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ABSTRACT

New evidence for global symmetry may be obtained by looking for pion-hyperon isobars with masses greater than that of Y_1^*. It is conceivable but not certain that the 1815-Mev resonance found in $K^- + p$ interactions is a state corresponding to the third pion-nucleon resonance. It is noted that for such studies the two-body reactions $K^- + p \rightarrow Y + \pi$ are particularly suitable. More experimental information on pion-nucleon scattering in the region from about 600 to 1000 Mev is necessary to provide an adequate basis for future comparison with the pion-hyperon interaction.

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ERRATUM

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Page 12, Reference 2 should read: "O. Chamberlain, K. Crowe, D. Keefe, L. Kerth, A. Lemonick, Tin Maung, and T. Zipf, . . ."

ON THE GENTLE ART OF HUNTING BUMPS IN THE PION-HYPERON SYSTEM*

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At present it is not clear whether the global-symmetry (GS) interpretation of Y_1^* has a chance to survive or not. The determination of spin (Y_1^*) is complicated by Bose-Einstein effects at lower incident K momenta ($\lesssim$ 850 Mev/c) and by high-feeding partial waves at higher momenta (~1150 Mev/c).[1] In spite of these complexities, one feature stands out at all these energies, namely that the mass of a (Y_1^*) is well defined within its width. It seems, therefore, that corroborative evidence for GS may be discovered by establishing the existence of a Y_2^*, with a mass of approximately 1530 Mev and a half width of approximately 70 Mev. If this were the case, one might then suspect that GS would provide us with a law of corresponding states for pion-hyperon as compared to pion-nucleon resonances.

Additional evidence for such a correspondence may come from experiments that cover an energy range sufficient to answer the question whether or not there exist hyperonic analogs of the so-called second and third pion-nucleon resonances. This note states briefly the properties of such "higher pion-hyperon resonances" which GS would lead one to anticipate. In the spirit of the foregoing remarks, the emphasis will again be on the mass regions where these resonances could be expected. It will also be noted that their identification should in some way be easier than is the case for Y_1^*. It should be mentioned that total-cross-section measurements on the K^- - p system have already shown a resonance,[2] which could conceivably be connected with one of these pion-hyperon isobars.[3]

First we collect in Table I some data concerning the three pion-nucleon resonances, denoted by $N^{(1)}$, $N^{(2)}$, and $N^{(3)}$. The (?) entries in the "state" column for $N^{(2)}$ and $N^{(3)}$ indicate that those states are dominant, though far from pure.[4] Also listed are T, the isotopic spin; p_N^*, the final-state momentum of $N^{(i)} \rightarrow$ nucleon + pion in the isobar rest system; and Γ_N, the energy width of the pion-nucleon isobar.

Table I. Data for the pion-nucleon resonances

Resonances	T	Q (Mev)	$(\Gamma_N/2)$ (Mev)	(p_N^*) (Mev/c)	State
$N^{(1)}$	3/2	160	45	230	$P_{3/2}$
$N^{(2)}$	1/2	430	30	450	$D_{3/2}$ (?)
$N^{(3)}$	1/2	600	50	570	$F_{5/2}$ (?)

As has so often been noted, to $N^{(1)}$ there corresponds a Y_1^* and a Y_2^*. In order not to have to introduce too many stars, let us call these states $Y_1^{(1)}$ and $Y_2^{(1)}$ henceforth to indicate that (at least for the purpose of the present discussion) they are corresponding states of the first pion-nucleon resonance. Subscripts will always refer to T.

Using similar arguments for the higher resonances, we are led to ask for states $Y^{(2)}$ and $Y^{(3)}$ corresponding to $N^{(2)}$ and $N^{(3)}$. In each case we get two multiplets; $Y_0^{(2)}$ and $Y_1^{(2)}$ go with $N^{(2)}$, $Y_0^{(3)}$ and $Y_1^{(3)}$ with $N^{(3)}$. To guess at the mass of these states, we generalize the argument of Amati-Vitale.[5] We write the isotopic spin T as the sum of two spins, $\underset{\sim}{T} = \underset{\sim}{I} + \underset{\sim}{K}$, where I is 1/2 for all doublets, and K is 1/2 for $\Sigma\Lambda$ and zero for nucleons. (For simplicity, cascades shall be omitted.) We assume the following phenomenological mass formulae

$$\text{Nucleons}, \ \Sigma\Lambda: \ M = m(K^2) + \Delta \underset{\sim}{I} \cdot \underset{\sim}{K} .$$

Because we have $\underset{\sim}{I} \cdot \underset{\sim}{K} = 1/4$ for Σ and $-3/4$ for Λ, Δ, the $\Sigma\Delta$ mass difference, is approximately 75 Mev. For the resonances we now assume

$$M^{(i)} = m(K^2) + \Delta \underset{\sim}{I}\underset{\sim}{K} + \mu + Q^{(i)} ,$$

where $i = 1, 2, 3$ and μ is the pion mass. Here $Q^{(i)}$ is as given in the third column of Table I and is assumed to be the same for $N^{(i)}$ or $Y^{(i)}$. With the help of these two formulae, we arrive at the mass values in Table II.

Table II. Parameters for the pion-hyperon isobars

Presumed GS Resonances		Mass (Mev)	$\Gamma/2$ (Mev)	p^* (Mev/c)	Branching ratio $\Lambda:\Sigma$
$N^{(1)}$	$Y_1^{(1)}$	1380	23	120 (Σ) 210 (Λ)	10:1
	$Y_2^{(1)}$	1530	70	270 (Σ)	0:1
$N^{(2)}$	$Y_0^{(2)}$	1685	14	400 (Σ)	0:1
	$Y_1^{(2)}$	1760	36	460 (Σ) 510 (Λ)	4:5
$N^{(3)}$	$Y_0^{(3)}$	1855	33	530 (Σ)	0:1
	$Y_1^{(3)}$	1930	82	586 (Σ) 638 (Λ)	1:1

An estimate of the expected half widths for the $Y^{(2)}$ and $Y^{(3)}$ states has been reached as follows. In the pure doublet picture ($\Delta = 0$), we have the branching ratios:

$$Y_1^{(i)+} \rightarrow (\Sigma^0\pi^+) : (\Sigma^+\pi^0) : (\Lambda\pi^+) = 1:1:1;$$

for $i = 2$ or 3; and

$$Y_1^{(1)+} \rightarrow (\Sigma^+\pi^0) : (\Sigma^0\pi^+) : (\Lambda\pi^+) = 1:1:4 .$$

We then give each final-state channel its appropriate isotopic-spin weight, further multiply with the ratio $(p^*/p_N^*)^{2\ell+1}$ to correct for phase space, and take the product of these two factors with the $\Gamma_N/2$ in question. Here ℓ is the orbital angular momentum of the state concerned. Quite apart from the fact that the simple power-law correction for phase space may need refinement,[6] we are here faced with two questions:

(1) The higher resonances $N^{(2)}$ and $N^{(3)}$ in the pion-nucleon system are clearly resonances in the $T = 1/2$ state. However, measurements of angular distributions for elastic scattering have shown that there is considerable interference from angular momentum states other than the $D_{3/2}$ and $F_{5/2}$ listed in Table I.[4] At present only $\pi^- + p$ cross sections have been measured (mixture of $T = 1/2$ and $3/2$), so that it is not possible to determine to which isotopic spin states the interfering partial waves belong. Since the two isotopic spin states scale differently when carried to the π-Y systems, we cannot say what the interfering states might be in the π - Y systems. Thus no reliable estimate can be made as to the partial widths of $Y^{(2)}$ and $Y^{(3)}$ due to π - Y decay. [Of course, in these widths, states with distinct (j, ℓ) values do not interfere.] By the same token, it is not feasible to give a reliable estimate of the angular distribution in the π - Y system.

(2) Isobars $N^{(2)}$ and $N^{(3)}$ are known to decay only partially in $N + \pi$ and very substantially in $N + 2\pi$. Our estimate for $Y^{(2)}$ and $Y^{(3)}$ widths has been made by scaling the $(N + \pi)$ width as indicated, and furthermore by assuming that the (baryon + 2 pions) width is about the same fraction for the nucleon as for the hyperon case.

Clearly, therefore, the estimates for $\Gamma^{(2)}$ and $\Gamma^{(3)}$ should be taken with even greater reservations than the rest of Table II. In this table, we have also indicated the Σ/Λ branching ratios (where Σ refers to all possible charge channels) for the (hyperon + pion) decay of the isobars. The estimate of the Σ/Λ ratios is independent of the ratio of decays involving one or two pions. Concerning the two-pion decay modes, we note that $Y_0^{(i)}$ cannot decay into $\Lambda\pi$, but there are no selection rules against $\Lambda 2\pi$.

The resonance observed in the $K^- + p$ total cross section mentioned earlier is indicated in Fig. 1.[2] It lies at 1815 Mev, with a half-width of approximately 60 Mev. The position and width do not agree exactly with that estimated for $Y_0^{(3)}$; however, since these estimates have many uncertainties, it may well be that the observed resonance is due to the $Y_0^{(3)}$. More measurements of the properties of this resonance (i.e., J and ℓ values) plus complete measurements of the pion-nucleon system (i.e., separation of T = 1/2 and 3/2 states) need to be made before any conclusions can be drawn.

As we said earlier, if such isobars as $Y_T^{(2)}$ and $Y_T^{(3)}$, T = 0, 1 do exist, they should be relatively easy to identify. This is because their respective masses are all larger than the $(K^- + p)$ rest mass (unlike $Y_1^{(1)}$) and their production as the one and only final-state product is not prohibited by isotopic spin (unlike $Y_2^{(1)}$). Thus, for example, reactions like $K^- + p \rightarrow Y_T^2 \rightarrow Y + \pi$ may be expected to dominate the (K^-, p) cross sections at (K^-,p) c.m. total energies equal to mass $(Y_T^{(2)})$. In the "$Y^{(2)}$ region" there are allegedly two isobars which with our naive estimates are only 75 Mev apart. Thus, for $Y - \pi$ systems, it will probably not be possible to find branching ratios in the various $Y - \pi$ channels characteristic for a pure T spin state. On the other hand, as both $Y^{(2)}$'s are supposed to be akin to $N^{(2)}$, it will be interesting to see if angular distributions are similar to those of $N^{(2)}$, namely, having essentially the character of an $(S_{1/2}, D_{3/2})$ superposition (suppression of the constant term).[4] Similar remarks apply to the "$Y^{(3)}$ region" where one would like to ask if $F_{5/2}$ waves play an important role. The K^- laboratory momenta characteristic for the respective masses of $Y^{(2)}$ and $Y^{(3)}$ can be read from Fig. 1, where we have also indicated the spread in these K momenta corresponding to the width of the hyperon isobars. Note how the momentum region 800 to 1300 Mev/c exhibits a sequence of practically overlapping resonances.

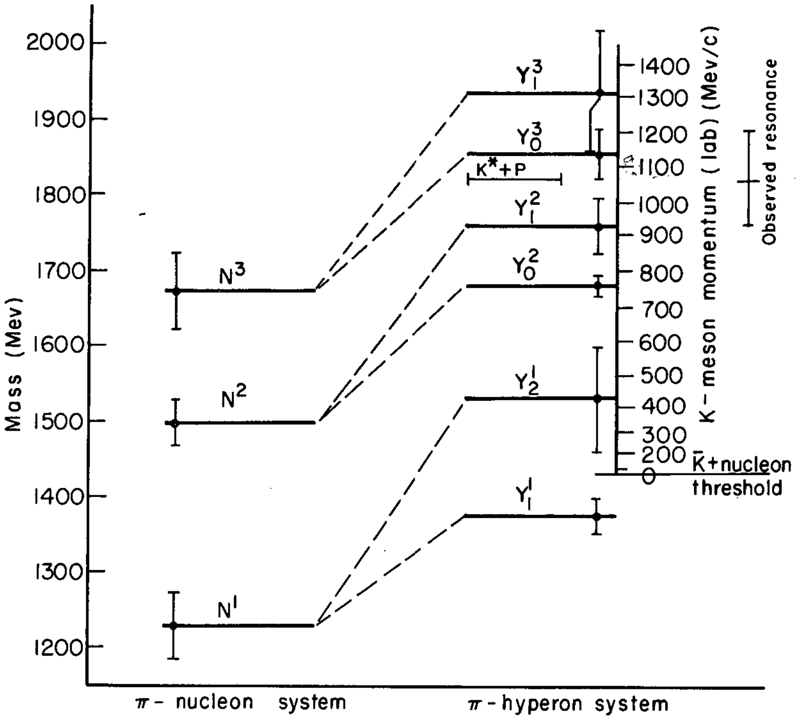

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Fig. 1. The pion-nucleon spectrum and a guess at the pion-hyperon isobar mass spectrum. The scale at the left is isobar mass in Mev, and the scale at the right is the laboratory momentum of the K^- to produce a center-of-mass energy equal to the given isobar mass. The vertical bars show the scaled resonance widths. The observed resonance in the $K^- + p$ scattering is shown at the right.

Thus, for such higher-mass isobars, we can use two-body reactions for their study, instead of three-body reactions as in the case of the $Y_1^{(1)}$. From the latter point of view, the Y-2π production is less favorable for the study of possible higher resonances because both reactions $K^- + p \rightarrow Y^{(2 \text{ or } 3)} \rightarrow Y + 2\pi$ and $K^- + p \rightarrow Y^{(2 \text{ or } 3)} + \pi$, $Y^{(2 \text{ or } 3)} \rightarrow Y + \pi$ can participate (with only a slight difference in threshold). It seems more directly important therefore to study the Y-2π production as a function of energy than as a function of configuration at a given energy—as is indeed also the case for the pion-nucleon problem.

A further observation can be made concerning the K^*.[7] It is possible that the $Y^{(3)}$ isobars decay as $Y^{(3)} \rightarrow K^* + p$ (for $Y_0^{(3)}$ only if $T(K^*) = 1/2$). Thus a possible production mechanism for the K^* is $K^- + p \rightarrow Y^{(3)} \rightarrow K^* + p$. If this is a leading production mechanism for K^*, we would expect a resonance-like behavior in the K^* production. The present note is meant to provide a few crude qualitative remarks concerning a phenomenon which promises to be quite complex. If some of this structure would turn up in the pion-hyperon states, we would then be faced with the problem of why GS is not bad in these particular instances, although GS cannot possibly be a generally valid symmetry of the strong interactions. This last point has often been emphasized[8] and the very existence of a Y_0^* at approximately 1400 Mev provides a new case in point.[9] Indeed, in the case of GS, this hyperon isobar cannot possibly have a nucleon analog. It is perhaps of interest in this connection to note that at 850 Mev/c, the cross section for Y_0^* production seems to be small compared to Y_1^* production.[10] It is therefore not ruled out that the GS resonances could be more dominant than other resonances. In conclusion, we repeat that it has not been ruled out as yet that GS is completely meaningless.

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*Work sponsored by U. S. Atomic Energy Commission.

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6. Relativistic phase-space corrections introduce a factor $\omega_1 \omega_2 (\omega_1 + \omega_2)^{-1}$, where ω_1, ω_2 are the respective energies of the decay products in the isobar rest frame. Such a factor would, for example, multiply the Λ/Σ ratio for $Y_1^{(1)}$ by a factor of 1.16. On the other hand, the use of an invariant phase space largely eliminates this effect. Corrections for a finite interaction range change the simple power law $k^{2\ell+1}$ for the width as follows. For $\ell = 1$, we have $x^3/(1 + x^2)$; for $\ell = 2$, $x^5/(1 + x^2/3 + x^4/9)$; for $\ell = 3$, $x^7/1 + x^2/5 + 2x^4/75 + x^6/225)$ where $x = ka$, and a is the interaction radius. If one scales with such factors included rather than with the simple power law, taking $a = \hbar/\mu c$, the Λ/Σ ratio is multiplied by 0.5 for $Y_1^{(1)}$, by 0.7 for $Y_1^{(2)}$, and by 1.2 for $Y_1^{(3)}$. It has been shown, however, by Klepikov, Mescheryakov, and Sokolov (Analysis of Experimental Data on the Total Cross Sections for Pion-Proton Interaction, D-584, Joint Institute for Nuclear Research, Dubna, USSR, Laboratory of Theoretical Physics, 1961) that a zero range gives the best fit to the higher resonances.
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