



3 Eightfold Way for Composite Quarks and Leptons

J.L. Chkareuli *

Center for Elementary Particle Physics, ITP, Ilia State University
0162 Tbilisi, Georgia

To memory of V.N. Gribov (1930–1997)

Abstract. The L-R symmetric composite model for quarks and leptons where constituent preons are bound by the $SO(n)_L \times SO(n)_R$ gauge forces is reconsidered. We find that just the eight left-handed and right-handed preons, their local metaflavor symmetry $SU(8)_{MF}$ and accompanying global chiral symmetry $SU(8)_L \times SU(8)_R$ may determine physical world at small distances. This result for an admissible number of preons filling the fundamental multiplet of some $SU(N)_{MF}$ symmetry group appears as a solution to the 't Hooft's anomaly matching condition precisely for $N = 8$, provided that this condition is satisfied separately for the L-preon and R-preon composites which fill individually a single multiplet of the $SU(N)$ rather than a set of its multiplets. We next show that an appropriate L-R symmetry violation reduces an initially emerged vectorlike $SU(8)$ theory down to the conventional $SU(5)$ GUT with an extra local family symmetry $SU(3)_F$ and three standard generations of quarks and leptons. Though the tiny radius of compositeness for universal preons composing both quarks and leptons makes it impossible to immediately confirm their composite nature, theory predicts the several extra heavy $SU(5) \times SU(3)_F$ multiplets located at the scales from $O(1)$ TeV up to the Planck mass scale that may appear of actual experimental interest.

Povzetek. Avtor obravnava model sestavljenih kvarkov in leptonov s simetrijo L-R, v katerem sestavne delce (preone) veže sila umeritve $SO(n)_L \times SO(n)_R$. Fiziko na majhnih razdaljah v tem primeru določa samo osem levoročnih in desnoročnih preonov z njihovo lokalno meta-okusno simetrijo $SU(N)_{MF}$ in ustrezno globalno kiralno simetrijo $SU(N)_L \times SU(N)_R$. Ta rezultat za $N = 8$ zadosti 't Hooftovemu pogoju za ujemanje anomalij, če velja posebej za gruč levoročnih in posebej za gruč desnoročnih preonov, če vsako od gruč določa bodisi levoročni bodisi desnočni multiplet. Avtor pokaže, da približna zlomitev simetrije L – R vodi do GUT $SU(5)$, ki pa ima dodatno lokalno simetrijo $SU(3)_F$, s katero opiše tri družine družine kvarkov in leptonov. Teorija napove več zelo težkih multipletov $SU(5) \times SU(3)_F$, ki imajo mase od $O(1)$ TeV do Planckove skale, kar bi lahko opazili pri poskusih.

Keywords: Composite, Preon, Family, Grand unified theory

* E-mail: j.chkareuli@iliauni.edu.ge

3.1 Preamble

It has long recognized that there is no meaningful internal symmetry scheme beyond the known Grand Unified Theories like as the $SU(5)$, $SO(10)$, or $E(6)$ GUTs which could be well suited for classification of all observed quarks and leptons. Any attempt to describe all three quark-lepton families in the grand unified framework leads to higher symmetries with enormously extended representations which also contain lots of exotic states that never been detected in an experiment. This may motivate us to continue seeking a solution in some subparticle or preon models for quark and leptons just like as in the nineteen-sixties the spectroscopy of hadrons had required to seek a solution in the quark model for hadrons in the framework of the so-called Eightfold Way. This term was coined by Murray Gell-Mann in 1961 to describe a classification scheme for hadrons, that he had devised, according to which the known baryons and mesons are grouped into the eight-member families of some global hadron flavor symmetry $SU(3)$ [1]. This concept had finally led to the hypothesis of quarks locating in the fundamental triplet of this symmetry, and consequently to a compositeness of baryons and mesons observed. We try to show now that the Eightfold Way idea looks much more adequate when it is applied to a next level of the matter elementarity, namely, to elementary preons and composite quarks and leptons. Remarkably, just the eight preons and their generic $SU(8)$ symmetry seem to determine in a somewhat special way the fundamental entities of the physical world and its total internal symmetry. Interestingly, not only the number "eight" for preons but also its breakdown into some special subdivisions corresponds to the spirit of the Eightfold Way that will be seen from a brief sketch given below.

In more detail, the Eightfold Way or Noble Eightfold Path [2] is a summary of the path of Buddhist practices leading, as supposed, to a true liberation. Keeping in mind the particle physics we propose that the eight spoke Dharma wheel which symbolizes the Noble Eightfold Path could be associated with eight preon fields (or superfields, in general) P_i ($i = 1, \dots, 8$) being the fundamental octet of the basic flavor symmetry $SU(8)$. They may carry out the eight fundamental quantum numbers which has been detected so far. These numbers are related to the weak isospin, color and families of quarks and leptons. Accordingly, we will refer to these preons as a collection of "isons" P_w ($w = 1, 2$), "chromons" P_c ($c = 1, 2, 3$) and "famons" P_f ($f = 1, 2, 3$). Surprisingly, the Noble Eightfold Path is also originally divided into three similar basic divisions. They are:

- (1) The Insight consisting of the Right view and the Right resolve,
- (2) The Moral virtue consisting of the Right speech, the Right action and the Right livelihood,
- (3) The Meditation consisting of the Right effort, the Right mindfulness and the Right Concentration.

This analogy with a similar decomposition of the sacred number eight, $8 = 2 + 3 + 3$, which appears in the expected breakdown of the generic preon $SU(8)$ symmetry

$$SU(8) \rightarrow SU(2)_W \times SU(3)_C \times SU(3)_F, \quad (3.1)$$

looks indeed rather impressive.

In principle, it is not necessary to generically relate the Eightfold Way concept to preons and composite quarks and leptons. First of all, it is related to the eight fundamental quantum charges of particle physics presently observed. They correspond in fact to the two weak isospin orientations, the three types of colors and the three species of quark-lepton families, all of which may be accommodated in the unified $SU(8)$ theory. Their carriers could be or could not be the elementary preons, though the preon model composing the observed quark and leptons at appropriate distances seems to reflect this concept in the most transparent way.

We find, resurrecting to an extent the old Eightfold Way idea in an initially L-R symmetric and $SU(N)$ invariant physical world, that just the eight left-handed and right-handed preons and their basic flavor symmetry $SU(8)$ appear as a solution to the 't Hooft's anomaly matching condition [3] providing the chiral symmetry preservation at all distances involved and, therefore, masslessness of emerged composite fermions. We show that this happens if (1) this condition is satisfied separately for the L-preon and R-preon composites and (2) each of these two series of composites fill only one irreducible representation of the starting $SU(N)$ symmetry group rather than a set of its representations. We next show that an appropriate L-R symmetry violation reduces an emerged vectorlike $SU(8)$ theory down to one of its chiral remnants being of significant physical interest. Particularly, this violation implies that, while there still remains the starting chiral symmetry for the left-handed preons and their composites, for the right-handed states we only have the broken chiral symmetry $[SU(5) \times SU(3)]_R$. Therefore, whereas nothing changes for the left-handed preon composites still filling the total multiplet of the $SU(8)$, the right-handed preon composites will fill only some particular submultiplets in it. As a result, we eventually come to the conventional $SU(5)$ GUT with an extra local family symmetry $SU(3)_F$ and three standard generations of quarks and leptons. Moreover, the theory has the universal gauge coupling constant running down from the $SU(8)$ unification scale, and also predicts some extra heavy $SU(5) \times SU(3)_F$ multiplets located at the scales from $O(1)$ TeV up to the Planck mass that may appear of actual experimental interest. For simplicity, we largely work in an ordinary spacetime framework, though extension to the conventional $N = 1$ supersymmetry with preons and composites treated as standard scalar superfields could generally be made. All these issues are successively considered in the subsequent sections 3.2–3.7, and in the final section 3.8 we present our conclusion.

Some attempt to classify quark-lepton families in the framework of the $SU(8)$ GUT with composite quarks and leptons had been made quite a long ago [4], though with some special requirements which presently seem not necessary or could be in principle derived rather than postulated. Since then also many other things became better understood, especially the fact that the chiral family symmetry subgroup $SU(3)_F$ of the $SU(8)$, taken by its own, was turned out to be rather successful in description of quark-lepton generations. At the same time, there have not yet appeared, as mentioned above, any other meaningful internal symmetry for an appropriate classification of all the observed quarks and leptons. All that motivates us to address this essential problem once again.

3.2 Preons - metaflavors and metacolors

We start formulating a few key elements of preon models (for some significant references, see [5,6]), partially refining some issues given in our old paper [4].

- We propose that there is an exact L-R symmetry at small distances where N elementary massless left-handed and right-handed preons, P_{iL} and P_{iR} ($i = 1, \dots, N$), possess a local metaflavor symmetry $SU(N)_{MF}$ including the known physical charges, such as weak isospin, color, and family number. The preons, both P_{iL} and P_{iR} , are located in its fundamental representation.
- The preons also possess a local metacolor symmetry $G_{MC} = G_{MC}^L \times G_{MC}^R$ with n metacolors (n is odd) which bind preons into composites - quarks, leptons and other states. In contrast to their common metaflavors, preons have different metacolors for the left-right and left-handed components, P_{iL}^α and $P_{iR}^{\alpha'}$, where α and α' are indices of the corresponding metacolor subgroups G_{MC}^L ($\alpha = 1, \dots, n$) and G_{MC}^R ($\alpha' = 1, \dots, n$), respectively. As a consequence, there are two types of composites at large distances being composed from them separately with a radius of compositeness, $R_{MC} \sim 1/\Lambda_{MC}$, where Λ_{MC} corresponds to the scale of the preon confinement for the asymptotically free (or infrared divergent) $G_{MC}^{L,R}$ symmetries. Obviously, the preon condensate $\langle \bar{P}_L P_R \rangle$ which could cause the Λ_{MC} order masses for composites is principally impossible. This is in sharp contrast to an ordinary QCD case where the left-handed and right-handed quarks forms the $\langle \bar{q}_L q_R \rangle$ condensate thus leading to the Λ_C order masses ($\Lambda_C \sim (0.1 \div 1) \text{ GeV}$) for mesons and baryons. Due to the L-R symmetry, the metacolor symmetry groups G_{MC}^L and G_{MC}^R are taken identical with a similar confinement for both of sets of preons. If one also proposes that the preon metacolor symmetry G_{MC} is generically anomaly-free for any matter content involved, then for independent left-handed and right-handed preons one comes to an input chiral orthogonal symmetry of the type

$$G_{MC} = SO(n)_{MC}^L \times SO(n)_{MC}^R, \quad n = 3, 5, \dots \quad (3.2)$$

for the n -preon configurations of composites. For reasons of economy, it is usually proposed that fermion composites have the minimal 3-preon configuration.

- Apart from the local symmetries, metacolors and metaflavors, the preons P_{iL}^α and $P_{iR}^{\alpha'}$ possess an accompanying chiral global symmetry

$$K(N) = SU(N)_L \times SU(N)_R \quad (3.3)$$

being unbroken at the small distances. We omitted above the Abelian chiral $U(1)_{L,R}$ symmetries in $K(N)$ since the corresponding currents have Adler-Bell-Jackiw anomalies in the triangle graph where they couple to two metagluons [7]. In fact, their divergences for massless preons are given by

$$\partial_\mu J_{L,R}^\mu = n \frac{g_{L,R}^2}{16\pi^2} G_{L,R}^{\mu\nu} G_{L,R}^{\rho\sigma} \epsilon_{\mu\nu\rho\sigma} \quad (3.4)$$

where $G_{L,R}^{\mu\nu}$ are the metagluon field strengths for the $SO(n)_{MC}^{L,R}$ metacolors, respectively, while $g_{L,R}$ are the appropriate gauge coupling constants. Thereby,

the chiral symmetries $U(1)_{L,R}$, which would present the conserved chiral hypercharges in the classical Lagrangian with massless preons, appear broken by the quantum corrections (3.4) that make us to leave only the non-Abelian chiral symmetry (3.3) in the theory. Nevertheless, one could presumably still use these symmetries at the small distances, $r \ll R_{MC}$, where the corrections (3.4) may become unessential due to asymptotic freedom in the metacolor theory considered. We will refer to this regime as the valent preon approximation in which one may individually recognize each preon no matter it is free or bound in a composite fermion. Therefore, the chiral preon numbers or hypercharges $Y_{L,R}$ related to the symmetries $U(1)_{L,R}$ may be considered in this approximation as the almost conserved classical charges according to which the preon and composite states are allowed to be classified.

- The fact that the left-handed and right-handed preons do not form the $\langle \bar{P}_L P_R \rangle$ condensate may be generally considered as a necessary but not yet a sufficient condition for masslessness of composites. The genuine massless fermion composites are presumably only those which preserve chiral symmetry of preons (3.3) at large distances that is controlled by the 't Hooft's anomaly matching (AM) condition [3]. For reasons of simplicity, we do not consider below boson composites, the effective scalar or vector fields. Generally, they being no protected by any symmetry will become very heavy (with masses of the order of the compositeness scale Λ_{MC}) and decouple from a low-lying particle spectrum.

3.3 AM conditions for N metaflavors

The AM condition [3] states in general that triangle anomalies related to N massless elementary preons, both left-handed and right-handed, have to match those for massless fermions (including quarks and leptons) being composed by the metacolor forces arranged by the proposed local symmetry $SO(n)_{MC}^L \times SO(n)_{MC}^R$. Based on the starting L-R symmetry in our model we will require, in some contrast to the original AM condition [3], that fermions composed from the left-handed and right-handed preons with their own metacolors, $SO(n)_{MC}^L$ and $SO(n)_{MC}^R$, have to satisfy the AM condition separately, whereas the metaflavor triangle anomalies of the L-preon and R-preon composites may in general compensate each other. Therefore, in our L-R symmetric preon model one does not need to specially introduce elementary metacolor singlet fermions, called the "spectator fermions" [3], to cancel these anomalies both at the small and large distances.

The AM condition puts in general powerful constraints on the classification of massless composite fermions with respect to the underlying local metaflavor symmetry $SU(N)_{MF}$ or some of its subgroups, depending on the extent to which the accompanying global chiral symmetry (3.3) of preons remains at large distances. In one way or another, the AM condition

$$\sum_r i_r a(r) = na(N) \quad (3.5)$$

for preons (the right side) and composite fermions (the left side) should be satisfied. Here $a(N)$ and $a(r)$ are the group coefficients of triangle anomalies related to the

groups $SU(N)_L$ or $SU(N)_R$ in (3.3) whose coefficients are calculated in an ordinary way,

$$a(r)d^{ABC} = \text{Tr}(\{T^A T^B\}T^C)_r, \quad \text{Tr}(T^A T^B) = \frac{1}{2}\delta^{AB} \quad (3.6)$$

where T^A ($A, B, C = 1, \dots, N^2 - 1$) are the $SU(N)$ generators taken in the corresponding representation r . The $a(N)$ corresponds a fundamental representation and is trivially equal to ± 1 (for left-handed and right-handed preons, respectively), while $a(r)$ is related to a representation r for massless composite fermions. The values of the factors i_r give a number of times the representation r appears in a spectrum of composite fermions and are taken positive for the left-handed states and negative for the right-handed ones.

The anomaly coefficients for composites $a(r)$ contain an explicit dependence on the number of preons N , due to which one could try to find this number from the AM condition. However, in general, there are too many solutions to the condition (3.5) for any value of N . Nevertheless, for some special, though natural, requirements an actual solution may only appear for $N = 8$, as we will see below.

Indeed, to strengthen the AM condition one could think that it would more appropriate to have all composite quarks and leptons in a single representation of the unified symmetry group rather than in some set of its representations. This, though would not largely influence the gauge sector of the unified theory, could make its Yukawa sector much less arbitrary. Apart from that, the composites belonging to different representations would have in general different preon numbers that could look rather unnatural. Let us propose for the moment that we only have the minimal three-preon fermion composites formed by the metacolor forces which correspond to the $SO(3)_{MC}^L \times SO(3)_{MC}^R$ symmetry case in (3.2). We will, therefore, require that only some single representation r_0 for massless three-preon states has to satisfy the AM condition that simply gives in (3.5)

$$a(r_0) = 3 \quad (3.7)$$

individually for L-preon and R-preon composites.

Now, calculating the anomaly coefficients for all possible three L-preon and three R-preon composites one respectively has (see also [4,8])

$$\begin{aligned} &\Psi_{\{ijk\}L,R}, N^2/2 + 9N/2 + 9, \\ &\Psi_{[ijk]L,R}, N^2/2 - 9N/2 + 9, \\ &\Psi_{\{[ij]k\}L,R}, N^2 - 9, \\ &\Psi_{\{jk\}L,R}^i, N^2/2 + 7N/2 - 1, \\ &\Psi_{[jk]L,R}^i, N^2/2 - 7N/2 - 1 \end{aligned} \quad (3.8)$$

with all appropriate $SU(N)_{L,R}$ representations listed (anomaly coefficients for right-handed composites have to be taken with an opposite sign). Putting then each of the above anomaly coefficients in (3.8) into the AM condition (3.7) one can readily find that there is a solution with an integer N only for the last tensors $\Psi_{[jk]L,R}^i$, and this is in fact the unique "eightfold" solution

$$N^2/2 - 7N/2 - 1 = 3, \quad N = 8. \quad (3.9)$$

Remarkably, the same solution $N = 8$ independently appears if one requires that the $SU(N)$ symmetry has to possess the right $SU(5)$ GUT assignment [5] for the observed quark-lepton families in order to be in fact in accordance with observations. This means that one of its specified representations has to contain an equal numbers of the $SU(5)$ anti-quintets $\bar{5}^k$ and decuplets $10_{[k,l]}$ (k, l are the $SU(5)$ indices). Indeed, decomposing $SU(N)$ into $SU(5) \times SU(N-5)$ one find that this equality does not exist for any 3-index representation (3.8) but the last one $\Psi_{[jk]}^i$, for which it reads as

$$(N-5)(N-6)/2 = N-5, \quad N=8 \quad (3.10)$$

thus leading again to the "eightfold" $SU(8)$ metaflavor symmetry.

Let us note that, apart the minimal 3-preon states, there are also possible some alternative higher preon configurations for composite quarks and leptons. Moreover, the $SO(3)_{MC}^{L,R}$ metacolors providing the three-preon structure of composite quarks and leptons may appear insufficient for the preon confinement, unless one invokes some special strong coupling regime [9]. For the asymptotically free $SO(n)$ metacolor, one must generally require $n > 2 + 2N/11$, due to which the composite quarks and leptons have to appear at least as five-preon states. Checking generally all possible n -index representations of $SU(N)$ we find that the AM condition only works for some combination of its "traced" tensors $\Psi_{[jk]L,R}^i$ and $\Psi_{iL,R}$ obtained after taking traces out of the proper n -index tensors $\Psi_{[jk\dots]L,R}^{i\dots}$. This eventually leads to the equation generalizing the above anomaly matching condition (3.9)

$$N^2/2 - 7N/2 - 1 + p = n \quad (3.11)$$

where p is a number of the traced fundamental multiplets $\Psi_{iL,R}$ for composites. One can see that there appear some reasonable solutions only for $n - p = 3$ and, therefore, one has again solutions for the "eightfold" metaflavor symmetry $SU(8)$.

Apart from the AM condition (3.5) there would be in general another kind of constraint on composite models which has been also proposed in [3]. This constraint requires the anomaly matching for preons and composites, even if some of introduced N preons become successively heavier than the scale of compositeness and consequently decouple from the entire theory. As a result, the AM condition should work for any number of preons remained massless (thus basically being independent of N) that could make generally classification of composite fermions quite arbitrary. Fortunately, such an extra constraint is not applicable to our L-R symmetric model where the Dirac masses for preons are not possible by definition, whereas the Majorana masses would mean breaking of the input local metaflavor $SU(N)_{MF}$ symmetry¹.

Most importantly, the orthogonal symmetry for metacolor (3.2) allows to consider more possible composite configurations than it is in the case of an unitary metacolor symmetry, as in the conventional $SU(3)$ color for QCD. The above strengthening of the AM condition, according to which composites only fill a

¹ Apart from that, it has been generally argued [5] that the nonperturbative effects may not be analytic in the preon mass so that for the large and small preon masses the theories may be quite different, thus avoiding this additional constraint.

single multiplet of the metaflavor $SU(N)_{MF}$ symmetry group, has unambiguously led us to the composite multiplets $\Psi_{[jk]L,R}^i$ having the same classical $U(1)_{L,R}$ fermion numbers or hypercharges $Y_{L,R}$ as the preons themselves. We argued in the previous section that these hypercharges may be considered in the valent preon approximation as the almost conserved classical charges according to which the preon and composite states could be classified. With all that in mind, one could assume that there may work some extra selection rule according to which only composites satisfying the condition

$$Y_{L,R}(\text{preons}) = Y_{L,R}(\text{composites}) \quad (3.12)$$

appear in physical spectrum in the orthogonal left-right metacolor case.

We can directly see that the condition (3.12) trivially works for the simplest composite states which could be constructed out of a single preon P_{iL}^α or $P_{iR}^{\alpha'}$, whose metacolor charge is screened by the metagluon fields $A_{L\mu}^\alpha$ and $A_{R\mu}^{\alpha'}$ of $SO(n)_{MC}^L$ and $SO(n)_{MC}^R$, respectively. These composites will also satisfy the general AM condition (3.5) provided that one admits the n left-handed and right-handed fundamental multiplets of the $SU(N)_{MF}$ to participate ($i_N = n$). In our L-R symmetric model, however, such massless composites will necessarily pair up, thus becoming very massive and decoupling from the low-lying particle spectrum, no matter the starting L-R symmetry becomes later broken or not. This in sharp contrast to the models [8] with the orthogonal metacolor group $SO(n)$ for the single chirality preons, where such massless composite generally appear to be in contradiction with observations. Moreover, in this case the composite multi-preon states for quarks and leptons seem hardly to be stable, since they could freely dissociate into three screened preon states.

One could wonder why the condition (3.12) does not work in the familiar QCD case with elementary quarks and composite baryons. The point is that, despite some conceptual similarity, QCD is the principally different theory. The first and immediate is that the unitary color $SU(3)_C$, in contrast to the orthogonal ones, allows by definition no other quark number for baryons but $Y_B = 3Y_q$. The most important aspect of this difference is, however, that the color symmetry $SU(3)_C$ is vectorlike due to which chiral symmetry in QCD is broken by quark-antiquark condensates with the corresponding zero-mass Goldstone bosons (pions, kaons etc.) providing the singularity of the three-point function. As a consequence, the AM condition implies in this case that dynamics requires spontaneous breakdown of chiral symmetry rather than an existence of massless composite fermions, as happens in the orthogonal metacolor case discussed above.

We find below in section 3.5 that, though the proposed condition (3.12) looks rather trivial in the L-R symmetry phase of the theory, it may become rather significant when this symmetry becomes spontaneously broken.

3.4 Composites - the L-R symmetry phase

So, we have at small distances the preons given by the Weil fields

$$P_{iL}^\alpha, P_{iR}^{\alpha'} \quad (i = 1, \dots, 8; \alpha = 1, 2, 3; \alpha' = 1, 2, 3) \quad (3.13)$$

belonging to the fundamental octet of the local metaflavor symmetry $SU(8)_{MF}$ and to triplets of the metacolor symmetry $SO(3)_{MC}^L \times SO(3)_{MC}^R$ which are local, and there is also the accompanying global chiral symmetry

$$K(8) = SU(8)_L \times SU(8)_R \quad (3.14)$$

of the eight preon species (3.13). At large distances, on the other hand, we have composites located, respectively, in the left-handed and right-handed multiplets of the $SU(8)_{MF}$

$$\Psi_{[jkl]L}^i(216), \Psi_{[jkl]R}^i(216), \quad (3.15)$$

where their dimensions are explicitly indicated. The chiral symmetry (3.14), according to the AM condition taken, remains at large distances. Due to a total L-R symmetry of preons and composites the triangle anomalies both at small and large distances appears automatically compensated. Decomposing the $SU(8)_{MF}$ composite multiplets (3.15) into the $SU(5) \times SU(3)_F$ components one has

$$216_{L,R} = [(\bar{5} + 10, \bar{3}) + (45, 1) + (5, 8) + (24, 3) + (1, 3) + (1, \bar{6})]_{L,R} \quad (3.16)$$

where the first term for the left-handed composites, $(\bar{5} + 10, \bar{3})_L$, could be associated with the standard $SU(5)$ GUT assignment for quarks and leptons [5] extended by some family symmetry $SU(3)_F$, while other multiplets are somewhat exotic and, hopefully, could be made heavy to decouple them from an observed low-lying particle spectrum.

The determination of the explicit form of the wave function for composite states (3.15) is a complicated dynamical problem related to the yet unknown dynamics of the preon confinement. We propose that some basic feature of these composites are simply given by an expression

$$\Psi_{[jkl]L}^i(x) \propto \epsilon_{\alpha\beta\gamma} \left(\bar{P}_L^{\alpha i} \gamma_\mu P_{L[j}^\beta \right) \gamma^\mu P_{k]L}^\gamma(x) \quad (3.17)$$

where indices α, β, γ belong to the metacolor symmetry $SO(3)_{MC}^L$. In the valent preon approximation, the preon current (3.17) corresponds to a bound state of three left-handed preons with zero mass ($p^2 = (p_1 + p_2 + p_3)^2 = 0$) being formed by massless preons ($p_1^2 = p_2^2 = p_3^2 = 0$) which are moving in a common direction. It is then clear that a state with a spin of $1/2$ (and a helicity $-1/2$) can be only obtained by assembling two preons and one antipreon into a quark or lepton. In a similar way one can construct the preon current $\Psi_{[jkl]R}^i$ which corresponds to a multiplet of states again with a spin of $1/2$ (but a helicity $+1/2$) composed from right-handed preons. This is simply achieved by making the proper replacements in (3.17) leading to the composite states

$$\Psi_{[jkl]R}^i(x) \propto \epsilon_{\alpha'\beta'\gamma'} \left(\bar{P}_R^{\alpha' i} \gamma_\mu P_{R[j}^{\beta'} \right) \gamma^\mu P_{k]R}^{\gamma'}(x) \quad (3.18)$$

where indices α', β', γ' belong now to the metacolor symmetry $SO(3)_{MC}^R$. For the simplest composite states which can be constructed out of a single preon P_{iL}^α or $P_{iR}^{\alpha'}$, whose metacolor charge is screened by the metagluon fields $A_{L\mu}^\alpha$ and $A_{R\mu}^{\alpha'}$ of $SO(3)_{MC}^L$ and $SO(3)_{MC}^R$, the wave functions may be written as

$$\Psi_{iL}(x) \propto A_{L\mu}^\alpha \gamma^\mu P_{iL}^\alpha(x), \quad \Psi_{iR}(x) \propto A_{R\mu}^{\alpha'} \gamma^\mu P_{iR}^{\alpha'}(x), \quad (3.19)$$

respectively.

Let us remark in conclusion that the whole theory so far considered is certainly vectorlike with respect to preons (3.13), as well as composites (3.15). This means that, while preons are left massless being protected by their metacolors, all the L-preon and R-preon composites being metacolor singlets will pair up due to some quantum gravitational transitions and, therefore, acquire some Dirac masses. We find below that due to closeness of the compositeness scale Λ_{MC} to the Planck scale M_{Pl} the masses of all composites appear very heavy that has nothing in common with reality. It is rather clear that such a theory is meaningless unless the L-R symmetry is somehow broken that seems to be in essence a basic point in our model. One could expect that such breaking may somehow exclude the right-handed submultiplet $(\bar{5} + 10, \bar{3})_R$ in the composite spectrum (3.16), while leaving there its left-handed counterpart, $(\bar{5} + 10, 3)_L$, which can be then uniquely associated with the observed three families of ordinary quarks and leptons.

3.5 Composites - partially broken L-R symmetry

We propose that there a partial breaking of the chiral symmetry (3.14) in the right-handed preon sector of the type

$$K(8) \rightarrow SU(8)_L \times [SU(5) \times SU(3)]_R \quad (3.20)$$

For convenience, we consider a supersymmetric model where this breaking may be caused presumably due to the asymmetric preon condensation

$$\epsilon_{\alpha\beta\gamma} \langle P_{iL}^\alpha P_{jL}^\beta P_{kL}^\gamma \rangle = 0, \quad \epsilon_{\alpha'\beta'\gamma'} \langle P_{iR}^{\alpha'} P_{jR}^{\beta'} P_{kR}^{\gamma'} \rangle = \delta_i^a \delta_j^b \delta_k^c \epsilon_{abc} \Lambda_{MC}^4 \quad (3.21)$$

emerging for preon superfields with their fermion and scalar field components involved. Here antisymmetric third-rank tensors $\epsilon_{\alpha\beta\gamma}$ and $\epsilon_{\alpha'\beta'\gamma'}$ belong to the metacolor symmetries $SO(3)_{MC}^L$ and $SO(3)_{MC}^R$, respectively, while ϵ_{abc} ($a, b, c = 1, 2, 3$) to the symmetry $SU(3)_R$. Remarkably, the breaking (3.20) is only possible when the number of metacolors n is equal 3 or 5, as is actually implied in our model. For the minimal case, $n = 3$, the vacuum configurations (3.21) could spontaneously appear in some L-R symmetric model with the properly arranged high-dimensional preon interactions²

$$\begin{aligned} & \sum_{n=1}^{\infty} \{ G_n^{LL} [(\bar{P}_L \bar{P}_L \bar{P}_L) (P_L P_L P_L)]^n + G_n^{RR} [(\bar{P}_R \bar{P}_R \bar{P}_R) (P_R P_R P_R)]^n \\ & + G_n^{LR} [(\bar{P}_L \bar{P}_L \bar{P}_L) (P_R P_R P_R)]^n + G_n^{RL} [(\bar{P}_R \bar{P}_R \bar{P}_R) (P_L P_L P_L)]^n \} \end{aligned} \quad (3.22)$$

with coupling constants satisfying the conditions $G_n^{LL} = G_n^{RR}$ and $G_n^{LR} = G_n^{RL}$. This model is evidently non-renormalizable and can be only considered as an effective theory valid at sufficiently low energies. The dimensionful couplings G_n

² This L-R symmetry breaking model looks somewhat similar to the well-known multi-fermion interaction schemes used in the other contexts for chiral symmetry breaking [10] or spontaneous Lorentz violation [11].

are proportional to appropriate powers of some UV cutoff Λ which in our case can be ultimately related to the preon confinement energy scale Λ_{MC} , $G_n \sim \Lambda_{MC}^{4-8n}$. For some natural choice of these coupling constants one may come to the asymmetric solution (3.21).

A more conventional way of getting the L-R asymmetry may follow from the symmetric scalar field potential [5]

$$U = M^2(\Phi_L^2 + \Phi_R^2) + h(\Phi_L^2 + \Phi_R^2)^2 + h'\Phi_L^2\Phi_R^2 + P(\Phi_L, \Phi_R) \quad (3.23)$$

containing two elementary third-rank antisymmetric scalar fields, $\Phi_L^{[ijk]}$ and $\Phi_R^{[ijk]}$, interacting with L- and R-preons, respectively. For some natural area of the parameters in the potential, $M^2 < 0$ and $h, h' > 0$, and properly chosen couplings for scalars $\Phi_L^{[ijk]}$ and $\Phi_R^{[ijk]}$ in the polynomial $P(\Phi_L, \Phi_R)$ they may readily develop the totally asymmetric VEV configuration

$$\langle \Phi_L^{[ijk]} \rangle = 0, \quad \langle \Phi_R^{[ijk]} \rangle = \delta_a^i \delta_b^j \delta_c^k \epsilon^{abc} M_{LR} \quad (a, b, c = 1, 2, 3) \quad (3.24)$$

where the mass M_{LR} corresponds to the L-R symmetry breaking scale and indices a, b, c belong to the $SU(3)_R$. Due to these VEVs, the higher dimension terms in the effective superpotential induced generally by gravity

$$\frac{G_L}{M_{Pl}}(P_{iL}P_{jL}P_{kL})\Phi_L^{[ijk]} + \frac{G_R}{M_{Pl}}(P_{iR}P_{jR}P_{kR})\Phi_R^{[ijk]} \quad (3.25)$$

($G_{L,R}$ are dimensionless coupling constants) will change the AM conditions for right-handed states leaving those for the left-handed ones intact. This modification is related to an appearance of a new Yukawa interaction for preons

$$G'_R \epsilon^{abc} (P_{aR}^{(f)} C P_{bR}^{(f)}) P_{cR}^{(s)}, \quad G'_R = G_R \frac{M_{LR}}{M_{Pl}} \quad (3.26)$$

where $P_{iR}^{(f,s)}$ are, respectively, the fermion and scalar field components of the right-handed preon superfield P_{iR} . This interaction will give some extra radiative corrections to the triangle graphs with circulating "family" preons $P_{aR}^{(f)}$ ($a = 1, 2, 3$) and their composites. As a result, the triangle anomalies corresponding to all generators of the $SU(8)_R$, besides those of the $[SU(5) \times SU(3)]_R$, are left uncompensated, that causes the proper decreasing of the chiral symmetry, just as is indicated in (3.20).

Eventually, while there still remains the starting chiral symmetry for the left-handed preons and their composites, for the right-handed states we only have the broken symmetry given in (3.20). Therefore, whereas nothing changes for the L-preon composites filling the total multiplet 216_L in (3.16), the R-preons will only compose some particular submultiplets in 216_R (3.16) which in general may not include the three right-handed quark-lepton families $(\bar{5} + 10, 3)_R$. We can simply postulate it as some possible ansatz being allowed by the different chiral symmetries in the L-preon and R-preon sectors in the L-R symmetry broken phase. Nonetheless, it would be interesting to argue it using the preon number matching

condition (3.12) which we discussed in section 3.3. Note first that the $U(1)_R$ symmetry in the right-handed sector reduces after the L-R symmetry breaking (3.21, 3.24) to

$$U(1)_R \rightarrow U(1)_R^{(5)} \times Z(3)_R^{(3)} \quad (3.27)$$

while the $U(1)_L$ symmetry is left intact. Here, $U(1)_R^{(5)}$ and $Z(3)_R^{(3)}$ stand for the survived continuous and discrete symmetries of quintet preons P_{sR} ($s = 1, \dots, 5$) of $SU(5)_R$ and triplet preons P_{aR} ($a = 1, 2, 3$) of $SU(3)_R$, respectively, which are thereby separated. Namely, the R-preon hypercharge group in the broken L-R symmetry phase is given by the product (3.27) rather than the universal $U(1)_R$ for all eight preons, as was in its unbroken phase. Now, if we require the preon number matching for preons and composites the states collected in $(\bar{5} + 10, \bar{3})_R$ will never appear in physical spectrum. Indeed, as one can easily check, both the $U(1)_R^{(5)}$ hypercharge and discrete $Z(3)_R^{(3)}$ symmetry values for these states are quite different from those for the preons P_{sR} and P_{aR} , respectively. At the same time, all other composite submultiplets in 216_R (3.16) readily match the both symmetry values for preons.

One way or another, the simplest combination of the 216_R submultiplets which may simultaneously satisfy the AM conditions for the $[SU(5) \times SU(3)]_R$ symmetry, as well as the above preon number matching condition is in fact given by the collection

$$(45, 1)_R + (5, 8 + 1)_R + 3(1, 3)_R \quad (3.28)$$

where the submultiplet $(1, 3)_R$ has to appear three times in (3.28) in order to appropriately restore the anomaly coefficient balance for the R-preon composites. Of course, this collection of states can also appear by its own without any reference to the preon number matching condition that we have used above as some merely heuristic argument.

3.6 Physical sector - quarks and leptons

We can see that after chiral symmetry breaking in the sector of the right-handed preon composites the starting metaflavor symmetry $SU(8)_{MF}$ at large distances is reduced to the product of the standard $SU(5)$ GUT and chiral family symmetry $SU(3)_F$

$$SU(8)_{MF} \rightarrow SU(5) \times SU(3)_F \quad (3.29)$$

presumably with the equal gauge coupling constants g_5 and g_{3F} at the grand unification scale. This is in essence the chiral remnant of the initially emerged vectorlike $SU(8)_{MF}$ symmetry. The massless composite fermions, due to pairing up of the similar L-preon and R-preon composites and decoupling them from a low-energy spectrum, are given now by the collection of the $SU(5) \times SU(3)_F$ multiplets

$$(\bar{5} + 10, \bar{3})_L + (24, 3)_L + 2(1, 3)_R + (1, \bar{6})_R \quad (3.30)$$

which automatically appear free from both the $SU(5)$ and $SU(3)_F$ anomalies. They contain just three conventional families of quarks and leptons plus massive multiplets located on the family symmetry scale M_F . In order to sufficiently suppress

all flavor-changing transitions, which would induce the family gauge boson exchanges, this scale should be at least of the order $10^{5\div 6}$ GeV, though in principle it could be as large as the SU(5) GUT scale. In the latter case, some of the heavy states in (3.30) could be considered as candidates for the superheavy right-handed neutrinos. One can argue that the physical composite multiplets (3.30) appear not only for the triple metacolor, $n = 3$, but in general case as well. Indeed, using the remark concerning the generalized AM condition (3.11) and properly extending the left-handed multiplets in (3.16) and the right-handed multiplets in (3.28) by the new $n - 3$ fundamental composite octets $[(5, 1) + (1, 3)]_{L,R}$ to have anomaly matching for any number n of metacolors, one comes after pairing of the identical multiplets to the same physical remnant (3.30) as in the triple metacolor case.

It is important to note that the tiny radius of compositeness for universal preons composing both quarks and leptons makes it impossible to directly observe their composite nature [12]. Indeed, one can readily see that the quark pair $u + d$ contains the same preons as the antiquark-antilepton pair $\bar{u} + e^+$ that will lead to the process

$$u + d \rightarrow \bar{u} + e^+ \quad (3.31)$$

and consequently to the proton decay $p \rightarrow \pi^0 + e^+$ just due to a simple rearrangement of preons in a proton. To prevent this one should take the compositeness scale Λ_{MC} of the order of the scale of the SU(5) GUT or even larger, $\Lambda_{MC} \gtrsim M_{GUT} \approx 2 \cdot 10^{16}$ GeV, and, respectively, $R_{MC} \leq 5 \cdot 10^{-31}$ sm.

This limit on the radius of compositeness may in turn cause limits on the composite fermions masses appearing as a result of the quantum gravitational transitions of the identical states in the left-handed multiplets (3.15) and right-handed multiplets (3.28),

$$(45, 1)_{L,R} + (5, 8 + 1)_{L,R} + (1, 3)_{L,R} , \quad (3.32)$$

into each other. From dimensional arguments related to a general structure of the composites proposed above (3.17), these masses could be of the order

$$(\Lambda_{MC}/M_{Pl})^5 \Lambda_{MC}$$

(that corresponds in fact to the 6-fermion interaction of the left-handed and right-handed preons) and, in fact, are very sensitive to the confinement scale Λ_{MC} . Actually, for the metacolor scales, $M_{GUT} \leq \Lambda_{MC} \leq M_{Pl}$, the heavy fermion masses may be located at the scales from $O(1)$ TeV up to the Planck mass scale. Therefore, the heavy composite states may be of direct observation interest if they are located near the low limit, or otherwise they will populate the SU(5) GUT desert. Interestingly, the screened preon states (3.19)

$$(5, 1)_{L,R} + (1, 3)_{L,R} \quad (3.33)$$

acquire much heavier masses when being pairing with each other. Again, from the dimensional arguments one may conclude that these masses has a natural order $(\Lambda_{MC}/M_{Pl})\Lambda_{MC}$ that is significantly larger than masses of the 3-preon states (3.17, 3.18).

Note that some of the heavy states (3.32) can mix with ordinary quarks and leptons given by the multiplet $(\bar{5} + 10, \bar{3})_L$ in (3.30). Particularly, there could be the large mixing term of the part $(\bar{5}, \bar{3})_L$ containing the lepton doublet and down antiquarks with the multiplet $(5, 8 + 1)_R$ in (3.32). This term has a form

$$(\bar{5}, \bar{3})_L (5, 8 + 1)_R (1, 3) \quad (3.34)$$

where $(1, 3)$ stands for some pure "horizontal" scalar field being a triplet of the family symmetry $SU(3)_F$. Actually, this mixing is related again to the 6-fermion gravitational interaction of the left-handed and right-handed preons, thus leading to the nondiagonal masses of the order $(\Lambda_{MC}/M_{Pl})^5 M_F$. Thereby, in order not to significantly disturb the masses of quarks and leptons in (3.30) one has to generally propose $M_F \ll \Lambda_{MC}$. This in fact is readily satisfied even for high family scales, namely, in the case when the scale M_F is taken near the grand unification scale M_{GUT} , while the scale Λ_{MC} near the Planck scale M_{Pl} . The more liberal limitations appears when that part $(\bar{5}, \bar{3})_L$ mixes with the screen preon states $(5, 1)_R$ in (3.33) due to the same scalar triplet $(1, 3)$ of the $SU(3)_F$. Now, this mixing caused by the 4-fermion interaction leads to the nondiagonal mass of the order $(\Lambda_{MC}/M_{Pl})^2 M_F$ that may be naturally much lesser than diagonal mass $(\Lambda_{MC}/M_{Pl})\Lambda_{MC}$ derived above for the screened preon state. Nevertheless, depending on real values of the scales Λ_{MC} and M_F there could be expected some violation of unitarity in the conventional 3×3 mass matrices of leptons and down quarks which may be of a special interest for observations. Other mixings of quarks and leptons with heavy states (3.32) and (3.33) will necessarily include an ordinary Higgs quintet of the grand unified $SU(5)$ (or a doublet of the SM) and, therefore, are negligibly small.

To conclude, our preon model predicts three types of states which are (1) three families of ordinary quarks and leptons $(\bar{5} + 10, \bar{3})_L$ in (3.30) with masses at the electroweak scale, (2) the heavy chiral multiplets $(24, 3)_L + 2(1, 3)_R + (1, \bar{6})_R$ (3.30) with the Majorana type masses at the family scale $M_F = 10^{6 \div 16}$ GeV and (3) the heavy paired multiplets (3.32) with masses in the interval $10^{3 \div 19}$ GeV which are related to the gravitational transition amplitudes of the L-preon composites into the R-preon ones. However, the most important prediction of the left-right preon model considered here is, indeed, an existence of the local chiral family (or horizontal) symmetry $SU(3)_F$ for quark-lepton generations which is briefly presented below.

3.7 The chiral family symmetry $SU(3)_F$

The flavor mixing of quarks and leptons is certainly one of the major problems that presently confront particle physics. Many attempts have been made to interpret the pattern of this mixing in terms of various family symmetries - discrete or continuous, global or local. Among them, the chiral family symmetry $SU(3)_F$ derived first in the similar preon framework [4] and developed then by its own by many authors [13-22] seems most promising. As was shown, the spontaneous breaking of this symmetry gives some guidance to the observed hierarchy between elements of the quark-lepton mass matrices, on the one hand, and to presence

of texture zeros in them, on the other, that leads to relationships between the mass and mixing parameters. In the framework of the supersymmetric Standard Model, it leads, at the same time, to an almost uniform mass spectrum for the superpartners, with a high degree of flavor conservation, that makes its existence even more significant in the SUSY case.

Generically, the chiral family symmetry $SU(3)_F$ possesses four basically attractive features:

(i) It provides a natural explanation of the number three of observed quark-lepton families, correlated with three species of massless or light ($m_\nu < M_Z/2$) neutrinos contributing to the invisible Z boson partial decay width;

(ii) Its local nature conforms with the other local symmetries of the Standard Model, such as the weak isospin symmetry $SU(2)_w$ or color symmetry $SU(3)_c$, thus leading to the family-unified SM with a total symmetry $SM \times SU(3)_F$;

(iii) Its chiral nature, according to which both left-handed and right-handed fermions are proposed to be fundamental triplets of the $SU(3)_F$, provides the hierarchical mass spectrum of quark-lepton families as a result of a spontaneous symmetry breaking at some high scale M_F which could in principle be located in the area from $10^{5 \div 6}$ GeV (to properly suppress the flavor-changing processes) up to the grand unification scale M_{GUT} and even higher. Actually, any family symmetry should be completely broken in order to conform with reality at lower energies. This symmetry should be chiral, rather than a vectorlike, since a vectorlike symmetry would not forbid the invariant mass, thus leading in general to degenerate rather than hierarchical mass spectra. Interestingly, both known examples of local vectorlike symmetries, electromagnetic $U(1)_{EM}$ and color $SU(3)_C$, appear to be exact symmetries, while all chiral symmetries including conventional grand unifications [5] $SU(5)$, $SO(10)$ and $E(6)$ (where fermions and antifermions lie in the same irreducible representations) appear broken;

(iv) Thereby, due to its chiral structure, the $SU(3)_F$ admits a natural unification with all known GUTs in a direct product form, both in an ordinary and supersymmetric framework, thus leading to the family-unified GUTs, $GUT \times SU(3)_F$, beyond the Standard Model.

So, if one takes these naturality criteria seriously, all the candidates for flavor symmetry can be excluded except for local chiral $SU(3)_F$ symmetry. Indeed, the $U(1)$ family symmetry does not satisfy the criterion (i) and is in fact applicable to any number of quark-lepton families. Also, the $SU(2)$ family symmetry can contain, besides two light families treated as its doublets, any number of additional (singlets or new doublets of $SU(2)$) families. All the global non-Abelian symmetries are excluded by criterion (ii), while the vectorlike symmetries are excluded by the last criteria (iii) and (iv).

Among applications of the $SU(3)_F$ symmetry, the most interesting ones are the description of the quark and lepton masses and mixings in the Standard Model and GUTs [13], neutrino masses and oscillations [15] and rare processes [16] including their astrophysical consequences [22]. Remarkably, the $SU(3)_F$ invariant Yukawa coupling are always accompanied by an accidental global chiral $U(1)$ symmetry, which can be identified with the Peccei-Quinn symmetry [18] provided it is not explicitly broken in the Higgs sector, thus giving a solution to

the strong CP problem [17]. In the SUSY context [19], the $SU(3)_F$ model leads to a special relation between (s)fermion masses and the soft SUSY breaking terms at the GUT scale in a way that all the dangerous flavor-changing processes are naturally suppressed. The special sector of applications is related to a new type of topological defects - flavored cosmic strings and monopoles appearing during the spontaneous violation of the $SU(3)_F$ which may be considered as possible candidates for the cold dark matter in the Universe [20].

Let us note in conclusion that if the family symmetry $SU(3)_F$ arises from the preon model proposed above one can expect that in the emerged $SU(5) \times SU(3)_F$ GUT the gauge coupling constants g_5 and g_{3F} should be equal at the $SU(8)_{MF}$ unification scale. The study of flavor changing processes $\mu \rightarrow e + \gamma$, $D^0 - \bar{D}^0$, $B^0 - \bar{B}^0$ and others caused by the $SU(3)_F$ gauge boson exchanges could in principle show whether the family symmetry has an origin in the preon model or it is, rather, independently postulated. However, the most crucial difference between these two cases is related to the existence in the preon model of some heavy $SU(5) \times SU(3)_F$ multiplets located at scales from $O(1)$ TeV up to the Planck mass. If they are relatively light, they may be of direct observational interest by them own. If they are heavy, they still strongly affect the quark-lepton mass matrices due to their large mixings with the down quarks and leptons, as was shown in (3.34). Remarkably, even if the family symmetry $SU(3)_F$ is taken at the GUT scale the difference between these cases is still left. Indeed, now all flavor-changing transitions due to the family gauge boson exchange will be extremely suppressed, while for the independently introduced family symmetry these transitions may significantly contribute into rates of the nondiagonal processes. Moreover, for the high scale family symmetry one has some natural candidates for massive right-handed neutrinos in terms of the extra heavy states given in (3.30).

3.8 Conclusion and outlook

We have shown that, apart from somewhat inspirational religious and philosophical aspects ensured by the Eightfold Way, the $SU(8)$ symmetry as a basic internal symmetry of the physical world is indeed advocated by preon model for composite quarks and leptons.

In fact, many preon models have been discussed and considered in the past (some significant references can be found in [5,6]), though they were not turned out to be too successful and attractive, especially compared with other theory developments, like as supersymmetry and supergravity, appeared at almost the same time. However, there is still left a serious problem in particle physics with classification of all observed quark-lepton families. As in the hadron spectroscopy case, this may motivate us to continue seeking a solution in some subparticle or preon models for quarks and leptons, rather than in the less definitive extra dimension or superstring theories.

Let us briefly outline the main results presented here. We have started with the L-R symmetric preon model and found that an admissible metaflavor symmetry $SU(8)_{MF}$ appears as a solution to the 't Hooft's anomaly matching condition

providing preservation of the accompanying chiral symmetry $SU(8)_L \times SU(8)_R$ at all scales involved. In contrast to a common point of view, we require that states composed from the left-handed and right-handed preons with their own metacolors, $SO(3)_{MC}^L \times SO(3)_{MC}^R$, have to satisfy AM condition separately, though their triangle anomalies may compensate each other. The point is, however, this $SU(8)_{MF}$ theory emerges as the vectorlike theory with respect both to preons and composites. As a consequence, while preons are left massless being protected by their metacolors, all L-preon and R-preon composites being metacolor singlets will pair up and, therefore, acquire superheavy Dirac masses. It is rather clear that such a theory is meaningless unless the L-R symmetry is partially broken that seems to be a crucial point in our model. In this connection, the natural mechanisms for spontaneous L-R symmetry breaking have been proposed according to which some R-preons, in contrast to L-preons, may be condensed or such asymmetry may be caused by the properly arranged scalar field potential. As result, an initially emerged vectorlike $SU(8)$ theory reduces down to the conventional $SU(5)$ GUT with an extra local family symmetry $SU(3)_F$ and three standard generations of quarks and leptons. Though the tiny radius of compositeness for universal preons composing both quarks and leptons makes it impossible to immediately confirm their composite nature, the theory necessarily predicts a few special $SU(5) \times SU(3)_F$ multiplets of composite fermions located at the scales from $O(1)$ TeV up to the Planck mass scale that may appear of actual experimental interest. Some of them may be directly observed, the others populate the $SU(5)$ GUT desert. Due to their mixing with ordinary quark-lepton families there may be expected some violation of unitarity in the mass matrices for leptons and down quarks depending on the interplay between the compositeness scale Λ_{MC} and scale of the family symmetry $SU(3)_F$.

For the reasons of simplicity, we have not considered here boson composites which could appear as the effective scalar or vector fields in the theory. Generally, they will become very heavy (with masses of the order of the compositeness scale Λ_{MC}) unless their masses are specially protected by the low-scale supersymmetry. The point is, however, that some massless composite vector fields could nonetheless appear in a theory as the Goldstone bosons related to spontaneous violation of Lorentz invariance through the multi-preon interactions similar to those given in the section 3.5 (3.22). In principle, one could start with a global metaflavor symmetry $SU(N)_{MF}$ which is then converted into the local one through the contact multi-preon interactions [11] or some nonlinear constraint put on the preon currents (see in this connection [23] and the later works [24]). If so, the quarks and leptons, on the one hand, and the gauge fields (photons, weak bosons, gluons etc.), on the other, could be composed at the same order distances determined by the preon confinement scale Λ_{MC} . In other words, there may be a lower limit to the division of matter beyond which one can not go. Indeed, a conventional division of matter from atoms to quarks is naturally related to the fact that matter is successively divided, whereas the mediator gauge fields (photons, gluons, gravitons etc.) are left intact. However, situation may be drastically changed if these spontaneously emerging gauge fields become composite as well. We will address this and other related questions elsewhere.

Acknowledgments

I am grateful to many people who had significantly contributed to the ideas presented here during the years when they were developed, especially to A.A. Anselm, V.N. Gribov, O.V. Kancheli, S.G. Matinyan and V.I. Ogievetsky. I would also like to thank the organizers and participants of the 20th International Workshop "What Comes Beyond the Standard Model?" (9-17 July 2017, Bled, Slovenia) M.Yu. Khlopov, N.S. Mankoč Borštnik, H.B.F. Nielsen and K.V. Stepanyantz for a warm hospitality and interesting discussions.

References

1. M. Gell-Mann and Y. Ne'eman, *The Eightfold Way* (W.A. Benjamin, New York, 1964).
2. https://en.wikipedia.org/wiki/Noble_Eightfold_Path.
3. G. 't Hooft, in *Recent Developments in Gauge Theories*, edited by G.'t Hooft et al (Plenum, New-York, 1980).
4. J.L. Chkareuli, JETP Lett. 32 (1980) 671;
J.L. Chkareuli, *Composite Quarks And Leptons: From $Su(5)$ To $Su(8)$ Symmetry*, In Proc. of the Int. Seminar QUARKS-82, pp 149-156, edited by A.L. Kataev (INR, Moscow, 1982).
5. R.N. Mohapatra, *Unification and Supersymmetry* (Springer-Verlag, New-York, 2003).
6. I.A. D'Souza and C.S. Kalman, *Preons: Models of Leptons, Quarks and Gauge Bosons as Composite Objects* (World Scientific, Singapore, 1992);
H. Terazawa, Y. Chikashige and K. Akama, Phys. Rev. D 15 (1977) 480 ; H. Terazawa, ibid. 22 (1980) 184.
7. G. 't Hooft, Phys. Rev. Letters 37 (1976) 8.
8. R. Barbieri, L. Maiani and R. Petronzio, Phys. Lett. B 96 (1980) 63.
9. K.G. Wilson, Phys. Rev. 10 (1974) 2245;
M. Creutz, Phys. Rev. Lett. 43 (1979) 553.
10. Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122 (1961) 345.
11. J.D. Bjorken, Ann. Phys. (N.Y.) 24 (1963) 174;
Per Kraus and E.T. Tomboulis, Phys. Rev. D 66 (2002) 045015.
12. A.A. Anselm, Sov. Phys. JETP 53 (1981) 23.
13. Z.G. Berezhiani and J.L. Chkareuli, Sov. J. Nucl. Phys. 37 (1983) 618;
Z.G. Berezhiani, Phys. Lett. B129 (1983) 99; ibid B150 (1985) 177;
Z. Berezhiani and M. Yu.Khlopov, Sov. J. Nucl. Phys. 51(1990) 935;
T. Appelquist, Y. Bai and M. Piai, Phys. Lett. B 637 (2006) 245 .
14. F. Wilczek, AIP Conf. Proc. 96 (1983) 313.
15. Z. G. Berezhiani, J. L. Chkareuli, JETP Lett. 37 (1983) 338;
Z.G. Berezhiani and J.L. Chkareuli, Sov. Phys. Usp. 28 (1985) 104;
T. Appelquist, Y. Bai and M. Piai, Phys. Rev. D 74 (2006) 076001 .
16. J.L. Chkareuli, Phys. Lett. B246 (1990) 498; ibid B 300 (1993) 361.
17. Z.G. Berezhiani and J.L. Chkareuli, *Horizontal Unification Of Quarks And Leptons*, In Proc. of the Int. Seminar QUARKS-84, vol. 1, pp 110-121, edited by A.N. Tavkhelidze et al (INR, Moscow, 1984);
Z. Berezhiani and M. Yu.Khlopov, Sov. J. Nucl. Phys. 51(1990) 739;
T. Appelquist, Y. Bai and M. Piai, Rev. D 75(2007) 073005.
18. R.D. Peccei and H.R. Quinn, Phys. Rev. D16 (1977) 1891.

19. Z.G. Berezhiani, J.L. Chkareuli, G.R. Dvali and M.R. Jibuti, *Supersymmetry and generations of quarks and leptons*, In Proc. of the Int. Seminar *QUARKS-86*, pp 209-223, edited by A.N. Tavkhelidze et al (INR, Moscow, 1986);
Z. Berezhiani, Phys. Lett. B 417 (1998) 287;
S.F. King and G.G. Ross, Phys. Lett. B 520 (2001) 243;
J.L. Chkareuli, C.D. Froggatt and H.B. Nielsen, Nucl. Phys. B 626 (2002) 307.
20. J.L. Chkareuli, Phys. Lett. B272 (1991) 207;
G. Dvali and G. Senjanovic, Phys. Rev. Lett. 72 (1994) 9;
D. Spergel and U.-Li Pen, Astrophys. J. 491 (1997) L67;
S.M. Carroll and M. Trodden, Phys. Rev. D57 (1998) 5189.
21. P. Ramond, hep-ph/9809459.
22. M. Yu. Khlopov, *Cosmoparticle Physics* (World Scientific, Singapore, 1999).
23. Y. Nambu, Progr. Theor. Phys. Suppl. E 68 (1968) 190.
24. J.L. Chkareuli, C.D. Froggatt, J.G. Jejelava and H.B. Nielsen, Nucl. Phys. B 796 (2008) 211;
J.L. Chkareuli, C.D. Froggatt and H.B. Nielsen, Nucl. Phys. B 848 (2011) 498.