Preon Model for Matter and Spacetime Unification

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Abstract

I consider a preon model for quarks and leptons based on constituents defined by mass, spin and charge. The preons form a finite combinatorial system for the standard model fermions. The color and weak interaction gauge structures can be deduced from the preon bound states. A unified picture for matter and spacetime is proposed by applying the area eigenvalues of loop quantum gravity to black hole preons producing a preon mass spectrum starting from zero. Gravitational baryon number non-conservation mechanism is obtained. Argument is given for unified field theory be based only on gravitational and electromagnetic interactions of preons.

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1 Introduction

The purpose of this note is to complete a draft model for particles, their interactions and spacetime [1, 2, 3]. The difficulty of constructing a unified picture of 'everything' is realized. It has been questioned whether any such in elements, like grand unified theories (GUT) of gauge interactions, supersymmetry and, most intriguingly, in superstring theory, does occur in nature. It would be mathematically satisfying to use current methods and start from the quantum and entanglement and proceed to spacetime, see eg. [4, 5, 6, 7, 8]. However, some of these elements lack experimental support, and some issues of theoretical nature remain unresolved. The history of quantum gravity perhaps indicates the need for a different approach. [1].

The phenomenological approach taken here is to divide the unification problem into component models. New proposal is made for the key component preon model. It provides the basis for a new paradigm for deducing the standard model (SM) properties and for a novel unification. The present analysis is based on the phenomenological success of the SM of particles up to LHC energies and, the somewhat doubted, stability supposedly up to Planck energies [11]. When coming to Planck scale energies there are no data available and we have to turn heavily to Gedanken experiments. I end up tentatively preferring spacetime being primary and favorable for creating the universe in steps with few assumptions.

I reanalyze a model of quarks and leptons proposed in [1]. The basic idea is to construct the quarks and leptons out of two preons which have spin $\frac{1}{2}$, charge $\frac{1}{3}$ or 0 and some light mass. The preons form a finite combinatorial system (modulo 3) for the $l = 0$ SM fermions. Furthermore, from this basis also the color and weak interactions of particles can be deduced. Unification of interactions is proposed on preon level together with gravity and electromagnetism only.

Originally the preons were assumed to be micro black holes (BH) leading to the serious problem of getting light quarks and leptons from them. New developments in quantum gravity studies have come to help [12, 13, 14]. The mass spectrum of BH preons is found to start from zero using the area eigenvalues of loop quantum gravity (LQG). A reason for point-like SM particles is indicated. The model predicts a mechanism the gravitational decay of the proton. This decay is due to an explicit preon interaction instead of a general black hole quantum number erasure process. The quantization of micro BHs is done based on the BH horizon model proposed in [15]. The model is a statistical mechanical construction based on area quantization of LQG.

This paper is organized as follows. In section 2 the main subject, the preon model, is discussed. Non-Abelian interactions of the SM are discussed in section 3. Kaluza-Klein theories as candidate theory for interaction unification are briefly reviewed in section 4. LQG area eigenvalues are applied to the preon model in section 5 to build matter spacetime unification. A few words are included in section 7 on spacetime fabric. Possible black hole cores are discussed in section 6. Finally in section 8 I give a brief summary of the results and conclusions. Being a scheme proposal the presentation is very concise throughout.

[1]Recently it has been shown that the relationship between spacetime geometry [9] and entanglement should exist, or have an analog, in quantum gravity with diffeomorphism invariance [10] in loop quantum gravity, of which we make use later in this note.

2 Preon Model of Matter

To build a model for unified picture of matter and spacetime implies some internal structure for quarks and leptons at scale of the order of Planck length $l_{\rm Pl}$. Such a model has been proposed in [1]. The basic idea there is that the quarks and lepton are made of preons, or maxons, characterized by three quantum numbers: mass, spin and charge. Their values are: mass provisionally the Planck mass (but later dynamically zero), spin $\frac{1}{2}$ and charge $\frac{1}{3}$ or 0. In addition there is 'color' (i, j, k) as a permutation index for identical fermions.

Requiring charge quantization $\{0, \frac{1}{3}, \frac{2}{3}, 1\}$, with physical particles having an integer charge and preon permutation antisymmetry for identical preons, one can define creation operators to pull out of vacuum these states:

(1) one preon makes nothing observable, it must combine with others,

(2.a) two preons may form a charged boson m^+m^+ (m^-m^-), which can combine with a preon m^- (m^+) to form a $\bar{d}$ (d) quark or with a preon m^+ (m^-) to form a positron (electron), the charged boson may also be a m^+m^0 (m^-m^0) state which may combine with a m^+ (m^-) to form a u ($\bar{u}$) quark or with a m^0 to form a $\bar{d}$ (d) quark,

(2.b) two preons may form a neutral boson $m^+m^-, m^0\bar{m}^0$ of spin 0 or 1 ($l = 0$),

(3) three preons may form the first generation quarks and leptons which are the following bound states

$$\begin{aligned} u_k &= \epsilon_{ijk} m_i^+ m_j^+ m^0 \\ \bar{d}_k &= \epsilon_{ijk} m^+ m_i^0 m_j^0 \\ e &= \epsilon_{ijk} m_i^- m_j^- m_k^- \\ \bar{\nu} &= \epsilon_{ijk} \bar{m}_i^0 \bar{m}_j^0 \bar{m}_k^0 \end{aligned} \tag{2.1}$$

The preons combine freely without extra assumptions into standard model fermion bound states. They form a finite combinatorial system (modulo 3). I assume that these states are bound by gravitational or scalar (or other Planck scale), preferably non-confining force between preons. The interaction must balance the repulsion between like charged preons. Properties of this interaction, together with the number of scalar and vector bosons, should be studied separately as a future project.

A useful feature in (2.1) with two identical preons is that the construction provides a three-valued index for quark SU(3) color, as it was originally discovered [16]. In addition, the weak SU(2) left handed doublets can be read from the first two and last two lines in (2.1). The SM structure can be deduced in this sense from the present preon model. [2]

One may now propose that the ultimate *unified theory is a preon theory with gravitational and electromagnetic interactions only.* The strong and weak forces are *generated later* and operate only with short range within the nuclei making atoms and molecules possible.

States with higher number of preons are possible but will not be considered here.

The proton, neutron, electron and ν can be constructed of 12 preons and 12 anti-preons as seen in Figure 1. The particles in the right hand column are the basic β-decay particles.

We will see in section 5 that BHs may undergo a phase transition at some T_C, so that above T_C spacetime approaches classical and BH masses are above Planck scale. But below T_C zero preon mass is possible.

[2] It is trivial to get the charges between 0 and 1 but its is pleasing that the gauge groups can be deduced.

Maxon	Particle
m+ m+ m+ m+	p
m- m- m- m-	e
m0 m0 m0 m0	
m0 m0 m0 m0	v
m0 m0 m0 m0	n
m+ m+ m- m-	

Figure 1: Preons, anti-preons and particles.

If the preon mass scale is the Planck scale (2.1) would be superheavy particles. To get the standard model particles the large mass reduction has to be explained. This is done in section 5: from (5.1) by setting $j_p = 0$, which leads by (5.2) to zero mass 'cold' black hole. This $j_p = 0$ preon may interact with the Higgs field and gain a light mass. Above the critical temperature, defined by (5.10), preons should have a phase transition into a Hawking radiating black holes.

The mass scale change is significant. It may be understood, using non-relativistic quantum mechanics as a heuristic guide, by assuming that when the continuum spacetime geometry ($j_p \gg 0$) changes to vacuum geometry ($j_p = 0$) the preon falls inside a potential well of depth $M_{\rm Pl}$ and acquires zero mass, see section 5. When the temperature after Big Bang cools down enough potential wells expand in space at $T \sim 0$ with the preons starting to dominate. Primordial BHs would form in regions with higher temperature $T > T_C$ (section 5).

At this point also the generalized uncertainty principle (GUP), $\Delta x \geq \frac{1}{\Delta p} + l_{\rm Pl}^2 \Delta p$, should be considered. This would need more consideration and is left for future task (beyond the general result $\Delta x_{min} = 2 l_{\rm Pl}$). For a review of GUP questions, see eg. [17].

Spin $\frac{3}{2}$ quarks and leptons are implied by this model. Neutral integer spin ≥ 2 states are possible.

The construction (2.1) is matter-antimatter symmetric on preon level, which is desirable for early cosmology. The model makes it possible to create from vacuum a universe with only matter: combine e.g. six m^+, six m^0 and their antiparticles to make the basic β-decay particles, see Figure 1. Corresponding antiparticles occur equally well.

The baryon number (B) is not conserved [18, 19, 20] in this model: a proton may decay at Planck scale temperature by a preon rearrangement process into a positron and a pion, see Figure 2. This is expected to be independent of the details of the preon interaction (effectively four fermion). Baryon number minus lepton number is conserved. [3]

The large mass reduction from Planck scale to zero would also imply shrinkage of the BH from three spatial dimensions to a point, which serves as the zero element of area addition (not necessarily meaning dropping out of spacetime). Thus point-like particles would be a consequence of quantum geometry.

The standard model gauge bosons and the Higgs would be elementary (but their composite nature is not ruled out). The three generations would be due to a gravita-

[3]Basically, I have followed the guide of [18] that "black holes should be subject to the same rules of quantum mechanics as ordinary elementary particles or composite systems". The question what is a particle is discussed in [21]

Figure 2: Proton decay by preon rearrangement.

tional or scalar interaction or a new symmetry as in [22, 23], see section 3.

In the early universe at high temperature the standard model quarks and leptons would not be formed immediately. Instead all matter would be in black holes interacting gravitationally and electromagnetically. Quarks and leptons would appear later when the temperature decreases substantially. Electroweak and QCD interaction come to play rather late.

Some fraction of primordial black holes should remain black making dark matter. Their masses are expected to be around $30M_{\odot}$. In [24] the authors discuss the possibility that LIGO has detected dark matter in black hole mergers.

3 Non-Abelian Gauge Interactions of SM

The traditional gauge unification picture does not hold in the present scheme. While the electroweak interaction does have the spontaneously broken symmetry phase at low energy the electromagnetic and weak forces take a separate way at high energy, the former melts away but the latter stays strong towards Planck scale. Likewise the quark color interaction suffers the same destiny as the weak force. One is left with the electromagnetic and gravitational forces only at Planck scale. The unification of forces takes place there. This has a long and diverse history, see section 4. The weak and strong forces provide the means for shorter scale structures in nuclei and operate also in stars.

To account for the fermion generations, I refer to the review of Yang-Mills theory and the SM [22], see also [23]. The authors want to understand first of all the origin of the Higgs mechanism and the generations of quarks and leptons. In the limited space of this note I mention that the authors introduce frame vectors in internal space as field variables, framons, in addition to the usual gauge theory boson and fermion variables. They obtain the standard Higgs scalar as the framon of the electroweak sector and a global color $\widetilde{su}(3)$ symmetry to provide the three fermion generations. Using renormalization of framon loops, which change the orientation in generation space of the vacuum, hence also the mass matrices of fermions and lets them rotate with changing energy scale. As a result they obtain tremendous fit to all data. The analysis leads automatically to CKM mixing and neutrino oscillations, hierarchical generation masses and the strong-CP problem.

4 Going Into Fifth Dimension

This section includes a summary of some important historical milestones that would be useful in building unified models, though the results are not yet exactly what is required. I start with a very brief summary of the well known, but underrated Kaluza-Klein (KK) theory [4] [25, 26].

Nordström showed [27] in 1914 and Kaluza [28] in 1921 that five dimensional GR contains both Einstein's four dimensional gravity and Maxwell's electromagnetism. Klein [29] in 1926 it was suggested to compactify the fifth dimension. These models have further three interesting properties: (1) matter (radiation) in 4D is a manifestation of pure geometry in 5D, (2) the higher dimensional theory is a minimal extension of GR, and (3) physics does not depend on the fifth coordinate.

On classical level the KK metric is

$$\tilde{g}_{AB} = \begin{pmatrix} g_{\mu\nu} + A_\mu A_\nu & A_\mu \\ A_\nu & 1 \end{pmatrix} \tag{4.1}$$

where Latin indices run from 0 to 4 and Greek from 0 to 3. The Einstein-Maxwell action is

$$I = \int d^4x dy \sqrt{-g}(R + \frac{1}{4}F_{\alpha\beta}F^{\alpha\beta}) \tag{4.2}$$

The fifth dimension integral dy is over a compactified angular variable with radius of the order of $l_{\rm Pl}$. This is a candidate for a unified classical gravitational and electromagnetic theory of preons, including the graviton $g_{\mu\nu}$, photon A_μ and a scalar field ϕ, which is sometimes set as constant like 1.

In quantum theory each of these fields, say f(x,y), are often written in terms of Fourier expansions

$$f(x, y) = \sum_{n=-\infty}^{\infty} f(x)e^{(iny/r)} \tag{4.3}$$

In the y-direction these modes have a momentum of the order of $|n|/r$, which for $r \sim l_{\rm Pl}$ reaches the Planck scale. Therefore only modes with $n = 0$ are observable.

Let us consider matter in the five dimensional theory, a massless scalar field ϕ in Minkowski space with action

$$S = -\int d^4x dy \sqrt{-\hat{g}}\partial^A\phi\partial_A\phi \tag{4.4}$$

where

$$\hat{g}_{AB} = \begin{pmatrix} \eta_{\alpha\beta} & 0 \\ 0 & -1 \end{pmatrix} \tag{4.5}$$

The field can be written as Fourier sum as in (4.3) and inserted into the action (4.4)

$$S = -(\int dy)\sum_n \int d^4x\sqrt{-g}\big[(\partial^\alpha + \frac{in\kappa A^\alpha}{r})\phi^{(n)}(\partial_\alpha + \frac{in\kappa A_\alpha}{r})\phi^{(n)} - \frac{n^2}{\phi r^2}\phi^{(n)2}\big] \tag{4.6}$$

One can read both the charge q_n and mass of the scalar modes $\phi^{(n)}$

$$q_n = \frac{n\kappa}{r}(\phi\int dy)^{-1/2} = \frac{n\sqrt{16\pi G}}{r\sqrt{\phi}} \tag{4.7}$$

[4] I believe this is because of the developments in quantum mechanics about 1925 and later discovery of new particles shifted the interests of the majority of physicists away from it and from gravity. While quantum mechanics deserved its attention Einstein's later works, though considered failure, may not have had a fair evaluation.

Taking $r\sqrt{\phi} \sim l_{\rm Pl}$ one gets

$$\alpha = \frac{q_1^2}{4\pi}\ \frac{\sqrt{16\pi}^2}{4\pi} = 4 \tag{4.8}$$

which is a reasonable value and illustrates the point of making the KK theory attractive with better agreement (the value of quantity $r\sqrt{\phi}$ could be determined more accurately).

The scalar mode masses behave rather badly. The electron mass m_1 would be $M_{\rm Pl}$. This problem can be avoided by three things. First, by identifying the light particles with $n = 0$. Thereafter the Higgs couplings are applied to make the masses in the observed region. But now the charge of the $n = 0$ mode is zero. This is arranged by going to one more higher dimension where massless particles are no longer singlets of the gauge group corresponding to the ground state. Massless scalar field $\phi_a(x)$ in the adjoint representation of the gauge group can be introduced as follows

$$\phi_a^\mu = \phi_a(x)K_a^\mu(y) \tag{4.9}$$

which have in general non-zero couplings to the gauge fields.

The KK theory, with its promising features, cannot be considered fully understood at the moment. It has been extended up to 11 dimensional supergravity theory with a possibility for SU(3) $\times$ SU(2) $\times$ U(1) gauge group but with difficulties for proper fermion quantum numbers [30]. The point of this note is to propose one more structural level below quarks and leptons but fewer interactions, gravity and EM only, and lower dimensions, tentatively five, at Planck scale.

5 Black Hole Area Eigenvalues

A brief description is given below of BH quantization using a statistical mechanical model where the areas, and therefore the energies, of the horizon are quantized and used to calculate the partition function. In LQG geometry the area eigenvalues are [12]

$$A = \gamma l_{\rm Pl}^2 \sum\nolimits_p \sqrt{j_p(j_p+1)} \tag{5.1}$$

where the sum is over punctures p of the spin network, $l_{\rm Pl}$ is the Planck length, γ is the Barbero–Immirzi parameter and the values of j_p are $0, \frac{1}{2}, 1, \frac{3}{2}, ...$ The spin number j_p describes the size of the quanta of space [31]. For comprehensive treatments of quantum geometry and black holes see e.g. [32, 33].

The energy of a black hole from the point of view of an observer on its stretched horizon is called Brown-York energy [34]

$$E = \frac{a}{8\pi G}A \tag{5.2}$$

where a is the constant proper acceleration of an observer on the stretched horizon and A is the area of the horizon. In [35] quasilocal isolated horizons are considered which capture the main local features of horizons. The energy expression (5.2) remains the same.

For the BH spacetime model the partition function for a spin network with N punctures is, for details see [15]

$$\begin{aligned} Z(\beta) &= \sum\nolimits_n g(E_n)exp(-\beta E_n) \\ &= \sum\nolimits_{n_1 n_2 \ldots n_N} exp(-\beta T_0 \sum_{p=1}^{N} \sqrt{n_p(n_p+2)} \end{aligned} \tag{5.3}$$

where $T_0 = \frac{a}{16\pi}\gamma$ and $n_p = 2j_p$, with $n_p = 0, 1, 2, ...$ The resulting $Z(\beta)$ is

$$Z(\beta) = \frac{1}{y-1}\Big[1 - \Big(\frac{1}{y}\Big)^N\Big] \tag{5.4}$$

where

$$y = y(\beta) = \Big[\sum_{n=1}^{\infty} exp\big(-\beta T_0 \sqrt{n(n+2)}\big)\Big]^{-1} \tag{5.5}$$

When $y = 1$ one has simply $Z(\beta) = N$.

The average energy at temperature $T = 1/\beta$ can be calculated from the partition function (5.3)

$$E(\beta) = -\frac{\partial}{\partial\beta}\ln Z(\beta) \tag{5.6}$$

of the black hole which yields

$$E(\beta) = \Big(\frac{1}{y-1} - \frac{N}{y^N - 1}\frac{1}{y}\Big)\frac{dy}{d\beta} \tag{5.7}$$

In LQG it is assumed that the number of punctures on the stretched horizon is very large, say about 10^{122}. Therefore for $y > 1$ (5.7) simplifies to

$$E(\beta) = \frac{1}{y-1}\frac{dy}{d\beta} \tag{5.8}$$

For $y < 1$, y^N approaches zero for large N and one gets

$$E(\beta) = \frac{N}{y}\frac{dy}{d\beta} \tag{5.9}$$

There is a jump in energy of the hole when $y = 1$. Since y depends on temperature according to (5.5) on sees that the hole undergoes a phase transition at the critical temperature T_C defined by the solutions of

$$\sum_{n=1}^{\infty} exp\Big(-\frac{T_0}{T_C}\sqrt{n(n+2)}\Big) = 1 \tag{5.10}$$

Below the critical temperature T_C the punctures of the stretched horizon are in vacuum and there is no ordinary black hole. Above T_C the punctures get excited and provide the possibility of falling back to vacuum with Hawking radiation being emitted simultaneously.

From $T_0 = \frac{a}{16\pi}\gamma$ and $x = T_0/T_C \approxeq 0.508$ (obtained numerically) and choosing $\gamma = 8x \approxeq 4.06$ one gets

$$T_C = \frac{a}{2\pi} \tag{5.11}$$

which is the Davies-Unruh temperature felt by an observer on the stretched horizon with constant acceleration a. The Hawking temperature can also be derived

$$T_H = \frac{1}{8\pi M} \tag{5.12}$$

6 Black Hole Core

This section contains a brief review of a concept which indicates possible issues in BH modeling. In [36] a core is assumed for a BH which is formed in the gravitational collapse of matter. In the model the core is originally small inside an inner horizon in the BH and it replaces the classicl singularity. The radius of the core increases with time because of Hawking radiation with Hawking partners residing in the core. By the Page time the horizon disappears and the information inside the core becomes free to escape.

This formulation supports the picture of Hawking radiation put forward in [37] for the formation of it. In [38] it is emphasized that a natural vacuum for gravitational collapse can be realized demanding in Schwarzschild metric in the $r > 2m$ region absence of incoming radiation at both past null infinity and the past horizon and regularity of the energy-momentum tensor on the future event horizon in the frame of a freely falling observer. A freely falling observer would see an enormous peak in the energy density if the radiation came from within Planck length from the horizon. In the Unruh picture the Hawking radiation is generated non-locally by the distortion of vacuum modes of quantum fields as they propagate in the BH spacetime geometry. In [36] a large BH radiates like a black body but it is not a quantum system in a thermal state. The von Neumann entropy $S_{vN} = -Tr\rho_{A+B}\ ln\rho_{A+B}$ of the system is associated with the area of the inner apparent horizon of the BH core. The Bekenstein-Hawking entropy of the BH is related to the outer horizon and it is an upper limit to the von Neumann entropy. In this picture a BH has a finite lifetime close to the Page time.

The von Neumann entropy and entanglement entropy are identical if the BH is formed from a pure quantum state. If the material and radiation collapsing into th BH are not entangled with the outside universe, it does not then contribute to the von Neumann entropy. Counting the number of Hawking partners contributes to von Neumann entropy and it is approximately equal to the von Neumann entropy of the emitted Hawking radiation.

In [39] a different kind of core was proposed. There it was a critical connecting state between classical GR and (GUT) field theory of particles. It would in particular replace the singularity of GR. Its mass was supposed to be of the order of Planck mass. It would decay into GUT or SM particles by emitting a graviton. The final state would be a horizonless remnant of end-radiated BH with a short lifetime and it may not have any information loss problem. In [3] it seems that the remnant of a BH is rather a particle, or a preon. Further studies are needed to clarify the concept of core.

7 Spacetime Fabric

BHs, originally introduced as solutions of classical Einstein equations in empty space, get their energy from the Big Bang or Bounce. It has been shown above how to tentatively quantize BHs using area quantization methods. Whether the geometry of LQG is the correct quantization of Riemann geometry of GR waits for final answer. It looks at the moment that spacetime fabric consists of strands which make loops as sides of more complicated forms with volume and area. Strands determine area quantization and therefore give the thermodynamics of spacetime. When the temperature of the universe decreases below the critical temperature T_C the geometry changes and BHs begin to make phase transition to preon states.

After Big Bang or Bounce one has to assume something: a natural choice is BHs. Of course possibilities exist for different kind of preons or even other type particles and different interactions of various gauge groups. I call this freedom 'scenery'. The other universes either do not exist or are at least non-observable.

The preons with the properties discussed above offer an economical way to build a layered universe stepwise. Large scale structure is organized by gravity. Electromagnetism is needed for atomic and molecular scale structures, including biology as well as the solar system up to the whole universe. Even smaller structures require strong and weak interaction to build and control nuclei for atoms.

8 Conclusions

There are at present a number competing candidate theories for quantum gravity like string theory, loop quantum gravity, causal dynamical triangulation, and others. The area eigenvalues of loop quantum gravity were used in section 5 for model building. It is hoped that LQG, or some other such theory, will soon provide a consistent picture of *quantum geometry* in 4D and 5D for a unified theory.

The model of sections 2 and 5 goes deep into the structure of the physical universe and can be considered a novel candidate for a unified scheme of 'everything', in the sense discussed here. In the scenario briefly outlined above, the composite quark and lepton model, the horizon properties of black holes and LQG area eigenvalues look promising ingredients on the road towards the origin of spacetime, quantum gravity and matter.

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