We conclude that zero-spin bosons of half-integral isospin must carry another quantum number. (This is hypercharge in the real world.) Our considerations are consistent with the universal validity of the Gell-Mann–Nishijima formula. For pair conjugate bosons (replace $a_{-\alpha}^*$ in Eq. (4) by $b_{-\alpha}^*$, where b_α^* creates the antiparticle multiplet) the restrictions are not so great since the operators entering into the field are dynamically independent.

An interesting consequency of the present result is the clarification of an apparent paradox which arises when one studies the crossing properties of self-conjugate bosons. Because of the structure of (4), one can express $a_\alpha(k)$ in terms of either $\varphi^{(\alpha)}$ or $\varphi^{(-\alpha)*}$. Taking advantage of these apparently equivalent forms, one finds a consistent crossing phase[1] only when the isospin of the crossed meson is integral. From the present analysis one sees that the hypothetical case of half-integral isospin would lead to a noncovariant S matrix, because Eq. (11) would render the T product noncovariant. For the allowed case of integral isospin, all the expressions of Ref. 1 for the crossing matrix are identical, allowing a considerable simplification in phase questions.

Consideration of higher spins and other internal symmetry groups will be given elsewhere.

The author has profited greatly from conversations with his colleagues at Cornell. Special thanks are in order for K. Wilson for his help in clarification of the problems involved.

*Research supported in part by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

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MESON + HYPERON FINAL STATES IN K^-p INTERACTIONS AT 4.1 AND 5.5 GeV/c*

J. Mott,† R. Ammar, R. E. P. Davis, W. Kropac, and F. Schweingruber‡
Northwestern University, Evanston, Illinois

and

M. Derrick, T. Fields,§ L. G. Hyman, J. Loken, and J. Simpson
Argonne National Laboratory, Argonne, Illinois
(Received 21 November 1966)

Differential cross sections for reactions of the type $K^- + p \rightarrow$ neutral hyperon + neutral meson have been measured. The cross sections for peripheral production of vector mesons satisfy certain relations yielded by the independent quark model and other symmetry schemes. The cross section for meson production in the backward hemisphere provides some information on the presence of various baryon-exchange processes.

In order to study hypercharge-exchange processes yielding quasi–two-body final states in high-energy K^-p interactions, we have analyzed ~5000 bubble-chamber events with two prongs plus a visible Λ decay. This sample represented 0.67 events/μb at 4.1 GeV/c and 1.5 events/μb at 5.5 Gev/c (corrected for undetected Λ decays) in the 30-inch hydrogen bubble chamber, using the high-purity separated beam at the Argonne zero gradient synchrotron (ZGS).

Our results are based on events which yielded kinematic fits to these final-state hypotheses: $\Lambda\pi^+\pi^-$, $\Lambda\pi^+\pi^-\pi^0$, $\Lambda\pi^+\pi^-\eta$, ΛK^+K^-, $\Sigma^0\pi^+\pi^-$, and $\Sigma^0K^+K^-$. The most serious ambiguity which was encountered in kinematic fitting was that of distinguishing Λ events from the corresponding Σ^0 events; e.g., $\Lambda\pi^+\pi^-$ (a four-constraint fit) from $\Sigma^0\pi^+\pi^-$ (a two-constraint fit). We postpone a discussion of that problem to later paragraphs in order to present our results with a minimum of experimental detail.

After obtaining clean samples of events fitting the above hypotheses, appropriate invariant-mass plots were made in order to search for production of ρ^0, ω, X^0, η, and φ mesons. Examples representing the ρ^0 and ω peaks are displayed in Figs. 1(a), 1(b), and 1(h). Clear signals were found for a number of these quasi-two-body processes; Table I summarizes the results. Production angular distributions for several of these two-body final states are shown in Fig. 2. These distributions each show a forward peripheral region as expected from single-meson-exchange processes and, in some cases, a backward peak which presumably arises from baryon exchange.

First considering the forward peripheral processes, we can compare our results with the predictions of the independent quark model of Alexander, Lipkin, and Scheck, and others.[1-3] Two predictions of this model which can be tested in this experiment are[1,4]

$$\bar{\sigma}(K^- + p \to \Lambda + \rho^0) = \bar{\sigma}(K^- + p \to \Lambda + \omega) \tag{1}$$

and

$$\bar{\sigma}(K^- + p \to \Lambda + m^0) = 3[\bar{\sigma}(K^- + p \to \Sigma^0 + m^0) + \bar{\sigma}(K^- + p \to Y_1^{*0}(1385) + m^0)]. \tag{2}$$

In these relations m^0 is any neutral quark-antiquark system and $\bar{\sigma}$ is proportional to the square of the transition matrix element. The quantity listed as $\bar{\sigma}$ in Table I is the cross section for production in the forward hemisphere, scaled to the phase space of the $\Lambda\rho^0$ final state, using a factor proportional to the final-state c.m. momentum,[5] and has been corrected for decay modes not seen in this experiment.

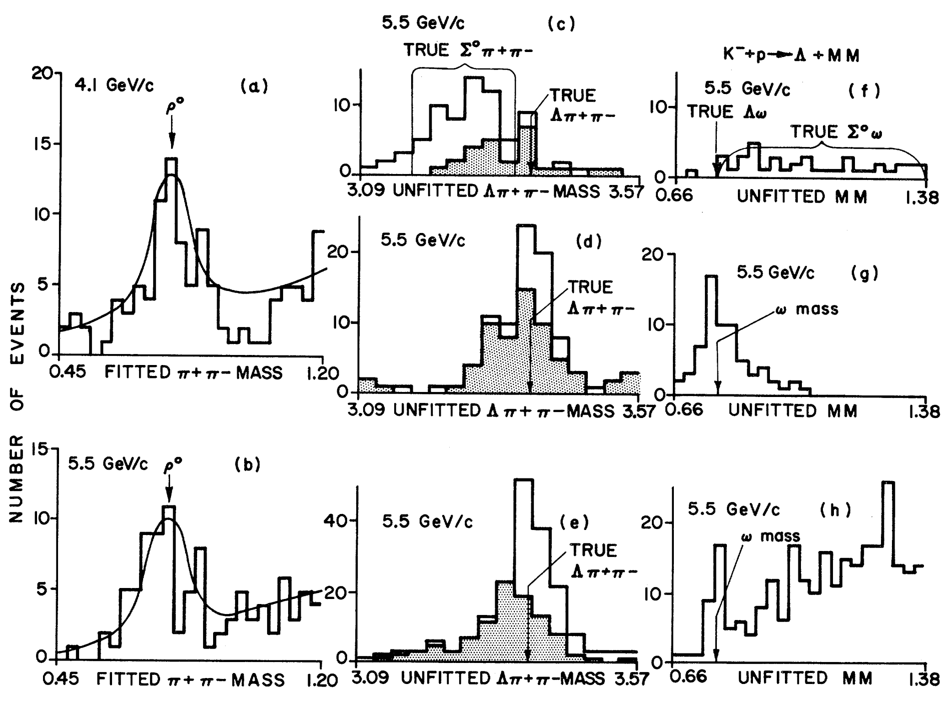

FIG. 1. Analysis of the $\Lambda\pi^+\pi^-$ and $\Lambda\pi^+\pi^-\pi^0$ final states for ρ^0 and ω resonances and possible Σ^0 contamination. (a), (b) Experimental $\Lambda\pi^+\pi^-$ fits. (c) $\Sigma^0\pi^+\pi^-$ events generated by FAKE. Without measurement errors, the true $\Lambda\pi^+\pi^-$ events have a $\Lambda\pi^+\pi^-$ mass of 3.386 GeV/c^2 while the true $\Sigma^0\pi^+\pi^-$ events range from 3.17 to 3.36 GeV/c^2. The shaded area represents the $\Sigma^0\pi^+\pi^-$ events which also fit $\Lambda\pi^+\pi^-$. (d) $\Lambda\pi^+\pi^-$ events generated by FAKE. The shaded area represents $\Lambda\pi^+\pi^-$ events which also fit $\Sigma^0\pi^+\pi^-$. (e) Experimental $\Lambda\pi^+\pi^-$ fits. The shaded area represents the $(\Lambda/\Sigma^0)\pi^+\pi^-$ ambiguities. (f) $\Sigma^0\omega$ events, generated by FAKE, which had kinematic fits to $\Lambda\pi^+\pi^-\pi^0$. Without measurement errors true $\Sigma^0\omega$ events have a missing mass ranging from 0.79 to 1.35 GeV/c^2. (g) $\Lambda\omega$ events generated by FAKE. (h) Experimental $\Lambda\pi^+\pi^-\pi^0$ fits.

Table I. Data on quasi-two-body processes.

Final state	K^- momentum (BeV/c)	No. of events after background subtraction	Percentage background estimated from neighboring regions of invariant mass plots	Cross section corrected for decay modes not observed[a] (μb)	Number of events in forward hemisphere	$\bar{\sigma}$, the forward-hemisphere cross section normalized to $\Lambda\rho^0$ phase space (μb)	Λ polarization (forward events only with an asymmetry parameter[c] $\alpha=0.66\pm0.05$)	Density matrix elements ρ_{11}	Density matrix elements ρ_{1-1}
$\Lambda\rho^0$	4.1	38 ± 16	40	57 ± 26	29 ± 12	44 ± 19	-0.9 ± 0.6	0.40 ± 0.08	$0.00^{+0.14}_{-0.00}$
	5.5	35 ± 12	33	23 ± 8	26 ± 9	17 ± 6	-0.8 ± 0.7	$0.45^{+0.05}_{-0.10}$	$0.00^{+0.14}_{-0.00}$
$\Lambda\omega$	4.1	37 ± 10	20	62 ± 17	26 ± 7	43 ± 12	-1.0 ± 0.5	$0.45^{+0.05}_{-0.08}$	0.18 ± 0.16
	5.5	32 ± 10	22	24 ± 8	26 ± 8	$19+6$	$+0.1\pm0.6$	0.40 ± 0.10	0.24 ± 0.16
$\Lambda\varphi$	4.1	15 ± 4	7	59 ± 16	15 ± 4	65 ± 17	$+0.2\pm0.8$	0.20 ± 0.10	$0.20^{+0.10}_{-0.14}$
	5.5	17 ± 5	6	30 ± 9	17 ± 5	32 ± 9	$+1.0\pm0.7$	$0.45^{+0.05}_{-0.15}$	0.23 ± 0.23
$\Lambda\eta$	4.1	7 ± 3	13	42 ± 18	7 ± 3	39 ± 17			
	5.5	3 ± 2	~0	8 ± 5	3 ± 2	8 ± 5			
ΛX^0	4.1	12 ± 4	15	51 ± 17	12 ± 4	55 ± 18			
	5.5	10 ± 4	10	19 ± 8	10 ± 4	20 ± 8			
$\Sigma^0\rho^0$ [b]	4.1	$\leq19\pm10$	50	$\leq38\pm20$	$\leq12\pm6$	$\leq24\pm13$			
	5.5	$\leq 7\pm5$	50	$\leq 6\pm4$	$\leq 5\pm4$	$\leq 5\pm4$			
$\Sigma^0\varphi$ [b]	4.1	$\leq10\pm4$	10	$\leq53\pm21$	$\leq10\pm4$	$\leq61\pm24$			
	5.5	$\leq11\pm4$	10	$\leq26\pm10$	$\leq11\pm4$	$\leq29\pm11$			
$Y_1^{*0}(1385)\rho^0$	4.1	0 ± 8	100	0 ± 13	0 ± 8	0 ± 16			
	5.5	11 ± 11	75	8 ± 8	$\leq11\pm11$	$\leq 9\pm9$			

[a]The cross sections have been corrected using the branching ratios given in A.H. Rosenfeld, A. Barbaro-Galtieri, W.H. Barkas, P.L. Bastien, J. Kirz, and M. Roos, University of California Radiation Laboratory Report No. UCRL-8030, 1966 (unpublished).
[b]Only an upper limit can be given since many of these $\Sigma^0\rho^0$ and $\Sigma^0\varphi$ events also fit the $\Lambda\rho^0\pi^0$ and $\Lambda\varphi\pi^0$ hypotheses.
[c]A.H. Rosenfeld *et al.*, *loc. cit.*

The predicted equality of the $\Lambda\rho^0$ and $\Lambda\omega$ reaction rates is seen to be supported by our results for $\bar{\sigma}$, within our over-all accuracy of about 30%. Further support for such similarity between these two reactions is seen in the density matrix elements and polarization results listed in Table I, as well as in the production angular distributions.

At lower momenta, such a comparison may not be a meaningful test for models involving peripheralism, since there the $\Lambda\rho^0$ and $\Lambda\omega$ angular distributions have large isotropic components.[6-8] For example, results[6] at 2.24 GeV/c indicate that the $\Lambda\omega$ forward-hemisphere cross section exceeds that for $\Lambda\rho^0$ by a factor of 1.7 ± 0.3.

A comparison of our results with Eq. (2) is limited by the fact that the $Y_1^{*0}(1385)$ can be fitted only in the $Y_1^{*0}\rho^0$ two-body state. Using the number of forward $Y_1^{*0}\rho^0$ events, we see that Eq. (2) is satisfied, within the rather large errors, for the particular case of the ρ^0 meson. For φ production, Table I shows that our results are not inconsistent with an inequality derived from Eq. (2):

$$\bar{\sigma}(K^- + p \to \Lambda + \varphi) \geq 3\bar{\sigma}(K^- + p \to \Sigma^0 + \varphi). \tag{2a}$$

If we assume only K and K^* exchange, the quark model connects the $\Lambda\varphi$ with the $\Lambda\rho^0$ and $\Lambda\omega$ cross sections as follows:

$$\bar{\sigma}(K^- + p \to \Lambda + \varphi) = 2\bar{\sigma}(K^- + p \to \Lambda + \rho^0) = 2\bar{\sigma}(K^- + p \to \Lambda + \omega). \tag{3}$$

Table I shows that the experimental $\Lambda\varphi$ cross sections divided by the values predicted by Eq. (3) are 0.75 ± 0.3 at 4.1 GeV/c and 0.9 ± 0.4 at 5.5 GeV/c. If a momentum-transfer region of 0.07 to 1.10 (GeV/c)^2 is used, these results become 1.0 ± 0.3 and 0.95 ± 0.4, respectively.

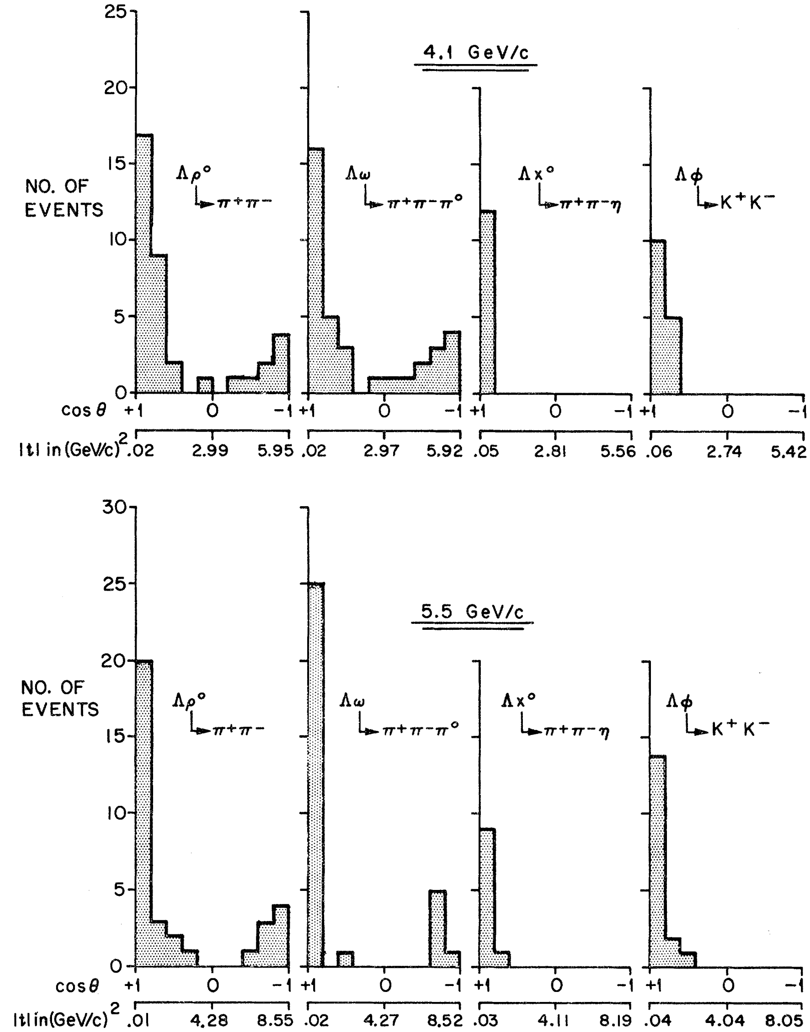

FIG. 2. Production angular distributions of the meson in the K^-p c.m. system for various quasi–two-body final states.

In any case, the density-matrix elements and Λ-polarization results for this state as given in Table I may be somewhat different from those for the $\Lambda\rho^0$ and $\Lambda\omega$ final states.

The backward (baryon-exchange) peak seems to be absent in the $\Lambda\varphi$, ΛX^0, and $\Lambda\eta$ processes, as shown in Fig. 2 and Table I. The lack of the backward φ peak has been observed with 3.0- and 3.5-GeV/c K^- mesons[7,8] and points to a weak $N\bar{N}\varphi$ coupling in agreement with quark and ω-φ mixing models.[9,10] We obtain the following 90% confidence limit for production in the backward hemisphere:

$$\sigma_B(K^- + p \to \Lambda + \varphi) \leq 0.14\,\sigma_B(K^- + p \to \Lambda + \omega).$$

We also observe from Fig. 2 that the backward peaks for ρ^0 and ω production are approximately equal.[11]

Approximately 50% of the events fitting $\Lambda\pi^+\pi^-$ also fit $\Sigma^0\pi^+\pi^-$. The problem of Σ^0 identification and Λ/Σ^0 ambiguities was treated by two methods, which we briefly describe:

(i) Events were examined using unfitted kinematic variables. In the case of true $\Sigma^0\pi^+\pi^-$ events, the observed $\Lambda\pi^+\pi^-$ invariant mass should yield a distribution systematically lower than the unique value expected for true $\Lambda\pi^+\pi^-$ events because of the energy carried away by the γ. Figures 1(c)-1(e) show the invariant-mass distribution for our events compared with that for artificially generated $\Lambda\pi^+\pi^-$ and $\Sigma^0\pi^+\pi^-$ events. It is clear that our events are consistent with the $\Lambda\pi^+\pi^-$ interpretation rather than with the $\Sigma^0\pi^+\pi^-$ interpretation. $\Lambda\rho^0$ events showed the same characteristics as the rest of the $\Lambda\pi^+\pi^-$ events. Similarly the ΛK^+K^- events (and $\Lambda\varphi$ events, in particular) were consistent with the ΛK^+K^- interpretation rather than the $\Sigma^0K^+K^-$ interpretation.

In the case of the $\Lambda\pi^+\pi^-\pi^0$ final state, the $\pi^+\pi^-\pi^0$ invariant mass, calculated from unfitted variables as the mass recoiling from the Λ, showed a fairly sharp ω mass. For true $\Sigma^0\omega$ events kinematic considerations indicate that the neutral mass recoiling from the Λ would not have a sharp ω mass, as shown in Fig. 1(f).

(ii) The program FAKE[12] was used to generate artificial events with Λ and Σ^0 final states. The observed kinematic variables were generated with realistic measurement errors and analyzed by our kinematic fitting program. For the $(\Lambda/\Sigma^0)\pi^+\pi^-$ final state, the results showed that $\Lambda\pi^+\pi^-$ events fit the $\Sigma^0\pi^+\pi^-$ hypothesis easily but the reverse was not true, indicating that most of the experimental $\Lambda\pi^+\pi^-$ fits were actually bona fide events. It was also determined that events generated as $Y_1{}^{*+}(1385)\pi^-$ and $\Lambda\pi^+\pi^-$ fit the $\Sigma^0\pi^+\pi^-$ hypothesis with equal frequencies. Since $Y_1{}^{*+}(1385)$ has only a small branching ratio for decay into $\Sigma^0\pi^+$, the amount of $Y_1{}^{*+}(1385)$ in the ambiguous events is a measure of the amount of $\Lambda\pi^+\pi^-$ final state. Experimentally, the fraction of $Y_1{}^{*+}(1385)$ is the same within errors for both the unique $\Lambda\pi^+\pi^-$ sample and for the $(\Lambda/\Sigma^0)\pi^+\pi^-$ ambiguities indicating, again, that the ambiguous events may be interpreted as being predominantly $\Lambda\pi^+\pi^-$.

We wish to thank B. Musgrave for help with the program FAKE. We have benefitted from discussions with H. Lipkin, K. C. Wali, and G. R. Goldstein. The experiment would not have been possible without the help of the ZGS and bubble chamber crew and the careful work of our scanners and measurers at Argonne and Northwestern.

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*Work supported by the U. S. Atomic Energy Commission and the National Science Foundation.

†This work forms part of a dissertation to be submitted to the Department of Physics, Northwestern University, in partial fulfillment of the requirements for the Ph.D.

‡Also at Argonne National Laboratory, Argonne, Illinois.

§Also at Northwestern University, Evanston, Illinois.

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