About parity violation in hadron physics

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April 22, 2017

Abstract

Strong interactions involve small CP violation revealing in the physics of neutral kaon and B meson. An interesting question is whether CP violation and also P violation could be seen also in hadronic reactions. QCD allows strong CP violation due to instantons. No strong CP breaking is observed, and Peccei-Quinn mechanism involving axion as a new but not yet detected particle is hoped to save the situation.

The de-confinement phase transition is believed to occur in heavy nucleus collisions and be accompanied by a phase transition in which chiral symmetry is restored. It has been conjectured that this phase transition involves large P violation assignable to so called chiral magnetic effect (CME) involving separation of charge along the axis of magnetic field generated in collision, chiral separation effect (CSE), and chiral magnetic wave (CMW). There is some evidence for CME and CSE in heavy nucleus collisions at RHIC and LHC. There is however also evidence for CME in proton-nucleus collisions, where it should not occur.

In TGD instantons and strong CP violation are absent at fundamental level. The twistor lift of TGD however predicts weak CP, T, and P violations in all scales and it is tempting to model matter-anti-matter asymmetry, the generation of preferred arrow of time, and parity breaking suggested by CBM anomalies in terms of these violations. The reason for the violation is the analog of self-dual covariantly constant Kähler form $J(CD)$ for causal diamonds $CD \subset M^4$ defining parallel constant electric and magnetic fields. Lorentz invariance is not lost since one has moduli space containing Lorentz boosts of CD and $J(CD)$. $J(CD)$ induced to the space-time surface gives rise to a new $U(1)$ gauge field coupling to fermion number. Correct order of magnitude for the violation for K and B mesons is predicted under natural assumptions. In this article the possible TGD counterparts of CME, CSE, and CMW are considered: the motivation is the presence of parallel E and B essential for CME.

Contents

1 Introduction

Strong interactions involve small CP violation revealing itself as small differences in the properties of neutral kaon and its anti-kaon. An interesting question is whether CP violation and also P violation could be seen also in hadronic reactions.

In QCD framework the de-confinement phase transition from a phase in which quarks are confined inside hadrons to quark-gluon plasma consisting of free quarks and gluons is believed to occur. This transition would be also accompanied by a phase transition in which chiral symmetry is restored. The breaking of chiral symmetry is due to the mass of quarks: one cannot assign definite chirality to massive quarks. When the massive quarks become massless or at least effectively massless, the chiral symmetry should be restored. What really happens in this transition is however not well-understood.

1.1 Effects associated with de-confinement phase transition

There are several effects associated with the de-confinement phase transition.

1. The so called chiral magnetic effect (CME) in which Poles receive opposite charges (Equator is defined by scattering plane) is proposed to be associated with the transition and would involve also P violation.

2. One also expects chiral separation effect (CSE) meaning separation of quarks and antiquarks having opposite chiralites along the magnetic axis. There are some experimental indications for CME and CSE.

3. Chiral magnetic wave (CMW) appearing in quark-gluon plasma is a combination of CME and CSE. In CWM Poles get a positive charge increment and Equator a negative charge increment. Chiral magnetic wave (CMW) is a combination of CME and CSE associated with the chirally symmetric phase. CMW involves transformation of electric dipole to quadrupole. I must admit that I do not really understand the mechanism giving rise to CMW.

To get an intuitive view about CME consider what happens in HN-HN collision, which is not head-on.

1. One can speak of scattering plane and the system possesses angular momentum transformed to a rotational angular momentum of quarks as the colliding nuclei fuse together. There is large positive charge density involved. Therefore rotating quarks create a magnetic field parallel to the rotation axis. The positive charge density creates radial electric field parallel to the magnetic field due to the quarks swirling in the reaction plane. Quarks and antiquarks flow to to opposite directions in the electric field and charge separation takes place.

2. The prediction would be that oppositely charged pions tend to flow to opposite directions orthogonal to the scattering plane. CME would occur near criticality for the formation of quark-gluon plasma and would be quantum critical phenomenon involving macroscopic quantum coherence. The experimental signature is a surplus of positive pions over negative pions in either hemisphere defined by scattering plane and surplus of negative pions over positive pions in the opposite hemisphere. CME means also P breaking.

3. CME should appear in heavy nucleus (HN-HN-) collisions and there are indications that something like this indeed takes place. CME should not occur in proton-nucleus collisions since the proton now goes through the nucleus and most collisions are central and there is no angular momentum so that no magnetic field is generated.

   Therefore the recent discovery of evidence for the charge separation also in proton-Pb collisions challenges CME (see `http://tinyurl.com/lt5reno` and `http://tinyurl.com/kkx4x2y`) and motivates the attempt to understand whether CME and related effects have analogs in TGD.

1.2 Timeline for CME

It is appropriate to begin with a brief time-line about CME.

1. 2005: Dimitry Kharzeev proposed that de-confinement transition involves chiral magnetic effect (CME). For a brief Wikipedia summary of CME see `http://tinyurl.com/lt93ve4`). The article *Parity violation in hot QCD: why it can happen, and how to look for it* [C3] (see `http://tinyurl.com/lwkl7cu`) considers a theoretical model based on QCD.

2. 2009: STAR collaboration found the first evidence for CME [C2].

3. 2015: STAR collaboration working at RHIC found evidence for the emerged evidence for CMW in heavy nucleus collisions. The popular article S*cientists see ripples of a particle-separating wave in primordial plasma* (see `http://tinyurl.com/mus4xz9`) might help to get an idea about what was found. The technical article *Observation of charge asymmetry dependence of pion elliptic flow and the possible chiral magnetic wave in heavy-ion collisions* [C3] can be found at `http://tinyurl.com/lwkl7cu`.

4. 2016: Evidence for CME is reported also in condensed matter physics (see *Chiral magnetic effect generates quantum current* at `http://tinyurl.com/mmet3h4`). Quarks are however replaced with quasiparticles which can be positively and negatively charged. What was found that when material called zirconium pentatellurite is placed in parallel electric and magnetic fields, it responds with an imbalance in the number of right and left handed quasiparticles - a chiral imbalance pushing opposite charged particles in opposite directions and creating an electric current. The current would not dissipate because it is topological. This suggests a new kind of super-conductivity, which does not involve spontaneous symmetry breaking.

5. 2017: Evidence for CME was discovered in proton-nucleus collisions. This was not expected. Rice physicists Wei Li and Zhoudunming (Kong) Tu proposed a new approach for studying CME and found that it is present also for proton-nucleon collision. This does not conform with the theoretical expectations. See the popular article *Proton-nuclei smashups yield clues about 'quark gluon plasma'* at `http://tinyurl.com/lt5reno`.

   The article *Observation of Charge-Dependent Azimuthal Correlations in p-Pb Collisions and Its Implication for the Search for the Chiral Magnetic Effect* [C1] by V. Khachatryan et al gives a representation for specialists (see `http://tinyurl.com/kkx4x2y`). I glue the abstract of the article here.

   Charge-dependent azimuthal particle correlations with respect to the second-order event plane in p-Pb and Pb-Pb collisions at a nucleon-nucleon center-of-mass energy of 5.02 TeV have been studied with the CMS experiment at the LHC. The measurement is performed with a three-particle correlation technique, using two particles with the same or opposite charge within the pseudo-rapidity range $|\eta| < 2.4$*, and a third particle measured in the hadron forward calorimeters (*$4.4 < |\eta| < 5$*). The observed differences between the same and opposite sign correlations, as functions of multiplicity and* η *gap between the two charged particles, are of similar magnitude in p-Pb and Pb-Pb collisions at the same multiplicities. These results pose a challenge for the interpretation of charge-dependent azimuthal correlations in heavy ion collisions in terms of the chiral magnetic effect.*

CME is not directly observed for p-Pb collisions but the three-particle correlations as functions of particle multiplicity and η gap for two charged particles are deduced. The differences between the same and opposite sign correlations interpreted as signatures of CME are found to be of similar magnitude in p-Pb and Pb-Pb collisions. Note that pseudorapidity $\eta = -log((|p|+p_L)/(|p|-p_L))$ (see `http://tinyurl.com/lg3goeh`) characterizes the angle θ between beam direction and particle momentum. η changes sign when longitudinal momentum p_L changes sign.

2 About CME and related effects in QCD framework

In the sequel I review briefly my non-specialist undestanding about strong CP breaking and CME and related effects.

2.1 Strong CP problem

QCD in principle allows strong CP violation. The origin of CP violation is the possibility of multi-instanton solutions in QCD. Instantons are either self-dual or anti-self-dual exact solutions of Yang-Mills equations. Instantons break the conservation of axial currents expected to hold true in massless theories. The divergence of the axial current is proportional to the instanton density, which reduces to a total divergence, whose space-time integral is however non-vanishing and integer valued and gives the change of total axial charge.

Atyiah-Singer index theorem (see `http://tinyurl.com/k6daqco`) implies that the change of axial charge is identifiable as the difference for the numbers of fermions with right-handed and left handed chirality. The fermions are assumed to be massless, and the argument is somewhat questionable when fermions are massive.

The vacuum can be written as a superposition of ground states with varying number of instantons. By simple argument one can conclude that the ground state with instanton number n has weight $exp(in\theta)$, where θ is an angle parameter about which QCD does not tell anything. One can describe the situation in a simple manner by adding to the QCD YM action, whose exponential defines the theory, an instanton term, which is θ times the integer valued instanton charge. In principle one must perform perturbation theory in instanton background for each value of n and sum up the results. The instanton term modifies the scattering amplitudes, and the evaluation of these non-perturbative effects is difficult mathematically since in instanton background one loses momentum conservation for the basic vertices and one must perform path integral over different instanton configurations.

Also the modification of Dirac action is possible. In this case one has second angle - θ' - replacing mass m with $exp(i\gamma_5\theta') \times m$ in massive Dirac action action. In massless case the modification is trivial. The factor $exp(i\gamma_5\theta')$ can be however absorbed to the definition of gamma matrices. The modification of YM action is non-trivial even in massless case. If at least one quark is massless, θ is claimed to become unobservable for a reason that I failed to understand. Unfortunately, there are no massless quarks.

The big problem of QCD is that strong CP violation have not been observed (see `http://tinyurl.com/phju9lj`): one has $\theta < 3 \times 10^{-13}$ from the electric dipole moment of neutron. Peccei-Quinn axion (see `http://tinyurl.com/q9p56ke` and `http://tinyurl.com/k2xlh6d`) has been proposed as a solution of the problem. θ is made a dynamical field - axion - coupling to the instanton density linearly. Several axion candidates have been proposed and excluded. Axion could be also very weakly interacting particle and thus dark matter: the mass scale should be between 50-1500 μeV from various constraints.

Remark: Pseudoscalar-instanton coupling appears also in other anomaly considerations. For instance, coupling of neutral pion to electromagnetic counterpart of instanton term appears in the model predicting the pion life-time from partial conservation of axial current hypothesis (PCAC).

2.2 Kharzeev's model for CME

For ordinary QCD vacuum the parameter θ characterizing strong CP breaking is essentially zero. The proposal of Kharzeev [C3] (see `http://tinyurl.com/lwkl7cu`) is that in de-confinement phase transition a metastable regions θ domains - with position dependent θ are formed and they induce separation of quark chiralities - chiral separation effect (CSE) - and charge separation by CME. The interpretation of $\theta(x)$ is left open. Could it correspond to some variant of Peccei-Quinn axion field?

For given value of instanton number n a chiral asymmetry is generated and instanton number tells the change of the chiral flips for fermions. Massless quark and antiquark have opposite chiralities and the transition can also generate asymmetry as asymmetric production of quarks and antiquarks. The model predicts fluctuations since the sign and value of n can vary so that the effect is not easily restable.

A net chirality generated by instanton defining the metastable state in question. The net chirality could be realized either by the spin flips for quarks and antiquarks in magnetic field and by opposite directions of motion for quarks and antiquarks. Kharzeev assumes that a mass field $m \times exp(i\theta(x))$ scattering quarks is present. I failed to understand why one does not have $m \times exp(i\gamma_5\theta)$ as in the original representation of the axial anomaly.

The definition of chirality for massive quarks is problematic since spinors are not eigenstates of γ_5. The idea is to assume that spin direction in some fixed frame defining spin quantization axis defines chirality: this is intuitively plausible if the quarks/antiquarks move parallel/antiparallel to this axis. In non-head-on collision the magnetic field generated by the incoming heavy nuclei defines the preferred spin quantization axis. For p-HN head on collison this is not the case.

3 CP breaking in TGD Universe

Chiral magnetic effect (CME) is very interesting effect from TGD point of view since it involves breaking of CP and P possibly relating to the breaking of CP in hadron physics.

3.1 Kähler form of M^4

Twistor lift of TGD forces to assume the analog of self-dual covariantly constant Kähler form $J(M^4)$ for Minkowski space M^4 contributing to the Kähler form (or rather for causal diamond of M^4). $J(CD)$ corresponds to the presence of parallel constant $U(1)$ electric and magnetic fields coupling to fermion number. This is the just prerequisite for charge separation in CME!

1. Does the M^4 Kähler form contribute to the $U(1)$ of em field or does it represent a classical field of its own? $J(CD)$ couples to fermion number. In particular, it has also a coupling to right-handed neutrinos! Since neutrinos are em neutral this allows only the interpretation as an additional $U(1)$ field coupling to fermion number. Right-handed neutrinos are known to be extremely weakly interacting, which demands that the preferred extremals are such that the electric component of $J(CD)$ is small. Alternatively, the corresponding gauge coupling is very small: a reasonable guess inspired by the size of CP breaking of K mesons is that the coupling is some power of l_P^2/R^2 [L3].

2. In TGD the induced $J(CD)$ field created by the density of nuclear baryonic number replaces the electromagnetic field created by a constant charge density in HN-HN collisions. For the canonical imbedding of M^4 the induced $J(CD)$ would be self-dual and charge separation would be forced by $J(CD)$ in the direction defined by the $M^4 = M^2 \times E^2$ decomposition defined by $J(CD)$. There is strong temptation to think that matter-antimatter asymmetry is basically due to CME along $U(1)$ magnetic flux tubes connecting the regions containing matter and antimatter.

3. $J(CD)$ couples to fermion number defined as $F = B + L$. Since leptons and and baryons have opposite fermion numbers, $U(1)$ flux tubes as counterparts of field lines can connect baryons and leptons. Note that atoms have vanishing $U(1)$ charge F.

4. What is important that space-time surfaces themselves satisfy the analogs of field equations for point like particles in $U(1)$ field. They are obtained by replacing point like particles 3-D objects. This is one of the key predictions of twistor lift of TGD predicting that 4-D action contains a volume term besides Kähler action. The volume term alone would give the analog of geodesic motion and Kähler action adds coupling to $U(1)$ force. Asymptotic state are minimal surfaces analogous to geodesics having vanishing $U(1)$ force. $U(1)$ force appears only in transient situations like particle scattering events. The first interpretation of volume term would be in terms of cosmological constant. It however seems that the more plausible interpretation of the entire action is in terms of cosmological constant.

5. Atomic nuclei have baryon number equal the sum $B = Z + N$ of proton and neutron numbers and neutral atoms have $B = N$. Only hydrogen atom would be also $U(1)$ neutral. The dramatic prediction of $U(1)$ force would be that neutrinos need not be so weakly interacting particles as has been though. If the quanta of $U(1)$ force are not massive, a new long range force is in question. $U(1)$ quanta could of course become massive via $U(1)$ super-conductivity causing Meissner effect.

   Suppose that $U(1)$ force is long ranged. Could $B = N$ be neutralized by neutrinos? Could the cosmic background of neutrinos neutralize the $U(1)$ charge of matter? Could this occur even at the level of single atom or does one have plasma like state?

I have earlier considered Z^0 atoms but these are are excluded in the recent model of elementary particle in which weak isospin is screened by neutrinos in the scale of Compton length of particle. Interestingly, for Z^0 force neutrino Bohr radius would be of order $a_0 = \hbar/\alpha_Z m_\nu$ and for $m_\nu = .1$ eV it would be of 12 μm, which corresponds to cell length scale.

What about $U(1)$ force? Suppose α_1 is of order of $\alpha_1 = l_P/R = 2^{-12}$ (l_P is Planck length and R is CP_2 radius as the arguments related to cosmological constant [K8] and to the size scale of CP breaking [L3] suggest. The Bohr radius of the neutrino atom would be for $m_\nu = .1$ eV about $a_0 = .8$ mm. Ground state binding energy would be about $E_0 = \alpha_1^2 m_\nu/2$ giving $E_0 = .34 \times 10^{-8}$ eV: this is below the thermal energy of cosmic neutrinos estimate to be about 1.95×10^{-4} eV (see `http://tinyurl.com/ldu95o9`). Thus matter would be $U(1)$ plasma. $U(1)$ superconductor would be second option. If right-handed neutrinos generate $\mathcal{N} = 2$ SUSY then $U(1)$ charge would break this symmetry.

One could neutralize $U(1)$ charge in atomic scale using also electrons giving exotic ions. For $\alpha_1 = 2^{-12}$ Bohr radius would be something like cell membrane size scale $a_0 = 43$ nm. Note that the diameter would roughly $L(157) \simeq 8$ nm, $MG, 157 = (1 + i)^{157} - 1$ is one of the miraculous Gaussian Mersennes associated with $k = 151, 157, 163, 167$ in the range of biologically most important length scales between 10 nm and 2.5 μm. The resulting state would be negatively charged and one can ask whether the negative charges of DNA and cell could relate to the formation of $U(1)$ neutral states. Binding energy for would be around $E_0 = .03$ eV, which rather near to membrane potential. These exotic ions could be thermally stable for $Z \geq 2$ due to the presence of N^2 factor.

One can represent an objection against the assumption that only covariantly constant $J(CD)$ are allowed: one can imagine also spherically and cylindrically symmetric and Lorentz invariant $J(CD)$s. Consider the $U(1)$ Coulomb field of point charge.

1. Should one assign the $U(1)$ electric flux with radial flux tubes? One would assign to each flux tube M^4 Kähler form $J(CD)$ for which the directions of electric and magnetic fields are in the direction of the flux tube. Every flux tube would be accompanied by its own CD and $J(CD)$! A lot of CDs, which also overlap! Isn't this too complex? Also the simple minimal surface solutions serving as models for stellar objects are lost if only covariantly constant $J(CD)$s are allowed and can appear as approximations only.

   One should have a good explanation for why so much CDs are allowed. The proposed explanation is that CD represents the perceptive field of a conscious entity and the preferred directions of CD fix the rest system and spin quantization axis associated with it [L4]. CDs would represent the analog for the covering by open sets defining topological space or manifold. In TGD the notion of adelic/monadic manifold requires an analogous covering with CDs associated with the discrete set of points of space-time surface with the property that the coordinates belong to an extension of rationals [L2].

2. Or should one accept also non-covariantly constant self-dual $J(CD)$s with radial electric and magnetic fields necessarily having electric charge and magnetic monopole at the time-like line connecting the tips of CD? Self-dual $J(CD)$ with $J_{\theta\phi} \propto sin(\theta)$ and $J^{0r} = \epsilon 0r\theta\phi J_{\theta\phi}$ (note that$\epsilon 0r\theta\phi$ is permutation symbol divided by $1/\sqrt{g_4}$ having em charge and magnetic monopole charge at the line connecting the tips of CD would satisfy the conditions. Genuine monopole singularity is not an attractive idea. Lorentz invariant solution in Robertson-Walker coordinates (a, r, θ, ϕ) is completely analogous. Cylindrically symmetric variant would have fermion charge density along 2-D surface within CD M^2 and is unphysical.

Clearly, the first option suggesting deep connection between the notions of topological space and manifold, number theory, and consciousness is the more plausible one.

3.2 Strong CP problem disappears in TGD

Does strong CP problem appear in TGD framework? Can one have analogs of instanton solutions in TGD?

1. M^4 chirality is replaced in TGD with H-chirality with different chiralities corresponding to leptons and quarks. 8-D chiral invariance is exact in TGD and all particles are massless in 8-D sense: this makes possible for the twistorialization of TGD to overcome the problems of ordinary twistor approach cause by particle masses [K8, L3]. 8-D chiral invariance does not have axial anomaly.

2. One can talk about M^4-chirality but axial current conservation is broken already at the level of the action since particles are not massless in M^4 sense and induced gamma matrices, which are mixtures of M^4 and CP_2 gamma matrices lead to the breaking of chiral invariance: particle with definite H-chirality does not possess well-defined M^4 chirality - this serves as a space-time signature form M^4-massivation.

3. One can argue that since intantons are topological objects they can be present at the QFT limit of TGD only if they are present at the level of many-sheeted space-time. Instantons would has analogs the maps $M^4 \rightarrow CP_2$ with non-vanishing winding number (CP_2 itself is gravitational instanton). One can regard these surfaces also as multi-valued maps $CP_2 \rightarrow M^4$.

   Self-duality poses strong conditions on the induced metric and self duality seems implausible. Instantons should be also vacuum extremals with 4-D M^4 and CP_2 projections. This is not possible. Note however that CP_2 type extremals with light-like geodesic as M^4 projection and 4-D CP_2 projection are however possible [K1, K7]. There is no strong CP problem in TGD.

One can of course argue that $J(CD)$ is a potential problem for TGD since it can imply large CP violation for both quarks and leptons. Why the breaking is so small experimentally? I have already earlier considered this problem and made a quantitative estimate based on the observation that the CP breaking should be characterized by a power of G/R^2. If CP breaking is small, one can however wonder why the associated P breaking is visible in HN-HN and even p-HN collisions [L3]?

Could a large value of h_{eff} implying "macroscopic" quantum coherence amplify the CP violation by a factor N^2, where N is essentially the total baryon number of colliding nuclei? For canonically imbedded M^4 the induced $J(CD)$ is non-vanishing but the action and energy momentum tensor vanish by self-duality. If M^4 projection of space-time surface is lower than 4-D, also then the $J(CP)$ action vanishes.

3.3 Quantitative picture about CP breaking in TGD

One must specify the value of α_1 and the scaling factor transforming $J(CD)$ having dimension length squared as tensor square root of metric to dimensionless $U(1)$ gauge field $F = J(CD)/S$. This leads to a series of questions.

How to fix the scaling parameter S?

1. The scaling parameter relating $J(CD)$ and F is fixed by flux quantization implying that the flux of $J(CD)$ is the area of sphere S^2 for the twistor space $M^4 \times S^2$. The gauge field is obtained as $F = J/S$, where $S = 4\pi R^2(S^2)$ is the area of S^2.

2. Note that in Minkowski coordinates the length dimension is by convention shifted from the metric to linear Minkowski coordinates so that the magnetic field B_1 has dimension of inverse length squared and corresponds to $J(CD)/SL^2$, where L is naturally be taken to the size scale of CD defining the unit length in Minkowski coordinates. The $U(1)$ magnetic flux would the signed area using L^2 as a unit.

How $R(S^2)$ relates to Planck length l_P? l_P is either the radius $l_P = R$ of the twistor sphere S^2 of the twistor space $T = M^4 \times S^2$ or the circumference $l_P = 2\pi R(S^2)$ of the geodesic of S^2. Circumference is a more natural identification since it can be measured in Riemann geometry whereas the operational definition of the radius requires imbedding to Euclidian 3-space.

How can one fix the value of $U(1)$ coupling strength α_1? As a guideline one can use CP breaking in K and B meson systems and the parameter characterizing matter-antimatter symmetry.

1. The recent experimental estimate for so called Jarlskog parameter characterizing the CP breaking in kaon system is $J \simeq 3.0 \times 10^{-5}$. For B mesons CP breading is about 50 times larger than for kaons and it is clear that Jarlskog invariant does not distinguish between different meson so that it is better to talk about orders of magnitude only.

2. Matter-antimatter asymmetry is characterized by the number $r = n_B/n_\gamma \sim 10^{-10}$ telling the ratio of the baryon density after annihilation to the original density. There is about one baryon 10 billion photons of CMB left in the recent Universe.

Consider now the identification of α_1.

1. Since the action is obtained by dimensional reduction from the 6-D Kähler action, one could argue $\alpha_1 = \alpha_K$. This proposal leads to unphysical predictions in atomic physics since neutron-electron $U(1)$ interaction scales up binding energies dramatically.

   $U(1)$ part of action can be however regarded a small perturbation characterized by the parameter $\epsilon = R^2(S^2)/R^2(CP_2)$, the ratio of the areas of twistor spheres of $T(M^4)$ and $T(CP_2)$. One can however argue that since the relative magnitude of $U(1)$ term and ordinary Kähler action is given by ϵ, one has $\alpha_1 = \epsilon \times \alpha_K$ so that the coupling constant evolution for α_1 and α_K would be identical.

2. ϵ indeed serves in the role of coupling constant strength at classical level. α_K disappears from classical field equations at the space-time level and appears only in the conditions for the super-symplectic algebra but ϵ appears in field equations since the Kähler forms of J resp. CP_2 Kähler form is proportional to $R^2(S^2)$ resp. $R^2(CP_2)$ times the corresponding $U(1)$ gauge field. $R(S^2)$ appears in the definition of 2-bein for $R^2(S^2)$ and therefore in the modified gamma matrices and modified Dirac equation. Therefore $\sqrt{\epsilon} = R(S^2)/R(CP_2)$ appears in modified Dirac equation as required by CP breaking manifesting itself in CKM matrix.

   NTU for the field equations in the regions, where the volume term and Kähler action couple to each other demands that ϵ and $\sqrt{\epsilon}$ are rational numbers, hopefully as simple as possible. Otherwise there is no hope about extremals with parameters of the polynomials appearing in the solution in an arbitrary extension of rationals and NTU is lost. Transcendental values of ϵ are definitely excluded. The most stringent condition $\epsilon = 1$ is also unphysical. $\epsilon = 2^{2r}$ is favoured number theoretically.

Concerning the estimate for ϵ it is best to use the constraints coming from p-adic mass calculations.

1. p-Adic mass calculations [K2] predict electron mass as

$$m_e = \frac{\hbar}{R(CP_2)\sqrt{5+Y}} \quad .$$

   Expressing m_e in terms of Planck mass m_P and assuming $Y = 0$ ($Y \in (0,1)$) gives an estimate for $l_P/R(CP_2)$ as

$$\frac{l_P}{R(CP_2)} \simeq 2.0 \times 10^{-4} \quad .$$

2. From $l_P = 2\pi R(S^2)$ one obtains estimate for ϵ, α_1, $g_1 = \sqrt{4\pi\alpha_1}$ assuming $\alpha_K \simeq \alpha \simeq 1/137$ in electron length scale.

$$\begin{aligned} \epsilon &= 2^{-30} \simeq 1.0 \times 10^{-9} \quad , \\ \alpha_1 &= \epsilon\alpha_K \simeq 6.8 \times 10^{-12} \quad , \\ g_1 &= \sqrt{4\pi\alpha_1} \simeq 9.24 \times 10^{-6} \quad . \end{aligned}$$

There are two options corresponding to $l_P = R(S^2)$ and $l_P = 2\pi R(S^2)$. Only the length of the geodesic of S^2 has meaning in the Riemann geometry of S^2 whereas the radius of S^2 has operational meaning only if S^2 is imbedded to E^3. Hence $l_P = 2\pi R(S^2)$ is more plausible option.

For $\epsilon = 2^{-30}$ the value of $l_P^2/R^2(CP_2)$ is $l_P^2/R^2(CP_2) = (2\pi)^2 \times R^2(S^2)/R^2(CP_2) \simeq 3.7 \times 10^{-8}$. $l_P/R(S^2)$ would be a transcendental number but since it would not be a fundamental constant but appear only at the QFT-GRT limit of TGD, this would not be a problem.

One can make order of magnitude estimates for the Jarlskog parameter J and the fraction $r = n(B)/n(\gamma)$. Here it is not however clear whether one should use ϵ or α_1 as the basis of the estimate

1. The estimate based on ϵ gives

$$J \sim \sqrt{\epsilon} \simeq 3.2 \times 10^{-5} \quad , \quad r \sim \epsilon \simeq 1.0 \times 10^{-9} \quad .$$

   The estimate for J happens to be very near to the recent experimental value $J \simeq 3.0 \times 10^{-5}$. The estimate for r is by order of magnitude smaller than the empirical value.

2. The estimate based on α_1 gives

$$J \sim g_1 \simeq 0.92 \times 10^{-5} \quad , \quad r \sim \alpha_1 \simeq .68 \times 10^{-11} \quad .$$

   The estimate for J is excellent but the estimate for r by more than order of magnitude smaller than the empirical value. One explanation is that α_K has discrete coupling constant evolution and increases in short scales and could have been considerably larger in the scale characterizing the situation in which matter-antimatter asymmetry was generated.

There is an intriguing numerical co-incidence involved. $h_{eff} = \hbar_{gr} = GMm/v_0$ in solar system corresponds to $v_0 \simeq 2^{-11}$ and appears as coupling constant parameter in the perturbative theory obtained in this manner [K4]. What is intriguing that one has $\alpha_1 = v_0^2/4\pi^2$ in this case. Where does the troublesome factor $(1/2\pi)^2$ come from? Could the p-adic coupling constant evolutions for v_0 and α_1 correspond to each other and could they actually be one and the same thing? Can one treat gravitational force perturbatively either in terms of gravitational field or $J(CD)$? Is there somekind of duality involved?

Atomic nuclei have baryon number equal the sum $B = Z + N$ of proton and neutron numbers and neutral atoms have $B = N$. Only hydrogen atom would be also $U(1)$ neutral. The dramatic prediction of $U(1)$ force is that neutrinos might not be so weakly interacting particles as has been thought. If the quanta of $U(1)$ force are not massive, a new long range force is in question. $U(1)$ quanta could become massive via $U(1)$ super-conductivity causing Meissner effect. As found, $U(1)$ part of action can be however regarded a small perturbation characterized by the parameter $\epsilon = R^2(S^2)/R^2(CP_2)$. One can however argue that since the relative magnitude of $U(1)$ term and ordinary Kähler action is given by ϵ, one has $\alpha_1 = \epsilon \times \alpha_K$.

Quantal $U(1)$ force must be also consistent with atomic physics. The value of the parameter α_1 consistent with the size of CP breaking of K mesons and with matter antimatter asymmetry is $\alpha_1 = \epsilon\alpha_K = 2^{-30}\alpha_K$.

1. Electrons and baryons would have attractive interaction, which effectively transforms the em charge Z of atom $Z_{eff} = rZ$, $r = 1 + (N/Z)\epsilon_1$, $\epsilon_1 = \alpha_1/\alpha = \epsilon \times \alpha_K/\alpha \simeq \epsilon$ for $\alpha_K \simeq \alpha$ predicted to hold true in electron length scale. The parameter

$$s = (1 + (N/Z)\epsilon)^2 - 1 = 2(N/Z)\epsilon + (N/Z)^2\epsilon^2$$

   would characterize the isotope dependent relative shift of the binding energy scale.

   The comparison of the binding energies of hydrogen isotopes could provide a stringent bounds of the value of α_1. For $l_P = 2\pi R(S^2)$ option one would have $\alpha_1 = 2^{-30}\alpha_K \simeq .68 \times 10^{-11}$ and $s \simeq 1.4 \times 10^{-10}$. s is by order of magnitude smaller than $\alpha^4 \simeq 2.9 \times 10^{-9}$ corrections from QED (see `http://tinyurl.com/kk9u4rh`). The predicted differences between the binding energy scales of isotopes of hydrogen might allow to test the proposal.

2. $B = N$ would be neutralized by the neutrinos of the cosmic background. Could this occur even at the level of single atom or does one have a plasma like state? The ground state binding energy of neutrino atoms would be $\alpha_1^2 m_\nu/2 \sim 10^{-24}$ eV for $m_\nu = .1$ eV! This is many many orders of magnitude below the thermal energy of cosmic neutrino background estimated to be about 1.95×10^{-4} eV (see `http://tinyurl.com/ldu95o9`). The Bohr radius would be $\hbar/(\alpha_1 m_\nu) \sim 10^6$ meters and same order of magnitude as Earth radius. Matter should be $U(1)$ plasma. $U(1)$ superconductor would be second option.

4 Is the analog of CME possible in TGD?

CME and related QCD effects involve violation of CP and P. The Kähler form of $J(M^4)$ is Abelian self-dual covariantly constant self-dual $U(1)$ field coupling to fermion number with B and E parallel and breaking both CP, P, and T. This field satisfy just the conditions pose on em field assigned to CME.

One can consider the situation at the level of space-time surface itself or at the level of string world sheets if one believes in strong form of holography (SH) predicting that the information about dynamics is coded by string world sheets and that action reduces to 2-D bosonic and fermionic action associated with them.

4.1 Description at space-time level

Consider first the model at space-time level.

1. In TGD framework SH implies and induced field concept imply that the set of field patters representable as induced fields at single space-time sheet is extremely limited. Various gauge fields of standard model correspond to sums of the induced gauge fields associated with space-time sheets with which particle is in contact (touches them). QFT limit is obtained by replacing the sheets with single curved region of M^4 and identifying gauge potentials with the sum of the induced gauge potentials: similar recipe applies to the deviation of induced metric from Minkowski metric.

   There is also topological field quantization. For instance, the classical em fields of colliding protons are at different space-time sheets. Furthermore, the fields are topologically quantized. For instance, electric flux from point charge flows along radial flux tubes if only covariantly constant $J(CD)$s are allowed.

2. At space-time surface itself $J(M^4)$ associated with flux tube gives rise both E and B and they are parallel to each other in the approximation that space-time surface is just a piece of M^4. The Abelian instanton density is non-vanishing. Quarks and antiquarks moving in this field rotate along the magnetic field and move in opposite directions and charge separation occurs.

   In HN-HN angular momentum conservation forces quarks swirl around circles in the scattering plane in the collision region. This creates closed magnetic flux tubes analogous to those associated with dipole field. There is net baryon number involved and if it serves as a source for $J(M^4)$. $U(1)$ field with roughly parallel E and B is generated and CME becomes possible. Quarks and antiquarks are driven to the opposite poles. This means that there is surplus of U and D type quarks at North Pole and their antiquarks at South Pole. North/South Pole have positive/negative em charge if the numbers of U and D type quarks are roughly the same. Baryon number separation would would give also separation of em charge.

3. What about p-HN collisions? Now the angular momentum conservation does not force generation of $U(1)$ magnetic field. If $U(1)$ field has fermion number as source, the $U(1)$ electric field is present since one has large baryonic number in the collision region. By self-duality $U(1)$ electric field is necessarily accompanied by magnetic field if the flux tube in question is near to canonically imbedded M^4.

4. Can one have say anything interesting about possible TGD counterpart of CMW? CMW would would be a charge wave adding positive charge to poles and negative charge to Equator.

Negative charge at Equator would mean excess of $\overline{U}$ and D at equator and excess of U and $\overline{D}$ at Poles. There would be asymmetry in em charge but not baryon number. Therefore this phenomenon would be related to em field. The minimum condition is that the total E_{em} and B_{em} as sum of em fields of colliding nuclei are not orthogonal. The instanton density for em field measures the non-orthogonality. This kind of situation is encountered in collisions, which tend to be peripheral.

A couple of remarks are in order.

1. I have proposed that electromagnetic instanton density serves as source of what I call lepto-pions, which are analogs of hadrons possible in TGD if the color octet excitations of leptons are light [K5]. Lepto-pions would have mass of ~ 1 MeV and would explain the anomaly observed in heavy ion collisions already at seventies. TGD strongly suggested the existence of several p-adically scaled up copies of hadron physics. One of them would be M_{89} hadron physics.

   The same mechanism could apply to the production of pseudo-scalar mesons of M_{89} hadron physics in peripheral HN-HN collisions and p-HN collisions [K3] [L1]. There are indeed two handfuls of bumps identifiable as M_{89} mesons with masses by factor 512 higher than those for ordinary mesons. Unfortunately, these bumps have been forgotten since it was not possible to identify them as Higgses of SUSY: one can find only what one wants to find!

The possible TGD counterparts of CSE, CME, and CMW and the emergence of dark variants of M_{89} hadrons would be quantum critical phenomena [K6] assignable to a phase transition (whatever it might be in TGD framework, where quark gluon plasma need not exist at all!). The quarks at the flux tubes would be dark with $h_{eff} = n \times h$. The value of n would be determined by the condition that the p-adic length scale associated with M_{89} hadrons is same order of magnitude as that associated with the ordinary M_{107} hadrons. Therefore $n = 2^9 = 512$ is a good guess. Note that "macroscopic" quantum coherence and analog of super-conductivity suggested to accompany also CME would be possible.

4.2 Description at the level of string world sheets

SH suggests a complementary of 4-D description with 2-D description based on string world sheets and quarks moving along their boundaries. At string world sheets quarks see the induced $U(1)$ field. One cannot speak about self-dual $U(1)$ field anymore. Maxwellian intuition suggests that also point like quarks see the $U(1)$ force. This is indeed the case. The world lines defined by string boundaries at the boundaries of string world sheet located at light-like 3-surfaces correspond to the orbits of fermions. They solve the equations of motion for a particle in $U(1)$ force field. The light-likeness of the word line (otherwise the world line is space-like) suggests that the the total force due to $J(M^4) + J(CP_2)$ vanishes.

Since the induced field is 2-dimensional both $U(1)$ electric and magnetic fields might be seen only in very special situations at string world sheets. If the M^4 projection of the string world sheet represented as surface in $M^2 \times E^2$ is such that one can represent it as graph $M^2 \rightarrow E^2$ both B and E in M^4 contribute to the net field to which quarks couple.

4.3 How the QFT-GRT limit of TGD differs from QFT and GRT?

Yesterday evening I got an intereting idea related to both the definition and conservation of gauge charges in non-Abelian theories. First the idea popped in QCD context but immediately generalized to electro-weak and gravitational sectors. It might not be entirely correct: I have not yet checked the calculations.

4.3.1 QCD sector

I have been working with possible TGD counterparts of so called chiral magnetic effect (CME) and chiral separation effect (CSE)proposed in QCD to describe observations at LHC and RHIC suggesting relatively large P and CP violations in hadronic physics associated with the deconfinement phase transition.

The QCD based model for CME and CSE is not convincing as such. The model assumes that the theta parameter of QCD is non-vanishing and position dependent. It is however known that theta parameter is extremal small and seems to be zero: this is so called strong CP problem of QCD caused by the possibility of istantons. The axion hypothesis could make $\theta(x)$ a dynamical field and θ parameter would be eliminated from the theory. Axion has not however been however found: various candidates have been gradually eliminated from consideration!

What is the situation in TGD? In TGD instantons are impossible at the fundamental space-time level. This is due to the induced space-time concept. What this means for the QFT limit of TGD?

1. Obviously one must add to the action density a constraint term equal to Lagrange multiplier θ times the instanton density . If θ is constant the variation with respect to it gives just the vanishing of instanton number.

2. A stronger condition is local and states that *instanton density* vanishes. This differs from the axion option in that there is no kinetic term for θ so that it does not propagate and does not appear in propagators.

Consider the latter option in more detail.

1. The variation with respect to $\theta(x)$ gives the condition that instanton density rather than only instanton number vanishes for the allowed field configurations. This guarantees that axial current having instanton term as divergence is conserved if fermions are massless. There is no breaking of chiral symmetry at the massless limit and no chiral anomaly which is mathematically problematic.

2. The field equations are however changed. The field equations reduce to the statement that the covariant divergence of YM current - sum of bosonic and fermionic contributions - equals to the covariant divergence of color current associated with the constraint term. The classical gauge potentials are affected by this source term and they in turn affect fermionic dynamics via Dirac equation. Therefore also the perturbation theory is affected.

3. The following is however still uncertain: This term *seems* to have vanishing *ordinary* total divergence by Bianchi identities - one has topological color current proportional to the contraction of the gradient of θ and gauge field with 4-D permutation symbol! I have however not checked yet the details.

   If this is really true then the sum of fermionic and bosonic gauge currents not conserved in the usual sense equals to a opological color current conserved in the usual sense! This would give conserved total color charges as topological charges - in spirit with "Topological" in TGD! This would also solve a problem of non-abelian gauge theories usually put under the rug: the gauge total gauge current is not conserved and a rigorous definition of gauge charges is lost.

4. What the equations of motion of ordinary QCD would mean in this framework? First of all the color magnetic and electric fields can be said to be orthogonal with respect to the natural inner product. One can have also solutions for which θ is constant. This case gives just the ordinary QCD but without instantons and strong CP breaking. The total color current vanishes and one would have *local* color confinement classically! This is true irrespective of whether the ordinary divergence of color currents vanishes.

5. This also allows to understand CME and CSE believed to occur in the deconfinement phase transition. Now regions with non-constant $\theta(x)$ but vanishing instanton density are generated. The sum of the conserved color charges for these regions - droplets of quark-gluon plasma - however vanish by the conservation of color charges. One would indeed have non-vanishing local color charge densities and deconfinement in accordance with the physical intuition and experimental evidence. This could occur in proton-nucleon and nucleon-nucleon collisions at both RHIC and LHC and give rise to CME and CSE effects. This picture is however essentially TGD based. QCD in standard form does not give it and in QCD there are no motivations to demand that instanton density vanishes.

4.3.2 Electroweak sector

The analog of $\theta(x)$ is present also at the QFT limit of TGD in electroweak sector since instantons must be absent also now. One would have conserved total electroweak currents - also Abelian U(1) current reducing to topological currents, which vanish for $\theta(x) = constant$ but are non-vanishing otherwise. In TGD the conservation of em charge and possibly also Z^0 charge is understood if strong form of holography (SH) is accepted: it implies that only electromagnetic and possibly also Z^0 current are conserved and are assignable to the string world sheets carrying fermions. At QFT limit one would obtain reduction of electroweak currents to topological currents if the above argument is correct. The proper understanding of W currents at fundamental level is however still lacking.

It is now however not necessary to demand the vanishing of instanton term for the U(1) factor and chiral anomaly for pion suggest that one cannot demand this. CP_2 actually represents a Kähler instanton. Also the TGD inspired model for so called leptohadrons is based on the non-vanishing elecromagnetic instanton density. In TGD also M^4 Kähler form J(CD) is present and same would apply to it. If one applies the condition empty Minkowski space ceases to be an extremal.

4.3.3 Gravitational sector

Could this generalize also the GRT limit of TGD? In GRT momentum conservation is lost - this one of the basic problems of GRT put under the rug. At fundamental level Poincare charges are conserved in TGD by the hypothesis that the space-time is 4-surface in $M^4 \times CP_2$. Space-time symmetries are lifted to those of M^4.

What happens at the GRT limit of TGD? The proposal has been that *covariant* conservation of energy momentum tensor is a remnant of Poincare symmetry. But could one obtain also now ordinary conservation of 4- momentum currents by adding to the standard Einstein-YM action a Lagrange multiplier term guaranteing that the gravitational analog of instanton term vanishes?

1. First objection: This makes sense only if vier-bein is defined in the M^4 coordinates applying only at GRT limit for which space-time surface is representable as a graph of a map from $M^4 toCP_2$.

2. Second objection: If metric tensor is regarded as a primary dynamical variable, one obtains a current which is symmetry 2-tensor like T and G. This cannot give rise to a conserved charges.

3. Third objection: Taking vielbein vectors e^A_μ as fundamental variable could give rise to a conserved vector with vanishing covariant divergence. Could this give rise to conserved currents labelled by A and having interpretation as momentum components? This does not work. Since e^A_μ is only covariantly constant one does not obtain genuine conservation law except at the limit of empty Minkowski space since in this case vielbein vectors can be taken to be constant.

Despite this the addition of the constraint term changes the interpretation of GRT profoundly.

1. Curvature tensor is indeed essentially a gauge field in tangent space rotation group when contracted suitably by two vielbein vectors e^A_μ and the instanton term is formally completely analogous to that in gauge theory.

2. The situation is now more complex than in gauge theories due to the fact that second derivatives of the metric and - as it seems - also of vielbein vectors are involved. They however appear linearly and do not give third order derivatives in Einstein's equations. Since the physics should not depend on whether one uses metric or vielbein as dynamical variables, the conjecture is that the variation states that the contraction of $T - kG$ with vielbein vector equals to the topological current coming from instanton term and proportional to the gradient of θ

$$(T - kG)^{\mu\nu} e^A_\nu = j^{A\mu} \quad .$$

The conserved current $j^{A\mu}$ would be contraction of the instanton term with respect to e_μ^A with the gradient of θ covariantized. The variation of the action with respect to the the gradient of e_μ^A would give it. The resulting current has only vanishing *covariant* divergence to which vielbein contributes.

The multiplier term guaranteing the vanishing of the gravitational instanton density would have however highly non-trivial and physically desirable consequences.

1. The covariantly conserved energy momentum current would be sum of parts corresponding to matter and gravitational field unlike in GRT where the field equations say that the energy momentum tensors of gravitational field and matter field are identical. This conforms with TGD view at the level of many-sheeted space-time.

2. In GRT one has the problem that in absence of matter (pure gravitational radiation) one obtains G=0 and thus vacuum solution. This follows also from conformal invariance for solutions representing gravitational radiation. Thanks to LIGO we however now know that gravitational radiation carries energy! Situation for TGD limit would be different: at QFT limit one can have classical gravitational radiation with non-vanishing energy momentum density thanks the vanishing of instanton term.

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