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DYNAMICAL MODELS AND THE POSSIBLE EXISTENCE
OF A $\frac{3}{2}^+$ 27-PLET

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B. Diu
CERN - Geneva

and

H.R. Rubinstein
Orsay - France

A B S T R A C T

The possibility that both a decuplet and a 27-plet of $\frac{3}{2}^+$ baryons exist is studied in the dynamical model generally used for such particles. In exact unitary symmetry, this possibility cannot be ruled out; however, the 27-plet should, in this limit, lie somewhat higher than the decuplet. When symmetry breakdown is taken into account by neglecting high channels, the N^* , Y_1^* , Ξ_1^* and Ω come out as they are expected to; on the other hand, difficulties appear with the members of the 27-plet, which could mean, if such dynamical arguments are correct and if this supermultiplet actually exists, that it is dynamically linked to other channels than just pseudoscalar mesons + $\frac{1}{2}^+$ baryons.

INTRODUCTION

The already known $\frac{3}{2}^+$ baryons (N^* , Y_1^* , Ξ^* and Ω) are considered, from a dynamical point of view, as created in pseudoscalar meson - $\frac{1}{2}^+$ baryon scattering, the main force responsible for their existence being due to $\frac{1}{2}^+$ baryon exchange (see for example references 1 and 2).

However, when one "explains" the $\frac{3}{2}^+$ baryons dynamically in such a way, one has a free parameter, the so-called F/D ratio, about which little is known experimentally. One usually chooses this ratio so that, in exact unitary symmetry, the force is strongest in the decuplet state.

Now, as discussed in reference 3, the existence of a $\frac{3}{2}^+$ 27-plet is not ruled out experimentally. In particular, an isospin $\frac{1}{2}$ resonance has recently been announced near 1415 MeV⁴), the spatial properties of which are likely to be $\frac{3}{2}^+$ [see footnote 5 of reference 3), and Section I below].

Are dynamical models for $\frac{3}{2}^+$ baryons compatible with the existence of a 27-plet, besides the already known decuplet? It is furthermore interesting to see whether such models can give arguments in favour of, or against, the strong 10-27 mixing scheme considered in reference 3).

SECTION I: Exact unitary symmetry considerations

Let us consider the scattering of a degenerate octet of pseudo-scalar mesons by a degenerate octet of $\frac{1}{2}^+$ baryons. Following the notations and results of reference 2, we write the forces arising from $\frac{1}{2}^+$ baryon exchange in terms of the π -N coupling constant $g(g^2 \simeq 14)$ and the unknown F-D mixing parameter f as (see Table I of reference 2):

$$\begin{array}{llll}
 \frac{4}{3}(5-10f-4f^2)g^2 & \text{for the representation 1 in the direct channel} & & \\
 \frac{8}{3}(1+f-2f^2)g^2 & " & 10 & " \\
 \frac{8}{3}(1-5f+4f^2)g^2 & " & \overline{10} & " \\
 \frac{4}{3}(1-2f+4f^2)g^2 & " & 27 & " \\
 -2(1-2f+4f^2)g^2 & \text{for the direct amplitude } 8 \rightarrow 8 & & \\
 -\frac{2}{3}(5-10f-4f^2)g^2 & " & 8' \rightarrow 8' & \\
 0 & " & 8 \rightarrow 8' &
 \end{array} \quad (1)$$

If one plots these forces as functions of f (see figure), the following features appear immediately:

- 1) The force in the decuplet state is the strongest one for

$$0.25 < f \lesssim 0.65 \quad (2)$$

which means that 10 cannot resonate alone if f lies outside this region.

- 2) For all values of f , the force in 27 is weaker than some other one.
- 3) However, the force in 27 is always attractive.
- 4) When the forces in 10 and 27 are equal, other representations have stronger ones.
- 5) It is a priori possible to have only 10 and 27 resonating, but then f must verify

$$0.37 \lesssim f \lesssim 0.60 \quad (3)$$

The possibility that there exist only a 27-plet of $\frac{3}{2}^+$ particles (see reference 5 and footnote 9 of reference 3) is then very unlikely in this scheme (point 2 above). On the other hand, point 3 shows that, as mentioned in reference 3), a $\frac{3}{2}^+$ 27-plet is always logically possible.

Point 4 discards the appearance, in the exact unitary symmetry limit, of a decuplet and a 27-plet of $\frac{3}{2}^+$ particles lying at the same degenerate mass or very close.

However, a 27-plet resonating at a higher energy than the decuplet cannot be ruled out (point 5). The values of f that could account for a decuplet and a 27-plet without other resonances are not unreasonable in the light of other arguments (see for instance reference 6), since the D-type coupling is stronger than the F-type one for $f < \frac{1}{2}$. In the region defined by 3, though, the $\Sigma\Sigma\pi$ coupling is of the same order or stronger than the $\Sigma\Lambda\pi$ one, which seems unlikely ⁷⁾. But one could very well be faced here with the same kind of difficulty as for the $\frac{3}{2}^+$ resonance widths (see for example reference 3).

SECTION II: The effects of SU_3 breakdown

It is, of course, difficult in these dynamical models to take proper account of the symmetry breaking interactions, since one does not know how these interactions come in. We will stick here to the rather conservative "philosophy" defined in reference 8), and which can be summarized as follows.

Dynamical arguments of the type we are considering here lean heavily on the hypothesis that the channels with lowest thresholds are primarily responsible for the existence of particles with the same quantum numbers. Now, when one takes the actual values for the masses of the particles, one sees that some of the channels which were

considered in the exact SU_3 limit lie so far away from the lowest one that to take them into account is not consistent with the hypothesis just mentioned; in particular, other states, which did not enter the unitary symmetric calculation, have lower or comparable thresholds.

One should perhaps mention at this point that, if one believes in the quantitative values obtained for the relevant integrals, one actually gets a non-negligible contribution from such high channels ¹⁹⁾. But this can mean either that many more states should be considered in these dynamical calculations, i.e., that the hypothesis of dominance of low thresholds is wrong, or that one should not trust the way quantitative results are obtained if one wants to keep this hypothesis.

The "philosophy" we take is then that the exact SU_3 dynamical "explanation" of particles is not correct if it does not remain practically unchanged when too high channels are neglected.

For the problem we are studying here, this has some consequences which may appear rather queer at first sight. For instance, when one considers the $Y = 1$, $T = \frac{3}{2}$ particles, they can be linked, in this scheme, to two channels: πN with a threshold around 1080 MeV, and $K\Sigma$, at about 1690 MeV. In the point of view we are adopting here, we will neglect the contribution from $K\Sigma$. But then, as these models give at most one pole per channel, we will not be able to account for the two $Y = 1$, $T = \frac{3}{2}$ resonances which are present in the exact SU_3 limit if 10 and 27 both resonate. In our opinion, this means that only the lower N^* can be "explained" by such simple models; the second one is linked a priori to higher channels, where the situation becomes so involved that arguments of the type used in these approaches are not sufficient. In other words, it may be true that the $N^*(1238 \text{ MeV})$ can be considered as created by the forces acting between the N and the π ; but if a second N^* exists, it seems a priori very arbitrary to link it only to πN and $K\Sigma$, when so many other channels could be important if $K\Sigma$ is.

Of course, if the arguments just developed are correct, they can allow for situations in which some high lying particles "disappear" when unitary symmetry breakdown is taken into account, which means that the corresponding supermultiplet would be incomplete: from the dynamical point of view, it seems possible that, when going from exact to broken unitary symmetry, some members of the previously degenerate supermultiplets no longer appear as resonances.

As mentioned in reference 8), though, this way of looking at the problem is perhaps too conservative, since it is difficult to reconcile with the SU_3 mass-formulae. The situation might be such that, for some unknown reasons related to unitary symmetry, the $K\bar{K}$ channels does play a role in generating the N^* 's, while all other ones are really negligible (apart from πN , of course). But, once again, it is very hard to imagine that a two-channel calculation could be quantitatively realistic when the second state has been picked up among a crowd of other ones.

Following the method and notations of reference 8), we then write the functions, the zeros of which give poles in the various states available; high channels are neglected, and the unknown integral I is supposed to depend primarily on $(W_s - W)$, W_s being the threshold for the corresponding scattering and W the position of the eventual pole. As we aim only at a qualitative understanding of the various particles, when several channels are taken into account, we take the same value of I for all of them, since their thresholds lie very close. The results are the following, for $f = 1/2$ (a value verifying inequalities 3):

$$Y = 2 \quad T = 1 \quad (KN) \quad 1 - \frac{4}{3}g^2 I \quad (4a)$$

$$T = 0 \quad (KN) \quad 1 + \frac{4}{3}g^2 I \quad (4b)$$

$$Y = 1 \quad T = \frac{3}{2} \quad (\pi N) \quad 1 - 2g^2 I \quad (5a)$$

$$T = \frac{1}{2} \quad (\pi N) \quad 1 + g^2 I \quad (5b)$$

$$Y = 0 \quad T = 2 \quad (\pi\Sigma) \quad 1 - \frac{4}{3}g^2I \quad (6a)$$

$$T = 1 \quad (\pi\Lambda, \pi\Sigma, \bar{K}N) \quad 1 - g^2I - \frac{28}{9}(g^2I)^2 + \frac{16}{9}(g^2I)^3$$

(6b)

(roots: $g^2I \simeq 0.48; 1.89$
and -0.62)

$$T = 0 \quad (\pi\Sigma, \bar{K}N) \quad 1 + \frac{5}{3}g^2I \quad (6c)$$

$$Y = -1 \quad T = \frac{3}{2} \quad (\pi\Sigma, \bar{K}\Sigma) \quad (1 + \frac{4}{3}g^2I)(1 - \frac{4}{3}g^2I) \quad (7a)$$

$$T = \frac{1}{2} \quad (\pi\Sigma, \bar{K}\Lambda, \bar{K}\Sigma) \quad 1 - \frac{4}{3}g^2I - \frac{34}{9}(g^2I)^2 + \frac{10}{27}(g^2I)^3$$

(7b)

(roots: $g^2I \simeq 0.44; 1.13$
and -0.55)

$$Y = -2 \quad T = 1 \quad (\bar{K}\Xi) \quad 1 - \frac{4}{3}g^2I \quad (8a)$$

$$T = 0 \quad (\bar{K}\Xi) \quad 1 - \frac{8}{3}g^2I \quad (8b)$$

The strongest force then appears in the $Y = -2, T = 0$ channel (Ω), where $g^2I = \frac{3}{8}$ is sufficient to give a pole. Next come the $Y = -1, T = \frac{1}{2}(\Xi_1^*)$; $Y = 0, T = 1(Y_1^*)$ and $Y = 1, T = \frac{3}{2}(N^*)$ states, where values of g^2I of the order of $\frac{1}{2}$ are needed to produce a particle. If g^2I passes through $\frac{3}{4}$, resonances will appear in: $Y = 2, T = 1$; $Y = 0, T = 2(Y_2^*)$; $Y = -1, T = \frac{3}{2}$; $Y = -2, T = 1$. Finally, g^2I would have to reach 1.13 and 1.89, respectively, in order for $Y = -1, T = \frac{1}{2}$ and $Y = 0, T = 1$ to resonate once more.

These last two states are certainly on the border line of the domain where such a model could work since, even if g^2I eventually reached such high values, it would do so in an energy region where other channels ought to be taken into account.

As for the other particles, it seems rather gratifying, at first sight, that the N^*, Y_1^* and Ξ_1^* , which are analogous resonances, come out with roughly the same forces, while these are somewhat stronger for the Ω , which is a bound state with respect to $\bar{K}\Xi$.

But two difficulties appear in this approach. The first one comes from the fact that, according to the above arguments, the Y_2^* should lie farther from the $\pi\Sigma$ threshold than the N^* does from the πN one, since the force is weaker in $Y = 0, T = 2$ than in $Y = 1, T = \frac{3}{2}$ (¹⁰). Now this is not the case if the mass of the Y_2^* is about 1415 MeV (⁴) (80 MeV above the $\pi\Sigma$ threshold, while N^* lies nearly 160 MeV above the πN one).

The second difficulty could have been anticipated. In a 27-plet constructed from pseudoscalar mesons and $\frac{1}{2}^+$ baryons, $\pi\Sigma$ contributes alone to the $Y = 0, T = 2$ state, as do KN and $\bar{K}\Xi$ to the $Y = 2, T = 1$, and $Y = -2, T = 1$ ones, respectively. This means that the forces in these three states will be roughly equal even in the model where higher channels are neglected. Now if these forces are able to produce a Y_2^* 80 MeV above threshold in $\pi\Sigma$, one also expects KN and $\bar{K}\Xi$ resonances at corresponding energies. This would in particular imply a low-lying, strangeness +1, $\frac{3}{2}^+$ baryon (around 1500 MeV), which seems rather unlikely from the experimental point of view.

CONCLUSION

It is difficult to draw definite conclusions from the considerations developed here, but the following points seem to emerge.

First, dynamical considerations appear to give further arguments against the strong 10-27 mixing possibility studied in reference 3): in the limit of exact unitary symmetry, one can have 10 and 27 resonating alone only if the force is substantially stronger in 10 than in 27, this implying fairly different degenerate masses for the two supermultiplets.

Secondly, if a $\frac{3}{2}^+$ 27-plet actually exists, and if such models as the one we have applied here have some relevance, then the difficulties encountered would mean that this 27-plet is dynamically linked to other states than just pseudoscalar mesons + $\frac{1}{2}^+$ baryons.

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- 10) Varying f in the region defined by inequalities 3 does not
qualitatively change this argument.

FIGURE CAPTION

The force F created by $\frac{1}{2}^+$ baryon exchange in the various representations of the direct channel, as a function of the F-D mixing parameter f .