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Abstract

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All simplest doublet composite schemes are classified. Four different doublet schemes are shown to be available. A new scheme with charge doublet $Q = (2/3, -1/3)$ rather advantageous as compared with the previous ones is being considered. Some difficulties in interpreting the colour as an effective symmetry are pointed out.

Аннотация

Пирогов Ю.Ф.
О дублетных составных схемах лептонов и кварков. Серпухов, 1981.
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Классифицируются все простейшие дублетные составные схемы. Показывается, что имеется четыре различные дублетные схемы, и проводится их сравнительный анализ. Рассматривается новая схема с дублетом зарядов $Q = (\frac{2}{3}, -\frac{1}{3})$, обладающая рядом преимуществ по сравнению с предшествующими. Отмечаются трудности интерпретации цвета как эффективной симметрии.

Abundance of elementary fermions-leptons and quarks ($2N_f \geqslant 42$), as well as their division into identical families ($N_f = f\ N$, $f \geqslant 3$, $N = 8$) may be considered as an indication on a composite nature of leptons and quarks and the existence of more elementary constituents /1/.

In the framework of a composite approach weak, strong and electromagnetic gauge interactions of leptons and quarks, described with a standard model $G_1 = SU(3)_{L+R} \times SU(2)_L \times U(1)_{L,\ R}$, may arise for the first time at the composite level and be absent at the level of constituents.

From a more general point of view at the energies $\mu < M_C$, where M_C is the scale of internal structure, the composite fields should be treated as elementary ones in the framework of some effective unified gauge group $G \supset G_1$. Under composite approach all the fields of unified gauge model- fermions, gauge and scalar bosons are composite to the same extent. Their common origin should eliminate the difficulties and uncertainties, connected with Higgs sector of the unified gauge model.

The spectrum of the fermions known at present is in agreement with the assumption that the families consist of $2N = 16$ fermions. Therefore it is of interest to consider a maximum gauge symmetry group of 16-fold family SU(16)[2] and its maximum subgroups SO(10)[3] and $SU(8)_L \times SU(8)_R \times U(1)_{L+R}$ [4] with 16-dimensional fundamental representations.

Anomaly-free representations of SU(16) group are $16_L + \overline{16}_L$ containing together with usual fermions "mirrir" antifermions of the same chirality which are transformed on conjugate representation. The same doubling is necessary for the absence of anomalies in the $SU(8)_L \times SU(8)_R \times U(1)_{L+R}$ model. This doubling had been interpreted in[4] as the fact that elementary fermions are four component conformal semi-spinors, decomposing into a pair of Weil spinors of opposite chirality $F = F_L + F'_R$.

The SO(10) group is maximum subgroup of SU(16) with respect to which each of the sets F_L and F'_R is anomaly-free. In this model, treated as it is, mirror doubling is redundant.

In the models of delayed unification SU(16) and SO(10) with the unification mass $M_{2N} \simeq 10^{15}$ GeV the internal structure may in principle manifest itself at $M_C \leqslant \mu \leqslant M_{2N}$ ("solved" substructure) i.e., prior to the fulfilment of the unified model. This requires some consistency conditions for the appearence of massless composite fermions [5]. Possibility to achieve such a description of real interactions remains open at present. The other possibility is a delay of manifestation of substructure up to very high energies $\mu \gtrsim M_C \gtrsim M_{2N}$, which makes it practically unobservable ("unsolved" substructure).

In this connection it is of interest to treat the $SU(8)_L \times SU(8)_R \times U(1)_{L+R}$ model, since there with account for one-loop radiation corrections effective constants g_n, $n = 1, 2, 3$ unify into one g_N at low $M_N = (10^6 - 10^7)$ GeV [4]. Due to a great number of scalar fields (tensors up to the fourth rank are required) the asymptotic freedom of the unified model is violated at $\mu > M_N$ which leads to appearance of Landau pole at $\mu = M_C > M_N$. An account for two-loop corrections should lead to the absence of complete unification of the constants g_n, so that the unification should in fact take place only in Landau pole M_C. In its neighbourhood the couplings become very strong and elementary field spectrum of the gauge theory should transform, so that the scale M_C is quite naturally considered as the scale of internal structure [4]. At early unification with asymptotic freedom violation the internal structure of "elementary" fields should occur only in the region $\mu \gtrsim M_C$ of inapplicability if the unififed gauge model.

At present the composite schemes of leptons and quarks are in statu nascendi. One of the leading principles of their construction is an analogy with the quark model of hadrons, based in turn on the superposition principle. Therefore we shall adopt that the electric charge at the level considered is still additive and conserved. In the absence of any indications on the nature of constituents and their interactions it is also natural to use the simplicity principle and to try and consider first the schemes with minimum number of constituents.

It can easily be seen that the charge spectrum of a fermion family f = (ν , e, u, d) etc., with the charges Q = $(0, -1, \frac{2}{3}, -\frac{1}{3})$ respectively, cannot be reproduced by combining an arbitrary odd number of a charged fermion constituent and its antiparticle. Consequently a minimum addimissible number of constituents is two and one should apply to doublet schemes.

Heuristic scheme of such a kind, with leptons and quarks consisting of doublet of subfermions χ of charges Q = $(\frac{1}{3}, 0)$ and spin J = $\frac{1}{2}$ in the form χ^3 and $\overline{\chi}^3$, was proposed by Harari and Shupe[6]. Another doublet scheme with a doublet of charges Q=$(\frac{2}{3}, \frac{1}{3})$ and with leptons and quarks consisting of an arbitrary odd number of χ and $\overline{\chi}$ was treated in[7]. Doublet schemes are quite naturally adopted for description of families with N = 8. In spite of many still open questions and the absence of concrete dynamical models, doublet schemes are of great interest, since they provide simple economical description of a great number otherwise elementary fields.

The present work is devoted to further study of doublet composite schemes. Namely all simplest doublet composite schemes are classified. It is shown that there essentially exist four different doublet schemes. Two of them coincide with the schemes /6,7/. Two other are similar but not equivalent to two first. Their comparative analysis is performed. A new doublet composite scheme which has a number of advantages as compared with the previous ones is being considered. Some difficulties in interpreting the colour as an effective symmetry, corresponding to some tripling of bound states, are pointed out.

Let us designate the components of a constituent doublet χ as χ = (U, D) and let us consider their internal symmetry SU(2) x x U(1) with the generators of internal isospin I, so that $I_3(U) = \frac{1}{2}$, $I_3(D) = -\frac{1}{2}$, and N-the net number of contituents (N(U, D) = 1, N($\bar{U}$, $\bar{D}$) = -1). Let us put

$$Q = x\, I_3 + yN,$$

so that

$$x = Q_U - Q_D,$$
$$y = \frac{1}{2}(Q_U + Q_D).$$

We shall adopt by definition that $Q_U > Q_D$, all the remaining cases are being obtained by redefinition. Let the charges of the doublet components be arbitrary multiple of $\frac{1}{3}e$ i.e., $Q = \pm\frac{e}{3}n$, $n = 0, 1, 2$. Here ± 0 distinguishes from each other the schemes when one and the same composite states contain some neutral constituent, or its antiparticle.

Apriori we have $C_6^2 - 1 = 14$ possible combinations with different charges. However it can easily be seen that the charge spectrum of leptons and quarks, considered as composed of three χ and $\bar{\chi}$, is reproduced by four combinations given in Table and by four other, obtained from the first ones by replacing $\chi \to \bar{\chi}$ and hence equivalent to them. Six remaining combinations corresponding to the pairs of charges $(\pm 0, \pm\frac{2}{3})$, $(\frac{1}{3}, -\frac{1}{3})$ and $(\frac{2}{3}, -\frac{2}{3})$ are not realized.

Scheme 1 is the original Harari-Shupe/6/ scheme. Scheme 2 was proposed in ref./7/. Schemes 3 and 4 may be derived from schemes 1 and 2, respectively, by replacing $U \to U$, $D \to \bar{D}$, $N_U \to N_U$, $N_D \to -N_D$ but with account for Fermi statistics they are not equivalent to the first ones. The numbers 1, 2 in parentheses at single-fermion composite states point to isotopic multiplicity of these states, corresponding to the presence of either some isotopically symmetric or symmetric and antisymmetric states of pairs of constituent.

Let us carry out a comparative consideration of these schemes in accordance with the Table.

Table

Nº	1	2	3	4
Q_U	$\frac{1}{3}$	$\frac{2}{3}$	$\frac{1}{3}$	$\frac{2}{3}$
Q_D	0	$\frac{1}{3}$	0	$-\frac{1}{3}$
ν	DDD(1)	$DD\bar{U}$(1)	$\bar{D}\bar{D}\bar{D}$(1)	$\bar{D}\bar{D}\bar{U}$(1)
e	$\bar{U}\bar{U}\bar{U}$(1)	$D\bar{U}\bar{U}$(1)	$\bar{U}\bar{U}\bar{U}$(1)	$\bar{D}\bar{U}\bar{U}$(1)
u	UUD(1)	$UD\bar{D}$(2); $UU\bar{U}$(1)	$UU\bar{D}$(1)	$UD\bar{D}$(2); $UU\bar{U}$(1)
d	$\bar{D}\bar{D}\bar{U}$(1)	$U\bar{D}\bar{U}$(2); $D\bar{D}\bar{D}$(1)	$DD\bar{U}$(1)	$UD\bar{U}$(2); $DD\bar{D}$(1)
|N|	3	1	1,3	1,3
$\|I_3\|$	$\frac{1}{2}$, $\frac{3}{2}$	$\frac{1}{2}$, $\frac{3}{2}$	$\frac{1}{2}$, $\frac{3}{2}$	$\frac{1}{2}$
Q	$\frac{1}{3}I_3 + \frac{1}{6}N$	$\frac{1}{3}I_3 + \frac{1}{2}N$	$\frac{1}{3}I_3 + \frac{1}{2}(B-L)$	$I_3 + \frac{1}{2}(B-L)$
B-L	$\frac{1}{3}(N_U-N_D)$	$\frac{1}{3}(N_U-N_D)$	$\frac{1}{3}(N_U+N_D)$	$\frac{1}{3}(N_U+N_D)$
$P_U P_D$	-1	-1	+1	+1
$(\nu\bar{\nu})$	$(D\bar{D})^3$	$(U\bar{U})(D\bar{D})^2$	$(D\bar{D})^3$	$(U\bar{U})(D\bar{D})^2$
$(e\bar{e})$	$(U\bar{U})^3$	$(U\bar{U})^2(D\bar{D})$	$(U\bar{U})^3$	$(U\bar{U})^2(D\bar{D})$
$(u\bar{u})$	$(U\bar{U})^2(D\bar{D})$	$(U\bar{U})(D\bar{D})^2$; $(U\bar{U})^3$	$(U\bar{U})^2(D\bar{D})$	$(U\bar{U})(D\bar{D})^2$; $(U\bar{U})^3$
$(d\bar{d})$	$(U\bar{U})(D\bar{D})^2$	$(U\bar{U})^2(D\bar{D})$; $(D\bar{D})^3$	$(U\bar{U})(D\bar{D})^2$	$(U\bar{U})^2(D\bar{D})$; $(D\bar{D})^3$
$(\nu\bar{e})$, $(u\bar{d})$	$(UD)^3$	$(UD)(U\bar{U})(D\bar{D})$	$(U\bar{D})^3$	$(U\bar{D})(U\bar{U})(D\bar{D})$
H=(euud)	$(U\bar{U})^4(D\bar{D})^2$	$(U\bar{U})^3(D\bar{D})^3$; $(U\bar{U})^4(D\bar{D})^2$	$(U\bar{U})^4(D\bar{D})^2$	$(U\bar{U})^3(D\bar{D})^3$; $(U\bar{U})^4(D\bar{D})^2$
(ν, e, 3u, 3d)	$6(U\bar{U})6(D\bar{D})$	$6(U\bar{U})6(D\bar{D})$	$6(U\bar{U})6(D\bar{D})$	$6(U\bar{U})6(D\bar{D})$

1. Single-fermion states.

As is seen all the schemes differ in the net number of constituents in single-fermion composite states. In first two schemes the algebraic number of the constituents in leptons and quarks is the same, in two other-different.

The internal isospin of single-fermion states takes the values $I = \frac{1}{2}, \frac{3}{2}$ in schemes 1, 2, 3 and only in scheme 4 it may be limited with the value of $I = \frac{1}{2}$. Therefore only in this scheme it can be associated with a weak isospin. In this scheme the expression for Q has the form corresponding to weak gauge symmetry $SU(2)_L \times SU(2)_R \times U(1)_L \times U(1)_R$, which is maximum weak subgroup of the unified $SU(8)_L \times SU(8)_R$ group.

Q and (B-L) are defined in schemes 1 and 2 by the sum and the difference of N_U and N_D, and in schemes 3 and 4 only by their sum $N = N_U + N_D$. The latter is in a better agreement with the assumption of complete (UD)-symmetry.

Under assumption of equality of internal parities of all fermions of a family $f = (\nu, e, u, d)$, the internal parities of U and D should be different $P_U P_D = -1$ in the first two schemes and coincide $P_U P_D = 1$ in two others. Since it is more natural to chose the internal parities of two members of the doublet coinciding, this in fact means that internal parities (ν, u) and (e, d) in the first two schemes should be chosen opposite. In other words, in these two schemes it is (ν, $\bar{e}$, u, $\bar{d}$) that should be considered to be a family rather than (ν, e, u, d).

2. Fermion-antifermion states.

As is seen from the Table all neutral ($f\bar{f}$) states have common components only in schemes 2 and 4 (in restriction with left columns). It means that in these schemes the processes of the form $(f\bar{f}) \to W^{o} \to (f\bar{f})$ may be presented by planar diagrams with two or four intermediate lines i.e., $W^{o} \sim (U\bar{U})$, $(D\bar{D})$ or $(U\bar{U})(D\bar{D})$.

Charged ($f\bar{f}$)-states, corresponding to $W^{\pm}$-bosons, have the same structure as W^{o} only in sheme 4, where $W^{+} \sim (U\bar{D})$, $(U\bar{D})(U\bar{U})$, $(U\bar{D})(D\bar{D})$. The requirement for the W^{o} and $W^{\pm}$ structures to be common makes this scheme quite distinguished.

3. Hydrogen atom H = (euud) is completely symmetric in U and D only in schemes 2 and 4 (in restriction with left columns). This symmetric H structure is to be expected in the case of formation of matter right in the neutral phase in the form of (ep)-pairs at an early stage, corresponding to (UD)-symmetry. In case of separate formation of e and p with further mutual neutralization, such a symmetric structure may not take place.

4. Fermion family with account for colour tripling (ν,e,3u,3d) have completely identical composition $6(U\bar{U})6(D\bar{D})$ in all the schemes, thus the regularity $\sum_f Q = 0$, $\sum_f (B-L) = 0$ finds natural explanantion in all the schemes.

5. Fermi statistics may be satisfied in all schemes when introducing both chirality doublets χ_L and χ_R.

6. Colour tripling.

In ref.[6] it was proposed to interpret the permutation tripling, e.g., $(U_1U_2D_3)$, $(U_1D_2U_3)$ and $(D_1U_2U_3)$ as a colour one. As an index that differes these constituents one cannot choose their coordinates, since there should be a complete symmetry over them in S-wave. It can be connected with a new degree of freedom-new colour, describing the interaction of constituents. However in this case it is natural to postulate colourlessness of the bound states in new colour i.e., either complete symmetry or antisymmetry. In this case tripling is absent as well. Right this situation takes place in the usual quark model where, for instance, p = (uud) without any tripling. Under such an approach tripling, postulated in ref.[6] for description of colour, is in fact absent.

In paper[7] it is proposed to consider the tripling in scheme of the Table as a colour one. For instance, for u two states $(UD\bar{D})$ with the (UD) pair possessing either J = 1, I = 1, or J = 0, I = 0 and the third state $(UU\bar{U})$ with (UU) in the J = 1, I = 1 state are possible (with account for additional antisymmetrization in new colour). A similar tripling is possible in scheme 4. However under such an approach the colour symmetry should remain exact under (UD)-symmetry breaking. Breaking of the latter one in turn is necessary for breaking of the weak isospin symmetry. Precise conservation of colour symmetry seems to be hardly possible.

A possible solution to the difficulty consists in explicit prescribing of colour to the constituents (besides new colour which bounds them in fermions, gauge and scalar fields). This is realized in a subsequent development of Harari-Shupe seheme[/8/]. To reproduce correctly the proper colour structure of leptons and quarks ($l \sim 1$, $q \sim 3$), one should put in chemes 1,2 $U \sim 3$, $D \sim \bar{3}$, and in shemes 3,4 $U \sim 3$, $D \sim 3$. Under such an approach only exact symmetries (colour and new colour) are considered at constituent level, approximate gauge symmetries being considered only at composite level.

Hence in our opinion doublet composite scheme has severe difficulties as far as the effective colour symmetry is conserned. Additional difficulty in schemes 2 and 4 is the necessity to explane the absence of bound states with $|Q| = \frac{4}{3}, \frac{5}{3}$ and the absence of degeneracy previously considered as colour tripling.

Nevertheless the doublet scheme is rather attractive since it is more economic than the unified gauge models in the sence that the constituents by themselves have minimal structure and are characterized only by charge Q, their number $N = \pm 1$ and spin $J = \frac{1}{2}$ (which are "primary"). Other structures, such as hypercharge and weak isospin, are dynamical and arise only at the composite level (i.e. they are "secondary"). In this sense such a scheme cannot be considered as the ultimate one, for the latter should describe in such an approach the appearence of all the structures out of structureless elements. A natural bound for such a structurelessness may be probably maximum scale in nature-Plank mass $M_p \sim 10^{19}$ GeV where quantum gravitation interaction should become essential. If all the structures arise from structureless elements then unification with gravity is to be expected at a level, deeper than the subquark and sublepton one.

In conclusion, four different doublet composite schemes have been considered. All these schemes have difficulties in interpreting tripling of composite quark states as an effective colour symmetry and demand the explicit introduction of colour at the level of constituents. From the point of view of a common structure of W° and $W^{\pm}$ and possibilitity to present their exchange in the form of planar diagrams the new scheme with charge doublet $Q = (\frac{2}{3}, -\frac{1}{3})$ is more preferable.

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