A study of $\Sigma^{\mp}\pi^{\pm}\pi^0$ events in our experiment is under way at present. The results, however, are too incomplete for us to be able to draw any definite conclusions.

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[1]Margaret Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. Wojcicki, paper presented at the Tenth Annual Rochester Conference on High-Energy Nuclear Physics, 1960 (to be published).

[2]P. Eberhard, M. L. Good, and H. K. Ticho, Lawrence Radiation Laboratory Report UCRL-8878 Rev, December, 1959 (unpublished); also Rev. Sci. Instr. (to be published).

[3]L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. Wojcicki, Phys. Rev. Letters 2, 215 (1959).

[4]L. W. Alvarez, in Proceedings of the 1959 International Conference on High-Energy Physics at Kiev (unpublished); also Lawrence Radiation Laboratory Report UCRL-9354, August, 1960 (unpublished).

[5]R. K. Adair, Phys. Rev. 100, 1540 (1955).

[6]E. Eisler and R. G. Sachs, Phys. Rev. 72, 680 (1947).

[7]M. Gell-Mann and K. Watson, Annual Review of Nuclear Science (Annual Reviews, Inc., Palo Alto, California, 1954), Vol. 4.

[8]M. Gell-Mann, Phys. Rev. 106, 1297 (1957).

[9]R. H. Capps, Phys. Rev. 119, 1753 (1960); R. H. Capps and M. Nauenberg, Phys. Rev. 118, 593 (1960); R. H. Dalitz and S. F. Tuan, Ann. Phys. 10, 307 (1960); M. Nauenberg, Phys. Rev. Letters 2, 351 (1959); A. Komatsuzawa, R. Sugano, and Y. Nogami, Progr. Theoret. Phys. (Kyoto) 21, 151 (1959); Y. Nogami, Progr. Theoret. Phys. (Kyoto) 22, 25 (1959); D. Amati, A. Stanghellini, and B. Vitale, Nuovo cimento 13, 1143 (1959); L. F. Landovitz and B. Margolis, Phys. Rev. Letters 2, 318 (1959); M. H. Ross and C. L. Shaw, Ann. Phys. (to be published).

SOME CONSIDERATIONS ON THE RECENTLY FOUND EVIDENCE FOR A $\pi\Lambda$ RESONANCE

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Some interest in the possible existence of resonant states in the pion-hyperon system has been raised of late by the analysis of the pion spectra in the reaction $K^- + p \to \Lambda + \pi^+ + \pi^-$.[1] The experimental data fit indeed a phenomenological picture where about 75% of the π^+ in the previous reaction are produced together with a resonant $\pi\Lambda$ state, whose Q value is peaked at about 115 Mev and whose half-width is ~30 Mev. A detailed analysis of such a resonant state is still missing and many of its characteristics (like its total and orbital angular momentum and the branching ratios in decay) are as yet unknown. It is, however, clear that the very presence of a resonant pion-hyperon state is of importance, as it will help in a deeper understanding of the processes among strongly interacting particles.[2]

On the other hand, the existence of this resonance can give us more confidence in the validity of some theoretical models for the investigation of the pion-hyperon interaction. This was indeed the case with the one-pion approximation static model of Chew and Low for pion-nucleon scattering. As a matter of fact the subsequent dispersive approach made us understand in a clearer way the fact that just the large 3-3 resonance, by enhancing the one-pion intermediate state, makes the other contributions relatively less important in low-energy pion-nucleon physics.

An analogous model for pion-hyperon interaction was studied some time ago for the case of equal Λ and Σ parities;[3] it is the purpose of this Letter to examine again its results and predictions in the light of the present evidence for the $\pi\Lambda$ resonance. In our case the presence of possible $\bar{K}N$ intermediate states does not make the one-meson approximation unreliable, as the mass of the $\bar{K}N$ states is higher than that of the $\Lambda\pi\pi$ states, and besides no enhancement or resonance is known in low-energy $\bar{K}N$ scattering.

The results of our model, in which the mass difference between Λ and Σ is taken into account explicitly, depend on three parameters: the two normalized pion-hyperon coupling constants, f_Λ and f_Σ, and a parameter Ω which is related to the cutoff energy. The binding energy of Λ in nuclear matter seems to indicate that f_Λ is of the order of the pion-nucleon coupling constant; nothing more can be said at present about the numerical values of f_Λ and f_Σ. We shall discuss in what follows the predictions of our model for values of

$$\delta = (f_\Lambda{}^2 - f_\Sigma{}^2)/(f_\Lambda{}^2 + f_\Sigma{}^2) \qquad (1)$$

smaller than, let us say, ~ 0.3 (which means $0.5 f_\Sigma{}^2 \lesssim f_\Lambda{}^2 \lesssim 2 f_\Sigma{}^2$). At the end we shall briefly indicate what conclusions can be obtained when more extreme relations between the two coupling constants are assumed.

With the limitation of δ just mentioned, our model predicts two resonant states for $J=3/2$, with $T=1$ and $T=2$, respectively; no resonance can appear either in the $J=3/2$, $T=0$ or in the $J=1/2$ states. The total resonant energies are given by

$$E_r{}^1 = m_\Lambda + \Omega - \tfrac{1}{2}\Delta - \tfrac{5}{8}\delta\Delta,$$

$$E_r{}^2 = m_\Lambda + \Omega + \tfrac{3}{2}\Delta + \tfrac{1}{2}\delta\Delta, \qquad (2)$$

where $\Delta = m_\Sigma - m_\Lambda = 80$ Mev.

It is also possible to predict the half-width of the two resonances, which turns out to be

$$\Gamma_1 = \tfrac{4}{3} f_Y{}^2 \bar{q}^3\, 0.72(1+0.66\delta),$$

$$\Gamma_2 = \tfrac{4}{3} f_Y{}^2 q^3 (1+0.15\delta), \qquad (3)$$

where

$$f_Y{}^2 = \tfrac{1}{2}(f_\Lambda{}^2 + f_\Sigma{}^2), \qquad (4)$$

and $\bar{q}$ and q are the pion momenta in the $\pi\Lambda$ ($T=1$) resonance and in the $\pi\Sigma$ ($T=2$) resonance, respectively.

As the $T=1$ resonance is present both in the $\pi\Lambda$ and in the $\pi\Sigma$ channel, from formulas (12) in I, we can also calculate the branching ratio R for the decay of the resonant state Y^* into either a $\pi\Lambda$ or $\pi\Sigma$ state. As is expected for a narrow resonance, R turns out to be nearly independent of the way the resonance was prepared, which means that

$$\langle \pi\Sigma | \pi\Sigma \rangle_{T=1} / \langle \pi\Sigma | \pi\Lambda \rangle \simeq \langle \pi\Lambda | \pi\Sigma \rangle / \langle \pi\Lambda | \pi\Lambda \rangle \quad (5)$$

at resonance. We obtain indeed

$$R = (Y^* \to \pi\Sigma)/(Y^* \to \pi\Lambda) \sim \tfrac{1}{2}(0.1)/(1+\delta)^2. \qquad (6)$$

Let us now briefly discuss the results contained in (2), (3), and (6). We note that no $\delta\Omega$ corrections are present in (2), which makes the corrections to the resonance energies due to δ rather small. It is interesting to note that, should we take $\Omega = 290$ Mev (as in the pion-nucleon case, as global symmetry would suggest), we would get $E_r{}^1 = 1365$ Mev, which means a Q value of 110 Mev, in quite good agreement with the experimental value for the $\pi\Lambda$ ($T=1$) resonance. Or putting it differently, we can determine the numerical value of Ω from the experimental position of the $T=1$ resonance and notice that it turns out to be practically coincident with the position of the 3-3 resonance.

Our model predicts a $J=3/2$, $T=2$ ($\pi\Sigma$) resonance at higher energy. The difference $E_r{}^2 - E_r{}^1$ does not depend on Ω, and is given by

$$E_r{}^2 - E_r{}^1 = 2\Delta + \tfrac{4}{3}\delta\Delta = (160 + 105\delta) \text{ Mev}. \qquad (7)$$

This formula represents a clear-cut prediction of the theory, based only on the assumption of equal Λ - Σ parities and small δ. Therefore, it would be extremely interesting to investigate experimentally the existence and position of a $T=2$ resonance, by studying for instance the processes $K^- + p \to \Sigma^- + \pi^- + \pi^+$ or $\pi^+ + p \to \Sigma^+ + \pi^+ + K^0$ in the Bev region.

As for the widths and the value of R, we note first that in the limited symmetry case (i.e., $\Delta = \delta = 0$) one would have simply

$$\Gamma_1 = \Gamma_2 = \tfrac{4}{3} f_Y{}^2 q^3, \quad R = \tfrac{1}{2}. \qquad (8)$$

In the expressions (4) and (6) we can therefore recognize the influence of the nonzero value of Δ (besides the q^3 kinematical factors) and the corrections in δ. We see that while E_γ and the relation (5) are practically insensitive to δ, this is not necessarily the case for the Γ.

The value of R given by (6) gives a preference for the resonance to decay into the $\pi\Lambda$ state, which seems in agreement with the experimental results,[1] even if as yet we have no reliable measurement of the branching ratio.

Several results of our model, obtained with positive Λ - Σ relative parity and small δ, are therefore either in agreement with experiment or susceptible to a direct experimental test. A positive check of the predictions of the model would therefore give a good argument in support of the abovementioned assumptions.

Should $f_\Lambda{}^2$ and $f_\Sigma{}^2$ be widely different, a new set of resonances could develop in our model. If for instance $f_\Sigma{}^2 \sim 0$ (we feel safer playing with $f_\Sigma{}^2$, since the order of magnitude of $f_\Lambda{}^2$, as already noted, is roughly known), then all three isotopic channels in the $J = 3/2$ states would present resonances; the $T = 0$ and $T = 2$ would coincide at 240 Mev above that for $T = 1$. The $J = 1/2$, $T = 1$ could also resonate at an energy that could be of the same order as that corresponding to the $J = 3/2$, $T = 0$ or 2 resonance. It is clear that an experimental investigation of the $T = 0$ resonance would also be of great interest. A small nonzero value for $f_\Sigma{}^2$ would, however, remove the $J = 1/2$ resonance and, less rapidly, the $J = 3/2$, $T = 0$ resonance. An independent idea of the relative value of $f_\Lambda{}^2$ and $f_\Sigma{}^2$ would therefore be highly desirable. Perhaps a way that in the near future can be experimentally accessible is the polology (extrapolation) procedure applied to the processes $\Sigma N \rightarrow \Lambda N$, $\Sigma N \rightarrow \Sigma N$ in the energy region of some hundreds of Mev.

In conclusion, the agreement found between one of the results of our model and the experiment is based on the assumption of equal Λ - Σ parity and depends, to a lesser extent, on the assignment of spin 3/2 to the observed resonance (as global symmetry would suggest). Should these assumptions turn out to be not valid, we could only repeat with Fontenelle[4]: "Je ne suis pas si convaincu de notre ignorance par les choses qui sont et dont la raison nous est inconnue, que par celles qui ne sont point et dont nous trouvons la raison."

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[1]M. L. Good, Proceedings of the Tenth Annual Rochester Conference on High-Energy Nuclear Physics (to be published).

[2]A detailed analysis of some implications of the pion-hyperon resonance is given by Ph. Meyer, J. Prentki, and Y. Yamaguchi (to be published).

[3]D. Amati, A. Stanghellini, and B. Vitale, Nuovo cimento 13, 1143 (1959); to be referred to in the following as I. A similar model was studied by M. Nauenberg, Phys. Rev. Letters 2, 351 (1959). For the case of opposite Λ and Σ parities, analogous calculations are in progress at CERN. In formula (12') of I, there is a fortuitous omission of $D_1{}^0$, which is given by

$$D_1{}^0 = 1 + 2(5f_\Lambda{}^2 - f_\Sigma{}^2)I\omega - 2(f_\Lambda{}^2 - f_\Sigma{}^2)I\Delta.$$

[4]Fontenelle, Histoire des Oracles (Paris, 1687).