quark states must however have quark number coming as a multiple of 3.

What can one say about the transformation of leptons to quarks by lepto-quark emission?

1. The charges of lepton and corresponding quark are different but this not a problem if one assumes the existence of lepto-quarks identified as gauge boson like states with quark (lepton with fractional charge) and lepton at opposite wormhole throats. For option I there is no reason why leptoquarks could not exist.

2. The most general assumption is that all possible combinations of quarks and leptons are allowed. Lepto-quarks qL and $\overline{q}\overline{L}$ have vanishing B-L for option I and vanishing L for option II: this makes them highly analogous to gauge bosons for option II. Lepto-quarks $q\overline{L}$ and $\overline{q}L$ have vanishing B+L for option I and have L=2 for option II. In the following only the option involving only qL and $\overline{q}\overline{L}$ is considered but the arguments generalize to the remaining cases trivially.

3. The transformation of antilepton to quark would take place by emission of lepto-quark $\overline{L}\overline{q}$ taking care of the conservation of various quantum numbers. The exchange of lepto-quarks is B and

L conserving process and cannot lead to a decay of proton. It however predicts a new and presumably very slow decay channel for the decay of proton-antiproton pair to leptons.

In the transformation $e^- \to \overline{u}$ a lepto-quark e^-u with charge $-1/3$ is emitted. In the transformation $e^- \to \overline{d}$ lepto-quark e^-d with charge $-4/3$ is emitted. More generally, $L \to \overline{q}$ proceeds via the emission of Lq type lepto-quark. Note that the lepton number of the lepto-quark vanishes for option II so that it represents an ordinary gauge boson with vanishing fermion number.

4. What happens to the emitted lepto-quarks? The lepto-quark can decay to $L + q$ so that the situation is the original one plus quark antiquark pair unless the lepto-quark has leaked outside the cosmic string. It the decay occurs inside cosmic strong, the process can continue and in principle single lepton or anti-lepton can generate a larger number of $q\overline{q}$ pairs. Kinematically these decays are not possible for ordinary on mass shell leptons but TGD allows the existence of scaled up copies of leptons, say leptons characterized by Mersenne prime M_{89} having mass scale about $2^{(127-89)/2}m_e \simeq 250$ GeV. These leptons could generate ordinary quarks through their decays.

5. This mechanism alone cannot generate matter-antimatter asymmetry. Suppose that the rates for the decays $\overline{L} \to q + \overline{Lq}$ are slightly lower than those for $L \to \overline{q} + qL$. A surplus of lepto-quarks Lq over $\overline{Lq}$ is generated. If there is a transfer of lepto-quarks Lq and their antiparticles from the interior of cosmic string to the environment and transfer rates are same, more Lq:s are transferred and their decays generate a net density of quark and lepton numbers in the environment. Inside cosmic string net density of opposite sign is generated by B and L conservation.

6. If the decay rate of lepto-quark is of order g^2M with M of order CP_2 mass, leakage is possible if the M^4 projection of the cosmic string is below $1/g^2M_{CP_2}$. Therefore the process could become active after the cosmic string dominated primordial period and could be associated with the phase transition from string dominated phase to radiation dominated phase during which space-time sheets corresponding to preferred extremals with large 4-D M^4 projection in the transversal scale of cosmic string emerge. Since the process conserves B and L separately, it could however take place also in much longer p-adic length scales.

   The masses of the lepto-quark could result from couplings to Higgs like bosons but the mass scale of the vacuum expectation value inside cosmic string corresponds to a rather small p-adic prime instead of M_{89} for weak interactions. Mersenne primes are the first guess for p-adic primes assignable to gauge bosons and $M_7 = 127$ is a reasonable guess for the p-adic prime during the transition to radiation dominated phases.

The conclusion is that lepto-quark mechanism works for both Option I and II and therefore Option II is not needed to understand generation of matter-antimatter asymmetry or even leptogenesis and baryogenesis. This does not of course mean that Option II would be necessarily excluded.

3.5 Generation of matter asymmetry accompanied with a genuine baryo-genesis for option II

One can also consider a generation of matter-antimatter asymmetry and baryo-genesis based on fusion of leptons to baryons by the proposed mechanism for the formation of baryons from anti-leptons at cosmic strings. If the rates for the fusion process are different for leptons and anti-leptons, a net density of baryon number is generated in environment.

Suppose that in the interior of cosmic string anti-leptons transform to baryons with a rate slightly higher that leptons to anti-baryons. As a consequence, the number densities of baryons and leptons become higher than those for anti-baryons and anti-leptons inside cosmic string. If the transfer rates for baryons and anti-baryons to environment are same, the outcome would be net density of baryon number in environment. The faster transfer of anti-leptons than leptons from environment to cosmic string induced by the larger density gradient would induce net density of lepton number in environment. As a consequence, oppossite net densities of B and L in environment and interior of string would be generated.

3.6 Could all matter be generated from right-handed neutrinos at magnetic flux tubes?

The idea about leptogenesis [B7] initiated form right-handed neutrinos and followed by baryogenesis [B10] is highly attractive. TGD leads to the vision that matter and dark matter has been generated from dark energy identified as Kähler magnetic energy for magnetic flux tubes which have evolved from cosmic strings by the gradual thickening of M^4 projection [K5] [L1]. I have not yet considered any detailed model for this process.

Right-handed neutrino has a unique role in TGD framework [K7] and an attractive idea is that during primordial phase - and perhaps even at magnetic flux tubes evolved from them - the physics started from something extremely simple and symmetric: only magnetic flux tubes containing right-handed neutrinos. This situation would correspond to a 4-D extension of super-conformal symmetry [K7], and the emergence of string world sheets would reduce this 4-D to super-conformal symmetry to ordinary 2-D one. Other fermions localized at string world sheets would have emerged only after the mixing of right handed neutrino to mixtures of left and right handed neutrinos localized at string worlds sheets. Neutrinos in turn would decay to charged leptons and W bosons by weak interactions. The decay $L \rightarrow \overline{q} + Lq$ in turn would have generated baryons and matter-antimatter asymmetry for both options. For option II also the direct fusion of leptons to baryons or more general color singlet quark triplets could have occurred.

One should construct a model for the mixing of right- and left-handed neutrinos.

1. Mixing should reduce to fermionic propagation and be dictated by the dynamics of the modified Dirac operator alone. The mixing amplitude would be obtained by calculating a transition amplitude between ν_R and ν_L located at partonic 2-surfaces at opposite ends of CD. This requires integration over CD inducing perturbation theory using fermionic propagator defined by the modified Dirac action with coupling to WCW degrees of freedom via the gauge coupling to induced CP_2 spinor connection. ν_R propagates 4-dimensionally and the other leptonic modes only 2-dimensionally. Also the mixing of lepton generations induced by the mixing of the topologies of fermion number carrying partonic 2-surfaces must be taken into account.

2. The overall parametrization at the QFT limit would be in terms of a generalization of CKM matrix, which is known to be non-trivial and force also neutrino massivation in turn forcing mixing of the right- and left-handed neutrinos.

3.7 Conclusions

The cautious conclusion is that option I - that is the "official" version of TGD identifying quarks and leptons and two chiralities of imbedding space spinors - leads to an elegant model for leptogenesis, baryogenesis, and generation of matter antimatter asymmetry and at the same time to a more detailed model for how the Kähler magnetic energy of magnetic flux tubes transforms to matter and dark matter. One cannot however exclude option II involving only leptons whose anyonic states would give rise to baryons.

Theoretical Physics

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