Decay Asymmetry of Σ^+ and Λ^0 Hyperons*

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Counter techniques have been used to measure decay asymmetries for polarized Λ^0 and Σ^+ hyperons. The Σ^+ hyperons were produced by 1.13-Bev/c π^+ in the reaction $\pi^++p\rightarrow\Sigma^++K^+$. The Λ^0 hyperons were produced by 1.00-Bev/c π^+ in the reaction $\pi^++d\rightarrow K^++\Lambda^0+p$. The asymmetry for each hyperon decay mode was measured with a counter arrangement which detected separately charged pions and γ rays from neutral pions. The protons from the hyperon decay were also detected to confirm the identification of the decay modes. The product $\alpha\bar{P}$ was measured, where α is the asymmetry parameter and $\bar{P}$ is the average polarization of the hyperon. The following results were obtained for the various decay modes:

$$\Sigma^+\rightarrow\pi^++n,\quad \alpha\bar{P}=+0.03\pm0.08;$$
$$\Sigma^+\rightarrow\pi^0+p,\quad \alpha\bar{P}=+0.75\pm0.17;$$
$$\Lambda^0\rightarrow\pi^-+p,\quad \alpha\bar{P}=+0.55\pm0.06;$$
$$\Lambda^0\rightarrow\pi^0+n,\quad \alpha\bar{P}=+0.60\pm0.13.$$

The results for Σ^+ are fitted to the triangular relationship demanded by the $|\Delta I|=\frac{1}{2}$ rule, and absolute values for the asymmetries of $\Sigma^\pm$ decay are predicted. The ratio $\alpha(\Lambda^0\rightarrow\pi^0+n)/\alpha(\Lambda^0\rightarrow\pi^-+p)=+1.10\pm0.27$ is in agreement with the value $+1.00$ predicted by the $|\Delta I|=\frac{1}{2}$ rule for hyperon decay.

INTRODUCTION

NONCONSERVATION of parity in the pionic decay modes of the hyperons can produce an asymmetry of the decay pions with respect to the initial hyperon spin direction. The form of the asymmetry is $1+\alpha\bar{P}\cos\theta$, where θ is the angle between the decay pion and the hyperon spin direction, $\bar{P}$ is the average polarization of the hyperon, and α is the parity-nonconserving parameter.[1] Asymmetry in the decay $\Lambda^0\rightarrow\pi^-+p$ is now well established.[2] It is necessary to measure the asymmetry for other hyperons as a first step towards understanding the particular weak interaction that is responsible for the decay.[3] In a previous paper (called paper I) we have reported measurements of the asymmetries for Σ^+- and Σ^--hyperon decays.[4] The results of those measurements were $(\alpha^-)_\Sigma\bar{P}=+0.02\pm0.05$; $(\alpha^+)_\Sigma\bar{P}=+0.02\pm0.07$; $(\alpha^0)_\Sigma\bar{P}=+0.70\pm0.30$.[5] The most significant conclusions which could be drawn from the results, namely that $|(\alpha^0)_\Sigma|\geq0.70\pm0.30$ and that $|(\alpha^+)_\Sigma|\leq0.03\pm0.11$, were based upon the value of $(\alpha^0)_\Sigma\bar{P}$ with its large statistical uncertainty. For this reason, we have repeated and confirmed the previous measurements of the Σ^+ decay asymmetries with greater accuracy. In addition, we have extended the technique to measure the asymmetries for the charged and neutral Λ^0 decay modes, of which the latter had not been previously measured. In particular, we have measured $\alpha\bar{P}$ for the following decay modes:

$$\Sigma^+\rightarrow\pi^++n,\tag{1}$$
$$\Sigma^+\rightarrow\pi^0+p,\tag{2}$$
$$\Lambda^0\rightarrow\pi^-+p,\tag{3}$$
$$\Lambda^0\rightarrow\pi^0+n.\tag{4}$$

EXPERIMENTAL PROCEDURES

Polarized hyperons were produced by the reactions

$$\pi^++p\rightarrow\Sigma^++K^+\tag{5}$$

and

$$\pi^++d\rightarrow\Lambda^0+K^++p,\tag{6}$$

at incident pion momenta of 1.13 Bev/c and 1.00 Bev/c

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[1] A discussion of parity nonconservation in hyperon decay is given by T. D. Lee, J. Steinberger, G. Feinberg, P. K. Kabir, and C. N. Yang, Phys. Rev. **106**, 1367 (1957).

[2] F. S. Crawford, Jr., M. Cresti, M. L. Good, K. Gottstein, E. M. Lyman, F. T. Solmitz, M. L. Stevenson, and H. K. Ticho, Phys. Rev. **108**, 1102 (1957); F. Eisler, R. J. Plano, A. G. Prodell, N. P. Samios, M. Schwartz, J. Steinberger, P. Bassi, V. Borelli, G. Puppi, G. Tanaka, P. Woloschek, V. Zoboli, M. Conversi, P. Franzini, I. Mannelli, R. Santangelo, and V. Silvestrini, Phys. Rev. **108**, 1353 (1957); *1958 Annual International Conference on High Energy Physics at CERN*, edited by B. Ferretti (CERN Scientific Information Service, Geneva 1958), pp. 150, 267, and 323.

[3] A review which discusses some hyperon decay theories is given by R. H. Dalitz, Revs. Modern Phys. **31**, 823 (1959).

[4] R. L. Cool, B. Cork, J. W. Cronin, and W. A. Wenzel, Phys. Rev. **114**, 912 (1959).

[5] We use a notation in which the superscript is the charge of the meson emitted in the decay; the subscript is the hyperon which decays. For example, $(\alpha^0)_\Lambda$ refers to $\Lambda^0\rightarrow\pi^0+n$; $(\alpha^+)_\Sigma$ refers to $\Sigma^+\rightarrow\pi^++n$.

for reactions (5) and (6), respectively. Figure 1 shows a schematic view of the apparatus. The reactions were selected by the identification of K^+ mesons in a counter telescope. A detailed discussion of the operation of the K^+ telescope has been given in paper I. The only change in the K^+ telescope was the additional requirement that the particle produced in the K^+ decay emerge from the stopping counter and pass through a scintillation counter that surrounded the stopping counter. This measure was taken to reduce the accidental background in the K^+ telescope. The incident pion beam had a momentum width that was $\pm 2.5\%$ of the mean momentum. The beam was 2 in. wide and $\frac{1}{2}$ in. high at the center of the target.

Pions from the hyperon decay were detected in two identical counter systems placed to the right and left of the production plane. Each system consisted of two 18-in. by 18-in. scintillation counters separated by 0.25 in. of lead. The counters closest to the target are called L' or R', the other counters are called L or R. The passage of a charged pion through the system was characterized by pulses from both L' and L or R' and R. The conversion of a γ ray from the π^0 decay in the lead was characterized by a pulse from L or R with no pulse from L' or R'. The kinematics of the hyperon production and decay are such that the decay nucleon rarely struck these counters. However a large fraction of these nucleons must pass through counters located downstream from the target. The geometry of this decay proton counter (called P) is such that 60% of the protons of decay mode (2) and 80% of the protons of decay mode (3) pass through it and give a pulse. The efficiency for neutron detection is very small, so that modes (1) and (4) rarely give a pulse in P. When a K^+ was detected, the coincident pulses of all the counters mentioned above were displayed on an oscilloscope and photographed.

The direction of the incident pion momentum $\mathbf{p}_{\pi\ \mathrm{inc}}$ and the K^+ momentum $\mathbf{p}_K$ determine the production plane. The polarization of the hyperons is along the direction $\pm(\mathbf{p}_{\pi\ \mathrm{inc}}\times\mathbf{p}_K)$. The asymmetry parameter α is defined as negative if the decay pions go more frequently in the direction $(\mathbf{p}_{\pi\ \mathrm{inc}}\times\mathbf{p}_K)$.

The angular distribution of single γ rays from the π^0 decay can be related in a simple way to the original π^0 distribution. If the π^0 distribution in the rest system of the hyperon is $1+\alpha\bar{P}\cos\theta$, then the distribution of γ rays, when detected individually, is $1+k\alpha\bar{P}\cos\theta$. The factor k is less than unity; it expresses the smearing of the asymmetry due to the π^0 decay into γ rays. The value of k depends principally on the energy of the π^0 in the hyperon decay. It also depends somewhat on the relative γ-ray detection efficiency as a function of energy.

For each decay mode we define an experimental asymmetry $\delta=(N_L-N_R)/(N_L+N_R)$, where N_L and N_R are the number of decays to the left and right,

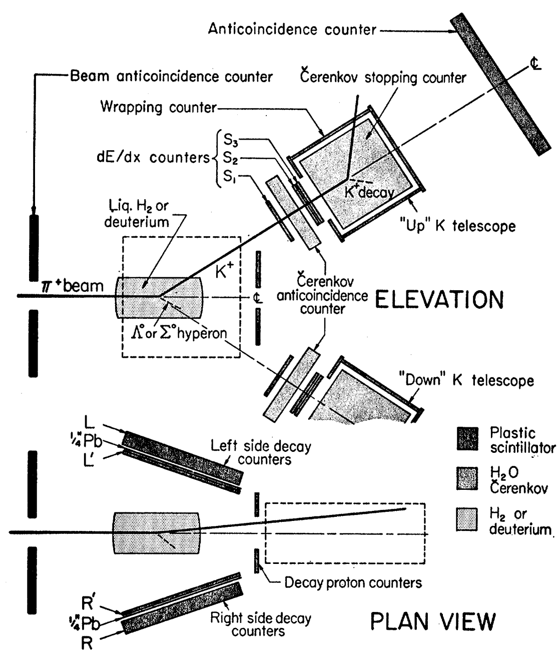

FIG. 1. Schematic view of experimental apparatus.

respectively. The values of δ for the up and down K telescopes should be equal but of opposite sign. An average $\bar{\delta}=(\delta_u-\delta_d)/2$ eliminates systematic errors due to misalignment of the apparatus or the pion beam. The value of $\alpha\bar{P}$ is related to $\bar{\delta}$ by $\alpha\bar{P}=(f/k)\bar{\delta}$, where f is a geometrical factor that takes into account the effective solid angle of the counters which detect the decay pions.

The symmetry of the apparatus was checked by selecting fast particles in the K^+ telescope. Charged particle or γ-ray counts in the pion counters come from inelastic pion production which can have no asymmetry. The experimental asymmetry for these events we call $\bar{\epsilon}$. The degree to which $\bar{\epsilon}$ is different from zero is a direct measure of any intrinsic asymmetry of the apparatus.

Σ^+ MEASUREMENTS

The Σ^+ hyperons were produced by reaction (5) with 1.13-Bev/c π^+ mesons striking the hydrogen-filled target. The Σ^+ hyperons selected by the K^+ telescope were produced at a center-of-mass angle of 87 ± 15 deg. The Σ^+ hyperons had an average momentum of 800 ± 40 Mev/c. The laboratory production angle was 15 ± 5 deg. The experimental yields for charged particles and γ rays per detected K^+ agreed within 5% with calculations of these yields based on the known branching ratio for Σ^+ decay. Half of the γ rays were accompanied by a count in the decay proton counter P which is consistent with the efficiency expected for that counter. Table I gives the experimental asymmetries and summarizes the steps leading to the value of $\alpha\bar{P}$. The following corrections were applied. A calculation showed that 8% of the charged particle yield was due to γ rays that converted

TABLE I. Derivation of $\alpha\bar{P}$ from the experimental asymmetries for the Σ^+ decay modes. The symbols are explained in the text.

Decay mode	$\bar{\delta}$	$\bar{\delta}$ (corrected)	k	f	$\alpha\bar{P}$	$\bar{\epsilon}$
$\Sigma^+ \rightarrow \pi^+ + n$	$+0.06 \pm 0.07$	$+0.03 \pm 0.07$	1.00	1.17	$+0.03 \pm 0.08$	-0.04 ± 0.03
$\Sigma^+ \rightarrow \pi^0 + p$	$+0.36 \pm 0.07$	$+0.43 \pm 0.10$	0.68	1.19	$+0.75 \pm 0.17$	-0.01 ± 0.03

in the target walls ahead of the counters L' and R'. Correction for this effect reduced $(\bar{\delta}^+)_\Sigma$ by 0.03.[6] In order to correct for background in the K^+ telescope and accidentals in the pion counters both $(\bar{\delta}^+)_\Sigma$ and $(\bar{\delta}^0)_\Sigma$ were increased 14%. The K^+ yield when the target was empty was 15% of the rate when full. Sufficient data to determine asymmetries with the empty target were not taken. If the empty-target events have no γ-ray asymmetry, $(\bar{\delta}^0)_\Sigma$ should be increased by 15%. It is unlikely, however, that the empty-target asymmetry can be any larger than the measured asymmetry. Therefore, $(\bar{\delta}^0)_\Sigma$ was increased by 7.5% and the uncertainty of $\pm 7.5\%$ was folded into the probable error. The conversion factors k and f were calculated from the kinematics of the reaction and the geometry. The errors in this calculation are small compared to the other sources of error. The value for $(\alpha^+)\bar{P}$ and $(\alpha^0)\bar{P}$ are given in column 6 of Table I. The instrumental asymmetry $\bar{\epsilon}$ is given in the last column for comparison.

Λ^0 MEASUREMENTS

The Λ^0 hyperons were produced by reaction (6). There is good experimental evidence[7] that in high-energy reactions the nucleons in the deuteron behave in most respects as free nucleons. In reaction (6) the proton, for the most part, plays the role of a spectator, and in the final state will be left with a momentum spectrum that is its internal momentum spectrum in the deuteron. Most of those protons then have momenta less than 200 Mev/c and do not emerge from the target. We were then effectively using the reaction

$$\pi^+ + n \rightarrow \Lambda^0 + K^+, \tag{7}$$

which is charge symmetric to the well-known reaction

$$\pi^- + p \rightarrow \Lambda^0 + K^0. \tag{8}$$

Reaction (8) shows a large polarization for the Λ^0.[2] The reactions

$$\pi^+ + n \rightarrow \Sigma^0 + K^+ \tag{9}$$

and

$$\pi^+ + p \rightarrow \Sigma^+ + K^+ \tag{10}$$

can also take place in the deuteron. For a nucleon at rest the threshold for these reactions is 1.03 Bev/c. In the deuteron, because of the internal motion of the nucleons, this threshold is reduced. The yields of Λ^0, Σ^0, and Σ^+ in association with K^+ were calculated as a function of incident π^+ momentum by using known production cross sections[8] and the estimated efficiency of the K^+ detector. The internal motion of the nucleons in the deuteron was inserted into the calculation in detail. Figure 2 shows the results of the calculation. Plotted on the same graph are experimental points from an excitation function measured with the apparatus. The agreement is very good. Charge symmetry holds between reactions (7) and (8) to an experimental accuracy of $\pm 30\%$. At 1.00 Bev/c, where the data were taken, the hyperon composition was computed to be 86% Λ^0, 9% Σ^0, and 5% Σ^+.

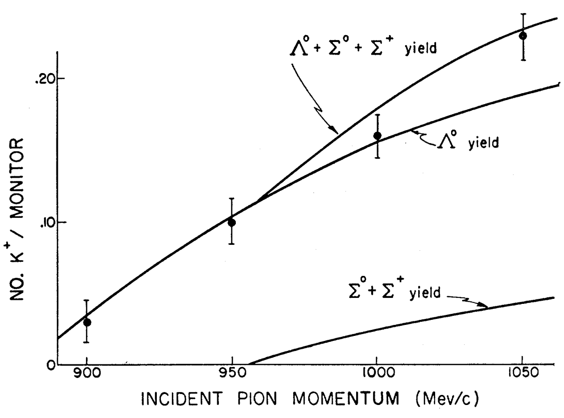

FIG. 2. Excitation function for K^+ produced by π^+ incident on the deuterium target.

The measured yields of γ-ray counts and charged pion counts that were accompanied by a count in P were in agreement with calculations that were based on the known branching ratio for Λ^0 decay. The Λ^0 hyperons were produced at a center of mass angle of 97 ± 15 deg. The laboratory angle of production was 15 ± 5 deg, and the momentum was 630 ± 70 Mev/c. Table II shows the results. The value of $(\bar{\delta}^-)_\Lambda$ was obtained only from those charged pion events that were also accompanied by a pulse in the counter P. The requirement of a pulse in P eliminated processes other than charged Λ^0 decay. Among these processes are (a) events from the small fraction of Σ^+ produced; (b) γ-ray events which convert in the target walls; (c) events in which the decay proton in the charged mode strikes the pion counters. All of these processes have asymmetries smaller than charged Λ^0 decay or asymmetries of the opposite sign. The experimental asymmetry for this kind of event is $\bar{\delta} = +0.19$

[6] We use the same notation described in the previous footnote for $\bar{\delta}$.

[7] A. P. Batson, B. B. Culwick, J. G. Klepp, and L. Reddiford, Proc. Roy. Soc. (London) **251**, 233 (1959).

[8] *1959 Annual International Conference in High-Energy Physics at CERN*, edited by B. Ferretti (CERN Scientific Information Service, Geneva 1958), p. 148. Also F. S. Crawford, Jr., Lawrence Radiation Laboratory (private communication).

TABLE II. Derivation of $\alpha\bar{P}$ from the experimental asymmetries for the Λ^0 decay modes. The symbols are explained in the text.

Decay mode	$\bar{\delta}$	$\bar{\delta}$ (corrected)	k	f	$\alpha\bar{P}$	$\bar{\epsilon}$
$\Lambda^0 \to \pi^0 + n$	$+0.20\pm0.032$	$+0.25\pm0.055$	0.495	1.20	$+0.60\pm0.13$	$+0.005\pm0.015$
$\Lambda^0 \to \pi^- + p$	$+0.41\pm0.033$	$+0.48\pm0.055$	1.000	1.14	$+0.55\pm0.06$	$+0.015\pm0.022$

±0.035 which shows the dilution of the asymmetry by these unwanted processes.

The following corrections to $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ were made. To correct for accidentals in the pion counters and background in the K^+ sample, we increase $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ by 7% and 9%, respectively. The yield of K^+ for the empty target is less than 5% of the full target yield. No correction is made for the empty-target yield. Corrections must be made for the presence of the small Σ^0 and Σ^+ contamination. The Λ^0 resulting from Σ^0 decay have a polarization which is $\frac{1}{3}$ of the Σ^0 polarization. If the Σ^0 and Σ^+ background both have high polarizations comparable to the Σ^+ polarization produced in hydrogen then both $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ should be raised by 5%. On the other hand, the polarization of the Σ^+ and Σ^0 may be small since they are produced with very little center of mass energy. In this case $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ should be increased by 7% and 16%, respectively. Assuming some intermediate situation, $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ were increased 6% and 16%, respectively. An uncertainty of $\pm5\%$ was folded into the probable error to account for the lack of knowledge of the polarization of the Σ^+ and Σ^0 background. The probability that a Λ^0 will scatter off the "spectator" proton in the same nucleus is about 10%.[9] It is not known if this process depolarizes. If depolarization were complete $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ should be increased by 5% and 10%, respectively. If there is no depolarization the correction is only kinematical and is very small. We assumed partial depolarization and increased $(\bar{\delta}^-)_\Lambda$ and $(\bar{\delta}^0)_\Lambda$ by 2.5% and 5%, respectively. A 2.5% uncertainty was folded into the probable error for $(\bar{\delta}^0)_\Lambda$. The errors in the calculated values of K and f are negligible. The values for $\alpha\bar{P}$ are given in column 6 of Table II and the corresponding intrinsic asymmetry of the apparatus is given in the last column.

CONCLUSIONS

The values for $(\alpha^+)_\Sigma\bar{P}$ and $(\alpha^0)_\Sigma\bar{P}$ are in excellent agreement with the measurements of paper I.[4] The experimental asymmetry $(\bar{\delta}^0)_\Sigma$ is five statistical standard deviations away from zero, so that the existence of an asymmetry for $\Sigma^+ \to \pi^0 + p$ is now well established. The value $(\alpha^0)_\Sigma\bar{P}$ is a lower limit for both $|(\alpha^0)_\Sigma|$ and $|\bar{P}|$. From the limit $|\bar{P}| > 0.75\pm0.17$ we can set the upper limit $|(\alpha^+)_\Sigma| < 0.04\pm0.11$.

The results can be understood within the framework of the $|\Delta I| = \frac{1}{2}$ rule for hyperon decay.[10] In general the asymmetry parameter in the decay of a spin-$\frac{1}{2}$ hyperon is

$$\alpha = 2\,\mathrm{Re}(s^*p)/(|s|^2+|p|^2),$$

where s and p are the amplitudes for s-wave and p-wave decay of the hyperon. Time-reversal invariance imposes the condition that s and p are real except for the effect of final-state interactions. The relative phase shift introduced between s and p by final-state interactions is negligible. The amplitudes s and p can be plotted in a two-dimensional space as a single vector $\mathbf{a}$, with the components s and p. The magnitude of $\mathbf{a}$ is $(|s|^2+|p^2|)^{\frac{1}{2}}$, which is proportional to the square root of the decay rate. The $|\Delta I| = \frac{1}{2}$ rule requires that $(\mathbf{a}^+)_\Sigma + \sqrt{2}(\mathbf{a}^0)_\Sigma = (\mathbf{a}^-)_\Sigma$. Since the rates for the three modes of Σ decay are nearly equal,[11] an approximate right triangle is formed with $\sqrt{2}(\mathbf{a}^0)_\Sigma$ as the hypotenuse. The experimental ratio $(\alpha^+)_\Sigma\bar{P}/(\alpha^0)_\Sigma\bar{P} = 0.04\pm0.11$ determines the angle between the vector $(\mathbf{a}^+)_\Sigma$ and the s or p axis to be 1 ± 3 deg. This determination is not affected by the uncertainty in the shape of the triangle. Figure 3 shows the orientation and shape of the triangle that is a best fit to the data. The s and p axes may be interchanged and the figure reflected about either axis. The triangle thus determined predicts the following absolute values for

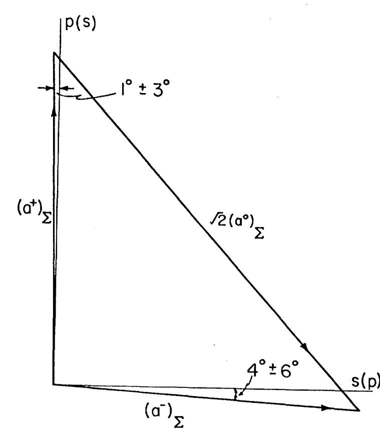

FIG. 3. Experimental determination of the orientation of the $\Sigma^\pm$ decay amplitudes for $|\Delta I| = \frac{1}{2}$.

[9] F. S. Crawford, Jr., M. Cresti, M. L. Good, F. T. Solmitz, M. L. Stevenson, and H. L. Ticho, Phys. Rev. Letters **2**, 174 (1959).

[10] M. Gell-Mann and A. H. Rosenfeld, Ann. Rev. Nuclear Sci. **7**, 407 (1957).

[11] *1958 Annual International Conference on High-Energy Physics at CERN*, edited by B. Ferretti (CERN Scientific Information Service, Geneva 1958), p. 271. The branching ratio $|(a^+)_\Sigma|^2/|(a^0)_\Sigma|^2$ is 1.00 ± 0.04. [D. A. Glaser, Ninth Annual International Conference on High-Energy Physics, Kiev, 1959 (unpublished)]. The error in this branching ratio is small compared to the relative error in the Σ^+ and Σ^- lifetimes.

the three asymmetry parameters:

$$|(\alpha^-)_\Sigma| = 0.14 \pm 0.20,$$
$$|(\alpha^0)_\Sigma| = 0.99_{-0.05}^{+0.01},$$
$$|(\alpha^+)_\Sigma| = 0.04 \pm 0.11.$$

The large error in $|(\alpha^-)_\Sigma|$ arises principally from the error in the relative $\Sigma^\pm$ lifetimes.

Recently Franzini *et al.* have measured $(\alpha^-)_\Sigma \bar{P}$ under conditions where the polarization of the Σ^- is known to be large.[12] The Σ^- were produced by the reaction

$$\pi^- + n \rightarrow \Sigma^- + K^0. \tag{11}$$

Reaction (11) is charge symmetric to reaction (5) which produces a large Σ^+ polarization, hence one expects a large Σ^- polarization. Under this circumstance, Franzini *et al.* find $(\alpha^-)_\Sigma \bar{P} = +0.01 \pm 0.17$ which indicates a small value for $|(\alpha^-)_\Sigma|$. Thus all the experimental data for $\Sigma^\pm$ decay asymmetries are in agreement with the predictions of the $|\Delta I| = \frac{1}{2}$ rule.

The value $(\alpha^-)_\Lambda \bar{P} = +0.55 \pm 0.06$ agrees in sign and closely in magnitude with the value $+0.7 \pm 0.1$ measured in bubble chambers.[2] Since we have produced the Λ^0 with a lower momentum pion beam than that used in most of the bubble chamber experiments, it is reasonable to expect a lower polarization. The ratio $(\alpha^0)_\Lambda/(\alpha^-)_\Lambda = +1.10 \pm 0.27$ is in agreement with the value of $+1.00$ predicted by the $|\Delta I| = \frac{1}{2}$ rule. The pionic decay of the Λ^0 has been discussed by using the universal Fermi interaction, which allows both $|\Delta I| = \frac{1}{2}$ and $|\Delta I| = \frac{3}{2}$ decays.[13] The predictions of the lowest order calculations are identical with the $|\Delta I| = \frac{1}{2}$ rule. Corrections to the lowest order calculations should reduce the ratio $(\alpha^0)_\Lambda/(\alpha^-)_\Lambda$ below unity. The experimental ratio is not sufficiently accurate to distinguish the $|\Delta I| = \frac{1}{2}$ rule from the universal Fermi interaction theory.

Using theories derived from the universal Fermi interaction, one has great difficulty in explaining the pattern of asymmetry in the $\Sigma^\pm$ decay modes.[3] There is a large amount of evidence in support of the $|\Delta I| = \frac{1}{2}$ rule and there is no substantial evidence against it.[14] Recently there have been a large number of theories of hyperon pionic decay which have the $|\Delta I| = \frac{1}{2}$ rule built in as a postulate. These theories predict relations between $\Sigma^\pm$, Λ^0, and $\Xi^{0,-}$ decay rates and asymmetries in addition to the triangular relation among $\Sigma^\pm$ decays discussed above. Feld has discussed these theories and finds they can be classified into two groups.[15] The first class of theories relate $\Sigma^\pm$, Λ^0, and $\Xi^{0,-}$ decay by stating that the decay amplitudes are the same for all hyperons for the same final isotopic spin state, apart from kinematic and phase space factors which are different for the different hyperons.[16,17] The second class of theories relate the various hyperon decays by means of global symmetry relations.[18–21] The experiments we have carried out cannot distinguish between these two classes of theories. A distinction can be made by examination of the longitudinal polarization of the protons from $\Lambda^0 \rightarrow \pi^- + p$ and $\Sigma^+ \rightarrow \pi^0 + p$. The first class of theories predicts the same sign for the two polarizations; the second class predicts the opposite sign. The sign of the polarization of protons from $\Lambda^0 \rightarrow \pi^- + p$ has been measured.[22] The protons have been found to have negative helicity. A measurement of the sign of the longitudinal polarization for $\Sigma^+ \rightarrow \pi^0 + p$ is needed to distinguish between the two classes of $|\Delta I| = \frac{1}{2}$ theories.

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[12] P. Franzini, A. Garfinkel, J. Keren, A. Michelini, R. Plano, A. Prodell, M. Schwartz, J. Steinberger, and S. E. Wolf, Bull. Am. Phys. Soc. **5**, 224 (1960); also M. Schwartz, Physics Department, Columbia University (private communication).

[13] S. Okubo, R. E. Marshak, and E. C. G. Sudarshan, Phys. Rev. **113**, 944 (1959).

[14] F. S. Crawford, Jr., M. Cresti, R. L. Douglass, M. L. Good, G. R. Kalbfleisch, M. L. Stevenson, and H. L. Ticho, Phys. Rev. Letters **2**, 266 (1959). A summary of the evidence is given in this paper. See also J. L. Brown, H. C. Bryant, R. A. Burnstein, D. A. Glaser, R. W. Hartung, J. A. Kadyk, D. Sinclair, G. H. Trilling, J. C. Vander Velde, and J. D. van Putten, Phys. Rev. Letters **3**, 563 (1959).

[15] B. T. Feld, Physics Department, Massachusetts Institute of Technology (private communication).

[16] S. A. Bludman, Phys. Rev. **115**, 468 (1959).

[17] In reference 4, relations between $\Sigma^\pm$ and Λ^0 decay were discussed following a suggestion of T. D. Lee.

[18] R. S. Sawyer, Phys. Rev. **112**, 2135 (1958).

[19] B. d'Espagnat and J. Prentki, Phys. Rev. **114**, 1366 (1959).

[20] G. Takeda and M. Kato, Progr. Theoret. Phys. (Kyoto) **21**, 441 (1959).

[21] S. B. Treiman, Nuovo cimento **15**, 916 (1960).

[22] E. Boldt, H. S. Bridge, D. O. Caldwell, and Y. Pal, Phys. Rev. Letters **1**, 256 (1958).

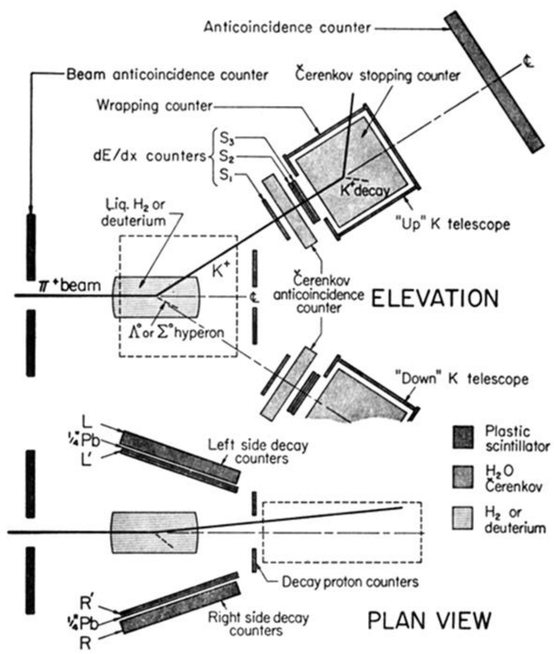

FIG. 1. Schematic view of experimental apparatus.