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DYNAMICAL SYMMETRY BREAKING WITH HYPERCOLOUR
AND HIGH COLOUR REPRESENTATIONS

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A B S T R A C T

We present a model in which the electroweak gauge group is spontaneously broken according to a dynamical scenario based on the existence of high colour representations. An unattractive feature of this scenario was the necessity to introduce elementary Higgs fields in order to obtain the spontaneous symmetry breaking of part of the theory. In the present model, this breaking can be understood also dynamically with the introduction of hypercolour interactions.

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It has been very widely recognized that the usual Higgs mechanism¹⁾ is one of the less satisfactory features of gauge theories. A number of important open problems such as the understanding of the fermion mass matrix in the standard electroweak model, or the hierarchies in GUTs are immediately related to the Higgs mechanism. The search for a dynamical mechanism of spontaneous symmetry breaking of gauge theories which could overcome the problems related to the existence of elementary Higgs fields has led to the development of various dynamical scenarios. A well-known example is the technicolour scenario²⁾ based on the assumption that there exists a new extra strong binding force that can produce fermionic condensates in complete analogy with the standard assumptions on chiral symmetry breaking in QCD. However, the full technicolour picture is ruled out by the unavoidable presence of flavour changing neutral currents³⁾. Another dynamical scenario is based on the assumption that there exist high colour representations in QCD in addition to the triplets⁴⁾⁻¹⁰⁾. The latter scenario has some clear advantages compared to technicolour given that the assumptions on which it is based found strong support from Monte Carlo lattice calculations¹¹⁾ and does not suffer from flavour changing neutral currents due to single gauge boson exchange. However, both schemes have the unattractive feature that they need Higgs fields at some stage of the spontaneous symmetry breaking. It has been shown¹⁰⁾ that in the high colour representation scheme the required Higgs fields have a natural "geometrical" origin in a dimensional reduction framework¹²⁾. However, it would be nice if all the breakings could be understood dynamically. Unfortunately, attempts based on the tumbling mechanism¹³⁾ have failed systematically to lead to a realistic model in both above schemes. It is the purpose of this note to suggest such a mechanism.

Let us briefly recall the dynamical scenario based on the existence of a high colour representation. It is assumed that the chiral symmetry breaking in the high representation quark sector occurs at much larger mass scales than the corresponding to ordinary quarks. Monte Carlo studies¹¹⁾ on the scales of chiral symmetry breaking support very strongly these assumptions. Namely, studying an SU(2)-colour model, they found that fermions in different representations indeed do condense at exponentially separated mass scales. If there exist such high colour representations, then neglecting current quark masses and electroweak interactions, the QCD Lagrangian for each of the quark sectors in some r-representation has a separate global chiral symmetry

$$SU(N_r)_L \times SU(N_r)_R \times U(1) \quad (1)$$

where N_r is the number of quark flavours in the r-representation ($r = 3, 6, 8, \dots$). As it is always assumed in QCD at some value of the effective strength of colour forces, condensates are formed from fermions-antifermions belonging to the r-representations. These condensates give rise to a vacuum that breaks the axial part of Eq. (1) and conserves the vector. In this way, $N_r^2 - 1$ Goldstone bosons are produced which are massless bound state excitations made up from r-fermions-antifermions. Switching on the electroweak interactions described by the standard model¹⁴⁾ with left-handed doublet and right-handed singlet quarks, the local $SU(2)_L \times U(1)$ symmetry is also broken into the U(1) of electromagnetism. The would-be Goldstone bosons are pions and other pseudoscalars and their couplings to weak currents are

$$\langle 0 | J_{5\mu r}^W(0) | \pi_r(p) \rangle = -i f_{\pi r} p_\mu \quad (2)$$

where $f_{\pi r}$ is the r-pion decay constant and $J_{5\mu}^W(p)$ is the weak axial current. In the absence of any source for r-fermion masses, the "pions" remain massless and some combination of them gives masses to W and Z. The so produced masses are proportional to the "Goldstone pion" effective decay constant which has to be 0(250 GeV) in order to fit the measured values of W and Z. Such a value for the decay constant is expected to appear in this scheme by introducing appropriate high colour representations.

Consider a model based on the gauge group $G = G_{HC} \times G_S \times G_{EW}$, where $G_{HC} = SU(N)$ is a hypercolour strong gauge group whose characteristic scale Λ_{HC} is much larger than the corresponding one Λ_{QCD} of QCD, $G_S = (SU(3) \times SU(3))_S$ is the strong sector and $G_{EW} = SU(2)_L \times U(1)$ is the standard electroweak sector. The fermions are assigned in the following representations:

$$G = SU(N)_{HC} \times (SU(3) \times SU(3))_S \times SU(2)_L \times U(1)$$

$$H_F^L = (N ; (\bar{3}, 1) ; 1 ; 0)$$

$$H_F^R = (N ; (1, \bar{3}) ; 1 ; 0)$$

$$(H_{\Delta}^{\nu})_L = (1 ; (\bar{3}, \bar{3}) ; 2 ; 1/3)$$

$$H_{\nu}^{\nu} = (1 ; (\bar{3}, \bar{3}) ; 1 ; 4/3)^{(3)}$$

$$H_R^D = (1 ; (\bar{3}, \bar{3}) ; 1 ; -2/3)$$

$$\begin{pmatrix} H^N_E \\ H^E_L \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} \bar{3}, 3 \end{pmatrix} ; \begin{pmatrix} 2 \\ 2 \end{pmatrix} ; \begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$H^N_R = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} \bar{3}, 3 \end{pmatrix} ; \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

$$H^E_R = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} \bar{3}, 3 \end{pmatrix} ; \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} -2 \\ -2 \end{pmatrix} \quad (3) \quad \text{Contd.}$$

where HF are hyperfermions transforming non-trivially under G_{HC} and H^F are the haptlons ($\equiv$ elementary fermions) of the high colour representation scheme.

The important point to be noted in this model is that there exists, among others and a chiral global symmetry

$$SU(3)_L \times SU(3)_R \quad (4)$$

consisting of the independent transformations of the left- and right-handed parts of the hyperfermions. This chiral symmetry is broken by the condensates $\langle H^F_L \cdot H^F_R \rangle = 0$ to the diagonal $SU(3)_V$. However, this breaking forces also the gauge $(SU(3) \times SU(3))_S$ to break into the diagonal $SU(3)$ which is identified to be the colour gauge group¹⁵⁾. This is because the introduction of the gauge group G_S can be considered as gauging the global symmetry (4). The axial parts of the $SU(3)_L \times SU(3)_R$ current can create, from the vacuum, hyperpions with decay constant $F_{H\pi}$. When these currents are identified with the corresponding currents of G_S , they still produce hyperpions but then they are coupled to the $G_S/SU(3)_{diag}$ gauge bosons which become massive according to the technicolour picture.

After the spontaneous symmetry breaking of G_S to $SU(3)_C$, the haptlons which transform as $(\bar{3}, \bar{3})$ under G_S are decomposed under $SU(3)_C$ into 3 and $\bar{6}$ while the $(3, \bar{3})$ are decomposed into 1 and 8. The condensation scale for the high colour representation is expected to be much higher than the corresponding one for the ordinary quarks. Assuming that the condensation scale of the sextet is 0(500GeV) it can then break the standard electroweak theory into $U(1)_{em}$. Moreover, the ordinary quarks obtain masses through contributions coming from the exchange of the heavy gauge bosons of $G_S/SU(3)_C$. Searches for a realistic model⁷⁾ suggest that the masses of these heavy vector bosons should be 0(10 TeV), which in turn means that Λ_{HC} should also be of the same order of magnitude. In a realistic model which is going to take into account the

multiplicity of the fermionic scales and flavour mixing, one has to introduce various haptlons representations according to the suggestions of Ref. 7).

In the present simple model, it is not difficult to cancel the anomalies. The G_{HC} has no anomalies since it is vector-like. An obvious way to cancel G_S anomalies is to introduce the following fermionic multiplets:

$$G = SU(N)_{HC} \times (SU(3) \times SU(3))_S \times SU(2)_L \times U(1)$$

$$\begin{pmatrix} H^N_d \\ H^E_d \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} 3, 1 \end{pmatrix} ; \begin{pmatrix} 2 \\ 2 \end{pmatrix} ; \begin{pmatrix} 1/3 \\ 1/3 \end{pmatrix} \quad (5)$$

$$H^N_R = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} 1, 3 \end{pmatrix} ; \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} 4/3 \\ 4/3 \end{pmatrix}$$

$$H^E_R = \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} 1, 3 \end{pmatrix} ; \begin{pmatrix} 1 \\ 1 \end{pmatrix} ; \begin{pmatrix} -2/3 \\ -2/3 \end{pmatrix}$$

Depending on the particular way that one chooses to cancel the G_S anomalies, a specific gauge group $SU(N)_{HC}$ is suggested. For example, here by introducing the multiplets (5), the G_{HC} has to be $SU(2)_{HC}$. With this choice, the resulting particles are ordinary quarks which, however, do not obtain a current quark mass radiatively. They can be identified with u and d quarks in the present simple model. In a more realistic model, they could obtain current masses by increasing their haptlons representation. Next, in order to cancel the electroweak anomalies, one can introduce fermionic multiplets which are, for example, singlets under G_{HC} anomaly free under G_S such as (1,27) and left-handed doublets and right-handed singlets under $SU(2)$ but with hypercharge such as to satisfy $\Sigma Q = 0$. Obviously the resulting particles after breaking of G_S to $SU(3)_C$ become very massive because they belong to high representations.

In conclusion, with a simple extension of the dynamical scenario involving high colour representations, all the spontaneous symmetry breakings are understood in a dynamical way.

We should recall that the present scheme with more than one family has no flavour changing neutral currents due to single vector boson exchange, a problem that ruled out technicolour models. On the other hand, the simplicity of the present scheme should be better appreciated when it is compared with the most recent attempts to overcome the problem of flavour-changing neutral currents in the technicolour models¹⁶⁾.

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