A Model of Lepton and Quark Structure

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Abstract

We propose a model of particles with two very massive fundamental constituents, maxons. One of them is a fractionally charged color triplet and the other is neutral color singlet. Leptons, quarks and the weak bosons are quasiparticles in the system of interacting maxons. Some implications of the model are discussed.

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In this note we should like to present some speculative thoughts on the structure of leptons and quarks and on their interactions. We fully recognise the recent successes of gauge field theories (and make use of them). For a recent review see [1]. Also the present ideas of grand unified theories [2] have chances of being on the right track. In spite of all this some worries have been expressed [3, 4] about possible defects in these theories, in particular, the mass generation of the weak bosons and the explanation for the origin of generations of lepton and quark doublets. We have here no mathematical solution to these problems. Instead we wish to propose an alternative formulation [5] for these questions in the hope to have better understanding, in particular, of the role of gravity in particle physics.

We start from the cosmological assumption that (a) the universe at a very early moment consisted of stable particles of minimal size, the Planck length $l_0 = \sqrt{hG/c^3} \simeq 10^{-33}$ cm (G is the gravitational constant) and of large mass, perhaps as large as the Planck mass $m_0 = \sqrt{hc/G} \simeq 10^{-5}$ g $\sim 10^{19}$ GeV [6]. We call these particles maxons and assume that (b) they are charged and colored but not necessarily flavored, and have spin $\frac{1}{2}$. We suppose further that (c) at a slightly later moment the maxons formed bound state systems, due to gravitational interaction. Especially, the masses of the maxon systems can be arbitrarily small and are quantized [6].

We think it might be of interest to try to guess what could have followed from these conditions from the viewpoint of particle physics. So we take the liberty of making of some model building on the basis of the ansätze (a)-(c). We go on to suppose that (d) leptons and quarks are bound states of the maxons. These bound states are pointlike to a good approximation down to distances $10^{-30} - 10^{-33}$ cm. (e) Gravitational, electromagnetic and strong interactions are exact gauge theories: the graviton, photon and gluon are the corresponding massless gauge bosons. The weak interactions, instead, are maxon rearrangement processes as will be described below.

Let us discuss briefly but more explicitly a possible maxon model for leptons and quarks. Assume that there is one fractionally charged color triplet maxon $m_i^+, e = +\frac{1}{3}$, i = 1, 2, 3 for color, and one electrically neutral color singlet maxon $\bar{m}^0$ and the corresponding antiparticles. Our main conjecture is now that the first lepton doublet can be constructed as the following three maxon bound states

$$\begin{aligned} e^- &= \epsilon_{ijk} m_i^- m_j^- m_k^- \\ \nu &= \epsilon_{ijk} m_i^0 m_j^0 m_k^0 \end{aligned} \tag{0.1}$$

The corresponding first generation quark doublet is

$$\begin{aligned} u_k &= \epsilon_{ijk} m_i^+ m_j^+ m^0 \\ d_k &= \epsilon_{ijk} m_k^- \bar{m}_i^0 \bar{m}_j^0 \end{aligned} \tag{0.2}$$

Note that the two leptons are color singlets but the u- and d-quarks are color antitriplets.

In [7] and [8] a model with three subquark constituents has also been proposed. The present model differs in dynamics from that model as follows. In [7] and [8] color is not fundamental but is some kind of constituent permutation property. Instead, in our scheme color is fundamental together with gravitation. The difference between (0.1) and (0.2) is, by construction, color. In the case of the e^- the gravitational collapse of three maxons leads directly to color neutralisation. Obviously, not all color need be neutralised in this way, and therefore maxons in the early universe, at temperatures below 10^{19} GeV, must have been able to form color singlet "molecules", i.e. hadrons. The origin of this phenomenon could mathematically be "solitonlike" solutions of Einstein-Yang-Mills equations. How these solutions would look like remains to be seen. A simple example with pure Yang-Mills field acting as the source of the gravitational field has been considered in [9].

We further speculate that small scale gravity interactions will also give an excitation spectrum corresponding the observed heavier lepton and quark states. At distances $d \gg l_0$ quantum gravity effects disappear; we therefore think the lepton and quark spectrum is finite in this kind of theory. Because the upper members of the doublets (0.1) and (0.2) contain three and two, respectively, like charges we conclude that the mass differences inside the doublets arise at least partly due to electromagnetic interactions.

A number of phenomenological consequences are common in our model and in the model of [7] and [8]. For example, the proton decays into πe^+. In the subquark scheme it goes $uud \to d\bar{d} + e^+$ via "leptoquark" exchange, which is in our case an m^0m^- state (plus neutral higher Fock space components). An interesting difference between the standard gauge models and the subquark schemes is that in the latter there is universal symmetry between matter and antimatter on the maxon level.

Flavor in our scheme is not fundamental but follows from the possibility to combine three maxons into different charge states as indicated in (0.1) and (0.2). To construct flavor dynamics we therefore have to allow the leptons and quarks to interchange their constituents (as in the proton decay). Since the upper and lower doublet states have no constituents in common the equivalents of the gauge bosons $W^{\pm}$ and Z^0 are here six maxon states: $3m^{\pm}3m^0$ ($e\nu$ and ud transition), $3m^+3m^-(ee), 3m^03\bar{m}^0(\nu\nu)$, $2m^+2m^-m^0\bar{m}^0(uu)$, and $m^+m^-2m^02\bar{m}^0(dd)$. There can also be doubly charged $6m^{\pm}$ states but because all maxons have now the same charge we expect these bound states to have higher mass ($M_{\pm\pm}$) than the other six maxon states. To make a rough estimate, we notice that in the cs quark doublet the mass difference is the average doublet mass which would give $M_{\pm\pm} \sim 250$ GeV, assuming approximately degenerate masses for the singly charged and neutral six maxon states. However, counting charges the $3m^{\pm}3m^0$ should be heavier than the neutral maxon states[1]

[1] The neutral six maxon systems have by definition an equal amount of maxons and antimaxons. Therefore these particles may have also lower Fock space components. This seems to make the model more flexible, in particular, the connection between the Z^0 and the photon after Glashow-Weinberg-Salam theory may emerge this way [7, 8].

which cause elastic transitions. This is clearly heresy in 1979 and it may be safer to assume that the mass differences of all six maxon states are smaller than their average mass, consequently all spin 1 boson masses should be below 200 GeV. The spin 0 bound states then should have their masses in the same region and slightly below the spin 1 masses.

We consider now the question whether transitions like $\mu \to e + X$ and $c \to u + X$ (X = photon, gluon or Z^0) can occur. If the second and higher generations of lepton and quark doublets are small scale gravitational excitations of the first generation probably the photon and gluon transitions can be excluded at this stage. The Z^0 instead is in this scheme a gravitational bound state and consequently in Z^0 induced transitions the generation number could change. We expect, however, this kind of transitions to be suppressed because of small overlap integrals of the transition matrix elements. The Cabibbo angle can be defined in any case in terms of the transition amplitude ratio $A(u \to s)/A(u \to d)$ [7]. But we have no argument why this angle is so large as about 15°.

Independent of the details of a model we want to emphasize that gravitation should be considered seriously as the key to understanding of particle physics. When formulating supersymmetric theories one wants to start with as few fields as possible. Our scheme might make e.g. the SO(8) supergravity [10] more realistic because $SU(3)_c \times U(1)$ of color and electromagnetic interactions are included there but no muon or W^+ occur as fundamental particles. On the other hand, experimental information is needed to choose between the various unification models - if any of them is realised in nature. At present it seems that our arguments are closer to the spacetime "foam" picture of Wheeler, Townsend and Hawking [11, 12, 13]. One may start with the gravity as a de Sitter group O(4, 1) gauge theory and introduce the Planck length l_0 in the commutator of the translation generators P_a: $[P_a, P_b] = -il_0^{-2} J_{ab}$ where J_{ab} is the Lorentz rotation generator. l_0 was then shown to be related to the gravitational constant by $l_0^2 = 16\pi G$ at length scales larger than l_0 [12]. One is tempted to go further and consider the effect of the foam to the particles themselves. In the cases studied for the present [13], the foam seems to have no effect on low energy light fermions or vector particles but has big, undesirable effects on light scalars. Massive fermions remain to be studied. Another exciting possibility to study would be the coupled Einstein and Yang-Mills field equations to find out whether for quarks the Planck mass and confinement would turn out to be somehow related.

Finally we summarize the main features of the above discussed - needless to say, incomplete - working hypotheses:

- only two (or four counting color states) fundamental fermions, maxons, are needed. The leptons and quarks are constructed of three maxons;

- three exact gauge interactions are supposed: gravity, electromagnetism and the strong interaction. Topological concepts seem to be relevant to the formulation of the idea. Unification of all interactions, if supported experimentally, should be possible with a "small" gauge group;

- weak interactions operate only between bound states, their universality holds at present energies. Leptoquark interactions proceed in a similar way. The exchanged bosons in both cases are stated with even number of maxons;

- the huge difference between maxon and lepton-quark mass scales is due to gravitational mass defect; and

- new phenomena (e.g. doubly charged bosons of mass $\geq$ 100 GeV) are predicted but no new dynamics should be seen before energies close to 10^{19} GeV.

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[5] (b) The first four paragraphs of the present manuscript were conceived in November 1974 at SLAC when the c-quark was discovered. I proposed the c-quark to be a gravitationally excited u-quark. Unpublished.]

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