A refined view of the phenomenology of hadron physics and p-adic mass calculations

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Abstract

In this article the implications of the updated vision of standard model physics and hadron physics are considered. The goal is to develop a phenomenological picture of hadrons based on the general mathematical framework of TGD and on the interpretation of strong and weak interactions as different aspects of color interaction.

The additivity of the mass squared values identified as conformal weights at the level of the embedding space H is a crucial assumption made also in the p-adic mass calculations. One must check whether this assumption is physically sensical and how it relates to the additivity of masses assumed in the constituent quark model and understand the relation between the notions of current quark mass and constituent quark mass. One should also identify various contributions to the hadron mass squared in the new picture and understand the hadronic mass splittings.

The results of the simple calculations deducing the p-adic mass scales of hadrons and quarks mean a breakthrough in the quantitative understanding of the hadronic mass spectrum. In particular, the identification of color interactions in fermionic isospin degrees of freedom as weak interactions with a p-adically scaled up range explains the mass splittings due to isospin. The smallness of the Weinberg angle for scaled up weak interactions can explain how the interactions become strong and why the parity violation for strong interactions is small. A formula for Weinberg angle is deduced in terms of fermion masses.

1 Introduction

The key question of this work is how do the recent (2023-2025) advances in the understanding TGD, the general structure of the TGD variant of the Standard Model, and of TGD view of hadron physics affect the concrete picture of hadrons and help refine the picture of p-adic mass calculations?

1.1 Geometric and number-theoretic visions of physics as duals of each other

TGD offers two visions of physics: physics as geometry and physics as number theory. Advances in recent years have led to the interpretation of these visions as a 4-D generalization of Langlands duality [L9, L12, L17], where the geometric and number-theoretic descriptions are dual and in a relation resembling momentum-position duality, $M^8 - H$ duality [L8] is indeed analogous to momentum position duality but formulated for particles identified as 3-surfaces or rather, with the analogs of their slightly-nondeterministic Bohr orbits implied by holography = holomorphy principle [L18, L6].

1. p-Adic thermodynamics has been reasonably well understood at the principle level [L5]. Much progress has been made in understanding the origin of the concepts of p-adicity and adelicity during the last couple of years.

   The function field counterparts of p-adic number fields follow from the holography = holomorphism principle [L12, L17, L14]. One can say that p-adicity generalizes from the 8-D level to the WCW level, where WCW is the "world of classical worlds" [K8, L7]. A structure-preserving morphism is obtained from the p-adic function fields to the ordinary p-adic number fields. The origin of the p-adic length-scale hypothesis is also understood. This correspondence generalizes to adeles. Also the notion of multi-p-adicity emerges [L5, L12].

2. Classical non-determinism corresponds to the p-adic non-determinism and is interpreted as a correlate for cognition. In the TGD Universe, cognition is present already at the elementary particle level so that this has quite interesting interpretation. Conformal symmetry breaking in p-adic thermodynamics is also understood. The violation of conformal invariance, which is related to non-determinism, makes vertices for fermion pair creation possible and is an essential part of the theory.

   A connection with exotic smooth structures [A2, A3, A1] is highly suggestive [L10, L4, L11] and suggests that non-trivial quantum dynamics is possible only in the space-time dimension $D = 4$.

   The defects of the ordinary smooth structure characterizing exotic smooth structure would correspond to edges of the space-time surface. The objection is that this kind of defects are possible also in other dimensions so that the question is whether the violation of the 4-D conformal invariance allows one to regard these edges as defects of the standard smooth structure.

1.2 New understanding of strong and other interactions

TGD Universe has the symmetries of the standard model but their interpretation and realization differs dramatically from that of the standard model [L15, L14, L16].

1. A hierarchy of copies of the standard model corresponding to a hierarchy of irreducible representation of the color group for the CP_2 partial waves of quarks and leptons labelled by an integer, is predicted. Also leptons would have color partial waves and obey color confinement. These copies of the standard model would be labelled by collections of p-adic primes labelling the associated fermions. Mersenne primes could label at least the nucleons and charged leptons of these copies of the standard model. Weak interaction in the hadronic scale becomes strong interaction. M_{89} hadron physics with the mass of nucleon 512 times that of ordinary proton is one particular prediction and in this work the question whether the top quark could be identifiable as a quark of M_{89} hadron physics with the mass scale of proton scaled up by factor 512. and the actual top could relate to the Aleph anomaly [C2] [K5].

2. Color interaction in CP_2 spin degrees of freedom is identifiable as weak interaction, which becomes strong when its scale becomes long [?]. One can equate the strong isospin with weak isospin with color isospin: $I_s = I_w = I_c$. The screening of weak interactions corresponds to color confinement in CP_2 spin degrees of freedom.

   There is color confinement also in CP_2 orbital degrees of freedom one and this is forced by the condition that the mass squared identified as the sum of mass squared values of the many fermion state is vanishing and proportional to the color Casimir operator as in the case of single fermion states [L15, L14, L16].

3. Weak screening, produced by neutrino-antineutrino pairs $\nu_L\overline{\nu}_R$ assignable to the closed flux tubes associated with quarks and leptons, realizes the color confinement in CP_2 spin degrees of freedom. Only the electromagnetic charge is not screened. For the creation of a quark pair one would have $\alpha_w \rightarrow N_c^2 \times \alpha_w \equiv \alpha_s$, where N_c is the number of colors. For $\alpha_w = \alpha_{em}/sin^2(\theta_W) \simeq .03$ this gives $\alpha_s = .27$. Another, perhaps equivalent, view is that Weinberg angle becomes small and makes α_w large and also implies that parity breaking effects are small for strong interactions. Strong interactions in CP_2 spin degrees of freedom would correspond to weak interactions but with a range which correspondd to hadronic, nuclear and even electron length scale.

4. This picture conforms with the phenomenological geometric view of hadrons [K5, K6]. Quarks correspond to closed monopole flux tubes as two-sheeted objects. The magnetic flux runs along Minkowskian space-time sheet A, flows to a parallel Minkowskian space-time sheet B through an Euclidean wormhole contact, flows back along B and returns to the sheet A through a wormhole contact. The wormhole contacts correspond to the "ends" of the string-like object at a given space-time sheet. Quarks and the neutrino pair, which screens its weak charge in scales longer than its length, are at the opposite "ends" of the flux tube.

1.3 Different perspectives on hadron physics

TGD provides several views of hadron physics.

1. There are two levels of description corresponding to the fermionic level and the geometric level. There is also a second division. The description of the hadronic phase, the $H = M^4 \times CP_2$ phase, is in terms of the modes of second quantized free H spinor fields and it provides a description of incoming and outgoing quantum states. H picture has a restriction to the level of causal diamond (CD) as a correlated for conscious entity [L14]: for this option M^4 has Hamilton-Jacobi structure [L6] and Kähler structure, which is trivial in hypercomplex degrees of freedom [L16]. This phase is the analog of the hadron phase appearing in the initial and final states of the scattering events.

   The massless phase, the X^4 phase, is based on the massless modes of the induced spinor fields as solutions of the induced, or possibly of the modified Dirac equation determined by the classical action and superconformal symmetry [L15] [K10]. This phase is the analog of quark-gluon plasma.

   The fundamental description of interactions in terms of the X^4 phase whereas many-fermion states correspond to the H phase. The parameterization of quantum states in the H phase is possible in terms of a phenomenological description and is the goal of this work.

2. For the H-picture for which second quantized free H spinor fields are fundamental. In the "world of classical worlds" (WCW) spinor fields of WCW are classical spinor fields and WCW spinor structure and WCW gamma matrices are expressible in terms of the oscillator operators of the second quantized H spinor fields. Their anticommutator defines WCW Kähler metric metric [K8] [L7].

3. Color confinement can be understood at H and WCW levels. The additivity of the mass squared allows us to predict color confinement [?] from the H Dirac equation alone. Also p-adic thermodynamics [K4] [L5] assumes the additivity of mass squared. Tachyons play a key role in the mechanism in the orbital degrees of freedom of CP_2 and neutrino screening takes care of color confinement in CP_2 spin degrees of freedom and reduces to weak confinement for weak interaction in hadron scale instead of intermediate boson scale.

   This leads to a general view about particle reactions generalizing the notions of hadronization and transition from hadron phase to quark gluon phase. Classical picture in the massless phase relies on the notion of a magnetic body for hadrons and quarks consisting of monopole flux tubes.

In this work the implications of the updated vision of standard model physics and hadron physics is considered. The goal is to develop a phenomenological picture of hadrons based on the general mathematical framework of TGD and on the interpretation of strong and weak interactions as different aspects of color interaction.

The additivity of the mass squared values identified as conformal weights at the level of the embedding space H is a crucial assumption made also in the p-adic mass calculations. One must check whether this assumption is physically sensical and how it relates to the additivity of masses assumed in the constituent quark model and understand the relation between the notions of current quark mass and constituent quark mass. One should also identify various contributions to the hadron mass squared in the new picture and understand the hadronic mass splittings.

The identification of color interactions in fermionic isospin degrees of freedom as weak interactions with a p-adically scaled up range explains the mass splittings due to isospin. The smallness of the Weinberg angle for scaled up weak interactions can explain how the interactions become strong and why the parity violation for strong interactions is small.Note however that there is evidence for a large parity violation in strong interactions from RHIC [C1] discussed from the TGD point of view in [K5]. A formula for Weinberg angle is deduced in terms of fermion masses.

In the sequel I describe the calculations in detail. The reason is that the results mean a breakthrough in the development of the TGD view of strong interactions. If some colleague raising a monthly salary could somehow become motivated to demonstrate that I am wrong, this would make it easy to go through the arguments to find mistakes.

2 Phenomenological description of strong interactions in TGD

The prediction that both leptons and quarks move in color partial waves of $H = M^4 \times CP_2$ spinor fields predicting a hierarchy of copies of standard model physics [L15, L14] and the identification of strong interaction as a weak interaction in a longer p-adic length scale than usually p-adic length scale [L16] are the perhaps the most dramatic modifications of the standard model view of particle physics.

2.1 The generalization of the QCD description of hadronic reactions

TGD modifies considerably the QCD description of strong interactions and this modification generalizes to all interactions.

2.1.1 H phase and X^4 phase as the TGD counterparts of hadron phase and quark-gluon plasma

Generalizations of the hadronic phase and quark-gluon plasma phase to what I call H phase and X^4 phase are in a well-defined sense universal and apply to both quarks,leptons, and gauge bosons and even gravitons [L16].

1. The hadronic description of the initial and final states of reactions as many-fermion states in H: one might speak of the H phase. The crucial difference to the standard model is that mass squared is assumed to be additive in H phase as a conformal weight. 8-D masslessness for the entire hadronic state plus the condition that mass is below the CP_2 mass scale requires the vanishing color Casimir operator and implies color confinement. Masslessness means conformal confinement, which requires the allowance of tachyonic conformal weights for composite fermions but not for physical states. Tachyons also appear in string models. The additivity of the mass squared at the hadronic level also makes it possible to understand color confinement. Note however that the conformal weight is not a conserved quantum number.

2. The description of reactions by means of induced spinors of space-time surface X^4 as massless solutions of the induced/modified Dirac operator [L15] generalizes the notion of quark-gluon plasma [L16]. By holomorphy = holography correspondence, the incoming particles correspond to the analogs of Bohr orbits, which are however slightly non-deterministic such that

the loci of non-determinism correspond to singularities to which interaction vertices can be assigned.

The interactions are contact interactions in the sense that they can be assigned to the intersection of space-time surfaces as Bohr orbits of 3-D particles. For the same Hamilton-Jacobi (or equivalently Kähler-) structure [L6, L18, L16] the intersections are 2-D string world sheets but otherwise consist of a discrete set of points. This means a stringy description of the interactions. Common H-J structure means that the interacting/ intersecting space-time surfaces have common light-like coordinates u and v as hypercomplex analogs of complex coordinate and its conjugate. The independence of the functions defining the space-time surface from say v, implies that it this coordinate is not dynamical so the intersections are analogous to the orbits of straight strings.

The emergence of the TGD analogy of the quark-gluon plasma phase *resp.* hadronization corresponds to the transition from the H phase to X^4 phase *resp.* X^4 phase to H phase.

2.1.2 Finding of a phenomenological description of H phase as a basic challenge

Interactions in the massless X^4 phase affect the hadronic final states as H states. The challenge is to develop a phenomenological parameterization of the consequences of these interactions at the hadronic level.

1. At the X^4 level, massless current quarks are a natural concept. At the hadronic level, massive constituent quarks are a more natural concept. Therefore the concept of constituent quark should be generalized from the Gell-Mann quark model to TGD.

2. One must understand the contributions to the hadron mass in the H phase at the level of phenomenology. Tachyonity is an additional element in the description at the level of H and means that constituent quarks are extremely massive. Apart from the covariantly constant right-handed neutrino, the H spinor modes have CP_2 mass scale, which is $10^{-4} \times m_{Pl}$. In an excellent approximation, the quarks are at rest at the level of H but this is true only when quark 3-momenta are measured with respect to the CP_2 mass scale. With respect to the hadron mass scale the quark momenta can be large.

3. In the H description the additivity of mass squared is natural. The additivity of energy and momenta is not in conflict with the additivity of mass squared. However, in the phenomenological description provided by the Gell-Mann model, the additivity of mass is natural if the constituent quarks are non-relativistic and as a good approximation at rest. The assumption about static quarks in a sharp conflict with the additivity of mass squared.

   H the additivity of mass squared is however consistent with the additivity of the 4-momenta if one has $(\sum p_i)^2 = \sum p_i^2$. This requires that the state satisfies the constraint

   $$\sum_{i,j} p_i \cdot p_j = 0 \ . \tag{2.1}$$

   This gives for the four-momenta $p = (E_i, p_{i,3})$ the condition

   $$\sum_{i,j} E_i E_j - p_{3,i} p_{3,j} cos(\theta_{i,j}) = 0 \ , \tag{2.2}$$

   which cannot be satisfied for positive energies unless the quarks are massless and have parallel momenta. This would require that interaction terms in the mass squared formula are needed. These terms would naturally relate to the presence of tachyonic momenta perhaps having interpretation as the counterpart of attractive interaction energy.

2.2 General form for the hadron mass formula assuming mass squared additivity

The goal is to deduce a master formula for the hadron mass. The additivity of mass squared identified as conformal weight is assumed at the fundamental level and the additivity of masses can hold true only for the effective quark masses if there is a large additional contribution identifiable as the TGD counterpart of the large gluonic contribution of QCD.

2.2.1 Various contributions to the hadron masses

The first challenge is to identify various contributions to hadron masses, or more precisely, to the mass squared of hadron interpreted as a conformal weight.

1. The contribution of the parton surface genus explains the mass differences between fermion generations. The simplest assumption is that it does not depend on the charge state except through the CKM mixing.

   This is supported by a comparison of the mass differences between baryons and off-diagonal mesons: the mass difference for hadrons that differ by replacing the d quark with the s quark, the additive mass formula is a good approximation. For example, D and D_s and B and B_s and light baryons for which the Gell-Mann mass formula works well. For diagonal mesons, mixing makes the comparison difficult. One must also consider baryons containing c and b and here deviations occur as will be found.

2. The internal self-interaction energy of a quark produced due its interaction with neutrino-antineutrino pair screening its weak charges.

   This energy is negative because the total isospin for a quark on a scale larger than its size is zero. The self-interaction energy corresponds to the interaction energy of a quark and neutron pair $\nu_L\overline{\nu}_R$ ($\overline{\nu}_L\nu_R$) and reduces to the interaction energy between a quark and its conjugate ν_L ($\overline{\nu}_L$). The quark and neutrino pairs reside at the opposite "ends" of a closed monopole flux tube, each of which corresponds to a Euclidean wormhole contact connecting 2 spacetime sheets with Minkowskian signature.

   It is noteworthy that the right-handed neutrino, which is the standard model's thorn in the side, plays a key role in TGD in both the quark and lepton sectors. It makes makes possible electroweak screening, which in turn essentially corresponds to the creation of a color singlet in the spin degrees of freedom of CP_2. The fundamental mode for a right-handed neutrino is massless because it is a covariant constant in CP_2.

3. Magnetic contribution from the monopole flux tube of quarks and hadrons

   The length of the flux tube associated with a quark characterizes the quark by giving a magnetic contribution to the energy that is proportional to the length of the flux tube and the string tension, which corresponds to the area of its M^4 projection. The lengths are different for U and D quarks except for u and d. The strings of U quarks are shorter than those of D quarks. Examples of this are c-s and t-b.

4. The contribution of the hadronic magnetic body.

   Fractality allows for hadronic flux tubes containing quark flux tubes inside them. Both quarks and hadrons are therefore characterized by string tensions that correspond to their mass scale, which would follow the p-adic length-scale hypothesis.

   If it makes sense to talk about a hadronic strings as parts of the hadron magnetic body, the the square of the reciprocal of the radius of the hadronic string could define the parameter chracterizing a given hadronic physics. In the hadronic string model, which preceded QCD, it was of the order $T = 1/\mathrm{GeV}^2 \simeq 1/m_N^2$. This parameter would be determined by the p-dis length-scale hypothesis. For ordinary hadrons it would be $k = 107$ and for M_{89} hadrons $k = 89$.

   The hadronic magnetic body is expected to have an onion-like structure such that large layers give small corrections to the mass squared.

5. Inside a hadron, the weak interaction for quarks corresponds to the traditional strong interaction in terms of strong isospin. It depends on the quark charges and spins and is important in understanding mass differences. Weak magnetic interaction gives rise to the TGD counterpart for the QCD description of color magnetic spin-spin splitting explains for instance $\rho - \pi$ and $\Delta - N$ mass splittings.

The general additive formula for the mass squared of the hadron, identified as a conformal weight, is a direct generalization of the additive mass formula:

$$M_H^2 = \sum_i m^2(q_i, \nu\overline{\nu}) + \sum_i m^2(g_i) + \sum_i m_i^2(magn, q_i) + m^2(magn, hadron) + \sum_{i,j} m^{2)}(q_i, \overline{q}_j) \ . \quad (2.3)$$

There are two additive quark level contributions, magnetic hadron level contribution and interaction contributions including scaled up weak Coulomb interaction and scaled up weak spin-spin interaction as an analog of color magnetic spin-spin interaction. Also the interactions of quark and neutrino spin with the weak magnetic field of the mopole flux tube assignable to the quark are involved.

2.2.2 Quark level parameters

Consider first the quark level contributions to the mass squared identified as conformal weight.

1. Genus contribution $m^2(g)$ is associated with the end second end of the quark string and is characterized by the p-adic length scale of the particle string. For a given p-adic length cale it does not depend on the charge of the quark (note however the effects caused by CKM mixing due to the different topological mixings of U and D type quarks).

2. The contribution $m^{2)}(q_i, nu\overline{\nu}) + m^{2)}(magn, quark)$ is associated with the quark string and depends on its p-adic length scale. The sign of $m^{2)}(q_i, \nu\overline{\nu})$ is always negative and could partially explain the mass differences of U and D type quarks and the dependence of the p-adic mass scale on the quark. Note that p-adic thermodynamics predicts slightly different masses for U and D type quarks with the same p-adic prime.

   The Coulomb interaction energy between isospins of the quark and neutrino is negative. It depends on the length of the string. The effective 1-D increases with distance. The string carries Kähler magnetic field. The competition between these two contributions determines the length of the string and the p-adic length scale of the particle. There could also be a spin-spin interaction proportional to the product of inverse of the neutrino and quark mass and analogous to the color magnetic spin-spin interaction energy. One can argue that the interaction energy of the neutrino with the strong monopole magnetic field of the quark flux tube dominates.

2.2.3 Hadron level parameters

At the level of hadron there are 3 kinds of contributions to the hadron's mass squared identified as conformal weight at the level of hadron.

1. The confromal weight $m^2(magn, hadron)$ is characterized by the hadronic string tension and the lengths of monopole flux tubes associated with the hadronic magnetic body characterized by the hadronic p-adic length scale. $p = 107$ is a good guess for nuclei.

2. $m^{2)}(q_i, q_j)$ correspond to weak interaction conformal weights associated with weak isospin but are strong in the sense of having a long range characterized by the p-adic length scale. This interaction corresponds to the standard view of the strong interaction. Here also magnetic spin-spin interaction between isospins analogous to corresponding interaction in QCD is involved.

3. Also the interaction conformal weights $m_q^{2)}(magn)$ and $m_{\nu_L}^{2)}(magn)$ of the quark and neutrino spins with the magnetic field B of the monopole flux tube must be included.

2.3 An estimate for the value of the parameter M_0^2 from color magnetic spin-spin splitting

Also the color magnetic spin-spin splitting between ρ and π and more generally between pseudoscalars and vector/axial vector mesons. This splitting occurs also for baryons, say as $N-\Delta$ splitting. I have discussed the splitting in [K7]. What is nice is that if the parameter M_0^2 is the same for the split pair, it would come as a prediction. In principle, this induces only a shift of the parameter M_0^2 when estimated without taking into account this splitting as is indeed done in the sequel. The hypothesis of this article that M_0^2 corresponds to octaves of the basic scale can be compared to the prediction from spin-spin splitting. In the case of light mesons this shift is large but for baryons it is very small.

Consider first the standard view of the splitting for the $\rho-\pi$ system.

1. The splitting is of the form

$$\begin{array}{ll} m(\rho)=m_0+\frac{3\Delta m}{4} \ , & m(\pi)=m_0-\frac{\Delta m}{4} \ , \\ m_0=\frac{m(\rho)+3m(\pi)}{4} \ , & \Delta=m(\rho)-m(\pi) \ . \end{array} \quad (2.4)$$

2. The splitting is proportional to the color coupling strength α_s and the product of the inverses of quark masses appear in the color magnetic moments of quarks. Also the factor $1/d^3$, where d is the distance between quarks appears so that one has

$$\Delta m \sim \alpha_s \frac{s_1\cdot s_2}{m_1 m_2 d^3} \ , \quad (2.5)$$

   where d is the distance between quarks.

3. For pions, one has $m_0 \simeq 280$ MeV, roughly twice the pion mass. A dimensional estimate for the splittings is as $\Delta m \simeq 630$ MeV which can be written as $\Delta m = \alpha_s m$, where m is a mass parameter. An estimate using light quark mass $m_u = m_d \simeq 5eV$ and $\alpha_s = .1$ gives nuclear length scale $d \simeq 10^{-14}$ m which is also the Compton scale of pion. This expression applies also to other meson pairs such as $K-K^*$ and $\eta-\omega$. For heavier meson the model does not work well. The splittings are larger than predicted splittings which should be inversely proportional to the product of the masses of the heavy quarks and therefore very small.

A natural guess is that this splitting has a TGD counterpart with $SU(3)$ replaced with a scaled up weak splitting for group $SU(2)_w$ representable as a subgroup of $SU(3)$. Since mass squared is now additive, it is not quite clear how to generalize the formula for the mass splitting. One can consider two options.

1. One could identify the masses of ρ and π in terms of the already given non-relativistic formula and calculate the mass squared values from this. This would bring nothing new. For the $N-\Delta$ system one can also consider a linear approximation $\Delta m_0^2 = 2m_0\Delta m$, as Δm. In the case of pion the splitting is however rather large so that one can challenge the linear approximation. Linearization is however a reasonable first guess and would have in the case of pion

$$\begin{array}{ll} m^2(\rho)^2=m_0^2+2m_0\frac{3\Delta m}{4} \ , & m^2(\pi)=m_0^2-2m_0\frac{\Delta m}{4} \ , \\ m_0=\frac{m(\rho)+3m(\pi)}{4} \ , & \Delta=m(\rho)-m(\pi) \ . \end{array} \quad (2.6)$$

   Δm can be estimated as the interaction energy of color magnetic dipole moments proportional to the spin and inverse of the quark mass. The product of spins gives a factor determining the spin dependence of the splitting.

2. One can consider also an ad hoc formula obtained by replacing the meson mass with the mass squared in the standard formula

$$\begin{array}{ll} m^2(\rho)^2 = m_0^2 + \frac{3\Delta m^{2)}}{4} \ , & m^2(\pi) = m_0^2 - \frac{\Delta m^{2)}}{4} \ , \\ m_0^2 = \frac{m^2(\rho)+3m^2(\pi)}{4} \ , & \Delta m^{2)} = m^2(\rho) - m^2(\pi) \ . \end{array} \quad (2.7)$$

   (a) In a linear approximation for m as square root of m^2, one obtains the non-relativistic formula for the mass splitting

$$\begin{array}{ll} m(\rho) \simeq m_0 + \frac{3\Delta m}{4} \ , & m(\pi) \simeq m_0 - \frac{\Delta m}{4} \ , \\ \Delta m = \frac{\Delta m^{2)}}{8m_0} \ . & \end{array} \quad (2.8)$$

   (b) The analog of the standard formula in terms of color magnetic moments is obtained from the identification

$$\Delta m^{2)} = 2m_0 \Delta m \ . \quad (2.9)$$

   where Δm is the analog for the standard expression for the spin-spin interaction energy having the same group theoretic structure. Now however the formula $m_0 = \sqrt{3 \times m^2(S) + m^2(V)}/2$, where S *resp.* V refers to scalar *resp.* vector, would replace the formula $m_0 = (3 \times m(S) + m(V))/4$.

   (c) For pion one would obtain for the parameter m_0^2 identifiable as M_0^2 the value $m_0^2/m_p^2 \simeq .18$ $m_0/m_p = .43$, that is 404 MeV and is larger than 280 MeV for the standard model.

   (d) Could this have implications in the case of heavy quarks? If the value of m_0 in the above formula is larger than the value given by the standard formula, this is the case. However, in the approximation $m_V = m_S + \Delta$, one obtains $m_0 = \sqrt{m_0^2} \simeq m_S + \Delta/4 + (15/16)\Delta^2/8m_s$, which is slightly larger than the prediction $m_0 = m_s + \Delta$ of the standard model.

3 p-Adic mass calculations and the phenomenological picture

In this section p-adic mass calculations for hadrons are discussed. Sections stars with objections, then various p-adic mass scales assignable to hadron are discussed, contributions to the masses of baryons and meson are identified and masses for quark are deduced from the mass spectra of baryons and mesons.

3.1 Some objections against p-adic calculations

It is good to start with some objections against p-adic thermodynamics.

1. The first objection is following. Quarks would correspond to different values for p-adic prime p determining their mass scale. One should sum over the mass squared values in different p-adic number fields. The proposal is that this problem might be solved by the concept of multi-p-adicity [L5] [K4], which is made possible by adelicity meaning that different p-adic number fields are combined to adele with the additional assumption that these fields intersect each other: the numbers that are power series with respect to an integer n are p-adic with respect to the prime factors of n. A hadron would be a multi-p-adic object.

2. The notion of n-adic thermodynamics is well-defined but the problem is that each factor of n gives rise to different values of real mass squared by canonical identification. Should one sum over the real mass squared values and interpret it as mass squared for a many-fermion

state? It is however far from clear whether this sum is identifiable as sum of the mass squared values for different particles.

Should one use adelic theorem stating that rational numbers can be expressed as the product of their p-adic norms. Could the real mass squared associated with n-adic mass squared be defined as a product of p-adic norms for the mass squared obtained using n-adic thermodynamics. Only the factors of n would appear in the product.

3. CKM mixing reduces in TGD to different topological mixings for the partonic 2-surfaces assigned with U and D type quarks: the same applies in the leptonic sector. In [K7] the number theoretically motivated hypothesis that the CKM matrix is a complex rational matrix was studied.

   This however led to very large CKM mixing for $g = 0$ and $g = 1$ topologies and changed their roles: the lowest mass would correspond to $g = 1$ topology! Since the number theoretic hypothesis was rather ad hoc, one cannot take this result seriously. There is also another problem: the real counterparts of the cosines and sines associated with the CKM mixing matrix in canonical identification does not give rise to a unitary matrix so that the rationality of the CKM matrix is the worst possible option!

   The most plausible solution of the problem relies on the fact that the matrix elements of unitary matrice are in general expressible in terms of cosines and sines. Only the sines and cosines associated with Pythagorean triangles are rational numbers. It can also happen that some genuinely algebraic numbers reduce to rational numbers in some p-adic number fields. If this does not happen, the associated phases can be mapped to themselves in canonical identification for the p-adic number field considered, In the case of n-adic numbers, the condition would be that this condition is true for all prime factors of n.

3.2 Does the Lorentz invariance for p-adic mass calculations require the p-adic mass squared values to be Teichmüller elements?

p-Adic mass calculations involve canonical identification $I : x = \sum_n x_n p^n \sum x_n p^{-n}$ mapping the p-adic values of mass squared to real numbers. The momenta p_i at the p-adic side are mapped to real momenta $I(p_i)$ at the real side. Lorenz invariance requires $I(p_i \cdot p_j) = I(p_i) \cdot I(p_j)$. The predictions for mass squared values should be Lorentz invariant. The problem is that without additional assumptions the canonical identification I does not commute with arithmetics operations.

Sums are mapped to sums and products to products only at the limit of large p-adic primes p and mass squared values, which correspond to $x_n \leq\leq p$. The p-adic primes are indeed large: for the electron one has $p = M_{127} = 2^{127} - 1 \sim 10^{38}$. In this approximation, the Lorentz invariant inner products $p_i \cdot p_j$ for the momenta at the p-adic side are indeed mapped to the inner products of the real images: $I(p_i \cdot p_j) = I(p_i) \cdot I(p_j)$. This is however not generally true.

The question following.

1. Should this slight failure of Lorentz invariance be accepted as being due to the approximate nature of the p-adic physics or could it be possible to modify the canonical identification? It should be also noticed that in zero energy ontology [K11], the finite size of the causal diamond (CD) reduces Lorent symmetries so that they apply only to Lorenz group acting on either vertex of the CD.

2. Or could one consider something more elegant and ask under what additional conditions Lorentz invariance is respected in the sense that inner products for momenta on the p-dic side are mapped to inner products of momenta on the real side.

A possible solution of this problem is based on the notion of Teichmüller elements defining a representation of finite field G_p in the field of p-adic numbers is discussed.

1. Teichmüller elements $T(x)$ associated with the elements of a p-adic number field satisfy $x^p = x$, and define therefore a finite field G_p, which is not the same as that given by p-adic integers modulo p. Teichmüller element $T(x)$ is the same for all p-adic numbers congruent modulo p and involves an infinite series in powers of p.

The map $x \rightarrow T(x)$ respects arithmetics. Teichmüller elements of for the product and sum of two p-adic integers are products and sums of their Teichmüller elements: $T(x_1+x_2) = T(x_1)+T(x_2)$ and $T(x_1x_2) = T(x_1)T(x_2)$.

2. If the thermal mass squared is Teichmüller element, it is possible to have Lorentz invariance in the sense that the p-adic mass squared $m_p^2 = p^k p_k$ defined in terms of p-adic momenta p_k is mapped to $m_R^2 = I(m_p^2)$ satisfying $I(m_p^2) = I(p^k)I(p_k)$. Also the inner product $p_1 \cdot p_2$ of p-adic momenta mapped to $I(p_1 \cdot p_2) = I(p_1) \cdot I(p_2)$ if the momenta are Teichmüller elements.

3. Should the mass squared value coming as a series in powers of p mapped to Teichmüller element or should it be equal to Teichmüller element?

   (a) If the mass squared value is mapped to the Teichmüller element, the lowest order contribution to mass squared from p-adic thermodynamics fixes the mass squared completely. Therefore the Teichmüller element does not differ much from the p-adic mass squared predicted by p-adic thermodynamics. For the large p-adic primes assignable to elementary particles this is true.

   (b) The radical option is that p-adic thermodynamics and momentum spectrum is such that it predicts that thermal mass squared values are Teichmüller elements. This would fix the p-adic thermodynamics apart from the choice of p-adic number field or its extension. Mass squared spectrum would be universal and determined by number theory. Note that the p-adic mass calculations predict that mass squared is of order $O(p)$: this is however not a problem since one can consider the m^2/p.

This would have rather dramatic physical implications.

1. If the allowed p-adic momenta are Teichmüller elements and therefore elements of G_p then also the mass squared values are Teichmm̈uller elements. This would mean theoretical momentum quantization. This would imply Teichmüller property also for the thermal mass squared since p-adic thermodynamics in the approximation that very higher powers of p give a negligible contribution give a finite sum over Teichmm̈uller elements. Number theory would predict both momentum and mass spectra and also thermal mass squared spectrum.

   What does it mean that the product of Teichmüller elements is Teichmüller element? The product xy can be written as $\sum_k (xy)_k p^k$, $(xy)_k = \sum_l x_{k-l}y_l$. For Teichmüller elements $(xy)_k$ has no overflow digits. This is true also for $I(xy)$ so that $I(xy) = I(x)I(y)$. Similar argument applies to the sum.

2. The number of possible mass squared values in p-adic thermodynamics would be equal to the p-adic prime p and the mass squared values would be determined purely number theoretically as Teichmüller representatives defining the elements of finite field G_p. The p-adic temperature [L13], which is quantized as $1/T_p = n$, can have only p values $0, 1, ...p-1$ and $1/T_p = 0$ corresponds to high temperature limit for which p-adic Boltzman weights are equal to 1 and the p-adic mass squared is proportional to $m^2 = \sum g(m)m/\sum(g(m))$, where $g(m)$ is the degeneracy of the state with conformal weight $h = m$. $T_p = 1/(p-1)$ corresponds to the low temperature limit for which Boltzman weights approach rapidly zero.

3.3 p-Adic mass calculations in the hadronic sector

The mass calculations of leptons using p-adic thermodynamics are reasonably well understood [K4, K1] [L5] and can serve as a useful guideline in the hadronic case. There are 2 basic contributions: fermionic contributions and the contributions related to the genus of the parton surface. Genus-generation correspondence explaining the family replication phenomenon and why there are only 3 fermion generations [K1] is essential. CKM mixing as a difference topological mixings for U and D type quarks is also important but in the following considerations it will be neglected. The partonic contribution is non-vanishing for $g > 0$ and dominates for $g = 2$.

The situation in the hadron sector not so clear and the recent progress in the TGD view of standard odel physics might help. Several questions can be posed.

1. In the TGD counterpart of the quark-gluon phase, X^4 phase, the fermions are massless, except mass parameters defined by Higgs expectations at the singularities defining the vertices.

   p-Adic thermodynamics [K4] applies also at the hadron level [K7] and the proper description is in terms of generalization of super-conformal representations of Kac-Moody algebra to the level of "world of classical worlds" (WCW) [K3, K2, K8] [L7]. At WCW level, the modes of the second quantize H spinor fields define ground states for these representations.

   Since hadrons consist of quarks, it makes sense to speak of quark masses at H level. Does it make sense to assign p-adic mass scales to both quarks and hadrons? The earlier answer "yes" conforms with the notion of many-sheeted space-time.

2. What p-adic mass scale does the fermionic contribution from the p-adic thermodynamics assigned to the conformal scaling generator L_0 (conformal weight as mass squared) correspond to? Are the p-adic length scales the same as for the genus contribution from the partonic surface? This is the case if the fermionic lines correspond to intersections of string world sheets with the partonic orbits and will be assumed in the sequel.

3. The favored number of direct summands of the Virasoro algebra is 5. How can one understand this in terms of fermionic and geometric contributions? There are fermionic contributions to the scaling generator L_0 from weak isospin identified as strong isospin, from the ordinary spin, and from U(1) charge (electromagnetic charge). This would 3 direct summands to the Virasoro algebra.

   Concerning geometric contributions,let us assume that the description of the space-time surface as a string world sheet or its deformation makes sense. In good approximation it has 2-D projections to M^4 and CP_2.

   There is a geometric contribution from the 2 real M^4 degrees of freedom orthogonal to the string. By holomorpy, this corresponds to a single complex degree of freedom. Also the deformations of the 2-D CP_2 projection give 1 complex degree of freedom. This would give 3+2 5 degrees of freedom.

3.3.1 What p-adic mass scales are involved?

What p-adic mass scales does the description of hadron involve?

1. The massdifference between a proton and a neutron would most naturally correspond to the difference associated with the weak isospin identifiable in the TGD framework as fermionic color isospin and strong isospin. This mass difference is of order 1 MeV and suggests that $k = 127$ space-time sheets with the size of order electron Compton length are involved with the description of the hadron.

   I have proposed that these sheets correspond to long monopole flux tubes assignable to the magnetic body of the hadron and proposed that they could solve the anomaly due to the slightly too large charge radius of the proton. These space-time sheets would play a key role in the description of the energy levels of the nuclei for which MeV defines the natural length scale. If these flux tubes correspond to the hadronic magnetic body, then their contribution to the mass squared would be small.

2. $\rho - \pi$ mass difference (see this and this) is large, of the order of 530 MeV. This suggests the presence of a hadronic p-adic length scale, which corresponds to either hadronic p-adic length scale $k = 107$ or $k = 109$. This space-time sheet could be accompanied to hadron itself characterized by hadronic mass scale.

   In QCD, color magnetic spin-spin interaction describes the mass squared difference and in TGD the corresponding interaction would be associated with isospin. This interaction explains also the large mass differences for baryons: $N - \Delta$ mass difference is the basic example.

3. The earlier considerations suggest that one can assign to pion a mass scale with is around the p-adic mass scale $k = 113$ assigned with the nuclei. The mass scale would be about $m_p/8 \simeq 940/9 = 100$ MeV and would relate to the description of strong interactions in terms of meson exchanges, in particular pion exchange.

4. What about the role the Kähler structure of M^4 important having also interpretation as Hamilton-Jacobi structure? It has become clear that the hypercomplex part of the Kähler form of M^4 must vanish. This conforms with the physical intuition that only 2 M^4 degrees of freedom are dynamical and corresponds to the degrees of freedom orthogonal to that string world sheet.

3.3.2 Contributions to the meson mass squared in the phenomenological picture

I have tried to develop a view of the contributions to mass or mass squared in the hope of getting estimates for the quark masses and other parameters.

1. Mass differences for the mesons are therefore informative. Off-diagonal mesons do not mix and are easy. They can be taken as a starting point. For diagonal bosons such as η, η' and heavier neutral mesons mixing brings in additional parameters. We can compare the mass (squared) differences of mesons containing s, c and b to those not containing them.

2. The contribution from the genus of the partonic 2-surface dominates in p-adic mass calculations for $g = 2$ and is non-vanishing and large also for $g = 1$ but vanishes for $g = 0$. This contribution depends on the p-adic length scale k_q of the quark and the simplest assumption is that k_q does not depend on the hadron.

   u, d, s, ... would correspond to a hierarchy of partonic 2-surfaces characterized by genus and p-adic length scale k_q. The CKM mixing due to the different topological mixings of partonic 2-surfaces must be also taken into account.

3. Quark would correspond to a fermion line as a boundary of a string world sheet at the orbit of a partonic 2-surface identifiable as an "end" of a closed 2-sheeted monopole flux tube. "Ends" of the flux tube would be Euclidean wormhole contacts between the Minkowskian space-time sheets.

   String tension and length would parameterize the monopole flux tube and the simplest assumption is that the p-adic prime is the same for the monopole flux tube and the partonic 2-surface carrying the quark and equals to k_q.

4. Electroweak screening and its scaled variant for hadrons would realize color confinement in CP_2 spin degrees of freedom as electroweak screening above the meson length scale. The second "end" of the flux tube carries $\nu_L \overline{\nu}_R$ neutralizing the weak charge.

   Can one assume that the p-adic prime of ν_L is the same as that for quark or that ν_L has the same p-adic length scale as the ordinary neutrino? The quark mass would contain a rather large additional contribution unless the negative contribution from the interaction of the quark with the left-handed member of the neutrino pair compensates for it. This cancellation might take place also for the ordinary neutrinos and explain why they are almost massless. One must of course keep in mind that this picture is only one possible option.

5. There is also a weak, or actually rather strong Coulomb interaction, between quarks. It can be repulsive or attractive. It could help to understand the "too large" $D_s - D$ mass difference, the "too small" $\Sigma_c - \Xi_c$ mass difference and the "wrong" sign of $\Sigma_b - \Xi_b$ mass differences which cannot be understood in a simple quark model without interactions. This will be discussed later.

6. There is a hierarchy of p-adic length scales reflecting the many-sheeted of the space-time and the scale of mass differences allows us to make tentative identifications of k_q and p-adic primes characterizing the hadron or its magnetic body.

   $k = 127$ would relate to the mass differences between u and d measured in MeVs. This scale could be assigned to hardon or its magnetic body of hadron with size about electron Compton length: this could relate to the anomalously large charge radius of proton.

   Muon and possibly also atomic nucleus corresponds to $k = 113$. It could also characterize u and d quark if the mass squared is additive. The s-d mass difference of order 400 MeV suggests that s quark could correspond to $k = 109$ or even $k = 107$ defining the nucleon mass scale.

3.3.3 Mass formula for mesons

The basis formula for the mass squared of a M is

$$\begin{aligned} m^2(M) &= \sum_{i=1,2} m_0^2(k_{q_i}) + m^2(g,k_{q_i}) + m^{2)}(k_{q_i}) + Y \\ &= \sum_{i=1,2} m_0^2(113) + m^2(g,113) + m^{2)}(113)]2^{k_{q_i}-113} + Y \quad . \end{aligned} \tag{3.1}$$

Here $m^{2)}$ denotes sum of the negative quark-neutrino interaction conformal weight and of the neutrino contribution to the mass squared of the quark monopole flux tube. $m^{2)}$ includes also a positive contribution from the string tension of the monopole flux tube.

Y denotes the contribution to the interactions of quarks and possible contribution from the magnetic body of the system. In the case of baryons this contribution is large and has interpretation in terms of the hadronic string tension. The color magnetic spin-spin splitting of the $\rho - \pi$ system implies that the mass of the pion without this splitting is around 330 MeV. This suggests a contribution to the magnetic body of the pion considerably larger than the quark contribution. This contribution could be interpreted in terms of hadronic string tension.

The almost masslessness of free neutrinos and the success of the mass squared formula for the pion suggest that this contribution for u and d quarks is very small but could be sizable for more massive quarks.

Using pion mass squared as a unit one can write the mass squared formula as

$$\begin{aligned} \frac{m^2(M)}{m(\pi)^2} &= \sum_{i=1,2} [X_1(i) + X_2(g_i) + X_3(g_i)]2^{113-k_{q_i}} + Y \quad , \\ X_1(i) &= \frac{m_0^2(113)}{m(\pi)^2} \quad , \\ X_2(g) &= \frac{m^2(g,113)}{m(\pi)^2} \quad , \\ X_3(g) &= \frac{m^{2)}(113)}{m(\pi)^2} \end{aligned} \tag{3.2}$$

Y counts for the strong isospin interaction energies between quarks and for the magnetic energy of the meson. It is useful to estimate the parameters appearing inside the brackets [] in the formula for a given value of g.

X_1 refers to the purely fermionic contribution, X^2 refers to the contribution from the genus of the partonic orbit, and X_3 to the contribution of from the magnetic energy and scaled weak interaction of fermion with the screening $\nu_L\overline{\nu_R}$ pair. The detailed formulas for the various contributions will be discussed later.

The original view was that the formulas can be applied to non-diagonal mesons M for which no mixing with other mesons takes place in the old fashioned quark models. However, it turned out that model works excellently for diagonal mesons without any mixing, even better than for non-diagonal ones.

3.3.4 Mass formula for baryons

One can also consider baryons. The Gell-Mann model with additive quark masses works nicely and it is far from obvious that additivity for quark masses could work. If one assumes that quark masses are for baryons the same as for mesons the only conclusion reached by studying nucleon mass is that the additive mass squared formula must contain a large contribution $M_0^2(B)$ which dominates over the quark mass squared values m_q^2. For baryons this would give in good approximation an additive mass formula but with quark masses replaced with effective quark masses $m_{q,eff} = m_q^2/2M_0(B)$. The interpretation $m_{q,eff}$ could be in terms of current quark masses deduced from the mass differences between hadrons.

It turns out that $M_0(B)$, and more generally $M_0(H)$, depends on the hadron. The requirement that the effective masses m_q do not depend on hadron implies that $M_0(H)$ is an octave of $M(N)$ or $M(\pi)$ and that m_q^2 scales like $M_0(H)$.

$M_0(H)$ is identifiable as the TGD counterpart of the gluon contribution in QCD and would correspond to the magnetic body of baryon. u and d masses are of order 2-5 MeV. $M_0^2(H)$ would correspond to hadronic string tension in a good approximation. This suggests an interpretation in terms of hadronic string model generalized so that quarks monopole flux tubes are associated with hadronic monopole flux tubes.

3.3.5 Mass formulas for quarks

It is possible to estimate quark masses from the p-adic mass formulas which include the contribution coming from genus [K4, K1] [L5]. From these formulas one can deduce convenient formulas for m_q^2/m_e^2 using $k_e = 127$ and simplifying the notation:

$$\begin{array}{l} \frac{m_q^2}{m_e^2} = \frac{2^{127-k_q}}{3}\frac{A_q}{A_e} \ , \\ \\ A_u = 5 + X_u \ , \quad A_c = 14 + X_c \ , \quad A_t = 65 + X_t \ , \\ A_d = 8 + X_d \ , \\ A_s = 17 + X_s \ , \quad A_b = 68 + X_b \ , \quad A(e) = 5 + X_e . \end{array} \tag{3.3}$$

The corrections X_q and X_e are positive and smaller than 1.

3.3.6 Mass splittings due to weak interactions in hadron scale

The identification of strong isospin, fermionic color isospin and weak isospin and strong interaction as a weak interaction with a p-adically scaled up range means a rather dramatic modification of the QCD picture.

1. The weak interaction would manifest itself as a Coulomb force analogous to the color Coulomb force possibly important for understanding the mass splittings of hadrons and as magnetic spin-spin interaction explaining $\rho - \pi$ and $\Delta - N$ mass splittings.

2. At the level of H spinors color triplets for quarks can be understood. How do they emerge at the level of X^4. CP_2 is analogous to a sphere but has 3 poles. This gives rise to the counterpart of 3-fold color at the space-time level. There are 3 types X^4 spinor modes associated with the space-time surfaces having a hole associated with one of these 3 poles. This implies that in the basic vertex describing creation of fermion pair α_w is replaced with $9\alpha_w \simeq \alpha_s$.

3. One can ask whether the increase of the p-adic length scale means that α_w increases so the scaled up weak force becomes even stronger in the hadronic scales - just as in QCD.

4. A serious objection is that large parity breaking effects in hadronic scales are predicted. I have discussed this objection in [L11]. The smallness of $sin^2(\theta_W)$ for the scaled up variants of weak interaction as strong interaction could make these effects small for hadrons.

3.3.7 Scaled up variant of weak Coulomb interaction and mass splittings of hadrons

p-Adic mass calculations predict different masses for U and D type quarks and the obvious question is whether this could explain the mass squared difference between hadrons. It turns out that this is not true. For pions one would obtain no mass splittings and for nucleons the predicted mass splitting is too small. Could the weak Coulomb force explain the splittings?

Consider nucleons as an example. Proton corresponds to uud and neutron to udd and in absence of electroweak contribution the additivity of mass squared gives

$$m_n^2 - m_p2 = m_d^2 - m_u^2 \ . \tag{3.4}$$

The sign is correct but for the $k_d = k_u = 113$ option for the p-adic mass scales the splitting is by a factor 1/4 too small.

1. For proton (uud) there is attractive weak Coulomb interaction between u-d pairs and repulsive interaction between the quarks of the uu pair. For neutrons (udd), the repulsive interaction is between members of the dd pair.

2. The first guess is that weak Coulomb force between quarks contribute to the mass squared m_H^2 of the hadron a contribution, which is given by

$$\Delta m_{ij}^2 = 2m_{ij}\Delta m_{ij} \ , \quad m_{ij} = \sqrt{m_i^2 + m_j^2} \ , \tag{3.5}$$

   where Δm_{ij} is identified as the weak Coulomb interaction energy of the quark pair in its rest system.

3. For the n-p mass squared difference this would give additional contribution

$$\Delta(m_n^2 - m_p^2) = 2(m_{dd}\Delta m_{dd} - m_{uu}\Delta m_{uu}) \ . \tag{3.6}$$

   Here the additivity of mass squared gives $m_{qq} = \sqrt{2}m_q$.

   The physical intuition suggests that Δm_{ij} corresponds to weak Coulomb interaction energy Δm_{qq} in the rest system of quark pair.

4. Since the quarks have the same isospin, the interaction is repulsive: this case is relevant for n-p mass difference. The distance between quarks q_i and q_j of the same isospin is of the order of the hadronic Compton length scale $L_c(H) = 2\pi/m_H$. This would give the estimate

$$\Delta m_{ij} \sim \frac{g_w^2}{L_c(H)} = 2\alpha_w m(H) \ .$$

   Here the vertex for the creation of quark pair suggests that one could have $\alpha_w \to \alpha_w^s = N_c^2\alpha_w$, $N_c = 3$. The formula $\alpha_w = \alpha_{em}/sin^2(\theta_w)$ suggests that the value of $sin^2(\theta_W)$ could be smaller for the p-adically scaled variants of weak interactions in long length scales and make α_w strong.

   The basic objection agains TGD view of strong interactions is that it can lead to large parity violation in hadron physics. The strength of parity violation is proportional to $sin^2(\theta_w)$ and its smallness could make these effects very small for the scaled variants of strong interaction.

5. From above formula, one would obtain

$$\begin{array}{ll} \Delta(m_n^2 - m_p^2) = 4\sqrt{2}\alpha_w(m_d m_n - m_u m_p) & \\ = 4(\sqrt{2}\alpha_w[x_d m_d^2 - x_u m_u^2] \ , & \\ x_d = 4\sqrt{2}\alpha_w \frac{m_n}{m_d} \ , & x_u = 4\sqrt{2}\alpha_w \frac{m_p}{m_u} \end{array} \tag{3.7}$$

   In the approximation $m_p = m_n$ the correction is proportional to $m_d - m_u$ and is positive as required. The contribution to the $n-p$ mass difference 1.3 MeV would be $\Delta(m_n^2 - m_p^2)/(m_n + m_p) = .65$ MeV and is of correct order of magnitude but lacks factor 2. The increase of α_w by factor 2 to 5×10^{-2} would give rise to the needed value. This indeed is the magnitude of the weak coupling strength.

6. If the quarks of opposite charge can be regarded free inside the hadronic volume, one obtains apart from sign the previous estimate apart for quark pairs of opposite charges. This contribution predic correct order of magnitude for $D_s - D$ and $B_s - B$ mass differences.

In the case of baryons one can also consider the possibility of bound states between quarks of opposite weak isospin and in the case of mesons between quark and its antiquark.

Atomic physics serves as a guideline making it possible to estimate the energetics.

1. The bound states energy scale for an atom consisting of electron and much heavier proton is given by $\alpha^2 m_e/2$. In the case of hadron the weak analog of this energy for a quark pair would be of the order $\alpha_W^2 m_{red}/2$, where the reduced mass is $m_{red} = m_1 m_2/(m_1 + m_2)$. If either quark is much lighter, the mass reduces to the mass of the lighter quark. For $m_1 = m_2$ one has $\mu = m_1/2$. This energy is considerably smaller that the estimate for the repulsive energy proportional to $\alpha_w m_H$.

2. For u and d quarks with mass scale of 100 MeV, the order of magnitude is .025 MeV for the energy of $q\overline{q}$ bound state. In this case, the possibility that a bound state is formed and here atomic physics provides a guideline. For the bound state of c quark and b quark this energy would be of the order of .5 MeV and could explain the deviation of the TGD prediction for D mass from the experimental value.

3.4 Deducing the quark masses from baryon masses

One deduce quark masses by using data for the hadron masses provided by the particle Data Tables. Additivity of mass squared is suggestive for the constituent quarks which in QCD would be explained in terms of the dominating gluonic contribution. One can compare hadronic mass differences and try to extract different contributions to the constituent quark masses. One can uses as data the masses of non-diagonal mesons, for which the mixing does not complicate the situation.

The motivation for considering baryons first is that for light mesons spin-spin splitting is large and the use of say pion mass as starting point to deduce quark parameters can lead to wrong conclusions.

The additive mass formula works well for Gell-Mann model for light baryons and the correspondence of the quark masses in the TGD based model and current quark masses and constituent quark masses is given by

$$\begin{aligned} \frac{m_q^2(TGD)}{2M_0} &\leftrightarrow m_q(current) \ , \\ m_q(TGD) &\leftrightarrow m_q(const) \ . \end{aligned} \tag{3.8}$$

The values of m_q can be deduced from the hadronic mass differences. From the formula

$$m_B = \sqrt{M_0^2(B) + \sum m_{q_i}^2} \simeq M_0 + \frac{\sum m_{q_i}^2}{2M_0(B)} \tag{3.9}$$

one can estimate the quark masses m_q^2 and compare them to the predictions of p-adic mass calculations. Note however that Ω baryon with mass 1672 MeV, the first order approximation $\sqrt{1+x} \simeq 1 + x/2$ is not so good anymore if one assumes $M_0(\Omega) = M_0(N)$.

3.4.1 Mass splittings due to different masses of u and d quarks

The mass splittings between hadrons quarks provide information about quark masses. The Gell-Mann type model assumes additivity of quark masses and TGD predicts additivity of mass squared values of quarks.

p-Adic mass calculations predict that the mass squared values for electron and quarks and the contributions to the masses of U and D quarks coming from standard model degrees of freedom are different.

An interesting question is whether these $U - D$ mass differences alone can explain the mass differences of hadrons differing only by the replacement $U \leftrightarrow D$. Let us assume that this is the case.

1. The contributions are

$$\frac{m_U^2}{m_0^2} = \frac{5+\Delta}{3} 2^{-k_U} \quad ,$$
$$\frac{m_D^2}{m_0^2} = \frac{8+\Delta}{3} 2^{-k_D} \quad . \tag{3.10}$$

   The parameter $\Delta \leq 1$ corresponds to higher order corrections.

2. The mass formula for electron reads as

$$\frac{m_e^2}{m_0^2} = \frac{5+\Delta_e}{3} \times 2^{-k_e} \quad ,$$
$$. \tag{3.11}$$

   $k_e = 127$ corresponds to the p-adic prime $M_{127} = 2^{127} - 1$ characterizing the electron.

3. These formulas allow to express quark masses in terms of electron mass:

$$\frac{m_U^2}{m_e^2} = \frac{5+\Delta_U}{5+\Delta_e} \frac{1}{3} 2^{k_e - k_U} \quad ,$$
$$\frac{m_D^2}{m_e^2} = \frac{8+\Delta_D}{5+\Delta_e} \frac{1}{3} 2^{k_e - k_D} \quad . \tag{3.12}$$

   $\Delta_e = \Delta_U$ looks plausible but $\Delta_u = \Delta_d$ is a questionable assumption.

4. The mass squared splitting for U and D type quarks contributes to the proton-neutron mass difference but, as will be found, not to pion mass difference. The mass squared values for proton and neutron are given by

$$m_n^2 = M_0^2(B) + m_u^2 + 2m_d^2 \quad , \quad m_p^2 = M_0^2(B) + 2m_u^2 + m_d^2 \quad . \tag{3.13}$$

   This gives

$$m_n^2 - m_p^2 = m_d^2 - m_u^2 \quad . \tag{3.14}$$

   This gives

$$\frac{m_n^2 - m_p^2}{m_e^2} = \frac{2^{k_e - k_d}}{X} \quad ,$$
$$X = (5+\Delta_e) \frac{3}{3 + \Delta_d - \Delta_u} \quad . \tag{3.15}$$

   This gives the prediction

$$2^{k_e - k_d} = \frac{m_n^2 - m_p^2}{m_e^2} \times X \quad . \tag{3.16}$$

   The neutron and proton masses are $m_n = 939.565$ MeV and $m_p = 938.272$. This gives $(m_n^2 - m_p^2)/m_e^2 = 9712.2$. For the simplest option $\Delta_u = \Delta_d$ and $\Delta_e = 0$, the right hand side equals $Y = 48561$.

5. The variation of the parameters Δ_u, Δ_d and Δ_e can transform the right-hand side of the previous equation a power of 2. The variation of Δ_e allows to vary the scale of X in the range $[5,6]$. The variation of Δ_u and Δ_d gives a factor varying in the range $[1/2,1/4]$ so that the value of X varies by an octave. This allows to tune the right-hand side of the equation so that an integer value of k_e-k_d is obtained. Due to the variation of $\Delta_d-\Delta_u$, the factor X varies in the range $[3/4,3/2]Y=[32768,65536]$.

6. The condition $k_e-k_d=16$ would give $k_d=111$ and the upper end $X=65536$. $k_e-k_d=112$ would give the lower end $X=32768$. For $k_u=k_d=111$, the estimate m_u^{eff} would be $m_u^{eff}=10.1$ MeV. $k_u=k_d=112$ would give $m_u^{eff}=5.0$ MeV. $k_u=k_d=113$ would give $m_u^{eff}=2.5$ MeV but is not allowed by the above estimate.

   Of course, the physically quite plausible possibility is that the $p-n$ mass difference is not solely due to the $u-d$ mass difference.

The prediction for the effective quark mass $m_q^{eff}=m_q^2/(2M_0(H))$ is

$$m_q^{eff} = \frac{1}{3}\times 2^{16}\times\frac{s_q+\Delta_q}{5+\Delta_e}\times\frac{m_e^2}{2M_0(H)} \quad . \tag{3.17}$$

One has $(s_d,s_u)=(8,5)$ and in an excellent approximation one has $M_0=m_p=940$ MeV and $m_e=.5$ MeV.

It is possible to test this prediction.

1. There are several empirical estimates for the current quark masses of u and d quark and they vary in a rather wide range. An earlier estimate that I have used in my own article, is $m_u^{eff}\simeq 5$ MeV and $m_d^{eff}\simeq 10$ MeV. The latest estimatem given by Google, is $m_u^{eff}\in[2.0,2.4]$ MeV and $m_d^{eff}\in[4.7,5.0]$ MeV. The above estimate favors the first option.

2. The $k_d=k_u=113$ option is not allowed by the assumption that the mass difference for nucleons are solely due to the u-d mass difference but deserves to be considered since it seems the most realistic one. For $(\Delta_e,\Delta_u,\Delta_d)=(0,0,0)$ the prediction $(m_u^{eff},m_d^{eff})=(2.91,4.65)$ MeV. The prediction for m_u^{eff} is slightly larger than the empirical esimate but the increase of Δ_e improves the situation and is almost consistent with the empirical values. $\Delta_e=1$ gives $(m_u,m_d)=(2.43,3.88)$ MeV. The increase of Δ_d allows to raise the value of m_d by at most a factor $9/8$ gives $(m_u^{eff},m_d^{eff})=(2.43,4.37)$ MeV to be compared with the smaller empirically estimated range $[2.0,2.4]$ MeV and $[4.7,5.0]$ MeV. This option gives $(m_u,m_d)=(67.6,90.6)$ MeV.

3. For the $k_d=k_u=112$ option allowed by the above argument, the effective quark masses become $(m_u^{eff},m_d^{eff})=(4.86,8.76)$ MeV. I have used this range in earlier considerations related to quark masses. For this option one has $(m_u,m_d)=(95.87,128.18)$ MeV.

4. For $k_d=k_u=111$ option the effective quark masses would be $(m_u^{eff},m_d^{eff})=(9.72,17.52)$ MeV. $(m_u,m_d)=(135.2,181.2)$ MeV is not consistent with the condition $M_0(\pi)\leq m(\pi)$ so that this option is excluded.

5. The values of quark masses (m_u,m_d) and $m_{\pi^+}=139.6$ MeV allows to estimate $M_0(\pi)$ from the formula $M_0(\pi)=\sqrt{(m_{\pi^+}^2-m_d^2-m_u^2)}$. For $k_d=k_u=113$ not favored by the above argument, one has $(m_u^{eff},m_d^{eff})=(2.43,4.37)$ MeV giving $M_0(\pi)\simeq 139.51$ MeV. $k_d=k_u=112$ and $k_d=111$ options would give an imaginary value of $M_0(\pi)$ so that they are excluded.

The outcome of these considerations is that $k_u=k_d=113$, which corresponds to Gaussian Mersenne prime and is assigned with atomic nuclei, is favored but that the assumption that proton mass difference is solely due to the different masses of U and D quarks does not favor this option. One can invent several explanations for the discrepancy. The scaled weak interactions between quarks in nucleon length scale contribute to the mass difference. For protons with uud composition the repulsive Coulombic weak interaction energy for uu pair is expected to be by a factor 4 larger than from dd pair. Suppose that the same is true also the interaction conformal weights $m^2)_u$ and $m_d^{2)}$. The difference $\Delta_w = m^2)_u - m_d^{2)}$ tends to decrease the $n-p$ mass difference. This contribution transforms the above used formula to

$$m_n^2 - m_p^2 + \Delta_w = \quad m_d^2 - m_u^2 \quad . \tag{3.18}$$

must be nearly the same as the mass difference due to $d-u$ mass difference in order to reduce the mass difference by factor 1/4.

$$m_n^2 - m_p^2 \rightarrow m_n^2 - m_p^2 + \Delta_w \simeq \frac{m_n^2 - m_p^2}{4} \quad . \tag{3.19}$$

3.4.2 The origin of mass splittings of pions

Also the mass differences of pions provide valuable information.

1. The mass of charged pion having $u\overline{d}$ type decomposition can be written as

$$m^2(\pi^\pm) = M_0^2(\pi) + m_u^2 + m_d^2 \quad . \tag{3.20}$$

   Here $M_0(\pi)$ corresponds to the ground state contribution which can depend on hadron and can be deduced one the p-adic mass scales k_u and k_d m_u and m_d are fixed.

2. The prediction for the mass $m(\pi^0) \simeq 134$ MeV of neutral pion is not straightforward. π_0 us superposition of $u\overline{u}$ $d\overline{d}$ and the additivity of mass squared would suggest that the mass formula is

$$\begin{aligned} m^2(\pi^0) &= \tfrac{1}{2}[m^2(u\overline{u}) + m^2(d\overline{d})] \quad , \\ m^2(u\overline{u}) &= M_0^2(\pi) + 2m_d^2 \quad , \qquad m^2(d\overline{d}) = M_0^2(\pi) + 2m_u^2 \quad . \end{aligned} \tag{3.21}$$

   This gives

$$m^2(\pi^0) = M_0^2(\pi) + m_u^2 + m_d^2 = m^2(\pi^\pm) \quad . \tag{3.22}$$

   so that no mass splitting for pions is predicted. This irrespective of the masses of u and d quark.

   The observed mass splittings must reflect electromagnetic and weak interaction between quarks: for $u\overline{d}$ they are repulsive and attractive for $q\overline{q}$ and this could explain the mass splitting.

   If one assumes that the masses rather than mass squared values appear in the quantum mechanical formula, one obtains

$$m(\pi^0) = \frac{1}{2}[\sqrt{2m_d^2 + M_0^2(\pi)} + \sqrt{2m_u^2 + M_0^2(\pi)}] \quad . \tag{3.23}$$

   Mass splitting would be obtained but in the TGD framework this formula is not logical.

3. In the QCD based model for $\rho - \pi$ color magnetic mass splitting, the predicted common mass of ρ and π before taking into account the spin-spin splitting, would be about 330 MeV and is rather large when compared with the pion mass. Therefore one must be very cautious in the estimates for quark masses. The TGD counterpart of color magnetic splitting is a scaled variant of electroweak splitting.

3.4.3 Are the effective quark masses hadron independent?

If the p-adic mass scale of a quark does not depend on a hadron, the TGD predictions differ from those of the G-M type model. For massive baryons and mesons the effective masses of quarks, which are light in the scale defined by the parameter $M_0(H)$, are given by $m_q^{eff} = m_q^2/2M_0(B)$. m_q^{eff} is predicted to decrease with $M_0(H)$ since there are reasons to expect that $M(B)$ is larger for baryons containing c and b quarks than for nucleons and $M_0(M)$ is larger for mesons containing s, c and b quarks than for pions.

The guess inspired by the additive mass model is that the mass differences for pairs of light hadrons obtained from each other by the replacement $u \rightarrow d$ or vice versa are nearly the same. Could this be true also for hadrons which contain heavier quarks than u, s, and d?

If this is the case then the p-adic mass scale of the quark depends on baryon and is such that the effective quark masses

$$m_q^{eff} = \frac{m_q^2}{2M_0(H)} , \tag{3.24}$$

appearing in the mass differences of hadrons, do not depend on the hadron.

A weaker condition would be that the differences

$$m_U^{eff} - m_D^{eff} = \frac{m_U^2}{2M_0(H)} - \frac{m_D^2}{2M_0(H)} , \tag{3.25}$$

where U and D refer to either u and d or c and s, depend only weakly on hadron.

Suppose that it is possible to assign to $M_0(H)$ a hadronic p-adic mass scale characterized by integer k_H so that one has

$$M_0(B) = M_0(N)2^{(k_B-k_N)/2} \quad , \quad M_0(M) = M_0(\pi)2^{(k_M-k-k_\pi)/2} \quad . \tag{3.26}$$

The condition

$$k_q - \frac{k_H}{2} = constant \quad . \tag{3.27}$$

would guarantee that the effective additivity of masses is achieved in a good approximation.

The proposal almost-predicts the values of M_0. Since k_q is a positive integer, the values of k_H must come as powers of 2, that is octaves.

1. If the mass of the baryonic quark m_q is smaller that 2 times $2m_N$, $k_B = k_N$ must be true for baryons containing this quark besides u and d. For baryons containing only u, d and s quarks this is the case. If the QCD estimate for the c quark mass about 2 GeV $\simeq 2M_0$ corresponds to m_c rather than m_c^{eff}, then for baryons containing c quark the value of k_N can be $2k_N$ so that one has $M_0(N) \rightarrow 2M_0(N)$. If the QCD estimate for the b quark mass $\simeq 4$ GeV corresponds to m_b rather than m_b^{eff}, then for baryons containing b quark it is possible to have $M_0(N) \rightarrow 4M_0(N)$.

2. $M_0(\pi) \sim 139.51$ MeV is the estimate following from the estimate for u and d masses. For strange meson K and other strange mesons it is in principle possible to have $M_0(\pi) \rightarrow 2M_0(\pi)$. Same applies to charmed and beautiful mesons and $M_0(\pi) \rightarrow 2M_0(N)$ for charmed and $M_0(\pi) \rightarrow 4M_0(N)$ for beautiful mesons is not excluded.

One cannot of course exclude the possibility that the quark mass scale does not depend on the hadrons but that M^0 comes in octaves. In this case the effective quark masses would be smaller for heavier hadrons. It will be found that this indeed the case for baryons containing c and b quarks.

To sum up, in the proposed model the p-adic primes of light quarks most plausibly correspond to $(k_u, k_d) = (113, 113)$. The surprisingly large value of k_q is due to the 1/3 factor of the mass squared formula absent from the leptonic mass squared formula.

3.4.4 Estimates for the masses of s, b and c and t quarks

One can also consider estimates for the masses of the heavier quarks. The earlier discussed mass formula for quarks in terms of electron mass allows to deduce the contributions of p-adic thermodynamics to the masses of s, c, b and t quarks. The basic mass formula [K4] reads as

$$\begin{aligned} \frac{m_q}{m_e} &= \sqrt{\frac{2^{127-k_q}}{3}\frac{A_q}{A_e}} \ , \\ A_u &= 5+X_u \ , \quad A_c = 14+X_c \ , \quad A_t = 65+X_t \ , \\ A_d &= 8+X_d \qquad A_s = 17+X_s \ , \quad A_b = 68+X_b \ , A_e = 5+X_e . \end{aligned} \tag{3.28}$$

Assuming that the corrections X_q and X_e vanish, one one obtains the following estimates

$$\begin{aligned} &(k_d, m_d/MeV) = (113, 90.6) \quad (k_s, m_s/MeV) = (108, 385) \quad (k_b, m_b/MeV) = (103, 4361) \ , \\ &(k_u, m_u/MeV) = (113, 67.6) \quad (k_c, m_c/MeV) = (103, 1979) \quad (k_t, m_t/GeV) = (93, 193) \ . \end{aligned} \tag{3.29}$$

The change of k_q by one unit, introducing a half octave scaling of m_q, cannot be excluded. *1. The mass of strange quark*

The standard model estimate for the effective mass/current quark mass of the strange quark is $m_s^{eff} \sim 100$ MeV. From this one can get an estimate m_s as $m_s = \sqrt{2M_0(N)m_s^{eff}}$ using $M_0 \simeq m_p$ as $m_s \simeq 434$ MeV to be compared with the prediction $m_s = 385$ MeV of p-adic mass calculations assuming $k_s = 108$. $k_s = 107$ would give $m_s = 544.5$ MeV.

The estimates $M_0(\pi) = 139.51$ MeV, $m_d = 90.6$ MeV and $m_s = 385$ MeV allow us to estimate the mass of kaon. This gives $m_K = 419.40$ MeV. The empirical value is $m_K = 493.677$ MeV. $M_0(\pi) \rightarrow 2M_0(\pi) = M_0(K)$ gives $m_K = 484$ MeV, which is rather near to the empirical value. This would however predict $m_s^{eff} = 265.6$ MeV, which is more than twice the value 100 MeV.

2. The mass of the charmed quark

p-adic mass calculation gives the estimate $m_c = 1979$ MeV for $k_c = 103$ whereas for $k_c = 105$ one obtains $m_c \simeq 1$ GeV. The QCD estimate $m_c^{eff} \simeq 1270$ MeV. Which value for k_c is nearer to truth?

1. An independent estimate for the value of m_c can be deduced from the mass $\Lambda_c = 2286$ MeV of Λ_c (csd) by using the formula

$$m(\Lambda_c) = \sqrt{M_0^2 + m_c^2 + m_s^2 + m_d^2} \tag{3.30}$$

giving

$$m_c = \sqrt{m^2(\Lambda_c) - M_0^2(N) - m_s^2 - m_d^2} \simeq 1.995 \ GeV \ . \tag{3.31}$$

2. This is a disturbingly large value. However, the scaling $M_0(N) \rightarrow M_0(\Lambda_c) = 2M_0(N)$ guaranteeing the hadron independence of effective masses, accompanied by the scaling of m_s and m_d by factor 2, gives $m_c = 1198$ MeV quite near to empirical estimate 1270 MeV. This suggests that the scaling hypothesis making effective masses independent of hadron works. The effective mass $m_c^{eff} = m_c^2/(4m_p)$ is 381.7 MeV and very near to the strange quark mass: is there an approximate isospin symmetry for effective masses! This could make it possible to test the hypothesis by comparing hadrons containing c quark and 2 c quarks.

3. The mass of b quark

In the standard model, b quark mass is estimated in QCD to be $m_b^{eff} = 4.19$ GeV. p-Adic length sale hypothesis gives $m_b = 4.36$ GeV.

1. One can estimate m_b from $m(\Sigma_b) = 5810$ MeV by using the formula $m(\Sigma_b) = \sqrt{M_0^2(B) + m_b^2 + 2m_u^2}$. For $M_0(N) \simeq m_p$ $m_b = \sqrt{m^2(\Sigma_b) - M_0^2(N) - 2m_u^2} \simeq 5722$ MeV, which is slightly below $m(\Sigma_b)$.

   This would give the estimate for the effective mass m_b^{eff} as $m_b^{eff} = m_b^2/2M_0(N) \simeq 8.45$ GeV larger than m_b. This does not make sense.

2. The second possibility is that scaling hypothesis for M_0 holds true and one has $M_0(B) = 4M_0(N)$. The condition that the estimate gives the p-adic value of $m_b = 4361$ MeV gives

$$M_0(B,b) = \sqrt{m^2(\Sigma_b) - m_b^2 - 2m_u^2} \simeq 3837 \text{ MeV} . \quad (3.32)$$

   This value is almost equal to $4M_N \simeq 3.760GeV$ and supports the scaling hypothesis for $M_0(H)$. m_s^{eff} is scaled down by factor $1/8to2.211$ GeV which is one half of the value of m_b deduced in QCD framework. This is somewhat disturbing and would force to interprete the empirically deduced value of b mass as m_b.

4. The mass of the top quark

The top quark mass m_t^{eff} is estimated to be in the range 172.5-173 GeV. The p-adic mass calculation gives 193 GeV for $k_t = 93$ so that the error is 11 percent cnd could be due the magnetic energy of the monopole flux tube assignable to top quark and to the negative interaction conformal weight of t with the screening neutrino pair $\nu_L\overline{\nu}_R$.

The reported mass of toponium candidate is in a good approximation twice the mass of top quark: this would require $M_0(topo,t) = \sqrt{2}m_t \simeq 2.6 \times M_0(N)$ ($M_0(N) \simeq .94$ GeV).

In TGD one can however challenge the identification of top quark. The p-adic mass scale of top quark is 175 GeV and suspiciously high when compared with the mass scale 4 GeV of b quark. In the TGD framework this suggests that the official candidate for top could be a quark of M_{89} hadron physics [K5] [L16] whereas the real top could have mass scale not much larger than that of b quark.

The Aleph anomaly [K5] produces jets with invariant mass 55 GeV. If a meson is in question the mass squared additivity suggests a quark with mass $m_q = 55/sqrt2 \simeq 39$ GeV, which is roughly 10 times more massive than m_b. Could the interpretation be as a pion of M_{89} hadron physics. The toponium for which some evidence exists, could in turn have interpretation as the kaon of M_{89} hadron physics. $k = 97$ would be a natural candidate for the p-adic length scale of this top candidate whereas the standard candidate has $k_t = 93$.

To sum up, the predictions for the p-adic mass scales of quarks are $(k_u, k_d, k_s, k_c, k_b, k_t) = (113, 113, 108, 105, 103, 93)$.

3.4.5 Test for the scaling of quark masses

Mass differences for beautiful and bottom containing baryons make it possible to test the scaling law for quark masses guaranteeing that effective quark mass hadron independent.

1. The mass of Ξ_c *resp.* Σ_c is in the range $[2470, 2500]$ MeV *resp.* $[2450, 2500]$ MeV. $\Xi_c - \Sigma_c$ mass difference using average masses is only 10 MeV although Ξ_c *resp.* Σ_c has 2 *resp.* 1 s quarks. Thefore the quark model with additive quarks masses is problematic for heavy baryons.

   The prediction of the TGD based model is

$$m(\Xi_c) - m(\Sigma_c) = \frac{(m_s^2 - m_d^2)}{m(\Xi_c) + m(\Sigma_c)} . \quad (3.33)$$

Using average masses for $m(\Xi_c)$ and $m(\Sigma_c)$ and masses $m_u, m_d, m_s =) = (67, 90, 385)$ MeV this predicts 11.7 MeV. This makes sense. However, the scaling hypothesis implies the scaling of $M_0(\Sigma) = 4M_0(N)$ and $m_s^2 - m_d^2$ by a factor 4 so that giving $m(\Xi_c) - m(\Sigma_c) = 80$ MeV. This favours the scaling of $M_0(N)$ but not that of quark masses m_q.

2. One can also consider the mass differences for beautiful baryons. The mass of Ξ_b *resp.* Σ_b is 5797.9 MeV and 5816 MeV: probably also now the error margins are large. From this $\Xi_b - \Sigma_b$ mass difference would be -16 MeV and has a different sign from expected. The TGD prediction for the mass difference is $m(\Xi_b) - m(\Sigma_b) = (m_s^2 - m_d^2)/(m(\Xi_b) + m(\Sigma_b) \simeq 4.8$ MeV. If one assumes the scaling of m_s^2 and m_d^2 by factor 4, one obtains 19.2 MeV. Also this favors the assumption that only M_0 is scaled.

   If the experimental mass difference really has a "wrong" sign, one can ask whether the weak (actually strong) b-s binding energy be larger than b-d binding energy. Assume that the analogy with atomic Coulomb energy can be used. The quark decompositions are $\Xi_c = dsc$ and $\Sigma_c = ddc$ and $\Xi_b = dsb$ and $\Sigma_c = ddb$. c-s *resp.* c-d system behaves like a system with a reduced mass $\mu = m_c m_s/(m_c + m_s)$, *resp.* $\mu = m_c m_d/(m_c + m_d)$.

   The weak Coulomb binding energy is proportional to α_w^2 and increases the value of μ and has larger magnitude for Ξ_c than for Σ_c. The magnitude in the case of c almost compensates for the positive mass difference. For b having larger mass it more than compensates it so that the mass difference changes sign.

To sum up, the predictions of p-adic length scale hypothesis for the quark masses deduced by applying the mass formula based on the additivity of the mass squared values are excellent.

3.5 Are the quark masses deduced from baryons consistent with the mass spectrum of mesons?

One can test whether the baryonic estimates for the p-adic mass scales $(k_u, k_d, k_s, k_c, k_b, k_t) = (113, 113, 108, 105, 103, 93)$ make sense for mesons. The values of k_q can vary by one unit for heavy quarks and it turns out that the value of $k_c = 103$ is favored for charmonium whereas $k_c = 104$ is favored for non-diagonal charmed mesons.

The first guess was that the parameter M_0 characterizing the magnetic body of meson and included in the parameter Y in the previous formulas, vanishes for mesons. This guess was wrong. It turns out that the octave hypothesis for M_0^2 works rather nicely but that the octave depends on the meson and in the case of charmed or beautiful mesons can be different for diagonal and non diagonal mesons.

The condition $m^{2)} = 0$ looks like a reasonable working hypothesis to start with. If the quark masses are same for mesons as for baryons, this condition need not to be considered separately. It could of course be used to improve the fit.

The mass splittings due to the isospin can be explained satisfactorily in terms assuming that the weak Coulomb interaction in hadronic scale in the role of color interaction. The splitting is proportional to the difference of masses of quark considered but in a good approximation does not depend on the meson mass.

3.5.1 Pions

The masses of pions were already found to be consistent with the p-adic length scales $k_d = k_u = 113$. The quark masses were estimated to be $(m_u, m_d) = (2.43, 4.37)$ MeV. The estimate for the value of $M_0(\pi)$ was $M_0(\pi) \simeq 139.51$ MeV. The effective quark masses are predicted to be very small: $(m_u^{eff}, m_d^{eff}) = (21, 68)$ keV.

3.5.2 Strange mesons

The neutral kaon has composition $s\bar{d}$. The mass of the kaon is $m_K = 494$ MeV. Baryonic estimate gives $k_s = 108$ and $m_s = 385$ MeV. Kaon mass squared is given by $m_K^2 = M_0^2(K) + m_s^2 + m_d^2$. $M_0^2(K) = 4 * M_0^2(\pi)$ gives $m_K = 484.0$ MeV. The error is 2 percent. The repulsive weak interaction between s and $\overline{d}$ could increase the mass by this amount. Note that in a good approximation, the correction does not depend on the meson mass.

The mass of η meson is predicted to be 544.5 MeV . The prediction is $m(\eta) = \sqrt{2}m_s = 544.5$ MeV. The experimental value is $m(\eta) = 547.9$ MeV. The deviation is .6 percent. This successful prediction suggests that no mixing between neutral mesons occurs as was believed in the original quark model.

3.5.3 Charmed mesons

Charmonium (Ψ) has mass $m(\Psi) = 3.098$ GeV. For $k_c = 103$, c quark is predicted to have mass $m_c = 1979$ MeV whereas the QCD based estimate gives a considerably smaller value $m_c^{QCD} = 1270$ MeV. For $k_c = 104$ the prediction is $m_c = 1379$ MeV.

For $M_0^2(\Psi) \simeq 2m_p^2$, m_c is predicted to be $m_c = \sqrt{m_\Psi^2 - 2m_p^2} \simeq 1.979$ and is equal to the experimental value.

D meson $c\overline{d}$ has mass $m(D) = 1870$ MeV, which is smaller than the value of $m_c = 1979$ MeV for $k_c = 103$. The mass formula $m(D) = \sqrt{M_0^2(D) + m_c^2 + m_d^2}$. For $M_0^2(D) = 2M_0^2(B)$ the mass squared formula gives $m_c = 1312$ MeV from to be compared with $m_c = 1397$ MeV for $k_c = 104$. The prediction for $m(D)$ is 1930 MeV and is by 60 MeV larger. The error is 3 percent. The attractive interaction between quark and antiquark increases the energy but seems too small to explain the discrepancy. It would seem that k_c has different values for Ψ and D. I have indeed considered the possibility that the p-adic length scales can vary.

The repulsive weak interaction between c and $\overline{c}$ would decrease the estimate for m_c. The reduction of mass squared by weak interaction should correspond to $m_c^2 - m_{c,exp}^2 = 3387$ MeV^2. Supposed that the weak interaction contribution is for a bound state of m_d with m_c and that $m_{red} = m_c m_d/(m_c + m_d) \simeq m_d$ is modified in the formation of bound state by

$$\Delta m_D^2 = 4\sqrt{2}\alpha_w(m_{red}^2) \ . \tag{3.34}$$

The formula

$$m(D) = \sqrt{M_0^2(D) + \Delta m_D^2 + m_c^2 + m_d^2} \tag{3.35}$$

gives the improved estimate for m_D as $m_d = 1932$ MeV. The contribution does not help.

3.5.4 Beautiful mesons

Consider next the mesons containing b quark. Bottonium () has mass $m_Y = 9.40$ GeV. $k_b = 102$ predicts $m_b = 6.167$ GeV whereas the mass derived theoretically from QCD is 4.19 GeV and considerably smaller. p-Adic mass calculation predicts $m_b = 4361$ MeV for $k_b = 103$. For $M_0^2(Y) \simeq 16m_p^2$ allowed by the scaling hypothesis, the mass of Y is predicted to be 9.50 GeV, being by .5 percent above the experimental estimate of 9.45 GeV. The attractive electroweak interaction between b and $\overline{b}$ could explain the deviation.

For B meson ($b\overline{s}$) with mass $m_B = 5279$ MeV, the contribution of d quark to the mass is negligible. Scaling hypothesis suggests $M_0^2(B) = 4M_0^2(N) \simeq 4m_p^2$. $M_0^2(B) = 8m_p^2$ gives $m_B = \sqrt{8m_p^2 + m_b^2 + m_s^2} = 5122$ MeV. The error is 2 percent. For $M_0^2(B) = 10m_p^2$, which does not confirm with the assumption that only the p-adic scalings by powers of 2 are allowed, one obtains $m_B = 5292$ MeV: the error is .2 percent. It seems that the value of $M^0(H)$ is different for bottonium and B meson.

The repulsive weak interaction between b and $\overline{s}$ has a wrong sign and cannot explain the discrepancy.

3.5.5 Mass differences between strange and non-strange beautiful mesons

For both charmed and beautiful c mesons the mass differences between strange and non-strange variants produce problems. Similar problem was encountered for baryons.

D_s meson $c\overline{d}$ has mass 1968 MeV. The $D_s - D$ mass splitting is 98 MeV. The additivity of mass squared would give $m_D = \sqrt{2M_0^2(N) + m_c^2 + m_d^2}$ and $m_{D,s} = \sqrt{2M_0^2(N) + m_c^2 + m_s^2}$ predicting

$m_{B,s} - m_B \simeq (1/2m_B) \times (m_s^2 - m_d^2) \simeq 2.86$ MeV, which is considerably smaller than 87 MeV. Here weak interaction correction $\Delta m_B^2 = 4\sqrt{2}\alpha_w \times m_b m_D$ and similar correction for D_s gives $m_{D_s} - m_D \simeq (m_b - m_d)/2 \simeq 41$ MeV for $\alpha_w = 0.5$, which has correct order of magnitude. For $\alpha_w = .1 \simeq \alpha_s$ the correction is 82 MeV. Note that in a good approximation the correction does not depend on M_D.

For B_s meson the mass is $m_{B_s} = 5366$ MeV. The mass difference $m_{B,s} - m_B = 87$ MeV is almost the same as in the case of the $D - D_s$ system. Also in this case weak correction predicts $m_{B,s} - m_B = 87 \simeq 82$ MeV for $\alpha_w = .1 \sim \alpha_s$. Note that for $sin^2(\theta_w) = .2326$, the values of $\alpha_w = .03$: earlier the value .05 has been used. The argument that $\alpha_s = N_c^2 \alpha_w$, $N_c = 3$ occurs in the vertex for a creation of a quark pair would give $\alpha_w = .27$.

4 Strong interactions as p-adically scaled weak interactions

In this section the view about strong interactions as p-dically scale weak interactions is studied in more detail.

4.1 Reflections on parity violation

In this section the problem of parity violation at the hadron level. Parity violation is visible at the level of atomic and nuclear physics via the interference between Z^0 and γ exchanges. The scattering of an electron and a hadron/nucleus/atom is an example of this. The absence of the violation in strong interaction is far from obvious: RHIC has actually reported evidence for a parity violation in the collisions of high energy heavy nuclei [C1] and I have considered this problem from the TGD point of view [L1, L11].

The Z^0 coupling is of the form

$$I_{3,L} - sin^2\theta_W Q_{em}) \ .$$

The coupling is purely left-handed when the Weinberg angle vanishes. In this case, there is no parity violation. Z^0 has a small vecorial coupling via electromagnetic charge.

Some basic formulas and facts will be needed in what follows. The weak coupling strength and $U(1)_Y$ coupling strength (see this) are given by the expressions

$$\alpha_w = \frac{\alpha_e m}{sin^2(\theta_W)} \ , \quad \alpha_Y = \frac{\alpha_e m}{cos^2(\theta_W)} \ . \tag{4.1}$$

Y corresponds to the hypercharge. The ratio of W and Z masses is given by $m_W/m_Z = cos(\theta_W)$. The value of the Weinberg angle depends on the p-adic length scale. It can be deduced from the parity violation of weak interactions and Möller scattering gives $sin^2(\theta_W) = .2397 \pm .0013$ (see this).

How would parity violation appear in hadronic physics and why would it be small? If the weak scale were replaced by the hadronic scale, large effects unless $sin^2(\theta_W)$ be very small? This would also make the weak interaction long ranged because the weak boson propagator involves the mass of the scaled intermediate boson, which is now p-adically scaled down.

First, we need to figure out how the screening of the weak interaction occurs at the quark and lepton levels. TGD provides a concrete model for this.

1. Neutrino screening would handle the screening at the quark level. Later it will be found that only the left-handed weak isospin can be shadowed but not the right-handed one, so the Z^0 interaction remains for the right-handed isospin. In fact, I have proposed many applications of TGD based on long-range classical Z^0 fields [L3]. For instance, the hydrodynamical vortices could correspond to the Z^0 magnetic analogs of vortices in superconductors [L2].

   Parity violation would make itself visible for the ordinary weak interactions for large values of h_{eff} increasing the weak boson Compton length but leaving their masses unaffected. Weak bosons would be effectively massless below the scaled up Compton scale. Chirality selection in biology provides a particularly interesting application.

2. If the p-adic length scale for intermediate bosons becomes large, the situation changes since weak bosons become light also outside their Compton length. In hadrons this would happen if strong interactions indeed are weak interactions with a scaled up range.

There are two challenges.

1. How to avoid large parity breaking effects (assuming that they are really absent, see [C1] [L1]!) that contradict the standard assumption that strong interactions couple vectorially? Here a crucial observation is that the isospin splitting occurs for the modes of H spinor fields so that symmetry breaking is coded to the geometry of CP_2.

2. How to avoid strong violation of isospin symmetry? In fact, there has been evidence of isospin symmetry violation [L19] disussed from the TGD point of view in [L19] [K5]. Here an important observation is that but the masses of left- and right-handed M^4 states (the notion can be defined although there is a mixing with opposite M^4 parity due to massivation) are identical. In the general case even the left- and right-handed masses would be different.

In the TGD framework, there is no strong vectorial isospin as a separate quantum number since weak or right weak isospin, em charge, and genus of the partonic 2-surface are enough to label quarks and leptons. Since the value of weak or right weak isospin dictages the em charge, one is forced to ask whether the large mass differences between U and D quarks and charged leptons and neutrinos can be interpreted as a large symmetry breaking related to the weak isospin in the TGD framework.

4.1.1 How to describe parity violation in TGD

Parity violation effects at the atomic and nuclear level have been studied using the interference between Z^0 and γ exchanges implying differences for the transition rates for for atom and its mirror atom (see this).

The Weinberg angle characterizes the $\gamma - Z^0$ interference terms in weak scattering and one can ask whether $sin^2(\theta_W)$ depends on p-adic length scale characterizing the scale copy of weak interactions so that these effects remain small.

1. Effects at the fermion level would come from the reaction vertices, which violate parity for weak bosons. Then there are also effects at the geometric level. For example, helical structures break mirror symmetry and this would be an essential aspect of the parity violation in biology.

2. In the TGD framework, $\overline{\nu}\nu$ screening at the quark level is proposed to make fermion parity violation small for ordinary $\hbar$. For large h_{eff} phases the effects are large below the weak boson Compton scaled up by factor $\hbar_{eff}/h$ since weak bosons are effectively massless. Note that the Weinberg angle would vanish in this phase. This could take place in biology. The masses of the intermediate bosons would remain large outside the scaled up weak scale.

3. For the p-adically scaled versions of weak bosons with standard value of Planck constant, the masses of the intermediate bosons would scale down. There are many questions. What happens to the vertices, which in the TGD framework are associated with the 3-D singular surfaces X^3 of the space-time surfaces at which the conformal invariance is violated. Does the magnitude of the analogue of the Higgs expectation as the trace of the second fundamental form scale down and involve the scaling up of the size of X^3.

If the TGD view of the parity violation is to be tested, states must be created for which fermions have a well-defined handedness, so that we can speak of a mirror image of a particle. The effect of mirroring at both the H and X^4 levels should be described. Parity violation is visible for fermions at both the H via the modes of the H-Dirac equation. The fermionic effects are visible also at the level of the space-time surface X^4. Also the geometry of X^4 reflects parity violation if holomorphy= holography vision is assumed.

Consider first the embedding space level (briefly H-level). What does 8-D masslessness mean? What does color confinement and ew screening mean at the H-level? What does $h_{eff} \geq h$ means? How is testing possible for the initial and final states of particles that are built from H fermion modes?

1. For the modes of H spinors M^4 mixing of handedness occurs and the fermion can be only dominantly left or right-handed. The covariantly constant right-handed neutrino is the only exception. In this case, a mirror image cannot be formed because there is none.

   However, a mirror image can be formed for the other modes. The momenta change their signs. The masses are the same for the modes and their mirror images. Spins are not affected.

2. Also in CP_2 degrees of freedom there is also mirroring and 8-D chiral symmetry implies correlation between M^4 and CP_2 chiralities characterizing quarks and leptons. A fermion can be constructed by operating $D(H) = D(M^4) + D(CP_2)$ on any right- or left-handed H spinor with a given H-chirality. Right- and left-handedness in M^4 sense would characterize these generating spinors.

3. Parity violation can appear at the H-level at the level of 3-momenta changing their sign in mirroring.

4. I have proposed that the Dirac equation for spinor modes inside the causal diamonds CD [L16] involves M^4 Kähler structure or Hamilton-Jacobi (H-J) structure . This would discretize the mass spectrum to string mass spectrum and involve reduction of Lorentz invariance.

The H-J structure [L6] can be defined for both X^4 and M^4 and one expects there are many such structures. The solutions of classical field equations are characterized by the H-J structure defining the generalization of complex structure of H involved also hypercomplex part in M^4.

1. The H-J structure involves two parts. At each point of X^4, the tangent space decomposes to a 2-D longitudinal hypercomplex part and complex part transversal to it. This defines local light-like momentum direction and complex polarization direction. These subspaces define integrable distributions of Minkowskian 2-D longitudinal and Euclidian transversal sub-spaces of the tangent space of X^4.

2. The simplest H-J structure corresponds to a global orthogonal decomposition of M^4 to $M^2 \times E^2$. M^4 is characterized by a light-like constant vector u and its hypercomplex conjugate v and E^2 regarded as a complex plane by a complex vector and its complex conjugate.

3. One can assign a Kähler form to the transversal degrees of freedom involving an integrable distribution of Minkowskian 2-D subspaces of the tangent space of X^4. It has turned out that the analog of Kähler form in the longitudinal space must vanish: this is the counterpart for the fact that these degrees of freedom are not physical in massless gauge theories.

What about the effect of reflection at the level of X^4 level when the holography = holomorphy vision holds true [L12, L18].

1. What happens to the H-J structure [L6] and associated Kähler structure in reflection. Holography = holomorphy principle does not leave much room since the solutions of field equations must go to new solutions. The study of the simplest H-J structure defined by the standard linear M^4 coordinates suggests the $u \leftrightarrow v$. It should not be visible if the hypercomplex part of Kähler is trivial as the phyhsical intuition requires. The complex coordinate w would naturally change sign. This would naturally generalize to a general H-J structure.

2. In $u \leftrightarrow v$ and $z \leftrightarrow -z$. The spacetime surface changes and at the same time the scattering amplitudes defined by it change. Do the two sheets of the spacetime surface related by hypercomplex conjugation $u \leftrightarrow v$ change their roles. Does a line at a given throat of a wormhole contact connecting the two space-time sheets drop to the opposite throat. The parity violation induced by the classical dynamics of X^4 would be thus visible at the level of the geometry and be visible in biology as chiral selection.

   Parity violation expresses itself in the spinor dynamics of the X^4 level through vertices: fermion lines move to the parallel sheet.

3. Parity violation is visible in atomic and nuclear physics. $Z^0+\gamma$ interference and Z^0 exchanges as well. In TGD, the classical Z^0 potential describes this but not as a mere approximation.

4.1.2 Parity violation in TGD

In TGD parity violation should show up as an internal property of hadrons or quarks. In standard model, the violation is realized as the interference of γ and Z^0 exchanges, say in the scattering of leptons and hadrons. This scattering should also be visible inside hadrons and even inside quarks could lead to too large parity violation in hadron physics. Above the scaled up intermediate boson Compton length the weak screening by neutrino pairs would screen left-handed weak isospin but not the right-handed component to which classical Z^0 field couples.

There is no virtual boson exchange in the sense of QFTs since bosons as particles correspond to bound states of fermions. Classical gauge fields correspond to induced spinor connection and the generalization of Higgs corresponds to the trace of the second fundamental form [L16]. The counterpart of gauge boson propagator however emerges from the correlations induced by the functional integral over superposition of space-time surfaces as analogs of Bohr orbits and also from the slight failure of the classical non-determinism of the holography giving rise to a discrete sum of space-time surface resembling in some respects path integral.

In TGD, the interactions are basically contact interactions associated with the intersections of the almost deterministic Bohr orbits of 3-surfaces. Here monopole flux tubes and "massless extremals" play a key role. The intersections are 2-D string world sheets if the H-J structures [?]re indentical. If H-J the structures are not identical, the intersections consist of discrete points. Space-time surfaces can also have this kind of self-intersections and they give raise to self-interactions also at the level of hadrons and quarks.

In principle, parity violation can be studied by comparing quantum dynamics for the initial states of hadrons which are mirror images of each other in both ermionic and geometric degrees of freedom. There are two levels to be considered. At the level of H the action of mirror symmetry and its action fermions is well-understood. It is essential that at the H level the masses are the same for the spinor modes with different M^4 chirality so the parity is not violated at the level of the fermion masses. This picture also applies at the level of CD proposed to be endowed with the M^4 Kähler structure. At the level of the space-time geometry, the mirror image of X^4 can be defined in the holography = holomorphy vision [L9, L12, L18]. 3 spatial coordinates are mirrored. This would mean that the light-like hypercomplex coordinates of X^4 are mapped to each by hypercomplex conjugation $u \leftrightarrow v$, maybe also in M^4 for the causal diamonds (CD). The complex coordinate w X^4 is mapped to its negative.

The model for the two-sheeted structures [L18] assigned to particles led to the proposal that the two parallel Minkowskian space-time sheets connected by wormhole contacts correspond mirror images of each other with respect to hypercomplex coordinates [L16]. The fermion lines at the partonic orbits associated would be mapped to the opposite wormhole throat. Spin direction of the fermion is not affected but momentum direction changes.

4.1.3 Is the isospin symmetry violation of strong interactions really small?

In the standard model it is assumed that strong interactions respect strong isospin symmetry. But do the strong interactions really respect the isospin symmetry? Could we have misinterpreted what we see? If the quantum numbers of quarks really reduce to weak isospin and hyperchange and parton genus serves as a topological characteristic, we can interpret the isospin symmetry violation directly as mass differences of U and D quarks and in the leptonic sector as mass differences of charged leptons and neutrinos.

At the level of H, the color representations associated with the modes of the H spinor field with different charges are different. Weak screening makes leptons color singlets and quarks color triplets in H, which in turn combine to form massless color singlets which get their mass by p-adic thermodynamics [L16]. The underlying violation of isospin symmetry manifests itself as different p-adic length scales for different charge states of quarks and leptons.

The massivation of the spinor modes of H-spinors implies that the modes do not have a pure M^4 chirality. Indeed, the 8-D chiral invariance, guaranteeing separate conservation of quark and lepton numbers, forces a complete correlation of M^4 and CP_2 chiralities and implies the mixing for all modes except covariantly constant right-handed neutrinos. Weak left-handed and right-handed iso-spin replaces the ordinary strong isospin.

For left-handed chiralities the strong isospin would correspond to the weak isospin $I_{3,L}$ and the change in the direction of strong isospin is manifested in weak (and also strong -) interaction occurring via charged currents. Only the classical Z^0 force detects the change of the direction of $I_{3,R}$. It deserves to be noticed that recently a violation of strong isospin symmetry has been reported [L19]. I have considered the interpretation of this observation in the TGD framework [L19].

4.2 Weak screening

One can consider two basic options for weak screening. The strong option screening is in terms of neutrino pairs. Left-handed fermions are screened also in the right-handed sector. For the right- handed mode the right-handed isopin cannot be screened so that long range Z^0 fields are possible. Super-fluidity as Z^0 analog of super-conductivity is one possible application and the hierarchy of effective Planck constants could make it possible analogs of quantum vortices even in hydrodynamics [L3, L2].

For a more general form also other fermion pairs are possible. Only the strong form of the screening will be discussed in what follows.

4.2.1 Is strong screening sufficient for left-handed fermions?

$\nu\overline{\nu}$ pair consists of a left(/right)-handed neutrino and right(/left)-handed neutrino. ν_R has no electroweak coupling and is massless if it is covariantly constant in CP_2 degrees of freedom. Also nontrivial color partial waves are possible. Right-handed fermions associated with the monopole flux tube couple with ν_L via Z^0 since the Z^0 charge contains a vectorial part $-sin^2(\theta_W)Q_{em}$.

1. Annihilation of the screening neutrino and screened fermion is not possible. Exchange of W and Z^0 between them is possible and so what Q_{em} is visible. For the right-handed screened fermions, only the exchange of Z^0 is possible in both cases. Q_{em} appears in the Z^0 coupling and this could partially explain the U-D asymmetry. W exchange and possibly also Z^0 exchange could induce the decay of the screened fermion involving also topological decay of the partonic 2-surface. Also the change of the genus could occur and induce CKM mixing.

2. One can also think of the analogy of the electroweak boson loops for screened fermions and also for screening neutrino and it could also lead to decay. There would be no emission of a virtual boson as a particle. Also the emission of virtual boson as a modification of the classical induced field associated with classical non-determinism could induce a topological decay of fermion as an emission of a partonic 2-surface.

3. The annihilation of $\nu_L-\overline{\nu}_L$ could lead to a classical analog for the emission of virtual Z^0. This could induce instability giving rise to a decay to Z^0 and pure ν_R and could produce a mixing of the screened neutrino with ν_R and massivation perhaps explaining neutrino massivation?

4.2.2 Why are quarks and leptons with smaller em charge more stable?

The instability against decay due to the TGD counterperts of electroweak interactions with the fermion could make it possible to understand why U type quarks are shorter-lived the D type quarks. This would be due to the decay of U to a lighter D by weak W emission. Same applies in the leptonic sector. p-Adic mass scale hypothesis characterizes the mass of the fermion and could be seen also as a characterizer of the stability: the higher the value of k_q, the longer the age.

1. The integer k_q defining the p-adic length scale as a function of the genus g grows faster for U than D and faster for L than ν_L. For neutrinos, the growth is very slow. Q_{em}^2 contributes to the conformal generator L_0 in p-adic thermodynamics giving a contribution to the mass squared of the fermion. The different-adic length scales for the two charge states of fermions must relate to this.

2. The generalization of the p-adic numbers fields to their functional variants allows us to interpret k_q as the number of the iterations of second order polynomials associated with definition of the space-time surfaces assignable to the fermion. Each iteration step involves classical non-determinism realizable as a vertex for the emissions of TGD counterpart of

virtual boson and can lead to a physical decay or topology change of the partonic 2-surface. The higher the value of k_q, the higher the stability.

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4.3 How to understand Weinberg angle in TGD framework

Weinberg angle is one of the basic parameters of the standard model. In the following I will consider the relation of the Weinberg angle to the quark mass spectrum and to the possible M_0^2 parameter assignable to the Z^0 and W bosons.

4.3.1 Charge representations for gauge bosons

The condition that the representations of gauge bosons as superpositions of fermion pairs represent their couplings to fermion pairs represented as charged matrices fixes their representations to a high degree.

The representations for Z^0 and W, neglecting the actual non-locality of the representations of the gauge bosons in terms of monopole flux tubes and treating the representative corresponding current like quantities as local currents looks in a simplified form like follows:

$$\begin{array}{ll} W_\pm = \frac{1}{N_W^2}\sum_g W_{\pm,g} \ , & \frac{1}{N_Z^2} Z_\pm = \frac{1}{N_W}\sum_g Z_{\pm,g} \ , \\ W_{\pm,g} = W_{\pm,g,q} + W_{\pm,g,L} \ , & Z_{\pm,g,U} + Z_{\pm,g,D} + Z_{\pm,g,L} \end{array} \tag{4.2}$$

N_W and N_Z are normalization factors discussed below. The contribution of a given genus g can be decomposed to contributions from the chiralities L, and R and to contributions from different em charges.

1. For W only the left-handed chirality contributes charges give the same contribution.

$$\begin{array}{l} W_{\pm,g,q} = 2\overline{U_L}_g I_\pm E D_{L,g} \ , \quad W_{\pm,g,L} = 2\overline{L,L}_g I_\pm E \nu_{g,L} , \\ E = \epsilon^k \gamma_k \ . \end{array} \tag{4.3}$$

2. For Z^0 one obtains

$$\begin{array}{l} Z_{\pm,g,q} = \overline{U_g}_L Q_Z E(U_g)_L + h.c + \overline{D_L}_g Q_Z E D_{L,g} + h.c. \ , \\ Z_{\pm,g,L} = \overline{L_g}_L Q_Z E(L_g)_L + h.c. + \overline{\nu_g}_L Q_Z E(\nu_g)_L + h.c. \ , \\ Q_Z = I_{3,L} - pQ_{em} \ , \quad p = sin^2(\theta_W) \ . \end{array} \tag{4.4}$$

4.3.2 Normalization factors defined by charge squared values

The normalization factors are important for what follows and are essentially sums of squares of charge matrices over the generations, which decompose to sums over charge states and left- and right-handed fermions

$$N_Z^2 = \sum Q_Z^2 \ , \quad N_W^2 = \sum Q_W^2 \ , \tag{4.5}$$

Here the sum is over all 3 fermion families that is generations g decomposing in turn to sums over 2 charge states and two M^4 chiralities.

The contributions to N_W^2 are identical and equal to $I_\pm I_\mp = 1/4$ and the sum contains $3\times 2 = 6$ contributions from both quark sector and leptonic sector so that one obtains

$$N_W^2 = \sum Q_W^2 = 3 \ . \tag{4.6}$$

In the of $\sum Q_Z^2$ over the states of single generation, the cross terms in the sum vanish since they are proportional to $I3, L$ and one obtains the sum over 3, generations, over charge states, and over M^4 left handed chirality for $I_{3,L}^2$ or both L and R for Q_{em}^2. One has $\sum Q^2 = 2\times 5/9$ for quarks of single generation and $\sum Q^2 = 2$ for leptons of single generation. This gives

$$N_Z^2 = \sum Q_Z^2 = \sum I_{3,L}^2 + p^2 Q_{em}^2 = 3\times[1/2 + 2p^2(5/9)] + 3\times[1/2+2p^2] = 3\times[1+2p^2+\frac{28}{9}p^2] = 3\times[1+4p^2]$$

The contributions are the same at the symmetry limit $p = 0$. The ratio

$$\frac{N_Z^2}{N_W^2} = 1 + 4p^2 \ , \tag{4.9}$$

4.3.3 Mass squared values for weak bosons

Mass squared values for weak bosons are sums over contributions to Q_W^2 and Q_Z^2 but multiplies by the mass squared values for each family weighted with mass squared values for U and D and for L and ν_L. squared values. Besides this there normalization by $1/N(W)$or $1/N_Z)$

Analogous calculation can be done for the sum, or rather averages of $M^2(W)$, values.

1. For $M^2(W)$ one obtains

$$M^2(W) = \frac{1}{3}\sum M^2(U_g) + M^2(D_g) + M^2(L) + M^2(\nu_L) \ . \tag{4.10}$$

2. For $M^2(Z)$ the contribution is equal to $\frac{3}{3+5p^2}M^2(W)$ as is clear from the fact that this term is what one obtains at the symmetry limit. Q_{em}^2 terms break the isospin symmetry.

   For leptons the contribution from Q_{em}^2 is

$$2p^2M^2(L_g)$$

   For quarks the contribution from Q_{em}^2 can be written as

$$2p^2\frac{4M^2(U_g) + M^2(D_g))}{9} \ .$$

   This gives a total contribution

$$M^2(Z) = \frac{1}{3(1+4p^2)} \times [3M^2(W) + 2p^2\sum_g[\frac{4}{9}M^2(U_g) + \frac{1}{9}M^2(D_g) + M^2(L_g)] \ . \tag{4.11}$$

3. The ratio $M^2(W)/M^2(Z)$ is given by

$$\begin{aligned}
\frac{M^2(Z)}{M^2(W)} &= \frac{1}{1+4p^2}(3+\frac{X_Z}{X_W}) \ , \\
X_Z &= 2p^2\sum_g[\frac{4}{9}M^2(U_g) + \frac{1}{9}M^2(D_g) + M^2(L_g)] \ , \\
X_W &= \sum M^2(U_g) + M^2(D_g) + M^2(L) + M^2(\nu_L) \ .
\end{aligned} \tag{4.12}$$

Note that in the $I_{3,L}^2$ contribution for Z^0 is related by the ratio $N_Z^2/N^2(W)$ to the W contribution.

4.3.4 The approximation in which the contribution of top quark to mass squared dominates

Since the top quark is so massive, the first approximation is to neglect the masses of other quarks and leptons. This would give

$$\begin{aligned} \frac{M^2(Z)}{M^2(W)} &= \frac{1}{1+4p^2)}(3+\frac{X_Z}{X_W}) \ , \\ X_Z &\simeq 2p^2\frac{4}{9}M^2(t) \ , \\ X_W &\simeq M^2(t) \ . \end{aligned} \tag{4.13}$$

This would give

$$\frac{M^2(Z)}{M^2(W)} = \frac{1}{1+4p^2)}(3+\frac{8}{9}p^2) \ . \tag{4.14}$$

The solution of the condition

$$\frac{M^2(Z)}{M^2(W)} = \frac{1}{1-p} \tag{4.15}$$

allows us to solve the Weinberg angle and it is interesting to see whether any solutions exist. Using the expression

$$\frac{M^2(Z)}{M^2(W)} = \frac{1}{1+4p^2}(3+\frac{X_Z}{X_W}) \tag{4.16}$$

leads to the expression of p as a root of third order polynomial equation

$$\begin{aligned} P(p) &= p^3 + a + bp + cp2 \ , \\ a = -frac94 + x \ , \quad b &= \tfrac{27}{8+2x} \ , \quad c = \tfrac{12-x}{4+x} \ , \end{aligned} \tag{4.17}$$

Here x denotes the ratio $m^2(b)/m^2(t)$, which is in a good approximation zero if one assumes that top quark is what it is believed to be. For $x=0$, $P(p)$ has indeed a root at $p \simeq 5/12 \simeq .42$ to be compared with the actual value $p \simeq .23$,

4.3.5 Could light top quark reduce the value of the Weinberg angle?

The value of Weinberg angle is too small. Could the problem be that the official top quark candidate is too massive as compared to the other quarks? As already discussed, the p-adic mass scale of top quark is 175 GeV and suspiciously high when compared with the mass scale 4 GeV of b quark. Could the official candidate for top be a quark of M_{89} hadron physics [K5] [L16] whereas the real top could have mass scale not much larger than that of b quark.

Unfortunately, this option does not work. For $x = m^2(t)/m^2(b)$ the root of $P(p)$ is only slightly larger so that even $m_t = m_b$ fails to help. It is not plausible that the contribution of other quark masses and lepton masses could move the root nearer to zero. However, the idea that the official top is not the real one, is very attractive in the TGD framework.

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4.3.6 Could a non-vanishing value of M_0^2 for weak bosons reduce the value of the Weinberg angle?

The above calculation assumes that $M_0^2(W) = M_0^2(Z) \equiv M_0^2 = 0$. Could $M_0^2 > 0$ allow an acceptable solution? The interpretation of M_0^2 would be in terms of the mass of the magnetic body of the weak boson. Also a negative weak binding energy giving a negative contribution to the mass squared can be considered.

Large values of M_0^2 force $M^2(W) = M^2(Z)$ so that $p = 0$ is implied. Could the modified polynomial $P(M_0^2, p)$ allow to reduce the too large root $p = 5/2$ to the experimental value? continuity suggest that for small values of M_0^2 there should be roots which are smaller than the root already found.Whether the reduction of p almost factor 2 can be seen as a small change, is of course questionable.

The modified condition relating the Weinberg angle to the parameter M_0^2 reads as

$$\frac{M_0^2 + M^2(Z)}{M_0^2 + M^2(W)} = \frac{1}{1-p} \quad . \tag{4.18}$$

It is convenient to study small perturbations of the solution already obtained by assuming that $M_0^2/M_0^2(W) \equiv \Delta$ is a small parameter inducing a small change of p. At the left hand side there is also a change $\Delta M^2(W)$ due to the change Δp of p. Using the fact that the non-deformed equation giving $p \simeq 5/12$ holds true, the equation can be reduced to the form

$$(1 - \frac{M^2(Z)}{M^2(W)})\Delta = \left[-\frac{dM^2(Z)}{dp} + \frac{1}{(1-p)^2} \right] \Delta p \tag{4.19}$$

and allows to deduce the needed value of Δ if the approximation works.

The derivative of $\frac{dM^2(Z)}{dp}$ is given by

$$\frac{dM^2(Z)}{dp} = -\frac{8p}{1+4p^2} \left[M^2(Z) + \frac{2}{p}(M^2(Z) - 3M^2(W) \right] \quad . \tag{4.20}$$

This quantity is positive. Therefore the reduction of the value of p requires a negative value of Δ. What could be the interpretation for this? If M_0^2 includes also weak binding energy between quarks forming W and Z, Δ can be negative. One can of course ask whether the tachyonic character of Higgs in the standard model and the predicted tachyonic states making possible light colored states [L14, L16] could relate to this.

Assuming that top quark mass dominates, one can simplify the equation for Δ and solve its value for a given value of Δp.

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