at which resonances occur. The structure in the charge-exchange data has been interpreted by the authors as a $T=\frac{1}{2}$ resonance at ~3.1 BeV/c (E^*~2.6 BeV), or as two $T=\frac{3}{2}$ resonances at ~2.6 and 3.5 BeV/c (E^*~2.4 and 2.7 BeV) or as a combination of all three of these together. Our present data and previous results[1] allow us to conclude that the structure observed in charge-exchange scattering can be explained as the combined effect of the three resonances at 2.5, 3.24, and 3.77 BeV/c. Presumably the discrepancy in energy is caused either by a large momentum variation in the difference of the real parts of the forward scattering amplitudes, $\frac{1}{2}(D^- - D^+)^2$, or by the statistical errors in the charge-exchange data.

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EXPERIMENTAL TESTS OF UNITARY SYMMETRY IN MESON-BARYON REACTIONS

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A large variety of relations among reaction amplitudes and cross sections are predicted on the basis of the SU(3) octet model.[1] However, experimental verification of these predictions is generally not feasible and has been done only in very few cases. Consider, for example, meson-baryon reactions of the form

$$m+B\to m+B,$$

where m and B denote pseudoscalar mesons and baryons belonging to the octet representations of SU(3). Straightforward calculation of the SU(3) predictions for these reactions involves 13 independent real parameters, characterizing 7 possible independent complex amplitudes.[2,3] Experimental cross sections are available for about 20 different m-B reactions, including some, like η and Ξ^0 production, for which data are not very accurate and are available for only a few energy values. The straightforward approach of fitting 20 pieces of data with 13 parameters in a set of nonlinear equations has not led to any significant results.[4]

We present here a few simpler predictions of SU(3) for these reactions, obtained with a slightly different approach, and the principal results of an analysis of meson-baryon reactions, comparing experimental facts with SU(3) predictions over a relatively wide energy range. Consider the following three sets of processes:

$$K^- + p \to K^- + p, \qquad (a_1)$$

$$\pi^- + p \to \pi^- + p, \qquad (a_2)$$

$$K^- + p \to \pi^- + \Sigma^+; \qquad (a_3)$$

$$K^+ + p \to K^+ + p, \qquad (b_1)$$

$$\pi^+ + p \to \pi^+ + p, \qquad (b_2)$$

$$\pi^+ + p \to K^+ + \Sigma^+; \qquad (b_3)$$

$$K^- + p \to K^+ + \Xi^-, \qquad (c_1)$$

$$K^- + p \to \pi^+ + \Sigma^-, \qquad (c_2)$$

$$\pi^- + p \to K^+ + \Sigma^-. \qquad (c_3)$$

These reactions are simply analyzed using U-spin technique.[5] Each of these sets consists of reactions between members of the same U-spin multiplets. In each set there are two possible U-spin channels, $U = 0$ and $U = 1$. The three reaction amplitudes in a given set are thus expressible in terms of two independent complex amplitudes, or any one amplitude can be expressed as a linear combination of the other two. Since the relative phases of these amplitudes are unknown, this leads to a triangular inequality between the three amplitudes of each set.

The reaction amplitudes are functions of s and t, and strict SU(3) symmetry requires that these triangular inequalities should hold for every set of values of s and t. In practice only total cross sections (for a given s, integrated over t) can be analyzed with available experimental data, and the choice of corresponding energy values for comparing different reactions is rendered difficult by the large mass differences between members of the same multiplet. Following Meshkov, Snow and Yodh,[6] we compare reaction cross sections at the same Q value, thus bringing all thresholds to the same point, and take into account symmetry breaking only by introducing a phase space factor $F = E^2 p_i / p_f$, where E, p_i and p_f are the total energy and initial and final momenta in the center-of-mass system, respectively. This prescription can be expected to fail in the vicinity of resonances, since the corresponding resonances within a given SU(3) supermultiplet do not appear at the same Q value in all channels. For example, the $N^*(1238)$ is above threshold and contributes strongly to reaction (b_2) but is below the threshold of reaction (b_3). Conclusions may be drawn from the behavior of reactions in nonresonant regions. We do not include any effects of the symmetry-breaking interaction on the reaction amplitudes themselves. Such effects should show up in the analysis as a discrepancy between theoretical predictions and experimental results.

Let us now consider the three sets of reactions in detail.

(a) Since the elastic K^-p and π^-p cross sections are much larger than $\sigma(K^- + p \to \pi^- + \Sigma^+)$, it is convenient to write our inequality in the form

$$[\bar\sigma(K^- + p \to \pi^- + \Sigma^+)]^{1/2} \geq |[\bar\sigma(K^- + p \to K^- + p)]^{1/2} - [\bar\sigma(\pi^- + p \to \pi^- + p)]^{1/2}|, \qquad (1)$$

where $\bar\sigma$ denotes the cross section multiplied by the phase-space factor F. In the low energy region below $Q \sim 700$ MeV, $\sigma(K^- + p \to \pi^- + \Sigma^+)$ is still above 1 mb. Both sides of the inequality (1) are plotted as a function of Q in Fig. 1, showing that the prediction is satisfied for all Q values in this region.[7]

For higher energies $\sigma(K^- + p \to \pi^- + \Sigma^+)$ decreases very rapidly and is comparable with the experimental errors in the elastic cross sections. In this region SU(3) symmetry predicts

$$\bar\sigma_{\rm el}(K^- + p) = \bar\sigma_{\rm el}(\pi^- + p) \qquad (2)$$

when $\bar\sigma(K^- + p \to \pi^- + \Sigma^+)$ is negligible. Figure 2 shows the two elastic scattering cross sections are equal within experimental error.[7]

The equality (2) should hold for the elastic amplitudes at all values of s and t, and therefore for the forward scattering amplitude. The optical theorem then leads to an equaltiy between the total K^-p and π^-p cross sections.[8] Experimental data shows 10%-20% differences.

(b) A similar situation occurs for the second

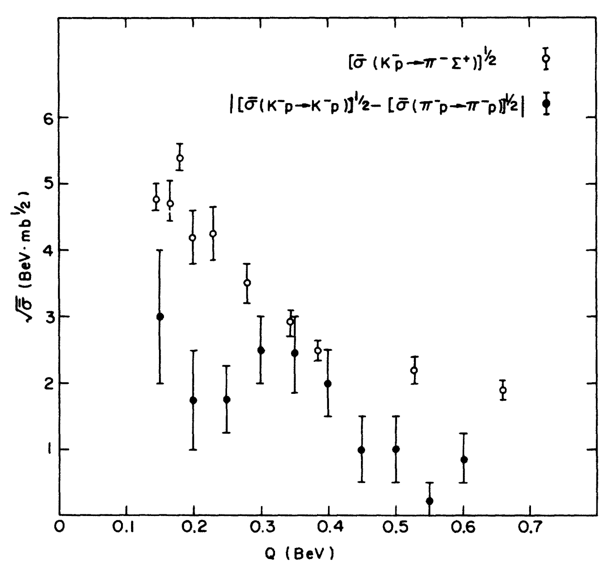

FIG. 1. Experimental data for inequality (1).

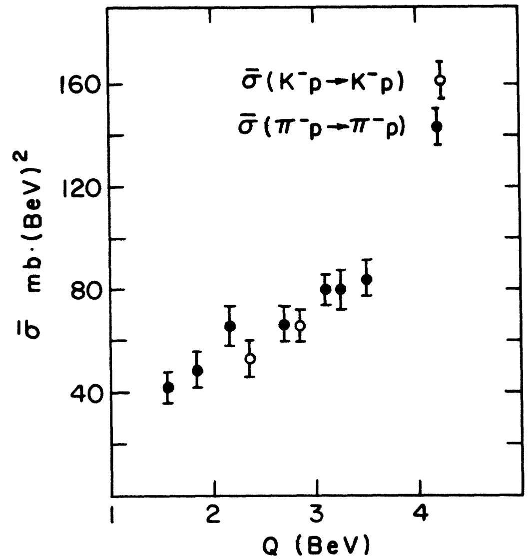

FIG. 2. $\bar{\sigma}_{el}(\pi^- p), \bar{\sigma}_{el}(K^- p)$ at high energies.

set of reactions. SU(3) predicts

$$[\bar{\sigma}(\pi^+ + p \to K^+ + \Sigma^+)]^{1/2} \geq |[\bar{\sigma}(\pi^+ + p \to \pi^+ + p)]^{1/2} - [\bar{\sigma}(K^+ + p \to K^+ + p)]^{1/2}|, \quad (3)$$

$$\bar{\sigma}_{el}(K^+ + p) = \bar{\sigma}_{el}(\pi^+ + p) \quad (4)$$

when $\bar{\sigma}(\pi^+ + p \to K^+ + \Sigma^+)$ is negligible. The available data indicate that the associated production $\bar{\sigma}(\pi^+ + p \to K^+ + \Sigma^+)$ never exceeds 1 mb and is negligible at all energies. Thus the elastic equality (4) should hold even at low energies. The experimental results shown in Fig. 3 indicate a very poor fit at high energies, while at low energies comparison is difficult because of resonances in the $\pi^+ p$ channel.[7]

(c) For the third set of reactions SU(3) predicts

$$[\bar{\sigma}(K^- + p \to \pi^+ + \Sigma^-)]^{1/2} \leq [\bar{\sigma}(K^- + p \to K^+ + \Xi^-)]^{1/2} + [\bar{\sigma}(\pi^- + p \to K^+ + \Sigma^-)]^{1/2}. \quad (5)$$

Experimental values for both sides of the inequality (5) are plotted in Fig. 4 as functions of Q.[7] Although the results show disagreement with (5) at all energies, the discrepancy is small outside the regions of the 1520- and 1660-MeV resonances in the $\pi^+\Sigma^-$ final state.

In addition to the relations (1)-(5) the following simple relation has been shown[1] to be predicted by SU(3):

$$\bar{\sigma}(K^- + p \to \pi^+ + \Sigma^-) = \bar{\sigma}(K^- + p \to K^0 + \Xi^0). \quad (6)$$

This prediction seems to be in striking disagreement with experiment. The only available datum on Ξ^0 production is $\sigma = 0.010 \pm 0.005$ mb at $Q = 185$

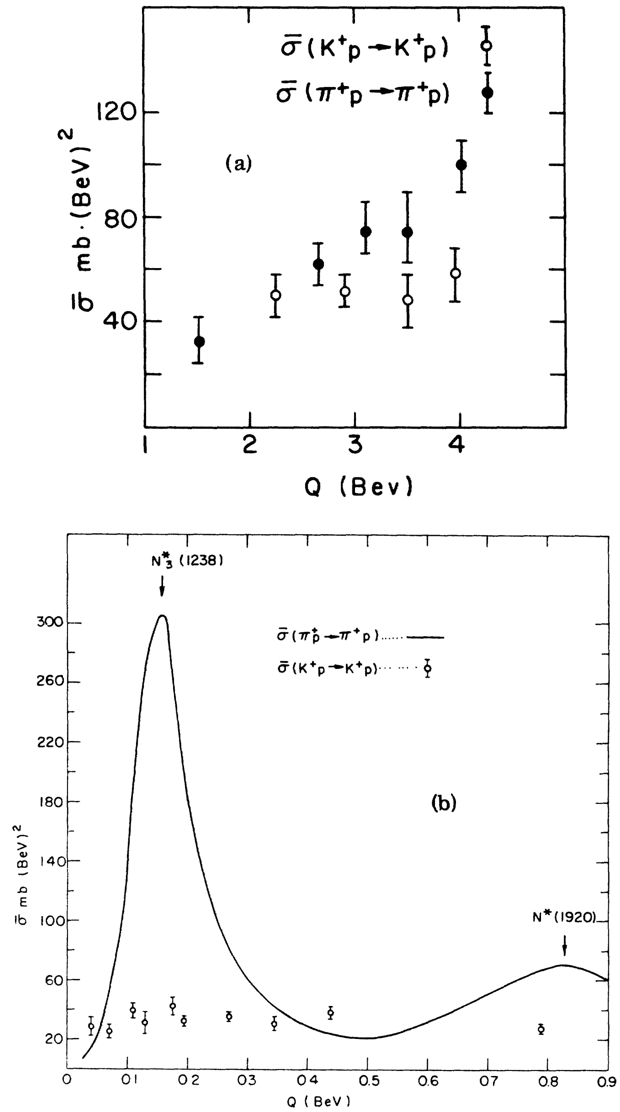

FIG. 3. $\bar{\sigma}_{el}(\pi^+ p), \bar{\sigma}_{el}(K^+ p)$ at high [Fig. 3(a)] and low [Fig. 3(b)] energies.

MeV,[9] while $\sigma(K^- + p \to \pi^+ + \Sigma^-) \sim 17$ mb at $Q = 185$ MeV. If Ξ^0 production is of the same order of magnitude as the observed Ξ^- production at higher energies, the disagreement with SU(3) is not so clear. However, at low energies SU(3) symmetry is badly violated for this case.

Inequalities analogous to (1), (3), and (5) are obtained for vector meson production processes by replacing the π and K mesons in the final states by the corresponding ρ and K^* mesons. So far the available experimental data is inadequate for checking these predictions. The equality (6) cannot be modified to apply to vector meson production, since it is based on time-reversal invariance as well as SU(3) and requires the same kind of meson in both initial and final states.

Similar inequalities are also obtainable for baryon resonance production processes, by replacing p and Σ^+ in the final states by N^{*+} and Y_1^{*+} for resonances in an octet or decuplet representation. For resonances in an octet, relation (5) holds with Σ^- and Ξ^- replaced, respectively, by Y_1^{*-} and Ξ^{*-}. For the production of negative resonances in a decuplet, the situation is different because these have $U=\frac{3}{2}$ rather than $\frac{1}{2}$ and a stronger relation than (5) is obtainable.[5] Corresponding inequalities are also obtainable for the simultaneous production of vector mesons and baryon resonances. Sufficient experimental data are not yet available for analysis of these processes, over a wide energy range.

Attempts to include the symmetry-breaking interaction in the relations between amplitudes have so far yielded only one relation[10] which can be compared with experiment:

$$2[\bar\sigma(K^- + p \to \bar K^0 + n)]^{1/2} \le 2[\bar\sigma(K^- + p \to K^0 + \Xi^0)]^{1/2} + [3\bar\sigma(K^- + p \to \eta + \Sigma^0)]^{1/2} + [3\bar\sigma(K^- + p \to \pi^0 + \Lambda)]^{1/2}$$
$$+ 3[\bar\sigma(K^- + p \to \eta + \Lambda)]^{1/2} + [\bar\sigma(K^- + p \to \pi^0 + \Sigma^0)]^{1/2} + [6\bar\sigma(\pi^- + p \to \eta + n)]^{1/2}$$
$$+ [6\bar\sigma(\pi^- + p \to K^0 + \Lambda)]^{1/2} + [2\bar\sigma(\pi^- + p \to \pi^0 + n)]^{1/2} + [2\bar\sigma(\pi^- + p \to K^0 + \Sigma^0)]^{1/2}. \qquad (7)$$

This relation seems to be satisfied as the processes

$$K^- + p \to \pi^0 + \Lambda, \quad \pi^- + p \to \pi^0 + n,$$
$$\pi^- + p \to \eta + n, \quad K^- + p \to \pi^0 + \Sigma^0$$

all have cross sections above 1 mb at Q values under 500 MeV. The sum of square roots of these cross sections is certainly larger than the square root of the charge-exchange cross section in the K^-p channel. For higher energies there are no data.

We conclude by remarking that the relations and comparisons presented here indicate the usefulness of this type of comparison of SU(3) predictions with experiment. Much more experimental data are needed to obtain a better estimate of the validity of unitary symmetry to describe these reactions in these energy regions and at higher energies. Of particular interest would be better values for cross sections for production of Ξ, η, vector mesons, and baryon resonances. A more detailed discussion of the results will be published elsewhere, including a full list of experimental data (hopefully more than available at the time of preparation of this Letter).

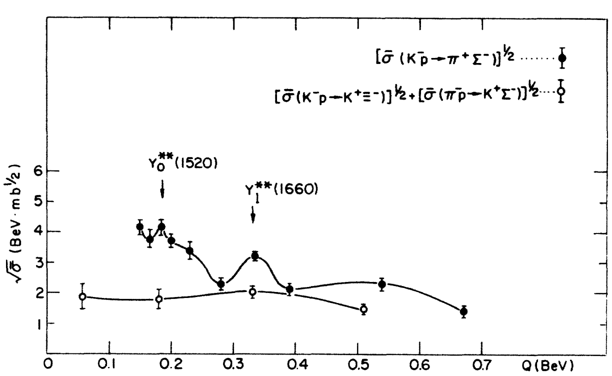

FIG. 4. Experimental data for inequality (5). Lines are drawn only as a guide.

[1]For a review of these predictions see, for instance, Y. Neeman, Proceedings of the International Conference on Nucleon Structure at Stanford University, 1963, edited by R. Hofstadter and L. I. Schiff (Stanford University Press, Stanford, California, 1964); Conference on Symmetry Properties of Elementary Particles, Coral Gables, Florida, 1964 (unpublished).

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[8]The equality of these elastic and total cross sections at "high energies" has already been pointed out (reference 3). The condition (2) specifies a precise criterion for which energies are "high enough".

[9]A. Fridman, reference 7.

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"U-SPIN EQUALITIES" AND OCTET SYMMETRY BREAKING

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An informative way to examine the role of unitary symmetry in strong interactions[1] is to consider the predictions that can be made about reaction cross sections.[2,3] The problem of comparing reactions with different incident energies and with various initial and final states has apparently been successfully overcome in an earlier analysis[4] of reactions of the type

$$\text{meson} + \text{proton} \rightarrow \text{baryon resonance} + \text{meson (vector meson)}. \quad (1)$$

The incident mesons were π^+ and K^+ mesons, and the baryon resonances belonged to the decuplet of $J^P=\frac{3}{2}^+$. Prior to this analysis, it had been proposed[3] that a test of the decuplet assignment could be made via a study of the scattering amplitudes of the "U-spin equalities" listed below,

$$(\pi^-p|N^{*-}\pi^+)/\sqrt{3} = -(\pi^-p|Y_1^{*-}K^+) = (K^-p|Y_1^{*-}\pi^+) = -(K^-p|\Xi^{*-}K^+), \quad (2)$$

$$(\pi^-p|N^{*-}\rho^+)/\sqrt{3} = -(\pi^-p|Y_1^{*-}K^{*+}) = (K^-p|Y_1^{*-}\rho^+) = -(K^-p|\Xi^{*-}K^{*+}). \quad (3)$$

In the present work we analyze the data that are available on these processes to see to what extent the SU(3) predictions are obeyed. Deviations from pure SU(3) symmetry by an order of magnitude are found. The role of symmetry breaking in the interaction matrix elements is explored and correlated with the possible appearance of super resonances.

The mode of comparison, still ad hoc in nature, is described in detail in reference 4. It consists of comparing the processes at the same $Q=E^*-M_3-M_4$, and weighting each cross section σ by a phase-space factor $F=E^{*2}(p_{\text{in}}/p_{\text{out}})$, to yield the squares of the scattering amplitudes, $|M|^2=F\sigma$. In Fig. 1 we plot the results of a comparison of the data, carried out in this manner, for the processes listed in Eq. (2). Table I lists the pertinent cross sections together with associated values of E^*, Q, and F. The data are still too sparse to do this for the production of vector mesons as in the amplitudes of Eq. (3).

The salient features of Fig. 1 are the following: The equalities among the $|M|^2$ of Eq. (2) seem to divide into two subsets of equalities below a Q of approximately 600 MeV. $|M|^2$ for the $(\pi^-p|N^{*-}\pi^+)$ and $(K^-p|Y_1^{*-}\pi^+)$ processes are large and roughly equal, with matrix elements rising rapidly above threshold, reaching a maximum at $Q\cong 300$ MeV, and falling to a small value above about 600 MeV. These curves may encompass considerable structure because they cover an energy range which contains several resonances in both the π^-p and K^-p systems. The