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June 30, 1966

New Σ Decay Parameters and Test of $\Delta I = 1/2$ Rule*

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ABSTRACT

New values for the three decay asymmetry parameters in the nonleptonic decays of Σ hyperons are presented. The $\Delta I = 1/2$ selection rule is found to be well-satisfied.

Evidence for a mild disagreement with the $\Delta I = 1/2$ selection rule in the nonleptonic decay of Σ hyperons has existed since 1962.[1] The principal source of this disagreement was the nonmaximal value reported[2] for the asymmetry parameter α_0 in the decay $\Sigma_0^+ \rightarrow p\pi^0$. In this letter we present results for the three asymmetry parameters α_+, α_0, α_- obtained from a partial analysis of a large number of well-polarized $\Sigma^\pm$. The new values listed in Table I are consistent with the $\Delta I = 1/2$ rule.

In the experiment the Lawrence Radiation Laboratory's 25-in. hydrogen bubble chamber was exposed to a beam of K^- mesons. About 15 000 $K^-p \rightarrow \Sigma^\pm \pi^\mp$ reactions have been analysed to date. The K^- momenta, ranging from 365 to 415 MeV/c, were chosen to excite $Y_0^*(1520)$ in such a manner that the resonant $D_{3/2}$ amplitude had the proper phase relationship with the dominant S-wave background to yield maximum $\Sigma^\pm$ polarization as given by the analysis of Watson, Ferro-Luzzi, and Tripp (referred to here as WFT).[3] Because of the different orientation of the S-wave amplitudes in these two charge states, the maximum Σ^- polarization occurs approximately at the resonant energy (394 MeV/c), while for Σ^+ it is maximum at about a half width below the resonance.

Figure 1a shows the measured product $-\alpha_0 P(\theta)$ for the decay $\Sigma_0^+ \rightarrow p\pi^0$. These events are divided into four momentum intervals, and each is further divided into ten angular intervals. The dotted curves are the expected polarizations $P(\theta)$ at each momentum as obtained from the analysis of WFT. In their analysis the nonresonant S-, P-, and D-wave amplitudes in all channels were parameterized by constant scattering lengths, while the resonant amplitude was taken in the Breit-Wigner form. Charge independence was assumed in relating various charge states. A least-squares fit made to the differential cross sections and polarizations in each channel yielded parameters from which the above curves are derived.

As seen in Fig. 1a the new polarization data which represent a twentyfold increase over the previous experiment agree well with the expected curve. This confirms the previous analysis and also indicates that α_0 is very nearly -1.

In order to quantitatively evaluate α_0, these new data points were introduced into the χ^2 minimization program of WFT, and with α_0 as an additional free parameter, a new minimum was obtained. This minimum corresponds very nearly to solution 1 of WFT with $\alpha_0 = -0.986$. The polarizations obtained from this reminimization are shown as solid lines in Fig. 1a. The uncertainty in α_0 was found by displacing it from its value at the minimum by an amount which increases χ^2 by unity after readjusting all other parameters. This yielded an uncertainty $\Delta\alpha_0 = \pm 0.072$.

The decay mode $\Sigma_+^+ \rightarrow n\pi^+$ was handled in two ways. One was to compare directly the small asymmetry in this mode with that for $\Sigma_0^+ \rightarrow p\pi^0$ at each of the 40 momentum and angular intervals. For known α_0 this gives $\alpha_+ = +0.014 \pm 0.052$. Alternatively one can compare $\alpha_+ P$ against the new best-fit polarization curves of Fig. 1a. This method yields $\alpha_+ = +0.031 \pm 0.050$. The former method is less model-dependent, so we shall use this value. Both methods resulted in a satisfactory χ^2 of 48, where 39 ± 9 is the expected value.

The Σ^- polarization is not directly measurable, since its decay asymmetry parameter is very small. One must therefore seek an experimental condition in which the production amplitudes are reasonably well-established so that the polarization can be calculated with some confidence. The energy region in the vicinity of $Y_0^*(1520)$ is particularly appropriate for two reasons: (1) the c.m. momentum is low (240 MeV/c), so that only a few partial waves contribute significantly, and (2) the resonant amplitude traces out a well-defined trajectory in the complex plane and in the process interferes with all components of the nonresonant amplitudes; this interference manifests itself in rapidly varying angular distributions as a function of momentum. The $\Sigma^{\pm}$ angular distributions observed in this experiment are, after preliminary correction for biases against short sigmas, in good agreement with those measured previously, which in turn were well-described by the model (see Figs. 32 and 33 of WFT).[4] Coupled with the measured Σ^{+} polarization, these angular distributions sense out all components of the nonresonant amplitudes, thereby allowing prediction of the Σ^{-} polarization. To obtain a quantitative estimate of the uncertainty in Σ^{-} polarization, we have reoriented the smaller and less-well-determined P_1, P_3, and nonresonant D_3 amplitudes in various extreme ways. These alterations caused significant departures from the measured angular distributions, but in no case changed the polarization in the region where it is large by more than 25%. Thus short of adopting a nihilistic viewpoint toward partial-wave analysis and rejecting the form of the resonant amplitude as well as charge independence, there cannot be gross uncertainty in the predicted polarization.

Figure 1b shows the measured $-\alpha_{-}P$ as a function of angle in four momentum intervals surrounding $Y^{*}(1520)$. The solid curves are the calculated Σ^{-} polarization obtained from the fit which incorporates our new Σ^{+} polarization, while the dotted curves correspond to the old predictions. The shaded area in the 385-to-395-MeV/c interval gives an indication of the uncertainty in the Σ^{-} polarization as discussed previously. A least-squares fit of the data to the solid curves yields

$\alpha_- = -0.010 \pm 0.043$. The χ^2 for the fit is 44, with 39 expected. Note that since the asymmetry parameter is small, the fractional uncertainty in α_- is very large. Thus any reasonable uncertainty in Σ^- polarization contributes negligibly to the uncertainty in the asymmetry parameter.

The three asymmetry parameters measured in this experiment are combined in Table I with other measurements of these parameters.[1, 2, 5] In addition we exhibit the other quantities relevant to a test of the $\Delta I = 1/2$ rule--the measured Σ^- and Σ^+ lifetimes and the $\Sigma_+^+/(\Sigma_+^+ + \Sigma_0^+)$ branching fraction.[6, 7] The $\Delta I = 1/2$ rule requires that, treated as vectors in the S-P plane, the three transition amplitudes form a triangle satisfying the relation $\sqrt{2}\,\Sigma_0^+ = \Sigma^- - \Sigma_+^+$. Decay rates are proportional to the square of the magnitude of the transition amplitudes, while the decay asymmetry parameters are given by $\alpha = 2\,\mathrm{Re}\,S^*P/[|S|^2 + |P|^2]$. Corrections for the mass differences between various members of each charge multiplet are made by dividing the measured rates by p/M_Σ where p is the decay momentum. The amplitudes are complex, with time reversal invariance relating these phases to the πN scattering phase shifts.[8]

We have searched for χ^2 minima in a least-squares fit of the six quantities listed in Table I to the four parameters S_1, P_1, S_3, and P_3, where the subscripts denote 2I. Two equally good solutions are found corresponding to an interchange of the S and P axes. The best fit shown in the last column of Table I corresponds to the choice of Σ^- decaying mainly via S-wave. The χ^2 for this fit is 2.06, where 2 is expected, so that the $\Delta I = 1/2$ selection rule is well-satisfied.

Figure 2 illustrates the sensitivity of the various measurements to the $\Delta I = 1/2$ test. Here we compare the best fit (dashed lines) with the combined values for the experimentally measured amplitudes and their errors (indicated by dotted lines). The two directions for Σ_0^+ correspond to the ratio $|S/P|$ being greater than or less than one. Because α_0 is very nearly -1, the orientation of the Σ_0^+ amplitude in the S-P plane is extremely dependent on the value of α_0, resulting in a large uncertainty in the Σ_0^+ direction. To reduce this uncertainty to a value comparable to that of Σ_+^+ and Σ^- would require a precision $\Delta\alpha_0 = \pm 0.001$ if α_0 is -1.

The nonleptonic Σ decay amplitudes also enter into the prediction by Lee[9] that $\sqrt{3}\,\Sigma_0^+ + \Lambda = 2\Xi^-$. A recent compilation shows that this relation is well satisfied.[10] The more precise values of Σ decay parameters presented here are, if anything, in even better agreement with Lee's prediction.

We wish to express our appreciation to Mr. Glenn Eckman and the crew of the 25-in. bubble chamber, and to Mr. Henry Laney and the scanners on this experiment. We are especially grateful to Dr. Margaret Alston for her help on many phases of the analysis. Finally we gratefully acknowledge the continued support and encouragement of Prof. Luis W. Alvarez.

FOOTNOTES AND REFERENCES

*Work done under the auspices of the U. S. Atomic Energy Commission.

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4. Since these bias corrections require further investigation, we do not include the new angular distributions in the present analysis. These biases should not affect the polarization.
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δ_1 = +9 deg, δ_3 = -12 deg, δ_{11} = 0 deg, and δ_{31} = -3 deg. Each phase shift has an uncertainty of about 1.5 deg. The $\Delta I = 1/2$ analysis described here is quite insensitive to these small phase shifts. Setting them all equal to zero reduces χ^2 slightly with a negligible alteration in the best fit of Table I.

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Table I. Asymmetry parameters, lifetimes, and branching fractions for Σ decays.

	This Experiment	Other Experiments	Combined	Least squares $\Delta I = 1/2$ fit
α_-	-0.010 ± 0.043	-0.16 ± 0.21^a	-0.017 ± 0.042	-0.037
α_+	$+0.014 \pm 0.052$	-0.03 ± 0.08^b -0.20 ± 0.24^a	-0.006 ± 0.043	-0.026
α_0	-0.986 ± 0.072	-0.80 ± 0.18^c	-0.960 ± 0.067	-0.9996
$\tau_-(\times 10^{10})$		1.58 ± 0.05^d 1.666 ± 0.026^e	1.648 ± 0.023	1.644
$\tau_+(\times 10^{10})$		0.794 ± 0.026^d 0.830 ± 0.018^e	0.818 ± 0.015	0.821
$\frac{\Sigma_+^+}{\Sigma_+^+ + \Sigma_0^+}$		0.490 ± 0.024^d 0.460 ± 0.020^e	0.473 ± 0.015	0.489

a. See Ref. 1.
b. See Ref. 5.
c. See Ref. 2.
d. See Ref. 6.
e. See Ref. 7.

FIGURE LEGENDS

Fig. 1. Measured product $-\alpha P$ plotted as a function of the c.m. production angle θ in four momentum intervals for the reaction sequences (a) $K^-p \rightarrow \Sigma_0^+\pi^-$; $\Sigma_0^+ \rightarrow p\pi^0$, and (b) $K^-p \rightarrow \Sigma^-\pi^+$; $\Sigma^- \rightarrow n\pi^-$. The dotted curves are the predicted polarizations based on the best solution of WFT (Ref. 3), while the solid curves are the reminimized fits using the new Σ^+ data shown in Fig. 1a as well as that of WFT. The shaded area in the 390-MeV/c interval for Σ^- shows the approximate extent of the uncertainty in the predicted Σ^- polarization.

Fig. 2. Measured amplitudes for Σ^-, Σ_+^+, and Σ_0^+ (solid lines) with their associated uncertainties (dotted lines) plotted on the S-P plane. The best fit of these six measurements to the $\Delta I = 1/2$ selection rule is indicated by the dotted triangle, which is evidently an adequate fit.

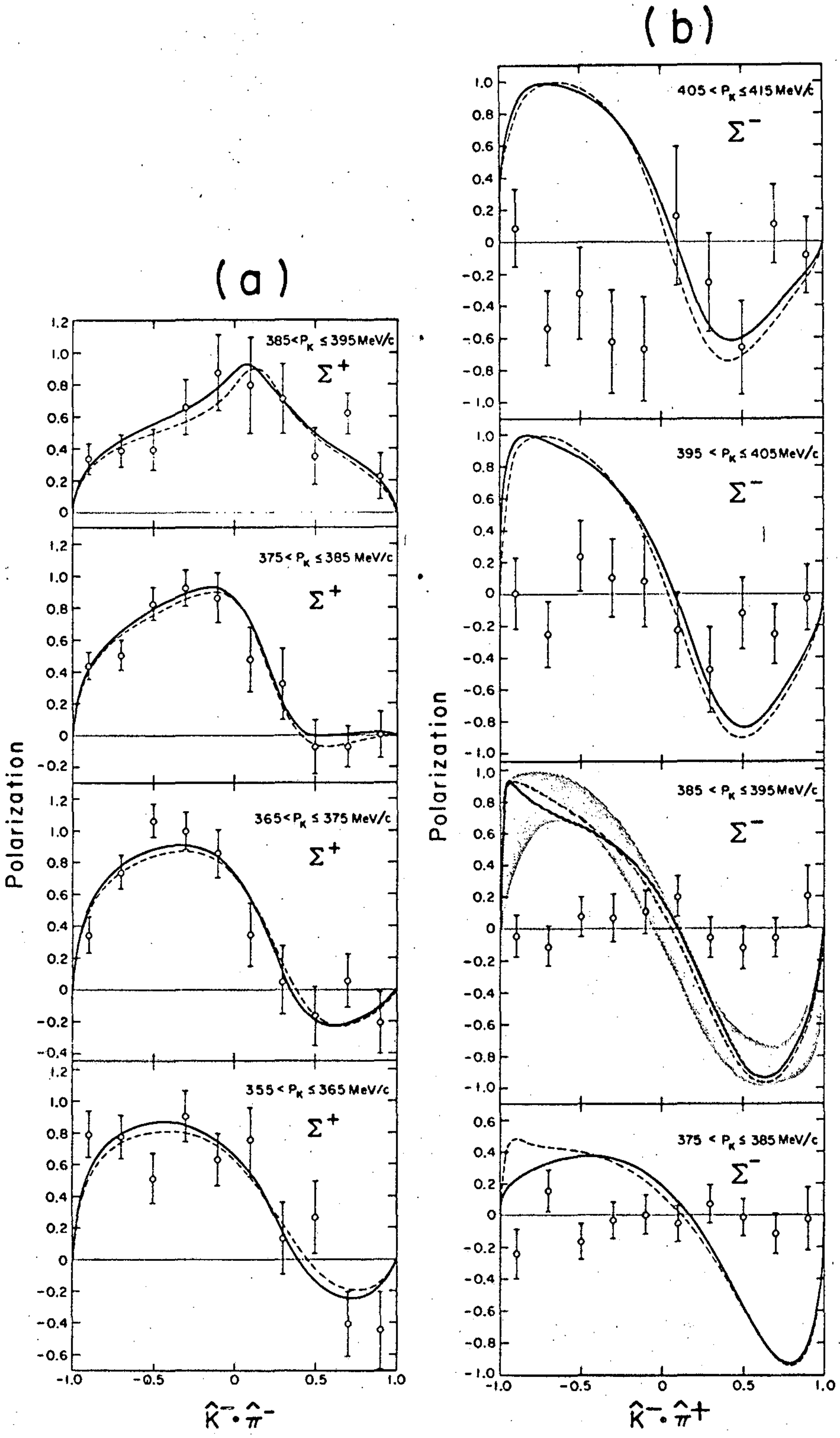
(a)
385<P_K ≤ 395 MeV/c
Σ+
375<P_K ≤ 385 MeV/c
Σ+
365<P_K ≤ 375 MeV/c
Σ+
355<P_K ≤ 365 MeV/c
Σ+
Polarization
K̂⁻·π̂⁻
(b)
405<P_K ≤ 415 MeV/c
Σ⁻
395<P_K ≤ 405 MeV/c
Σ⁻
385<P_K ≤ 395 MeV/c
Σ⁻
375<P_K ≤ 385 MeV/c
Σ⁻
Polarization
K̂⁻·π̂+
-1.0
-0.5
0
0.5
1.0

Fig. 1

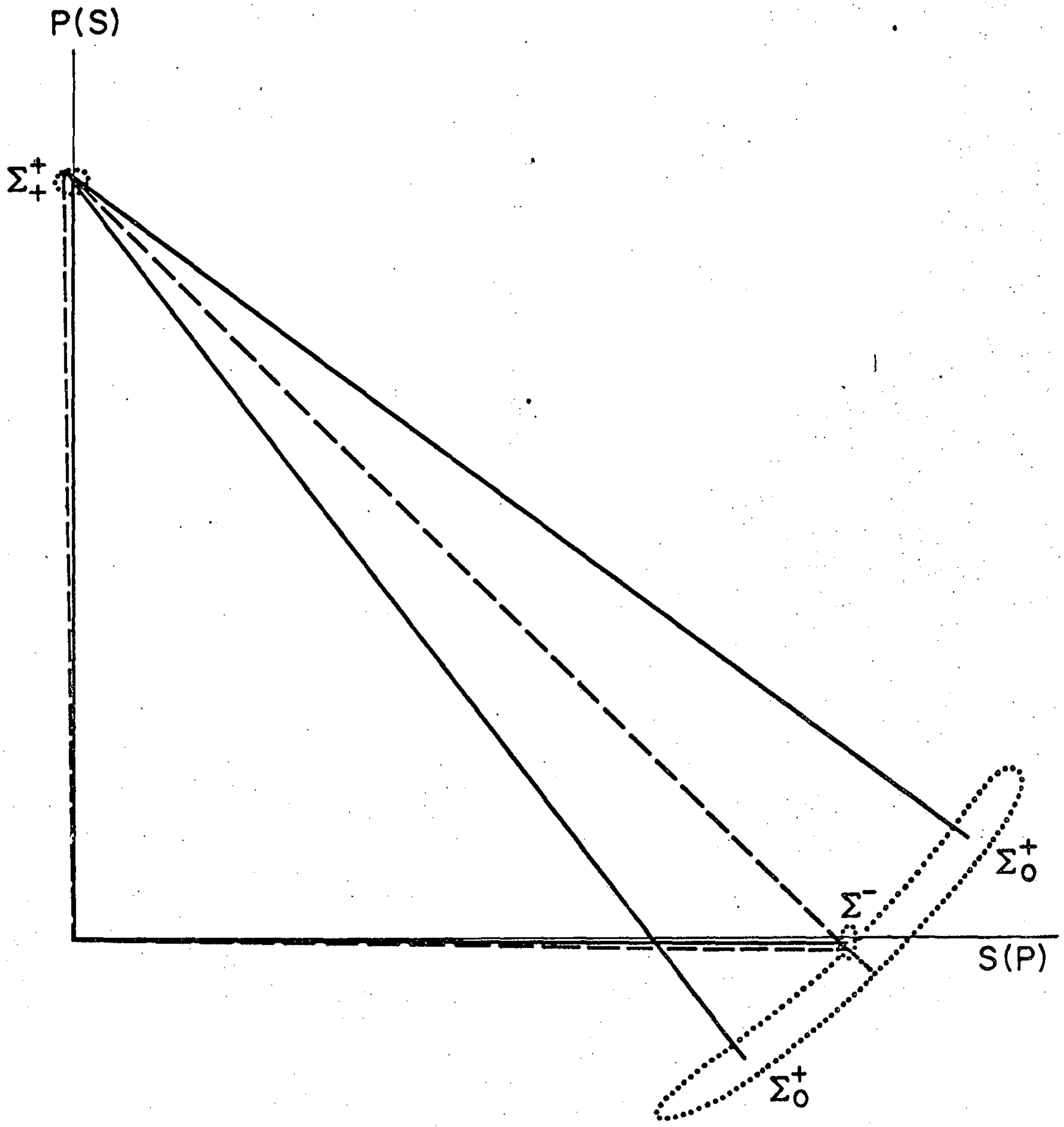

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Fig. 2