COO-264-308
CONF-650947-4
CFSTI PRICES
H.C. $ 1.00; MN .50

TRIPLETS, STATIC SU(6), AND SPONTANEOUSLY BROKEN CHIRAL SU(3) SYMMETRY

Y. Nambu

The Enrico Fermi Institute for Nuclear Studies and
Department of Physics, the University of Chicago,
Chicago, Illinois

Outline of Talks
Delivered at the International Conference
on Elementary Particles and at the
Symposium on Elementary Particles
Kyoto, September 1965
Revised January 1966

Contract No. AT(11-1)-264

EFINS 66-19

DISCLAIMER

TRIPLETS, STATIC SU(6), AND SPONTANEOUSLY BROKEN CHIRAL SU(3) SYMMETRY

Y. Nambu

The Enrico Fermi Institute for Nuclear Studies and
Department of Physics, the University of Chicago,
Chicago, Illinois

I would like to present here my view of the current problems of elementary particle theory. It is largely inspired by the recent successes of SU(3) and SU(6) symmetries, and more or less summarizes what I have been pursuing lately. For the details of individual problems I must refer to the original papers. However, what is emphasized here is not the details, but a coherent overall picture plus some speculations which cannot yet be formulated precisely.

I. Triplets

a) The successes of the "Eightfold Way"[1] and of the recent SU(6) theory[2] point very strongly to the possibility that there is hitherto unsuspected substructure in all the hadrons we know up to now. This may not be the consensus of most physicists, but this seems to me the most natural way to interpret those successes, and besides would provide us with a very refreshing and probably useful point of view even if it did not turn out to be substantiated.

By substructure of course I mean that the known hadrons are made up of more fundamental subunits[3]. The main question is whether they are a mere mathematical concept as carriers of the SU(3) or SU(6) quantum numbers, or they also carry momentum and energy, especially with a well defined mass. Even if they have not been observed yet, I think the physicists will learn more by assuming their reality until it is proven otherwise. Coming down to a more technical level, people have indeed utilized the "quark" fields to write down currents and Hamiltonians as in the ordinary field theory, and have derived interesting and useful consequences out of it. It is most natural then to include the quark states for a complete description of the Hilbert space of the world.

b) Granting the reality of fundamental subnuclear particles, the next question is their properties and variety. These are intimately related to their stability, charge assignment, and the more dynamical problem of constructing the known hadrons (low lying levels). I will especially discuss the following models among other things:

1. One triplet (Quarks)[3,4]
2. One quartet[5,6,8]
3. Two triplets (Trions)[6,8]
4. Three triplets[7]

Although the quark model is most econimical and most drastic, there are some merits in considering other models too, which can avoid fractional charges and therefore also their absolute stability. The quartet model, however, does not adapt itself easily to SU(6) symmetry. The two- and three-triplet models are good on this point. In these models mesons (M) and baryons (B) are constructed schematically

as $\quad M \sim t_1\bar{t}_1$ or $t_2\bar{t}_2$, $B \sim t_1 t_1 t_2$;

and $\quad M \sim t_1\bar{t}_1 + t_2\bar{t}_2 + t_3\bar{t}_3$, $B \sim t_1 t_2 t_3$

respectively. An interesting point is that we can utilize the extra quantum numbers (supercharge or charm in the two-triplet model, and the second (SU(3) quantum numbers in the three-triplet model) to account for the fact that the low lying levels of hadrons are all triality zero states, as we shall see in a moment.

c) Constructive and interactive forces.

The forces that bind the fundamental triplets into orginary hadrons must be very strong since the latter are presumably quite massive ($\sim$ 10 Bev)[6,8] whether they are stable or not. With Professor Yukawa I am inclined to make a distinction between constructive (superstrong) and interactive (strong) forces. The former acts between triplets themselves, whereas the latter are secondary forces arising from the exchange of the hadrons which are in turn formed as a result of the former. In the two- or three-triplet models, we may in fact devise a dynamical model in which the constructive forces are coupled to the extra quantum numbers. We can then show that the triality zero states have the strongest binding and therefore the lowest masses just as electrically neutral systems have the lowest electrostatic energy. In this way we arrive at a gross level structure of hadrons[9]. It is a self-consistent dynamical picture in the sense that the massiveness of the triplets themselves are attributed to the superstrong forces. Besides that, these forces will have saturation property, namely for the low lying states (triality zero) the mass will increase more or less linearly with the number of constituents.

d) Observable effects of subnuclear structure.

Our viewpoint concerning the reality of triplets naturally compels us to search observable manifestations of the presence of fundamental particles inside hadrons, much like the presence of electrons in an atom or of nucleons in a nucleus. As one such example, we have pointed out that the analog of the A. Bohr effect may be present in the hyperfine structure of hydrogen[10], if the proton is composed of slowly moving triplets. In fact the effect is in the right direction to remove the present discrepancy between theory and experiment.

II. Static SU(6) and Spontaneously Broken Chiral SU(3)

a) Just as I was led to the existence of subnuclear units in order to understand SU(3) and SU(6) symmetries, I am equally justified to infer that the SU(6) symmetry is most easily understood if the constituents are moving slowly inside a hadron so that we can treat the system like an atom or a nucleus. I am well aware of one big difference, namely the very strong binding energy in the present case. Although this does not necessarily conflict with small average internal velocity in a purely non-relativistic model (like a square well potential), I would rather leave it as an unsolved theoretical difficulty for the time being.

Once we take the static aspect of internal hadron dynamics as its characteristic feature, then the SU(6) symmetry need not be regarded as something fundamental and intrinsic, but more like a dynamical accident, just as in nuclear physics the SU(4) is sometimes useful but by no means of fundamental significance. We are reminded of the fact that in atomic and nuclear physics the symmetry of the spin wave function is often determined indirectly by the symmetry of orbital wave function through the interplay of dynamical forces and the exclusion principle.

b) Whether the SU(6) symmetry is fundamental or not, it might still be a useful symmetry governing all the low lying (triality zero) hadrons. This is an interesting and important question to be tested experimentally, because we have in the static model another, even simpler, possibility. This is the kinetic SU(6) [or $SU(6)_t \times SU(6)_{\bar{t}}$] x O(3) in which the excited states of baryons and mesons correspond to orbital excitations of the ground states (kinetic supermultiplets). Since orbital excitations do not change the number of constituents, we do not get larger representations of SU(3) than are already found in the lowest levels. For example, the higher meson resonances will be a good place to look at as the following table shows. Besides the obvious occurrence of strangeness ± 2 resonances in SU(6) 189 and 405 multiplets, there are more subtle differences between SU(6) and kinetic supermultiplets. For example, in SU(6) cases the singlets are missing in 1^+ states, and the 0^+ mesons show inverted Okubo-Gell-Mann splitting ($K < \pi$).

c) Chiral SU(3) symmetry

Finally we would like to take up the question of chiral (γ_5) symmetry. Contrary to the static SU(6) symmetry which may be useful in the systematics of low lying states but probably is not a symmetry of the fundamental dynamical laws, I tend to regard chiral symmetry as one of the basic (if approximate) symmetries of the fundamental Lagrangian, which is "hidden" from us as a result of spontaneous breakdown, and hence will not directly serve us in classifying the levels. The reason for this view is the well known success of the partially conserved axial vector current (PCAC) hypothesis[11]. Besides, the chiral symmetry is a relativistic symmetry whereas the SU(6) is not. For the precise definition of spontaneous breakdown we must refer to earlier papers[12], but it essentially means in our present context that the large masses of baryons and triplets are entirely (or almost entirely) of dynamical nature, being self-energies arising from the superstrong and strong interactions. As I mentioned above, such an assumption is consistent with the dynamical model of hadron systematics based on two or three triplets.

Thus our basic picture may be described as follows. The fundamental triplet fields have zero or small ($\sim$ muon mass?) bare masses and are subject to superstrong interactions that are γ_5 invariant. Except for the small bare masses, and electromagnetic and weak interactions, the Lagrangian possesses $SU(3)_L \times SU(3)_R$ symmetry[13]. [The violation of ordinary SU(3) itself may also be attributed to these same causes.]

Because of spontaneous breakdown, however, the triplets acquire large effective masses, and as a result, it becomes a good approximation to treat hadrons as being made up of heavy triplets. The static SU(6) symmetry also results from this dynamical situation. At the same time, the original chiral symmetry tends to manifest itself by forcing the pseudoscalar mesons to be the lowest (and even massless) states, thereby insuring the PCAC relations[11]. The interplay of SU(6) and chiral SU(3) symmetries then causes the relatively large splitting of 0^- and 1^- mesons.

This is only speculation, without direct supporting evidence or detailed theory to substantiate it. But I believe it is a logically consistent picture. In this way, the apparent incompatibility of SU(6) [or $SU(6)_t \times SU(6)_{\bar{t}}$ according to Casimir decomposition] and $SU(3)_L \times SU(3)_R$ [or perhaps $U(6)_L \times U(6)_R$ according to Weyl decomposition] symmetries will be resolved, and we need not tax our brains trying to reconcile SU(6) with relativity. The validity of SU(6) is largely a dynamical problem. Its difficulties must be recognized as dynamical difficulties.

Table I. Higher Meson Resonances and their SU(6) Contents

	SU(6)		Kinetic SU(6)×SU(6)×O(3)
Composition	$tt\bar{t}\bar{t}$		$t\bar{t}$, L = 1
Multiplicity	189	405	108
$J^P = 2^+$	1,8	1,8,27	1,8
1^+	8,8,10,10^*	8,8,10,10^*,27	1,1,8,8
0^+	1,8,27	1,8,27	1,8

REFERENCES

1. M. Gell-Mann, Cal. Inst. Tech. Report CTSL 20, 1960; Phys. Rev. 125, 1067 (1962).

   Y. Ne'eman, Nucl. Phys. 26, 222 (1961).

2. F. Gürsey and L. A. Radicati, Phys. Rev. Letters 13, 173 (1964).

   B. Sakita, Phys. Rev. 136, B1756 (1964).

3. M. Gell-Mann, Phys. Letters 8, 214 (1964).

4. G. Zweig, CERN preprints 8182/TH. 401; 8419/TH. 412, unpublished.

5. Z. Maki, Prog. Theor. Phys. 31, 331, 333 (1964).

6. H. Bacry, J. Nuyts and L. van Hove, Phys. Letters 11, 255 (1964); Y. Nambu, Second Coral Gables Conference on Symmetry Principles at High Energy, edited by B. Kursunoglu et al., p. 274 (W. H. Freeman and Co., San Francisco and London, 1965).

7. M. Y. Han and Y. Nambu, Phys. Rev. 139, B1006 (1965).

8. T. D. Lee, F. Gürsey and M. Nauenberg, Phys. Rev. 135, B467 (1964).

9. Y. Nambu, Preludes in Theoretical Physics in honor of V. F. Weisskopf, p. 133 (North Holland Publishing Co., Amsterdam, 1966).

10. S. Fenster and Y. Nambu, Suppl. Prog. Theor. Phys., Commemoration Issue for the 30th Anniversary of the Meson Theory, p. 250 (1965). See also S. Fenster, R. Köberle and Y. Nambu, Phys. Letters 19, 513 (1965).

11. Y. Nambu, Phys. Rev. Letters 4, 380 (1960).

    M. Gell-Mann and M. Levy, Nuovo Cimento 16, 705 (1960).

12. Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122, 345 (1961); 124, 246 (1961).

13. M. Gell-Mann, Phys. Rev. 125, 1067 (1962); Physics 1, 63 (1964).

    R. E. Marshak and S. Okubo, Nuovo Cimento 19, 1226 (1961).