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ON COEXISTENCE OF THE HIGGS MECHANISM WITH THE
ASYMPTOTIC FREEDOM

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The possibility for the Higgs mechanism to coexist with the asymptotic freedom is discussed in detail for Grand unification models. It is shown within the $SU(N)$ gauge groups that any realistic asymptotically free models which retain, in particular, the $SU(3) \times U(1)$ symmetry unbroken are hardly possible to be constructed basing on ultraviolet stable fixed points. It is found that there is no alternative and that the only way to provide the coexistence lies in building asymptotically free models using the ultraviolet unstable fixed points which realize the special solutions of the renormalization group equations.

The discovery of the phenomenon of the spontaneous symmetry breaking [1] as well as the asymptotic freedom [2] for nonabelian gauge fields gave recently the possibility of building a number of models [3,4] which may be thought of as seriously claiming to be realistic theories of unified interaction. Among these the asymptotically free models of unified interaction [4] deserve special attention since they on one hand include all the merits and achievements of the other models and are on the other hand, also examples of mathematically consistent theories. These models are free of the "zero-charge" difficulty [5] and all the Wightman axioms are consistently fulfilled.

However, when building asymptotically free theories one encounters essential difficulties. They mainly lie in making the Higgs mechanism coexist with the asymptotic freedom, whereas most often they exclude one another. The matter is that the scalar field multiplets used in such theories for exercising the Higgs mechanism usually destroy the asymptotic freedom since the effective couplings of these fields do not themselves possess the property of being asymptotically free. Therefore solution of the coexistence problem becomes possible only through very careful selection of models as well as under very restrictive conditions imposed on their multiplet contents. This fact was explicitly demonstrated in ref. [6], although no constructive solution of this problem has been up to now found.

An essential progress was here achieved rather recently when the property of being asymptotically free for Grand unification models has been obtained by using a set of the

so-called ultraviolet unstable fixed points [7,8,9] . For such theories, tight relations among effective charges are intrinsic while the multiplet contents of the spinor and scalar fields is also strictly fixed. Under this view such models have much in common with the supersymmetric theories where the asymptotic freedom occurs also via special solutions of the renormalization group equations [10]. Unlike the supersymmetric theories, however, for which there is no need of investigating the stability of such solutions, in the present case the analysis of stability is very crucial and it is only recently that this problem has been solved in positive [11]. We have every reason to believe now that such theories are proved to exist. The latter lead to very interesting predictions in the domain of high and superhigh energies thus expanding the accepted phenomenology of the low energy physics without contradiction.

The goal of this article is to discuss different possibilities of constructing asymptotically free models which come from the use of the set of ultraviolet stable fixed points when solving the renormalization group equations. A hope exists that such models must be more convenient for practical purposes due to some arbitrariness left in the choice of the multiplet contents of the spinor fields and to the absence of the firm connections among their effective charges. As a matter of fact we return here to more careful analysis of the contents of ref. [6] basing on our present understanding of this problem. Unfortunately the result of our study does not lead to constructive solu-

tion of the problem. We come to the conclusion that, apparently, to build models of such kind is impossible, at least as long as the gauge group is the simple $SU(N)$ group.

The crucial point here is removal of the "redundant" massless Abelian gauge fields which disagree with the accepted phenomenology of the low energy physics. A few such "redundant" Abelian fields appear when the original gauge symmetry is broken since the Higgs mechanism goes for such models via too poor a set of scalar fields. Certainly, one could readily overcome this obstacle by changing the multiplet contents of the scalar fields, however, the asymptotic freedom lost in this case. To remove the "redundant" massless abelian fields without loss of the asymptotic freedom is possible here only through the radical change of the charge quantization, that which would be hardly reasonable.

Within the models discussed all the difficulties arise at the moment when we agree that the Higgs mechanism is unable to do its duty without the adjoint scalar field multiplet, at least. In particular, it is unable to separate namely the $SU(3) \times U(1)$ subgroup of strong and electromagnetic interactions and remove, as this is adopted now, the nonobservable interference between the leptonic and barionic worlds. However, the adjoint multiplet of the scalar fields, when taken alone, is also unsatisfactory for such models. Here, to provide the due phenomenology of weak interactions one needs to add, at least, one basic scalar field multiplet in order to exercise the Higgs mechanism with the properties required. It is assumed here, therefore, that one adjoint and one basic

multiplets of scalar fields are, for the theories under consideration, the minimum admissible set which may allow one to build a physically reasonable model of unified interaction.

Asymptotical freedom for the such models is studied by the methods of ref. [6]. It is important that the effective charges responsible for Yukawa-like interaction are not directly involved into this analysis and may be eventually omitted. The set of spinor multiplets determines only (in equation for the effective gauge charge) the value of the coefficient "b"

$$16\pi^2 \dot{q} = -b q^3 \quad (1)$$

which must have here minimum value admitted within this model. According to [6] if $b=0$ and one has one adjoint and one basic multiplets of scalar fields the asymptotically free behavior of all effective charges (i.e. the gauge charge and those responsible for the interaction between the scalar fields) takes place only for $N \geq 7$ (as long as the $SU(N)$ group is dealt with). The restriction ($N \geq 7$) obtained is very important here and it is this inequality that determines the minimum rank of the gauge group for the models under investigation. Note, however, that (unlike ref. [6]) one cannot always provide $b=0$ in eq. (1) by selecting spinor multiplets for such models and it is not clear either if, in the case $b=0$, the model is in fact asymptotically free or not. Now the higher approximations contribute essentially when the coefficient "b" being calculated and once they are taken into consideration one can but express optimistic belief

about what the value of the coefficient δ may be. Moreover, even if the condition $\delta=0$ survives under the higher approximations, the corresponding theory is rather a conformally invariant than asymptotically free theory. Note to the point that for every $SU(N)$ -group with N even δ is in principle different from zero as long as we adopt the necessity of excluding the Adler-Bell-Jackiw anomalies [12] from the theory. Nevertheless, closing the discussion, let us indicate that these refinements are not essential here since already the $SU(7)$ group does not fit us. The Higgs mechanism with such a set of scalar multiplets turns out to be able here to create the due hierarchy of masses of the vector fields only for $N \leq 6$.

Spontaneous symmetry breaking due to the Higgs mechanism occurs when the vacuum expectation values of the scalar fields

$$w_a^\delta = \langle \Phi_2 \left(\frac{\lambda^a}{2} \right)_a^\delta \rangle, \quad v_a = \langle M_a \rangle \quad (2)$$

are different from zero. The vacuum expectation values are to provide minimum to the effective potential of the scalar fields interaction which it suffices to take here within the tree approximation only

$$\begin{aligned} V[w, v] = & -\frac{N^2}{2} \text{Sp} w^2 - m^2 (v^\dagger v) \\ & + \frac{\lambda_{\Phi^4}^2}{8} (\text{Sp} w^2)^2 + \frac{\delta_{\Phi^4}^2}{4} \left[\text{Sp} w^4 - \frac{1}{N} (\text{Sp} w^2)^2 \right] \\ & + \frac{\lambda_{M^4}^2}{2} (v^\dagger v)^2 + \frac{\lambda_{\Phi^2 M^2}^2}{2} (\text{Sp} w^2) (v^\dagger v) + \frac{\delta_{\Phi^2 M^2}^2}{2} \left[v^\dagger w^2 v - \frac{1}{N} (\text{Sp} w^2) (v^\dagger v) \right] \end{aligned} \quad (3)$$

We do not consider higher perturbative corrections for $V[w, v]$ since there exists a belief [13] that, even with these corrections kept, one is able to avoid any qualitative alteration of the results obtained from (3). Equations for minimizing the potential (3) are readily found to be as follows (the equality $\delta p w = 0$ has been taken into account)

$$\begin{aligned} & \left[\mu^2 - \left(\frac{\lambda_{\phi^4}^2}{2} - \frac{\delta_{\phi^4}^2}{N} \right) \delta p w^2 - \left(\lambda_{\phi^2 M^2}^2 - \frac{\delta_{\phi^2 M^2}^2}{N} \right) (v^+ v) \right] w - \\ & - \delta_{\phi^4}^2 w^3 - \frac{\delta_{\phi^2 M^2}^2}{2} [(w v) v^+ + v (v^+ w)] + \lambda \cdot I = 0, \quad (4) \\ & [m^2 - \lambda_{M^4}^2 (v^+ v) - \left(\frac{\lambda_{\phi^2 M^2}^2}{2} - \frac{\delta_{\phi^2 M^2}^2}{2N} \right) \delta p w^2] v - \frac{\delta_{\phi^2 M^2}^2}{2} (w^2 v) = 0. \end{aligned}$$

Complete analysis of their solutions may be easily carried out as usual. In the process, one should be aware, however, that the matrix $\mathcal{W}$ may be always diagonalized by a gauge transformation.

An important consequence of the equations (4) is the fact that at the most only two components of the vector v may be nontrivially different from zero for any group $SU(N)$. One may readily check this fact by considering directly the first equation of the set (4) for nondiagonal components of the matrix $\mathcal{W}$. Therefore, the maximum group of weak interactions within such models may be only $SU(3)$ since otherwise there necessarily appear massless particles among the W -bosons responsible for the weak interaction, that being inadmissible. In other words, at the most two among the $\mathcal{Z} = N-1$ massless fields of the $SU(N)$ group representable by diagonal matrices acquire mass while the rest $(N-2)$ fields

remain massless for any choice of the matrix W . To avoid the "redundant" massless abelian fields under these circumstances is possible only by breaking the initial $SU(N)$ group gauge down to $SU(N-3) \times U(1)$ by means of an appropriate choice of the matrix W . Since the color group must be $SU(3)$ we come to the conclusion that the given set of scalar multiplets is able to provide the due hierarchy of masses of the gauge fields only within the $SU(6)$ group. In this case, however, the asymptotic freedom is absent for such model.

To change the situation one may act in several ways. The simplest way is to change the color group by taking the higher rank group $SU(N)$ for it instead of $SU(3)$. Then all the problems may be solved, for example, within $SU(9)$ gauge group. However, the quantization, of the electric charge is here essentially different since even the group of color is $SU(6)$. By this reason such way must be rejected as the one that would lead to profound revision of the present understanding of Grand unification that which would be hardly justified now.

All the other possibilities of improving the situation depend (more or less) on solving the problems of the "redundant" massless abelian gauge fields, whose appearance is not, however, admissible in the physical sector of the theory. All the hopes of building a model with "redundant" abelian fields that would not, nevertheless, affect the phenomenology of the low energy physics have up to now been a failure. The impossibility of separating out the "redundant" massless abelian gauge fields is definitely due to the fact that one wishes to retain the old form of the charge operator when

handling the physical sector within the higher rank $SU(N)$ gauge group. To alter the charge operator without essentially affecting the existing phenomenology is not possible, either.

The attempts of altering the multiplet set of scalar fields for such models proved unsatisfactory, too. We do not encounter here any problems due to the spontaneous symmetry breaking, but the coexistence of more than one tensors of the same rank in the multiplet set of scalar fields leads inevitably to the loss of asymptotic freedom. This loss takes place even if the two equal-rank tensors form different representations of the $SU(N)$. For instance we did not observe the asymptotic freedom in any $SU(N)$ gauge group for one basic, one adjoint multiplet and one antisymmetric second rank tensor of scalar fields. We also studied a number of other possibilities in choosing the multiplex contents of scalar fields and came unfortunately to the same negative result.

We thus incline to the conclusion that such models cannot exist at least as long as the simple $SU(N)$ group is taken for the gauge group. It is not unprobable that the efficient solution to this problem may be found within a more complicated gauge group, e.g. a semisimple one. However, the preliminary analysis of this question carried out tells that in that case, too, the situation is, to the essential extent, the same. The use of a mechanism of dynamical symmetry breaking would be certainly of great importance also. Relying on the latter mechanism one might hope to eliminate the "redundant" massless abelian fields at the second (dynamical) stage

of the symmetry breaking. This may be thought of as a promising way of investigation, although the situation here is still more unclear. Therefore, up to now we have every reason to believe that there is no alternative way in building asymptotically free models of unified interaction and that the only way of solving this problem is in building models with the asymptotic freedom based on the use the ultraviolet-unstable fixed points [4].

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