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INCONSISTENCY OF A CLASS OF GAUGE THEORIES BASED ON HAN-NAMBU-LIKE QUARKS *

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ABSTRACT

It is argued that gauge theories of SU(3) x SU(3)" variety, which generate the known weak interactions using both SU(3) and SU(3)" degrees of freedom and strong interactions using a neutral singlet gluon are likely to meet with difficulties in being reconciled with the observed spectra of low-lying hadrons.

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A number of proposed models of gauge theories of the weak and electromagnetic interactions are based in an essential manner on a Han-Nambu-like [1] structure for the quarks (i.e. three SU(3) triplets, or a more generalized version involving three SU(4) quartets; in both cases the quarks may be either integrally or fractionally charged and the (three) quark multiplets transform as 3* under an SU(3)"). All such models assume that SU(3) x SU(3)" is an approximate symmetry, useful for the classification of the hadronic states and the low-lying hadrons are, to a good approximation, singlets under SU(3)".

The proposed gauge theories of weak and electromagnetic interactions based on such Han-Nambu-like quarks fall into two distinct classes:
I) those [2] in which SU(3)" degree of freedom is used for generating (partly) the weak gauge interactions, and II) those [3],[4] in which only SU(3) (or SU(4)) but not SU(3)" is used for generating weak interactions. In II), the weak currents are pure SU(3)" singlets, while in I) they are not [5].

We believe that a simple argument may be used against models belonging to Class I, if one requires that strong interactions are to be introduced into any such model in a manner so as not to destroy renormalizability. The argument is based on the following considerations.

1) Weinberg [6] has argued that unified gauge theories of weak and electromagnetic interactions in general lead to parity and strangeness violation to order α in the presence of strong interactions, unless the latter are generated either [6] a) by a neutral vector gluon coupled to the conserved quark number, or [7] b) by a set of non-abelian gauge vector mesons interacting with the same quarks which couple with the weak gauge bosons. (In either case the weak and strong gauge group generators must commute with each other so as to save renormalizability as well as conservation of parity to order G_{Fermi}.)

It is clear that the first possibility of utilizing neutral gluons for strong interactions is available for models of Class I as well as Class II. As regards the second possibility, since both gauge groups are non-abelian, it may be realized if and only if: i) the quarks are "coloured" [8], i.e. they are classifiable as non-singlets with respect to two appropriate commuting symmetry groups such as SU(3) and SU(3)" of Ref.1; and furthermore ii) the weak gauge interactions have not made use of "colour" (i.e. SU(3)"). (If they have, the requirement of renormalizability of the scheme would prevent the possibility of gauging the SU(3)" direction for generating strong interactions.) It follows, therefore, that in models of Class I, strong interactions may be introduced in one and only one way (without conflicting with conservation of parity and renormalizability), i.e. via a neutral vector gluon coupled to the conserved quark number current, while, in models of Class II, they may be introduced through either of the two mechanisms. (Note that strong Yukawa interactions of a multiplet of scalar and pseudoscalar mesons with the quarks would have been compatible with renormalizability, but are excluded by the Weinberg argument on grounds of conservation of parity.)

2) Now remark that a Han-Nambu-like scheme, in which strong interactions are generated only via a neutral vector gluon, is inconsistent with the observed spectrum of hadrons. This may be seen simply by noting that such an interaction does not see any distinction between SU(3) and SU(3)". Thus, to the extent that one may neglect SU(3) and SU(3)" breaking terms corresponding to quark mass splittings, the "bound state" of $(q\bar{q})$ and (qqq), etc., generated by neutral vector gluon interactions, should not exhibit any marked distinction between SU(3) and SU(3)". And since low-lying hadrons belonging to 1, 8 and 10 of SU(3) exist, one should expect to see similar low-lying hadrons belonging to 1", 8" and 10" of SU(3)". This, however, is inconsistent with experiments.

The above argument may in principle be affected by the SU(3) and SU(3)" breaking quark mass terms, which may be asymmetric with respect to the two symmetries. However, these effects must be small, or else one will contradict one's own initial assumption (see Ref.5) that both SU(3) and SU(3)" are useful approximate symmetries for the classification of the hadrons. In other words, such symmetry-breaking effects cannot be solely responsible for a gap of at least a few BeV between the so-called SU(3)" singlet low-lying hadrons and the yet unobserved SU(3)" non-singlets without at the same time causing mass splittings within SU(3)" (and/or SU(3)) multiplets of the same order (i.e. a few BeV).

The problem is more acute than outlined above. The interactions of a neutral vector gluon coupled to the quark number current made up of nine Han-Nambu-like quarks is invariant under an internal SU(9) group (with twelve quarks it will be SU(12)). The observed spectrum of hadrons, on the other hand, is totally inconsistent with such a super internal symmetry. In fact, the maximum useful internal symmetry relevant for classification of hadrons seems to be SU(3) x SU(3)". Thus, one way or another, SU(9) symmetry must be broken badly in a way such that SU(3) x SU(3)" is preserved, but no trace of the super symmetry remains. It is easy to convince oneself that this cannot be done solely through quark mass terms; if one wishes to break SU(9) symmetry badly, through mass terms only, one will simultaneously break SU(3) or/and SU(3)" equally badly.

In summary, we conclude that a Han-Nambu-like scheme with a singlet vector gluon mediating strong interactions (and, therefore, all gauge models of Class I) are likely to meet with difficulties with the observed spectrum of low-lying hadrons.

One may now remark about the status of models of Class II specially with respect to the questions raised above. In these models, since the weak interactions are generated entirely by a subset of $SU(4)_L \times U(1)$ gauges, the strong interactions can be generated, without losing renormalizability and conservation of parity, by an $SU(3)''$ octet of vector gauge gluons, as proposed in Refs.3 and 4. The corresponding interaction does not encounter the sort of difficulties mentioned above, because i) it is not invariant under the super symmetry group SU(9) (or SU(12)). For the 12-quark model [3),4)], the global invariance group of strong interactions is [9)] $SU(4) \times SU(3)''$. ii) Furthermore, it manifestly distinguishes between SU(3) and $SU(3)''$, since the gauge vector particles transform as singlets under SU(3), but as an octet under $SU(3)''$. In fact, it has been argued [10)] that such an interaction provides a natural mechanism for the lowest-lying hadronic states observed in nature to be $SU(3)''$ singlets.

While these considerations favour models of Class II, an independent objection may be raised against such models, assuming that strong interactions are generated in these models by non-abelian $SU(3)''$ gauges. This is because one must break $SU(3)''$ spontaneously to give masses to the vector mesons. One can, however, show that spontaneous symmetry breaking can be introduced through three triplets [11)] of Higgs-Kibble particles in such a manner that the quarks, the vector mesons, as well as the Higgs-Kibble particles all form pure multiplets of a new global symmetry group [12)] $SU(3)'''$ which coincides with $SU(3)''$ so far as quarks and vector mesons are concerned, and of which the Higgs-Kibble particles form two singlets and an octet after spontaneous symmetry-breaking has been introduced. In this model $SU(3)'''$ symmetry is exact (up to order α); and $SU(3)''$ survives to order $(m/m_\sigma)^2$ where m and m_σ are typical hadron and Higgs-Kibble meson masses.

Before concluding, it ought to be noted that a completely independent line of argument, based on the interesting criterion of asymptotic freedom of field theories, would also have led to a conclusion similar to that arrived at here, since it favours [13)], in general, non-abelian gauge theories of strong interactions and disfavours the abelian one. Opinions seem to differ, however, as to whether asymptotic freedom ought to be regarded as an absolute criterion, since scaling is perhaps not yet known to be a "true" asymptotic property of the hadrons. The present argument, based on the observed spectrum of hadrons, is not subject to similar uncertainties.

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REFERENCES AND FOOTNOTES

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A.N. Tavkhelidze in Proceedings of the Seminar on High Energy Physics and Elementary Particles held at the International Centre for Theoretical Physics, Trieste, 1965 (IAEA, Vienna 1965), p.763.

2) Models of this class of which we are aware are:
H. Georgi and S.L. Glashow, Phys. Rev. D7, 561 (1973);
H. Lipkin, Phys. Rev. D7, 1850 (1973);
R.N. Mohapatra, University of Maryland Tech. Report No.72-022, to be published;
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Y. Achiman, University of Heidelberg preprint, December 1972;
J.M. Rawls and L.P. Yu, Phys. Rev. D7, 2463 (1973).

3) J.C. Pati and Abdus Salam, Phys. Rev. D (to be published in the August 1973 issue).

4) C. Itoh, T. Minamikawa, K. Miura and T. Watanabe, "Unified gauge theory of weak,electromagnetic and strong interactions", preprint 1973. This model is similar to that of Ref.3, except that the strong gauge mesons are massless and the quarks are fractionally charged.

5) Because of this, the consistency of models of Class I with known selection rules and/or phenomena such as CVC depends rather crucially on the goodness of the SU(3)" classification scheme and the pure SU(3)" singlet nature of the low-lying states. For example, in the model of Beg and Zee (Ref.2), it is required that the low-lying hadrons be

SU(3)" singlets to an accuracy of one part in a thousand. Such a degree of purity is not necessary in models of Class II.

6) S. Weinberg, MIT preprint No.343 (1973).

7) R.N. Mohapatra, J.C. Pati and P. Vinciarelli, University of Maryland Technical Report No.73-145 and S. Weinberg, MIT preprint No.366 (1973).

8) We use the word "colour", first introduced by W. Bardeen, H. Fristz and M. Gell-Mann (CERN preprint TH-1538, 1972), to denote a non-abelian degree of freedom of the quarks which is independent of the SU(3) or SU(4) degree of freedom. The concept, however, was first introduced in Ref.1 in a manner relevant for classification of the hadronic states and implicitly by O.W. Greenberg, Phys. Rev. Letters 13, 598 (1964) through the use of parastatistics for quarks. The Fermi quarks with colour may be fractionally or integrally charged.

9) Note that SU(4) can be broken to SU(3) by the mass of the charmed quark being considerably heavier than the (p,n,λ) triplet. Thus one may realise only SU(3) x SU(3)" as a useful internal symmetry for classification of hadrons as desired (see remarks later about SU(3)").

10) M.Y. Han and Y. Nambu, Phys. Rev. 139B, 1006 (1965);
O.W. Greenberg and S. Zwanziger, Phys. Rev. 150, 1177 (1966);
H.J. Lipkin, Weizman Inst. preprint (June 1973).

11) Each of these triplets transform as $(1,1,3^*)$ under the $SU(2)_L \times U(1) \times SU(3)''$ gauge group of Ref.3 with charges $(0,-1,-1)$, $(+1,0,0)$, $(+1,0,0)$ and vacuum expectation values $(\delta,0,0)$, $(0,\delta,0)$ and $(0,0,\delta)$, respectively. These, together with the ϕ-doublet

transforming as (2,1,1), lead to a satisfactory pattern of masses and particles in the scheme. This will be discussed elsewhere.

12) The relationship of SU(3)" to SU(3)"' follows a pattern similar to that discussed by de Wit (preprint, Utrecht 1972) for U(3) gauge symmetry breaking, which we refer to for details (see Sec.2 of his paper). We are indebted to Dr. J. Strathdee for a discussion on these questions.

13) D.J. Gross and F. Wilczek, Phys. Rev. Letters 30, 1343 (1973); H.D. Politzer, Phys. Rev. Letters 30, 1346 (1973).