IMPLICATIONS OF A POSSIBLE $J^P = \frac{3}{2}^+$ OCTET

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(Received 24 June 1964)

There is at present sufficient experimental evidence for the existence of a $\frac{3}{2}^+$ baryon-meson resonance, Y_1^*, with a mass of 1660 MeV to raise a serious question of where it could fit into the unitary symmetry scheme.[1] The reported decay branching ratios alone,[2] if taken seriously, are sufficient to place the state in an octet.[3] In addition, nonobservation of counterpart states provides an argument against the assignments $\underline{10}$, $\underline{10}^*$, and $\underline{27}$.[4] The octet assignment would be consistent with the present experimental situation if we assign the $Y=1$, $T=\frac{1}{2}$ component to the 1512-MeV second pion-nucleon resonance. Though this state is conventionally given the spin-parity $\frac{3}{2}^-$, there is insufficient experimental evidence to make the parity assignment firm.[5] If we accept the $\frac{3}{2}^+$ value for $Y_1^*(1660)$ the SU(3) scheme points to the assignment $\frac{3}{2}^+$ for $N^*(1512)$ also.[6]

In the present note we consider the bearing which such a $\frac{3}{2}^+$ octet in the 1600-MeV region would have on dynamical models for producing the decuplet $\frac{3}{2}^+$ states. Our basic assumption will be that the mechanism which produces the decuplet should also produce the octet. We shall be concerned largely with the relationships of partial widths, for the decays of the decuplet and octet states, to dynamical mechanisms for producing these states.

Of particular interest will be the $Y_1^*(1660)$ partial widths. In the coupling of an octet Y_1^* to baryon plus meson, the parameter $f' = F'/(F'+D')$ enters.[7] Here F' and D' are the coefficients of F- and D-type coupling of the isobar octet to the baryon octet and pseudoscalar octet. The data of reference 2 indicate a value $\frac{1}{4} \leq f' \leq \frac{1}{2}$ for this parameter.[8] We shall also make comparisons of the Y_1^* partial widths with the widths of $N^*(1512)$ and of the decuplet states, though the absolute numbers from reference 2 which we shall use are probably even less reliable than the branching ratios.

(1) In the dynamical model in which single baryon (octet) exchange provides the force which gives rise to the decuplet isobars, we may make some qualitative predictions by studying the relative attractions in the various baryon-meson states.[9] In the unitary-symmetry limit the coupling constants are functions of the parameter f for the meson-baryon coupling. According to reference 9 we may obtain a reasonably strong attraction in both the states $\underline{10}$ and $\underline{8}$ in the vicinity of $f = 0.65$.

However, there are two inconsistencies with the observed partial widths in this scheme: (a) In this model the parameter f' for the octet $\frac{3}{2}^+$ decays, into baryon plus meson, is equal to unity. This disagrees strongly with the Y_1^* branching ratios. (b) If we take the reported absolute widths of $N^*(1512)$ and $Y_1^*(1660)$ seriously, the measured octet widths are all much too small compared to those predicted from the decuplet widths.[10]

Thus additional forces or additional channels would be required to fit the $\frac{3}{2}^+$ octet into this model. An additional closed channel entering the dynamics of the octet states would be an effective way of reducing the octet widths.

(2) In Schwinger's W_3 symmetry such a channel is provided.[11] The above picture is modified in two ways: (a) There is a contribution from the exchange of the ninth baryon, Y_0^* (mass 1405 or undiscovered), and from channels containing Y_0^* plus a pseudoscalar meson; (b) the parameter f is fixed at $\frac{1}{2}$ in the symmetry limit.

As a number of authors have pointed out, the W_3 representation of dimension 45, containing the SU(3) representations $\underline{8}$, $\underline{10}$, and $\underline{27}$, is attractive in the single baryon exchange model.[12] Breaking of W_3 symmetry is expected to be quite large[13] and it is conceivable that the $\underline{27}$ could be raised out of sight and that of $\underline{8}$ retained nearby $\underline{10}$ (i.e., in the 1600-MeV region).

In this case there are a number of predictions concerning partial widths. In W_3 symmetry the f' parameter for the octet $\frac{3}{2}^+$ decays is fixed by symmetry considerations. A straightforward calculation of Clebsch-Gordan coefficients for

W_3 gives the value $f'=\frac{5}{2}$, in complete disagreement with experiment [if we take $N^*(1512)$ and $Y_1^*(1660)$ as octet members from 45].

There is also disagreement when octet widths are compared with decuplet widths. Some predictions of W_3 are the following relative squared coupling constants for isobar decays:

decuplet	$N_{3/2}^*(1238)\to p+\pi^+$,	g^2;
octet	$N_{1/2}^*(1512)\to p+\pi^0$,	$g^2/120$;
octet	$Y_1^*(1660)\to\bar{K}^0+p$,	$4g^2/15$;
	$\to(\Sigma^+\pi^0)$,	$5g^2/24$;
	$\to\Lambda\pi^+$,	$g^2/40$.

The remaining coupling coefficients of 45 to the various states in $9\otimes 8$ may be read off from the appropriate coefficients in de Swart's tables (see Eq. 10.6 of reference 14), multiplied by the factors

$+\sqrt{2}g$ for 10,

$\sqrt{2}g$ for 27,

$-g/2\sqrt{2}$ for 8_1,

$(\frac{5}{8})^{1/2}g$ for 8_2,

$\sqrt{5}g/2$ for Y_0^* plus meson octet.

The $\bar{K}N$ and $\Sigma\pi$ partial widths predicted from the observed $N_{3/2}^*$ width and the above coupling constants are both much larger than the observed partial widths. The model based on the representation 45 is thus rather unpromising.

(3) In W_3 symmetry it is possible to have the SU(3) states from 10 to 8 united in the representation 18.[16] With Schwinger's assignments of particles to W_3 representation, 18 is not coupled to the meson-baryon system in the W_3 limit ($9\otimes 8=9+18^*+45$).[17] This means that the basic dynamics which produces the 18 isobar would have to be in another channel. The isobar decays into baryons plus pseudoscalars would come from the failure of W_3 symmetry, expected to be strong in any event.[13]

Though the idea of the dynamics of $\frac{3}{2}^+$ isobar being largely in another channel appalls many theorists, there is no convincing argument against it known to us.[18] Just as an example of how one might proceed let us assume that the baryons belong to (3*, 3); that the pseudoscalar octet is in the representation (1, 8); but that the vector nonet lies in (8, 1) and (1, 1) instead of in (1, 8) and (1, 1) as in references 11 and 16. The notation is that of reference 16, with the exception that we now call a basic Schwingerian triplet 3*, instead of 3; the decuplet is thus denoted by 10 instead of 10*, in conformity with conventional notation. Now the representation 18 can be formed from bound vector mesons and baryons and

$$(3^*,3)\otimes(8,1) \text{ contains } (6,3).$$

Note that both isobar decays and vector meson decays will be W_3 violating; we shall need strong W_3 breaking.

We have used as a symmetry-breaking mechanism the vector meson decays into two pseudoscalar mesons and calculated some branching ratios for isobar decays according to the diagram of Fig. 1. Here the violation of W_3 comes only at the vector meson decay vertex; the coefficients for the dissociation of isobars into baryons and vector mesons come from W_3, as do those for the absorption of one of the pseudoscalar mesons. The value $f'=\frac{1}{4}$ is obtained for the octet isobar decays, independently of the form factors involved. The main point of the model is to show that reasonable physical models based on 18 are conceivable, rather than to derive numerical results. The main virtue of the scheme based on the representation 18 is thus that it allows a common dynamical origin for the decuplet and conjectured octet of $\frac{3}{2}^+$ states. Since the isobar decays are symmetry breaking [breaking W_3 but presumably not SU(3)], the fact that the (experimental) decay coupling constants for the octet are considerably smaller than for the decuplet is no defect of the theory.

An additional prediction of the W_3-invariant

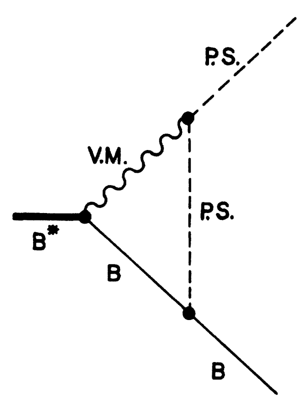

FIG. 1. A model for $J^P=\frac{3}{2}^+$ isobars (belonging to the representation 18) decaying into the pseudoscalar meson octet and the baryon nonet.

model with the $\frac{3}{2}^+$ states in 18 is that the decay $Y_1^*(1660) \to Y_1^*(1385) + \pi$ is expected to be enhanced relative to the other Y_1^* decays. This coupling is nonvanishing in the W_3 limit, in which the other isobar decay couplings vanish. There is some evidence for such a strong $Y_1^*(1660) \to Y_1^*(1385) + \pi$ decay mode.[2]

The authors would like to thank Dr. A. W. Martin for helpful discussions.

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*Research supported in part by the U. S. Atomic Energy Commission.

†Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]M. Taher-Zadeh et al., Phys. Rev. Letters 11, 470 (1963).

[2]L. W. Alvarez et al., Phys. Rev. Letters 10, 184 (1963); P. L. Bastien and J. P. Berge, Phys. Rev. Letters 10, 188 (1963).

[3]S. L. Glashow and A. H. Rosenfeld, Phys. Rev. Letters 10, 192 (1963); A. W. Martin, to be published.

[4]J. J. Sakurai has suggested [Phys. Letters 10, 132 (1964)] that $Y_1^*(1660)$ belongs to the representation $\underline{10}^*$ along with $N^*(1512)$ and a kaon-nucleon bound state (with hypercharge +2). This bound state has yet to be discovered.

[5]The latest phase-shift analyses [L. David Roper, Phys. Rev. Letters 12, 340 (1964); Auvil and Lovelace, to be published] use only angular distributions in elastic scattering to determine the phase shifts in the second resonance region. The parity ambiguity is removed by a continuity argument, which is somewhat unjustified in view of the large gaps in the data in the energy region between the first and second resonances. On the other hand, these analyses demonstrate convincingly that more than one phase shift is large and rapidly changing in the second resonance region. We know of no analysis of photoproduction in this region which takes more than one final state in addition to the first resonance into account, and therefore we doubt that the parity ambiguity is yet resolved.

[6]This assignment has also been suggested recently by Sakurai (reference 4) and no doubt by many others.

[7]We are using the notation of A. W. Martin and K. C. Wali, Nuovo Cimento 31, 1324 (1964).

[8]Very rough partial widths from reference 2 are

$$\Gamma_{\Sigma\pi} = 13 \text{ MeV}, \quad \Gamma_{\Lambda\pi} = 11 \text{ MeV}, \quad \Gamma_{\bar{K}N} \leq 3 \text{ MeV}.$$

See Glashow and Rosenfeld, reference 3. It is the smallness of the $\bar{K}N$ decay mode that constrains f' to the region near $\frac{1}{2}$.

[9]A. W. Martin and K. C. Wali, Phys. Rev. 130, 2455 (1963).

[10]We have used Eq. (6) of reference 7 to relate coupling constants to partial widths for the isobar decays.

[11]J. Schwinger, Phys. Rev. Letters 12, 237 (1964).

[12]R. E. Cutkosky, Phys. Rev. Letters 12, 530 (1964).

[13]S. L. Glashow and D. J. Kleitman, to be published.

[14]J. J. de Swart, Rev. Mod. Phys. 35, 916 (1963).

[15]It seems clear, if W_3 symmetry should have some approximate validity, that one must still have an intermediate stage of SU(3) symmetry. This was the viewpoint from which mass relations for the representation 18 were derived in reference 16. In commenting on this work I. S. Gerstein and K. T. Mahanthappa [Phys. Rev. Letters 12, 570 (1964)] give an argument to the effect that an SU(3) stage of approximation is impossible. Their argument is entirely incorrect.

[16]E. Johnson and R. Sawyer, Phys. Letters 9, 212 (1964).

[17]A fact clearly pointed out in reference 16. There are two reasons for not changing the assignments in Schwinger's scheme in order to make 18 (rather than $\underline{18}^*$) coupled to the baryon-pseudoscalar channel, as was done by Gerstein and Mahanthappa. In the first place the pion nucleon coupling would then vanish in the symmetry limit. In the second place, as pointed out by several authors (references 12 and 13) the single baryon-exchange mechanism would be repulsive in the representation 18.

[18]The argument that single baryon exchange must drive some $\frac{3}{2}^+$ resonances is unimpressive; there are too many simplifying assumptions in the calculation and too many other forces at work.

COMMENTS ON HIGHER RESONANCE MODELS

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(Received 26 June 1964)

Some time ago, it was observed[1] that in the elastic scattering of an unstable particle ("isobar") on one of its decay products ("meson"), the exchange diagram, Fig. 1(a), can be an energy-conserving process in the physical region [see Fig. 1(b)]. As a consequence, the diagram of Fig. 1(a) has a singularity near the physical region, in fact, in the physical region in the limit of vanishing isobar width (we shall call such singularities P singularities). This singularity contributes a peak to the isobar-meson scattering cross section.[2] But since all physically observed interactions are initiated with stable particles (weak interactions ignored),