The hourly readings of a 30-inch diameter pulse-counting ion-chamber filled with 12 atmos of argon and surrounded by 1.5 cm of lead are shown in Fig. 1(b). This ion-chamber records pulses of at least 4 electrons produced in the lead shield by photons and electrons of the soft component. These photons and electrons originate from primary cosmic rays of very much higher energies than those from which the sea level neutrons mainly arise. The rate unfortunately is comparatively low—only 10 000 per hour—and so 12-hourly as well as hourly totals have been plotted in Fig. 1(b).

The three Forbush decreases are seen clearly; they are about one-sixth of the size of the neutron decreases; the increase on July 17 may be absent; there is a decrease seen as a downward spike between 0100 and 0400 on July 18, which is probably significant statistically and may indicate that primary cosmic radiation of rather high energy was affected at this time when the neutron intensity was pushed down to such a low value.

[1]Preliminary Report of Solar Activity, TR411 and Supplemental Report, High Altitude Observatory, Boulder, Colorado, 1959 (unpublished).

[2]These features do not show in the plot of hourly totals in Fig. 1(a) and they will not be seen in the standard bi-hourly listings of the International Geophysical Cooperation.

[3]J. F. Steljes and H. Carmichael, Nuovo cimento 10, 393 (1958).

[4]Preliminary Report, University of Minnesota Cosmic-Ray Group, July 23, 1959 (unpublished).

[5]J. Atmospheric Terrest. Phys. 8, 274 (1956); Progress in Cosmic-Ray Physics, edited by J. G. Wilson (North Holland Publishing Company, Amsterdam, 1952), Vol. 1, Chap. 8.

CHARGE INDEPENDENCE IN HYPERON PRODUCTION*

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If the reactions

$$\pi^+ + p \to \Sigma^+ + K^+ \text{ (amplitude } f^+), \quad (1)$$

$$\pi^- + p \to \Sigma^0 + K^0 \text{ (amplitude } f^0), \quad (2)$$

and

$$\pi^- + p \to \Sigma^- + K^+ \text{ (amplitude } f^-), \quad (3)$$

satisfy charge independence, then the three amplitudes involved are not independent. If one makes the usual isotopic spin assignments of a $(\Sigma^+, \Sigma^0, \Sigma^-)$ triplet and a $(K^+\ K^0)$ doublet, then the complex amplitudes f^+, f^0, and f^- are related to the two independent amplitudes $f_{3/2}$ and $f_{1/2}$ that correspond to total isotopic spin 3/2 and 1/2. The relations are

$$f^+ = f_{3/2}, \quad (4)$$

$$f^0 = (\sqrt{2}/3) f_{3/2} - (\sqrt{2}/3) f_{1/2}, \quad (5)$$

$$f^- = (1/3) f_{3/2} + (2/3) f_{1/2}. \quad (6)$$

The linear dependence which then follows,

$$\sqrt{2} f^0 = f^+ - f^-, \quad (7)$$

corresponds to a triangle in the complex plane, and therefore the "triangle inequality"[1]

$$[2\sigma(\Sigma^0)]^{1/2} \leq [\sigma(\Sigma^+)]^{1/2} + [\sigma(\Sigma^-)]^{1/2} \quad (8)$$

must hold for the differential cross sections $\sigma(\Sigma)$ at each production angle and for the integrated cross sections. [The two additional inequalities obtained by permutation of Eq. (8) must also hold, but do not concern us. They are not contradicted by any experiments.]

Previous experimental results of Brown et al.[2] for 1.1-Bev pions incident on a 12-in. propane bubble chamber without magnetic field have indicated a sharp contradiction with Eq. (8) for backwards-produced Σ's. If substantiated, this observation would imply either that charge independence does not hold for Reactions (1), (2), and (3), or, alternatively, that the usual isotopic spin assignments are wrong.[3]

We have measured absolute differential cross sections for Reactions (2) and (3), using 1.09 ± 0.01 Bev (i.e., 1.22-Bev/c) π^- incident on the Alvarez 10-in. liquid hydrogen bubble chamber, with an 11-kilogauss magnetic field. Our results differ substantially from those of Brown et al., both as to magnitudes and as to angular dependences. In view of the disagreement it is perhaps unwise to compare our results for Reactions (2) and (3) with those of Brown et al. for Reaction (1) in order to check the triangle inequality Eq. (8). We nevertheless make this comparison, and find that, within the statistics, there is no contradiction with charge independence.

Figure 1 shows our results, and those of Brown et al.,[4] for Reactions (2) and (3). Our results do not substantiate the strong suppression of forward Σ^0's and of backward Σ^-'s observed by Brown et al.

Figure 2 shows the experimental results of Brown et al. for $\sigma(\Sigma^+)$, together with the lower limit $\sigma(\Sigma^+)_{LL}$ which we predict from our results for $\sigma(\Sigma^0)$ and $\sigma(\Sigma^-)$, and the inequality (8). Our predicted lower limit is thus given by

$$\sigma(\Sigma^+)_{LL} = \{[2\sigma(\Sigma^0)]^{1/2} - [\sigma(\Sigma^-)]^{1/2}\}^2. \qquad (9)$$

From Fig. 2 we see that in the backward quarter of the hyperon solid angle our predicted lower limit exceeds the measured value of $\sigma(\Sigma^+)$ of Brown et al. by 1.6 standard deviations. This is to be compared to the 4.2-standard deviation violation of charge independence first reported by Brown et al.[2] Within the statistics we find that there is no longer any contradiction with charge independence.

It is perhaps worth noting that if the suppression of backward Σ^- (relative to our result) observed by Brown et al. is due to the carbon content of propane, then by charge symmetry a similar suppression could perhaps be expected for backward Σ^+. In that case even the small remaining discrepancy with Eq. (9) would disappear.

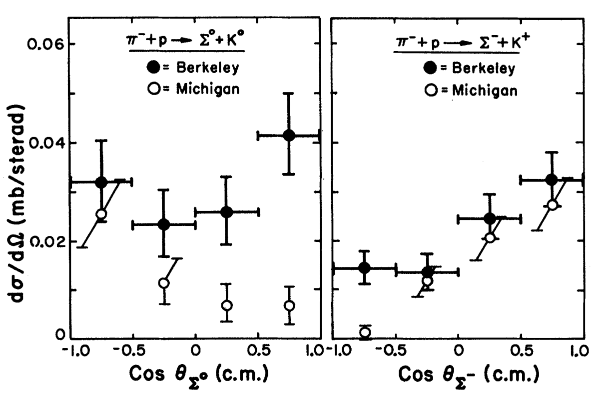

FIG. 1. (Left) Absolute differential cross sections for $\pi^- + p \rightarrow \Sigma^0 + K^0$. (Right) $\pi^- + p \rightarrow \Sigma^- + K^+$. See text.

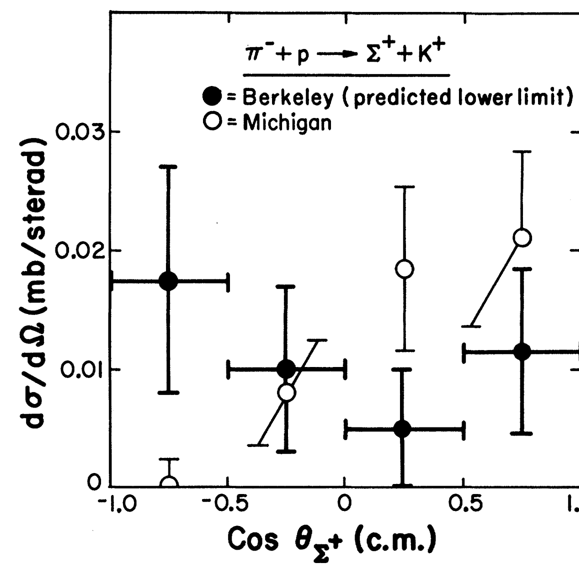

FIG. 2. Absolute differential cross section for $\pi^+ + p \rightarrow \Sigma^+ + K^+$. The open circles represent measured values by the Michigan propane-chamber group. The solid circles represent the lower limit allowed by combining the (Σ^0, K^0) and (Σ^-, K^+) production results of the present experiment with the triangle inequality (8) implied by charge independence.

From Fig. 2 it is apparent that within the statistics our predicted values for $\sigma(\Sigma^+)_{LL}$ are, at all production angles, consistent with $\sigma(\Sigma^+)$ as measured by Brown et al. It is thus reasonable to assume that the inequality (8) degenerates into an equality, at all production angles. Under that hypothesis the triangle of Eq. (7) collapses into three parallel segments, or a triangle with zero area. Aside from a common phase factor, f^+, f^0, and f^- may be then taken as real. Our results for $\sigma(\Sigma^0)$ and $\sigma(\Sigma^-)$ then suffice to determine $f_{3/2}$ and $f_{1/2}$ by means of Eqs. (4) and (5) and (6).

For the total cross sections in Reactions (2) and (3), we find

$$\sigma(\Sigma^0) = 0.39 \pm 0.037 \text{ mb}, \qquad (10)$$

$$\sigma(\Sigma^-) = 0.27 \pm 0.028 \text{ mb}. \qquad (11)$$

Correspondingly we find, subject to the assumption of a triangle of zero area, and using only our own data, the amplitudes

$$f_{1/2} = +(3.05 \pm 0.11) \times 10^{-14} \text{ cm}, \qquad (12)$$

$$f_{3/2} = -(1.14 \pm 0.16) \times 10^{-14} \text{ cm}, \qquad (13)$$

up to an undetermined common phase factor. In terms of intensities, the results (12) and (13) correspond to (Σ^0, K^0) production that is 88 % in the $I = 1/2$ state, and (Σ^-, K^+) production that is 96 % in the $I = 1/2$ state.

The remainder of this Letter is concerned with experimental details. The (Σ^-, K^+) events were distinguished by the scanner from other "two-prong" events through the characteristic decay of the Σ^-. For both total-cross-section and angular-distribution determinations the following "cutoff" criteria are employed. The production event is required to take place inside a restricted fiducial volume in the chamber. The Σ^- decay must occur inside a slightly larger fiducial volume. The Σ^- must travel at least 0.6 cm before it decays. The decay π^- must make a projected angle of at least 8.0° with the direction of the Σ^-. The calculated geometrical detection probability under these criteria remains within the limits 0.50 and 0.56 over the entire angular range. In making the calculation we use our own value for the Σ^- mean life, 1.45×10^{-10} sec. By a second scanning we find that noncutoff (Σ^-, K^+) events are found by the scanner with an efficiency of 97.2 ± 1.3 %. The angular distribution and total cross section for (Σ^-, K^+) are based on 96 noncutoff events.

In the (Σ^0, K^0) determination, the same fiducial volumes for production and decay are used as for (Σ^-, K^+). To be accepted as "detectable" a Λ or K^0 must travel at least 0.3 cm from the production point and undergo charged decay inside the fiducial volume. In calculating the detection probabilities we use our values for the decay branching ratios,[5]

$$(K^0 \to \pi^+ + \pi^-)/(\text{all } K^0) = 0.339,$$

$$(\Lambda \to p + \pi^-)/(\text{all } \Lambda) = 0.627,$$

and our mean lifetime values $\tau_1{}^0 = 0.94 \times 10^{-10}$ sec, and $\tau_\Lambda = 2.72 \times 10^{-10}$ sec. Scanning efficiencies are 97.7 ± 0.7 % for single V's (noncutoff), and 99.4 ± 0.6 % for double V's. The total number of noncutoff (Σ^0, K^0) events is 134, consisting of 30 single K^0 decays (in which the Λ decay is either not observed or is cut off), 75 single Λ decays (K^0 decay not observed or cut off), and 29 doubles (neither decay cut off). In determining the shape of the angular distribution the 75 single Λ decays were not used, since (a) the angular distribution of the Λ's is somewhat washed out relative to the Σ^0 angular distribution because of the recoil from the 75-Mev γ ray in the decay $\Sigma^0 \to \Lambda + \gamma$, and (b) there is a possibility of contamination from the reaction $\pi^- + p \to \Lambda + K^0$. That is, because of the recoil from the γ ray, a complete separation of (Σ^0, K^0) events from (Λ, K^0) events is not possible for single Λ decays. By examining the double V's, where a complete separation is obtained, we estimate that 5 ± 3 % of the 75 single Λ decays attributed to (Σ^0, K^0) production are in fact (Λ, K^0) events, and that an equal number of single Λ decays from (Σ^0, K^0) have been called (Λ, K^0) events. Thus no systematic error is introduced into the total cross section by including the single Λ events. [In the single K^0 decays there is negligible contamination from (Λ, K^0) production.] In the (Σ^0, K^0) total cross section all 134 events are used. In the angular distribution (Fig. 1) the shape is determined by the 59 events involving K^0 decays, and the normalization by all 134 events. The errors are calculated taking into account the correlation involved in the fact that the 59 counts are included in the total of 134.

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[1]J. J. Sakurai, Phys. Rev 107, 908 (1957).

[2]Brown, Glaser, Meyer, Perl, Vander Velde, and Cronin, Phys. Rev. 107, 906 (1957).

[3]For instance, A. Pais, Phys. Rev. 112, 624 (1958), suggests that present experimental evidence does not overwhelmingly require that (K^0, K^+) form a doublet in charge space.

[4]The results of Brown et al., shown in Figs. (1) and (2), differ slightly from and supersede those given in reference 2, and were obtained by private communication from John Vander Velde (University of Michigan) to Frank Crawford.

[5]Crawford, Cresti, Douglass, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Letters 2, 266 (1959).