Pion-Hyperon Resonances and Possible Nonconservation of Isotopic Spin*

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A possible explanation of the pion-hyperon resonances is suggested in terms of global symmetry and the possibility that there may be some violation of isotopic spin conservation in strong interactions. In this connection, an alternative spin assignment of $P_{\frac{3}{2}}$ is proposed for the 1520-MeV pion-hyperon resonance. Some possible experimental tests of these ideas are suggested.

IT is our purpose to suggest a possible explanation of much of the current data in pion-hyperon physics in terms of two ideas: first, the concept of the so-called global symmetry of the pion-hyperon interaction,[1] and secondly, the suggestion that isotopic spin conservation may be rather weakly violated within the realm of the strong interactions, perhaps by the same part of the interaction which gives rise to the mass splittings among the hyperons. In this connection, an alternative explanation of the spin of the 1520-MeV excited state reported by Ferro-Luzzi *et al.*[2] will be given. Several possible experimental checks of these ideas will also be suggested.

We wish to consider the following pieces of information:

1. There is a $\Lambda\pi$ resonance at 1385 MeV in the $T=1$ state, first reported by Alston *et al.*,[3] and which has come to be designated Y_1^*. Measurements showing that it decays preferentially in a direction perpendicular to the plane of production indicate that its spin $\geqslant 3/2$.[4]

2. The presence of a $T=0$ resonance, designated Y_0^*, is suggested in the $\pi\Sigma$ system at a not terribly well-defined energy of about 1405 MeV, the cross section for whose production in the reaction

$$K^-+p\rightarrow Y_0^*+\pi^0$$

appears to be of the order of 1/20 of the cross section for the production of Y_1^* in the same reaction.[5]

3. There is an apparent enhancement or resonance in the $\pi\Sigma$ system at an energy of 1520 MeV.[2] Ferro-Luzzi *et al.* assign isotopic spin zero to this state, although their published data do not appear to exclude an enhancement of the $T=1$ interaction also. We shall designate this state by Z_0^*.

4. Global symmetry predicts two spin-3/2 pion-hyperon resonances, with $T=1$ and $T=2$, analogous to the 3/2, 3/2 pion-nucleon resonance. The energy, width, and spin of the Y_1^* make it reasonable to identify this as the predicted $T=1$ global symmetry resonance. If this is done, one is then led to conjecture that the $T=2$ resonance will occur at an energy of about 1540 MeV.[6]

It is apparent from the above list that resonances, or at least enhancements, in the pion-hyperon interactions (Y_0^* and Z_0^*) occur near the energies of the expected global symmetry resonances but in different isotopic spin states. In the case of the Y_0^* a possible explanation is at hand in terms of a $\bar{K}N$ bound state. This may well be correct, though we are here exploring an alternative explanation. There is no obvious mechanism to produce Z_0^*. Leaving aside for the moment the possibility that we are dealing simply with coincidence, we should like to suggest the possibility that, due perhaps to the K-particle interactions, the global symmetry resonances contain slight admixtures of other isotopic spin states. In this view, the Y_0^* results from the decay of the lower energy global symmetry resonance through the $T=0$ channel; the small cross section for Y_0^* production is thus an indication that the coupling between states of different isotopic spin is quite weak, though stronger than would be expected simply from electromagnetic effects. The reported energy of Y_0^* does lie about 20 MeV above that of Y_1^*. However, the rather low statistics available on Y_0^* do not seem to exclude a somewhat lower energy for it. In particular, Alston *et al.*,[3] in one of their experiments, obtained a Y_0^* peak at 1386 MeV. As they point out, the energy of the peak may be somewhat influenced by interference terms in the cross section.

Similarly, the Z_0^* would result from an admixture of a small amount of $T=0$ (and possibly $T=1$) in the (conjectured) higher energy global symmetry resonance. Ferro-Luzzi *et al.* have concluded that Z_0^* is a $D_{3/2}$ state. However, we present in Table I a set of amplitudes for direct and charge-exchange K^-p scattering which appear to fit their data adequately with Z_0^* resulting from a resonant $P_{3/2}$ state as expected from global symmetry. Table II compares the predicted total cross sections and angular distributions resulting from the amplitudes in Table I with the experimental re-

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[1] Murray Gell-Mann, Phys. Rev. **106**, 1296 (1957).

[2] M. Ferro-Luzzi, R. Tripp, and M. Watson, Phys. Rev. Letters **8**, 28 (1962).

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[4] R. P. Ely, Sun-Yiu Fung, George Gidal, Yu-Li Pan, W. M. Powell, and H. S. White, Phys. Rev. Letters **7**, 461 (1961).

[5] M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters **6**, 698 (1961); P. Bastien, M. Ferro-Luzzi, and A. H. Rosenfeld, Phys. Rev. Letters **6**, 702 (1961).

[6] D. Amati, A. Stanghellini, and B. Vitale, Nuovo cimento **13**, 1143 (1959); Phys. Rev. Letters **5**, 442 (1960); T. D. Lee and C. N. Yang, Phys. Rev. **122**, 1954 (1961).

sults. The worst agreement is in the parameter B for direct scattering at 390 MeV/c, which lies about two standard deviations above the experimental result. It does not seem unreasonable, however, to suppose that the narrow experimental dip in the value of B at resonance may be a statistical fluctuation, since either a resonant $D_{3/2}$ or $P_{3/2}$ amplitude whose phase is correct to produce a large positive C at resonance should raise B above its value at lower energies. The energies involved seem somewhat low for a D wave $\bar{K}N$ or $\pi\Sigma$ resonance, which perhaps lends additional plausibility to the P-wave fit. The latter could perhaps be somewhat improved, as the amplitudes of Table I in no sense represent an attempt to achieve a best fit to the data. It is also possible to obtain a fit with perhaps 25% to 30% of the $P_{3/2}$ amplitude occurring in the $T=1$ state, rather than confined to the $T=0$ state as in Table I.

It should be noted, perhaps, that if the P wave is accepted as possible, then some doubt is cast on the measurement of the $\bar{K}\Sigma N$ parity,[7] which was basedn o the assumption that only S and D waves were important. A repetition of that analysis for the P-wave case does not seem possible because of the difficulty of disentangling the more or less comparable S and $P_{1/2}$ amplitudes at resonance.

Some tentative support for the idea that the observed resonance at 1520 MeV may be a manifestation of a resonance in the $T=2$ channel may be gained from looking at the branching ratios of inelastic processes at resonance. Presumably the result of such a resonance, combined with isotopic spin nonconservation, would be to cause the production of final states with $T=2$, thus explaining why the cross section for $\Sigma\pi$ and $\Lambda\pi\pi$ production is enhanced at resonance, while that for $\Lambda\pi$ production shows no enhancement to within the statistical accuracy of the experiment. Moreover, the production ratio $\Lambda\pi^0\pi^0/\Lambda\pi^+\pi^-$ is found experimentally to be 0.93±0.19, whereas the maximum value which it could have consistent with isotopic spin conservation is 0.5. Unfortunately, this ratio is hard to measure experimentally, as Ferro-Luzzi *et al.* point out, and might be subject to large systematic errors, so that this result is far from conclusive. One would expect that the $\Sigma^0\pi^0$ cross section should show four times the enhancement at resonance of the $\Sigma^\pm\pi^\mp$ cross section if the enhancement is mainly in $T=2$ final states. This effect is not evident in the data, but its absence can be accounted for by the statistical errors. One also observes enhancement in the elastic charge-exchange cross section, which does not involve a $T=2$ final state, but this could be explained by the effect that increased absorption into the $T=2$ channel could have, on account of unitarity, on the elastic scattering amplitudes in the $T=0$ and $T=1$ channels.

The observed 1520-MeV resonance is much narrower than would be predicted from global symmetry.[6] However, neither the predictions of global symmetry on the width of the $T=2$ resonance, nor the present ex-

TABLE I. Possible amplitudes for the reactions $K^-+p\to K^-+p$ and $K^-+p\to\bar{K}^0+n$ at incident laboratory momentum p (in MeV/c). The notation for the amplitudes follows reference 7. The P_1 amplitudes have the expected energy dependence, and the S amplitudes go over into those of reference 2 at low momentum.

Reaction	p	S	P_1	P_3
K^-p	290	$-0.35+i$	$0.18+0.27i$	0
$\bar{K}^0n$	290	$0+0.5i$	$0+0.09i$	0
K^-p	350	$-0.5+0.85i$	$0.3+0.45i$	0
$\bar{K}^0n$	350	$0+0.44i$	$0+0.15i$	0
K^-p	390	$-0.66+0.4i$	$0.4+0.60i$	$0+0.45i$
$\bar{K}^0n$	390	0	$0+0.2i$	$0+0.45i$
K^-p	434	$-0.67+0.35i$	$0.4+0.9i$	$0+0.3i$
$\bar{K}^0n$	434	$-0.2-0.12i$	$0+0.26i$	$0+0.3i$

TABLE II. The rows K^-p_e and $\bar{K}^0n_e$ give the experimental cross sections, σ, (in millibarns) and angular distribution coefficients A, B and C for the direct and charge exchange reactions, and the total K^-p cross section, σ_{tot}, reported in reference 2. The rows K^-p_I and $\bar{K}^0n_I$ give the same quantities computed from the amplitudes of Table I at the corresponding momentum, p.

Reaction	p	A	B	C	σ	σ_{tot}
K^-p_e	290	1.05±0.2	0.1 ±0.2	0.4 ±0.4	47.8±4.1	89.3±4.6
K^-p_I	290	1.22	0.41	0	43.5	91
$\bar{K}^0n_e$	290	0.15±0.08	0.2 ±0.15	0.15±0.3	8.0±1.2	
$\bar{K}^0n_I$	290	0.26	0.09	0	8.5	
K^-p_e	350	1.4 ±0.2	0.6 ±0.2	−0.3 ±0.4	33.5±3.5	69.3±4.5
K^-p_I	350	1.28	0.465	0	33	66.5
$\bar{K}_0n_e$	350	0.25±0.05	0.1 ±0.08	0 ±0.3	5.1±1.1	
$\bar{K}_0n_I$	350	0.22	0.13	0	5.6	
K^-p_e	390	0.7 ±0.1	0.1 ±0.3	2.6 ±0.4	34.7±3.2	77.8±3.6
K^-p_I	390	0.78	0.66	2.2	31.8	79.5
$\bar{K}_0n_e$	390	0.05±0.05	0.05±0.15	1.25±0.25	8.8±0.7	79
$\bar{K}_0n_I$	390	0.06	0	1.15	9.2	
K^-p_e	434	1.0 ±0.2	0.5 ±0.3	1.6 ±0.6	32.8±3.9	62.8±4.6
K^-p_I	434	1.1	0.51	1.9	30	64
$\bar{K}_0n_e$	434	0.15±0.1	−0.03±0.28	0.55±0.3	6.0±1.2	
$\bar{K}_0n_I$	434	0.06	0.21	0.75	5.2	

[7] R. Tripp, M. Watson, and M. Ferro-Luzzi, Phys. Rev. Letters 8, 175 (1962).

perimental data on the width are completely conclusive. Moreover, it is conceivable that the amount of admixture of isotopic spin states could vary as a function of energy, so that it does not seem that the question of width of the state is an insuperable objection to the present model.

A few remarks may be made on how these ideas might be tested experimentally. The first order of business would seem to be to see if the conjectured $T=2$ resonance in the vicinity of 1530 MeV actually exists. This could be done by studying the Q values for the Σ^+ and π^+ in the reaction

$$K^- + p \rightarrow \Sigma^+ + \pi^+ + \pi^- + \pi^-$$

at a sufficiently high bombarding energy. Unfortunately, sufficient energy was not available in the experiments in reference 4 to allow reasonable amounts of phase space in the region of interest. An alternative would be to use a deuterium target and study the $\pi^-\Sigma^-$ spectrum in the reaction

$$K^- + d \rightarrow p + \Sigma^- + \pi^- + \pi^+,$$

selecting those events in which one has a slow proton in the final state.

An attempt could also be made to verify the basic idea of the model, that, e.g., the Y_1^* and Y_0^* are really simply different decay modes of the same state, by measuring the production angular distributions and decay anisotropies of the neutral Y_1^* and the Y_0^*. If the model is correct, the production and decay distributions should be the same for the two cases. Both of these experiments may be quite difficult. The Y_0^*, although it has charged decay modes ($\Sigma^\pm\pi^\mp$), is not a terribly strong resonance, and may be quite difficult to disentangle from the background, while the study of the neutral Y_1^*, since the decay in the $T=1$ channel leads almost entirely to Λ emission, means dealing with the difficult reaction

$$K^- + p \rightarrow \Lambda + \pi^0 + \pi^0, \qquad (1)$$

with three neutral particles in the final state; the experiment may, however, be feasible, especially in a bubble chamber containing some high-Z material to render the γ rays from the π^0 decays more visible. Incidentally, the measurement of the cross section for reaction 1, together with the cross sections for charged Y_1^* production allows an additional check of isotopic spin conservation, since, if σ_+, σ_0, and σ_- represent the cross sections for the production of the three different charge states of the Y_1^* in reactions analogous to (1), conservation of isotopic spin leads in the usual way to the following inequality:

$$\sigma_+ + \sigma_- - 2(\sigma_+\sigma_-)^{\frac{1}{2}} \leqslant 4\sigma_0 \leqslant \sigma_+ + \sigma_- + 2(\sigma_+\sigma_-)^{\frac{1}{2}},$$

which holds for either differential or total cross sections.

An alternative approach is to produce the Y_0^* and the neutral Y_1^* by the reaction

$$K_2^0 + p \rightarrow Y^* + \pi^+.$$

Some data on Y_1^* production in this reaction has already been obtained.[8] This may again, however, be quite a difficult experiment to do with sufficient accuracy to permit a comparison of the angular distributions.

Lastly, we may comment briefly on what presently seems to be known with regard to isotopic spin conservation at high energies and in interactions involving strange particles. A recent experiment on π^--nucleon charge-exchange scattering at 960 MeV, combined with earlier data on elastic πN scattering, is consistent with a charge independent πN interaction at this energy.[9] This does not, however, provide a strong test for small violations of charge independence, and, in any event, if the source of the violation is the moderately strong interactions involving K mesons, this might be expected not to show itself very strongly in πN scattering. In strange-particle physics, the experiment reported in reference 8 furnishes evidence for isotopic spin conservation, but it is far from clear that, due to the statistical limitations of accuracy, a small violation of isotopic spin conservation of the type we are here considering, would have been revealed. In addition, a measurement of the ratio of charged to neutral pion production in K^- capture at rest in deuterium yields a value 2.12 ± 0.1 consistent with the value 2 predicted by isotopic spin conservation.[10] However, in addition to the fact that this result is at a different energy, it is quite conceivable that the effect of coupling between different isotopic spin channels is easily observable only when a resonance occurs in one of the channels, thus producing large effects in the others.

The author is indebted to Alfred Weinberg for a most useful discussion concerning these ideas.

Note added in proof. Since the preparation of this manuscript, two experimental results have become available which confirm the existence of a neutral $\pi\Sigma$ resonance at about 1520 MeV, but seem to give no indication of a resonance in the singly or doubly charged $\pi\Sigma$ system.[11,12] This would support the original interpretation of Ferro-Luzzi *et al.* that the 1520 MeV resonance is in a pure $T=0$ state, as opposed to the suggestion in this paper. Indeed, the absence of any strong indication of a charged $\pi\Sigma$ resonance in the region between 1500 and 1600 MeV, if it persists, certainly casts grave doubt on the validity of global symmetry. This, of course, has no bearing on the question of whether the 1520 MeV resonance is in a $P_{3/2}$ or $D_{3/2}$ state; the former possibility, discussed above, remains open.

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[11] M. Alston *et al.*, Postdeadline paper at the Washington meeting of The American Physical Society, April 26, 1962.

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