Existence of a Baryon Antidecuplet

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We discuss, in the context of certain recent experimental results, the possibility that baryon antidecuplets exist in nature, and conclude that current data are consistent with this possibility. Analysis of long-range elastic forces in meson-baryon systems suggests that an antidecuplet may have spin-parity $\frac{1}{2}^+$.

The possible occurrence in nature of "exotic particles"[1] has great significance to our understanding of hadrons. Should exotic states be discovered, the conventional quark model would have to be modified or even abandoned. We feel that the evidence suggesting the existence of a baryon antidecuplet has reached the point where this possibility warrants serious consideration. The purpose of this Comment is to point out the relevance of recent data[2-4] to this subject and to discuss the results of a related calculation.

We shall begin by considering the $T=0$ KN system. Early work by Stenger *et al.*[2] showed a large, positive KN $T=0$ P-wave phase shift, reaching 30° by a momentum of about 600 MeV/c. Recent polarization analysis of $K^+d \to K^0pp$ by Ray *et al.*[3] has proved that this effect occurs in the spin-parity channel $J^P=\frac{1}{2}^+$. In addition, from experiments on K^+d total and inelastic cross sections,[4] one can deduce that the $T=0$ elastic KN cross section rises from a small threshold value *to essentially the unitarity limit* in the center-of-mass-energy interval $1700 \lesssim W\,(\text{MeV}) \lesssim 1900$. Precise inelasticity values and branching ratios have not yet been obtained. However, Hirata *et al.*[5] have observed that the reaction $KN \to K^*(890)N$ appears to proceed mainly through single-pion exchange and not predominantly via the excitation and decay of a $J^P=\frac{1}{2}^+$ direct-channel resonance, perhaps implying a small coupling ratio for $(Z_0^* \to K^*(890)N)/(Z_0^* \to KN)$. At any rate, the $T=0$ KN data, viewed as a whole, rather strongly suggest the existence of a Z_0^*, and further, even hint at the importance of elastic forces in Z_0^* dynamics.

If the Z_0^* exists, it must belong to the $SU(3)$ multiplet $\underline{10}^*$. The $Y=1$ member of this multiplet would have $T=\frac{1}{2}$ and $J^P=\frac{1}{2}^+$. In the following, we point out some features of a $\underline{10}^*$ assignment for $N^*(1750)$ and discuss arguments for and against it in view of recent experiments[6,7] involving this resonance. In the experiment of Crennell *et al.*,[6] a $T=\frac{1}{2}$ resonance of mass 1730 MeV and width 130 MeV, distinct from the πN resonance at 1690 MeV, was produced. Decay modes were dominated by $\pi\pi N$, πN, $K\Lambda$, and ηN, and no significant $\pi\Delta(1236)$ mode was observed. *If $N^*(1750)$ belongs to $\underline{10}^*$, the absence of a $\pi\Delta(1236)$ mode is simply attributable to an SU(3) selection rule.* In addition, the resonance observed by Crennell *et al.* most likely has $J^P=\frac{1}{2}^+$, as deduced from partial-wave analyses of previous experiments,[8] and thus is consistent with the spin-parity assignment for Z_0^*. Finally, no significant ρN decay mode was seen, which is perhaps related to the lack of a $K^*(890)N$ mode for the Z_0^*. At present, statistics on the πN, $K\Lambda$, and ηN modes of $N^*(1750)$ are not sufficient to allow a definitive $SU(3)$ analysis. Along a line of investigation distinct from the above, recent photoproduction data from the reaction $\gamma p \to \eta p$ have been analyzed by Heusch and Ravndal[7] in terms of the conventional quark model, and by Bajpai and Donnachie[9] in terms of an interference model (direct-channel resonances plus Regge exchange). The data exhibit a large, sharp peak just above threshold and a much shallower, broad structure for the energy range $1700 \lesssim W\,(\text{MeV}) \lesssim 1800$. The latter is interpreted in Refs. 7 and 9 as an effect produced by photoexcitation and decay of $N^*(1750)$. Upon a comparison of photoexcitation amplitudes in the conventional quark model, it is deduced in Ref. 7 that $N^*(1750)$ has $SU(6)\times O(3)$ classification ($\underline{70}$, $L^P=0^+$), which is a linear combination of the three-quark configurations $(1s)^2(2s)$ and $(1s)(1p)^2$. If the above interpretations of the second $\gamma p \to \eta p$ bump as the $N^*(1750)$ are indeed correct, and if $SU(3)$ breaking and mixing effects are negligible, it follows from conservation of U spin that the $N^*(1750)$ cannot belong to $\underline{10}^*$. Although we agree that this interpretation appears at this time to be quite plausible, we feel that it would be premature to abandon the possibility of a $\underline{10}^*$ assignment on this basis alone. In view of the ambiguities present in parametrizing reaction amplitudes at these energies, the $SU(3)$ classification of $N^*(1750)$ should be viewed with an open mind for as long as possible. A more conclusive situation[10] would exist if precise measurements of $N^*(1750)$ and Z_0^* decay modes were available. In Table I we give values for various Z_0^* and N^* partial widths assuming both $\underline{8}$ and $\underline{10}^*$ assignments for the latter. We have used the following formula, relevant for $\frac{1}{2}^+ \to \frac{1}{2}^+ 0^-$ transitions, to relate $SU(3)$ coupling constants and experimental decay widths:

$$\Gamma = \frac{g^2}{4\pi} \frac{q}{M_r} (E - m) ,$$

where M_r is the resonance mass, q is the decay momentum in the resonance rest frame, and M and E are the decay-baryon mass and energy. Physical values for masses have been used, so $SU(3)$ breaking is in part taken into account. Since we present these numbers for use as guides in future experimental work, we have allowed the partial widths to take on a wide range of values by using two different Z_0^* and N^* masses each and several coupling strengths. From part (a) of Table I ($\underline{10}^*$ predictions), we see that the Z_0^* width always exceeds the N^* partial widths, and that the N^* widths are ordered in decreasing size as πN, ηN, $K\Lambda$, $K\Sigma$, the ηN partial width being $K\Lambda$, and $K\Sigma$, the ηN partial width being roughly half that of πN. On the likelihood that $N^*(1750)$

TABLE I. $SU(3)$ partial-width relations: (a) $\underline{10}^*$ assignment for Z_0^* and N^*, (b) $\underline{8}$ assignment for N^*. All energy units are MeV. In our normalization, $g^2/4\pi$ represents the πN coupling. For generality, in (a) we have allowed two mass values each for Z_0^* and N^*; in (b), we use $SU(3)$ $D/(D+F)$ parameters $\alpha = \frac{3}{5}$ and $\frac{3}{8}$ appropriate for assignment of $N^*(1750)$ to $\underline{56}$ and $\underline{70}$, respectively.

(a) Antidecuplet

	Mode \ $g^2/4\pi$	Partial widths 0.5	1.0	2.5
$Z_0^*(1700)$	KN	51	102	254
$Z_0^*(1863)$	KN	101	202	505
$N^*(1750)$	$K\Lambda$	4	8	20
	$K\Sigma$	1	2	5
	ηN	13	26	65
	πN	32	64	160
$N^*(1900)$	$K\Lambda$	12	24	61
	$K\Sigma$	7	14	36
	ηN	25	50	125
	πN	44	88	222

(b) Octet

		Partial widths $\alpha = \frac{3}{8}$		$\alpha = \frac{3}{5}$	
	Mode \ $g^2/4\pi$	1.0	4.0	1.0	4.0
$N^*(1750)$	$K\Lambda$	14	55	9	35
	$K\Sigma$	0.1	0.5	0.0	0.4
	ηN	20	78	3	13
	πN	64	256	64	256

occurs in $\underline{56}$ or $\underline{70}$ if the octet assignment is correct, we have used in part (b) of Table I the corresponding $D/(D+F)$ parameters, $\alpha = \frac{3}{5}$ and $\frac{3}{8}$, respectively. The $\underline{56}$ octet assignment with $\alpha = \frac{3}{5}$ clearly differs from that of $\underline{10}^*$ by the suppression of the ηN mode in the former. However, the $\underline{10}^*$ and $\underline{70}$-octet ($\alpha = \frac{3}{8}$) assignments are more difficult to distinguish, the main difference being the $K\Lambda$ mode, which is nearly a factor of 2 greater for the octet.

We shall now consider some theoretical aspects of the antidecuplet problem. One approach which can in principle accommodate antidecuplets is the bootstrap theory. As emphasized by Carruthers,[11] we can use the bootstrap approach to formulate a qualitative picture of the baryon spectrum simply by studying in meson-baryon systems the long-range forces generated by the exchange of various particles. That is, rather than attempt calculation of precise values of masses and widths, which is generally a complicated affair involving in a crucial way unphysical parameters like cutoffs, it can be profitable just to see in which channels the forces are largest. Hopefully, the pattern of observed resonances can then be unraveled, and even new states predicted. A program of this type, involving evaluation of forces in all meson-baryon isospin and hypercharge channels with $J \leq \frac{11}{2}$, has been carried out.[12] The results are generally successful – predicted baryonic states agree with the experimental spectrum and in some cases, uncertainties in $SU(3)$ assignments are resolved. We have updated the input to this calculation and have studied the forces in all $\underline{10}^*$ channels with $J \leq \frac{11}{2}$. *We find that the only large, attractive forces for* $\underline{10}^*$ *occur for the* $\frac{1}{2}^+$ *channel.* Thus, to the extent that meson-baryon elastic forces contribute significantly to resonances with mass $\lesssim 2$ GeV, we conclude that an antidecuplet, should it exist, probably has spin-parity $\frac{1}{2}^+$. Not only do studies of the forces indicate which multiplets exist, they also indicate the ordering of various states within a multiplet.[12] For nonexotic multiplets such as the $\frac{3}{2}^+$ decuplet, the predicted ordering agrees with that observed in nature, even to the extent of implying splittings of Gell-Mann–Okubo type. Our study of the $P_{1/2}$ antidecuplet surprisingly indicates that the equal-spacing rule, characteristic of octet dominance, may not hold here.[13] The Z_0^* should be lowest in mass, followed by a slightly more massive N^*, and finally be much more massive, but approximately degenerate Y_1^* and $\Xi_{3/2}^*$ states.[14] If the Z_0^* mass lies in the interval 1700–1850 MeV, then the N^* should lie at or below 2 GeV, and the remaining $\underline{10}^*$ states well above 2 GeV if our ideas are correct.

We shall conclude by considering other approaches to the antidecuplet problem. Aaron, Amado, and Silbar[15] have analyzed the $I = 0$ KN system using an *inelastic* mechanism, the strong opening of the K^*N channel, to generate resonant states. They predict the occurrence of $S_{1/2}$ and $D_{3/2}$ resonances. Although the questions of which inelastic channels dominate[16] or whether they succeed in generating resonant behavior[17] are far from being settled, the calculation of Aaron, Amado, and Silbar does give a clear alternative to the scheme suggested in this paper. The strong-coupling theory of Goebel[18] is another way to produce $\frac{1}{2}^+$ antidecuplet states. However, one difficulty with strong-coupling models appears to lie in the host of exotic states predicted; strong-coupling hadronic excitations tend to include states carrying large amounts of isospin and hypercharge. The evidence for the predicted $\underline{27}$ and $\underline{35}$ multiplets at or below 2 GeV is not at all clear at this time.[17] Finally, there is the three-triplet model of Greenberg and Nelson[19] in which two relatively low-mass Z_0^*'s are predicted, $Z_0^*(1863)$ and $Z_0^*(1962)$ with $J^P = \frac{1}{2}^+, \frac{3}{2}^+$, respectively. We feel that the experimentalist can proceed most effectively in unravelling the above theories by concentration on the $N_{1/2}^*$ and Z_0^* systems. It is of the utmost importance to extend carefully the $P_{1/2}$ phase-shift analysis to higher energies and to determine not just whether Z_0^*'s exist, but also, how many.

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[1]These are defined as particles whose quantum numbers differ from those which appear if baryons and mesons are three-quark and quark-antiquark composites, respectively.

[2]V. J. Stenger *et al.*, Phys. Rev. 134, B1111 (1964).

[3]A. K. Ray *et al.*, Phys. Rev. 183, 1183 (1969).

[4]R. J. Abrams *et al.*, Phys. Letters 30B, 564 (1969), and references cited therein.

[5]A. A. Hirata *et al.*, Lawrence Radiation Laboratory Report No. UCRL-19774 (unpublished); also see G. Goldhaber, Lawrence Radiation Laboratory Report No. UCRL-19832 (unpublished).

[6]D. J. Crennell *et al.*, Phys. Rev. Letters 25, 187 (1970).

[7]C. A. Heusch and F. Ravndal, Phys. Rev. Letters 25, 253 (1970); C. A. Heusch *et al.*, *ibid.* 25, 1381 (1970).

[8]M. Roos *et al.*, Phys. Letters 33B, 1 (1970).

[9]R. P. Bajpai and A. Donnachie, Nucl. Phys. B12, 274 (1969).

[10]If the $N^*(1750)$ belongs to an octet which couples to 0^- meson: $\frac{1}{2}^+$ baryon states with pure F-type coupling, then analysis of its partial widths cannot distinguish between the octet and antidecuplet assignments. However, no octet in $\underline{56}$ or $\underline{70}$, one of which probably contains $N^*(1750)$ if the octet assignment is valid, has this feature.

[11]P. A. Carruthers, in *Lectures in Theoretical Physics*, edited by W. E. Brittin and L. Marshall (Univ. of Colorado Press, Boulder, Colo., 1965), Vol. VIIb, p. 82.

[12]E. Golowich, Phys. Rev. 139, B1297 (1965).

[13]Of course, inelastic effects could conceivably induce appropriate forces to restore the equal-spacing rule. However, our model raises the intriguing possibility that exotic multiplets might not share the octet-dominance feature of nonexotic states.

[14]On the basis of this analysis, we would *not* assign the Roper resonance, $N^*(1470)$, to $\underline{10}^*$.

[15]R. Aaron, R. D. Amado, and R. H. Silbar, Phys. Rev. Letters 26, 407 (1971).

[16]J. J. Brehm and G. L. Kane, Phys. Rev. Letters 17, 764 (1966).

[17]Cutkosky and coworkers have performed a very interesting study of the K^+p system in this regard. See C. C. Shih *et al.*, Bull. Am. Phys. Soc. 16, 90 (1971).

[18]C. J. Goebel, Phys. Rev. Letters 16, 1130 (1966); 17, 66(E) (1966).

[19]O. W. Greenberg and C. A. Nelson, Phys. Rev. 179, 1354 (1969).