Strangeness +1 Baryons in $U(6)\otimes U(6)$

ARCHIBALD W. HENDRY, R. G. MOORHOUSE, AND J. E. PATON
Rutherford High Energy Laboratory, Chilton, Didcot, Berkshire, England
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The allocation of $I=0,1$ strangeness-(+1) baryons to the **700** and **1134** representations of $U(6)\otimes U(6)$ is examined. The **1134** representation is favored if these baryons have $J^P=\frac{1}{2}^-, \frac{3}{2}^-$, respectively.

RECENT experiments by Cool *et al.*[1] and Goldhaber *et al.*[2] on K^+-nucleon reactions have revealed the possible existence of resonances with strangeness +1 (hypercharge $Y=+2$). As seen in Fig. 1, the total cross section for isospin $I=0$ has a sharp, pronounced peak around 1.15 GeV/c laboratory momentum, and strongly suggests the presence of a reasonably elastic resonance Z_0 with mass 1863 ± 20 MeV and width 150 MeV. The situation is much less clear in the case of the $I=1$ total cross section which has a small enhancement at about 1.25 GeV/c. This could be attributed to a nearby resonance Z_1 with mass 1910 ± 20 MeV and width 180 MeV, but the picture is complicated since the cross sections for the inelastic processes $K^+p\rightarrow KN^*$ (with threshold around 1728 MeV) and $K^+p\rightarrow K^*N$ (with threshold around 1828 MeV) both show a strong energy dependence in this region. It is therefore likely that Z_1, if it exists, is a mainly inelastic resonance strongly coupled to the KN^* and K^*N channels. (There are several mainly inelastic resonances already known in the πN and KN systems, e.g., the s_{31} resonance in πN scattering.) Unfortunately, the spin and parities of Z_0 and Z_1 are as yet undetermined.

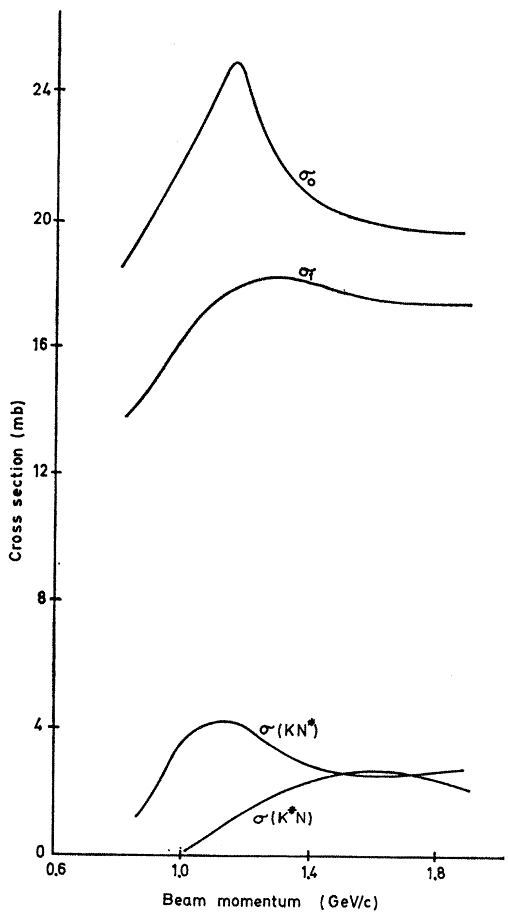

FIG. 1. Total cross sections σ_0, σ_1 for kaon-nucleon scattering in the $I=0$, 1 states, and the cross sections for $K^+p\rightarrow KN^*$, K^*N, as functions of laboratory beam momentum (Refs. 1 and 2).

The existence of a baryon with $Y=2$ is of vital importance as far as higher symmetry schemes are concerned. In particular, the L-excitation quark model[3] in its simplest form, in which baryons are considered to be composites of three quarks with orbital angular momentum excitation, cannot accommodate such a baryon since three quarks can form only singlets, octets, and decuplets in $SU(3)$, all of which have $Y\leq1$. The Z_0 resonance can be a member of a $\overline{\mathbf{10}}$ representation of $SU(3)$ and the Z_1 a member of a **27** representation. These correspond to systems with more than three quarks, such as four quarks and an antiquark.

The Z_0 and Z_1 can thus be accommodated in the higher representations of $U(6)\otimes U(6)$,[4] the simplest possibilities for which are

$$\begin{aligned}(126,\bar{6})&=56^-\oplus700^-,\\(210,\bar{6})&=56^-\oplus70^-\oplus1134^-.\end{aligned}\tag{1}$$

All the representations on the right-hand sides occur in the product of $56\otimes35$, and the negative parity comes from the antiquark. The first case is equivalent to having all four quarks coupled completely symmetrically in $U(6)$, while the second corresponds to the four quarks in the mixed $U(6)$ symmetry [31].

The **700** and **1134** contain several $\overline{\mathbf{10}}$ and **27** representations. Their couplings to the different decay modes B^*V, B^*P, BV, and BP (where B^*, B are the usual

[1] R. L. Cool, G. Giocomelli, T. F. Kycia, B. A. Leontic, K. K. Li, A. Lundby, and J. Teiger, Phys. Rev. Letters **17**, 102 (1966).
[2] G. Goldhaber *et al.*, as reported by M. Ferro-Luzzi, *Thirteenth International Conference on High Energy Physics, 1966* (University of California Press, Berkeley, California, 1967); also CERN report TC/66-29.
[3] R. H. Dalitz, *Quark Models for Elementary Particles* (Gordon and Breach Science Publishers, Inc., New York, 1966).
[4] A. Salam, R. Delbourgo, and J. Strathdee, Proc. Roy. Soc. (London) **A284**, 146 (1965); **A285**, 312 (1965); R. F. Dashen and M. Gell-Mann, Phys. Letters **17**, 142 (1965); H. Harari, D. Horn, M. Kugler, H. J. Lipkin, and S. Meshkov, Phys. Rev. **140**, B431 (1965).

decuplet and octet of baryons; V, P are the usual octets of vector and pseudoscalar mesons) have been calculated, and the results are presented[5] in Table I.

The decays for each representation have been calculated according to $SU(6)_W$, using tables of $SU(6)$ Clebsch-Gordon coefficients[6] and S-W mixing matrices.[7] Final states of definite orbital angular momentum L can be obtained from the resulting helicity states by using the formalism of Jacob and Wick.[8] In these representations (though not for the other representations in the **700** and **1134**), spin is conserved.[9] Thus for $J=\frac{1}{2}$, the final state has spin $S=\frac{1}{2}$, $L=0$; for $J=\frac{3}{2}$ and $\frac{5}{2}$, we have $S=\frac{3}{2}$, $L=0$, 2 and $S=\frac{5}{2}$, $L=0$, 2, 4, respectively. States of different orbital angular momentum will be accompanied by different phase-space factors. Table I gives the $L=0$ projections; these are the only ones required in the subsequent discussion. The numbers listed have of course to be used in conjunction with $SU(3)$ Clebsch-Gordan coefficients[10] to determine the various reduced partial decay widths for a state of definite Y, I in a $\overline{\mathbf{10}}$ or **27**.

It will be seen immediately from the table that, in the exact symmetry, some of the possible decay modes are forbidden, for example the $\mathbf{27}_B{}^4$ representation of the **1134** has zero transition to the BP system. These selection rules have previously been pointed out by Horn, Lipkin, and Meshkov[9] who have shown them to follow from invariance under a subgroup of $SU(6)_W$. Here we also give the coupling coefficients for the allowed transitions.

Let us now consider the properties of the $Y=2$, $I=0$ and 1 particles in the $\mathbf{700}^-$ and $\mathbf{1134}^-$ and see how they compare to the observed characteristics of the Z_0 and Z_1 baryons.[11]

$Y=2$, $I=0$. The $\overline{\mathbf{10}}^4(\mathbf{1134})$ corresponds to a particle which is primarily a NK^* resonance and coupled only weakly (through symmetry breaking) to NK. This is obviously unlike the Z_0 which seems to be mainly an elastic NK resonance. For the $\overline{10}^2(1134)$, the ratio of the partial reduced decay widths into the NK and NK^* channels is

$$\gamma(NK):\gamma(NK^*)=3:1, \qquad (2)$$

whereas for the $\overline{10}^2(700)$ the ratio is 1:3. The result (2) for the $\overline{10}^2(1134)$ is in the correct direction to agree with the observed elasticity of Z_0, since the NK^*

TABLE I. Couplings of $\{SU(3)\}^{2J+1}$ representations in the **700** and **1134** of $U(6)\otimes U(6)$ to the channels B^*V, B^*P, BV, BP with zero orbital angular momentum.

		B^*V	B^*P	BV	BP
700	10^2	...	...	$-\frac{1}{2}\sqrt{3}$	$\frac{1}{2}$
	27^4	$-1/12\sqrt{30}$	$+\sqrt{2}/4$	$-\sqrt{6}/3$	0
	27^2	$-\sqrt{3}/3$	0	$-\sqrt{6}/6$	$-\sqrt{2}/2$
1134	10^4	...	...	-1	0
	10^2	...	...	$-1/2$	$-\sqrt{3}/2$
	27^6	-1	0	...	...
	$27_A{}^4$	$-\sqrt{6}/4$	$-\sqrt{10}/4$	...	...
	$27_B{}^4$	$-\sqrt{15}/6$	$+1/2$	$+\sqrt{3}/3$	0
	$27_B{}^2$	$-\sqrt{6}/3$	0	$+\sqrt{3}/6$	$+\frac{1}{2}$
	$27_C{}^2$	...	...	$+\sqrt{3}/2$	$-\frac{1}{2}$

channel will be further damped by a small phase-space factor (due to the nearness of its threshold). This same phase-space factor will of course reduce the effect of the NK^* channel for the $\overline{\mathbf{10}}^2(\mathbf{700})$, but it is difficult to see how it can counteract sufficiently the comparatively large reduced width unless the mass of Z_0 was somewhat lower than that observed.

$Y=2$, $I=1$. The only two **27**'s which seem to fit the experimental description of the mainly inelastic Z_1 are the $\mathbf{27}^4(\mathbf{700})$ and the $\mathbf{27}_B{}^4(\mathbf{1134})$; they couple to the N^*K, NK^* channels and weakly to the NK channel. For the $\mathbf{27}_B{}^4(\mathbf{1134})$, the ratio of the partial reduced widths for the N^*K, NK^* channels is

$$\gamma(N^*K):\gamma(NK^*)=3:4, \qquad (3)$$

whereas for the $\mathbf{27}^4(\mathbf{700})$, the ratio is 3:16. Again the NK^* channel is reduced (relative to the N^*K channel) by phase space, but comparison with Fig. 1 shows that it is in fact rather difficult to fit the situation with the $\mathbf{27}^4(\mathbf{700})$.

The conclusion therefore is that the $Y=2$, $I=0$ member of the $\overline{\mathbf{10}}^2(\mathbf{1134})$ and the $Y=2$, $I=1$ member of the $\mathbf{27}_B{}^4(\mathbf{1134})$ have partial decay widths very similar to those of the observed $Y=2$ enhancements. It seems difficult for the corresponding members of the **700** representation to fit the data. It remains to be seen, of course, whether the experimental enhancements do indeed correspond to resonances Z_0, Z_1 with spins and parities $\frac{1}{2}^-$, $\frac{3}{2}^-$, respectively (from the present data, the strong coupling of Z_1 to the N^*K channel near its threshold certainly suggests $J^P=\frac{3}{2}^-$ for Z_1). If it is found that they have spins different from $\frac{1}{2}$, $\frac{3}{2}$ or have positive parity, it may be necessary to examine other even larger representations of $U(6)\otimes U(6)$, or to consider the L excitation of complicated quark and antiquark systems in $U(6)\otimes U(6)\otimes O(3)$.

It is perhaps interesting to mention that the **1134** is possibly preferable to the **700** if quarks obey parastatistics of type $p=3$. In that case, the quarks can be in a totally symmetric s-wave configuration-space state for the **1134**, but not for the **700**; such a state may be preferred as a ground state in a "concrete" quark model.

[5] The suffices A, B for the **27** representations are the same as in Carter, Coyne, and Meshkov (Ref. 6).

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[9] D. Horn, H. J. Lipkin, and S. Meshkov, Phys. Rev. Letters **17**, 1200 (1966).

[10] J. J. de Swart, Rev. Mod. Phys. **35**, 916 (1963); P. McNamee and F. Chilton, *ibid.* **36**, 1005 (1964).

[11] A full analysis of all the states in the **700** and **1134** is being presently carried out by the authors.