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NEW Σ DECAY PARAMETERS AND TEST OF $\Delta I = \frac{1}{2}$ RULE*

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(Received 12 July 1966)

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

Evidence for a mild disagreement with the selection rule $\Delta I = \frac{1}{2}$ 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 $\Sigma_0^+ \to p + \pi^0$. In this Letter we present results for the three asymmetry parameters α_+, α_0, and α_- obtained from a partial analysis of a large number of well-polarized $\Sigma^\pm$. These parameters are defined as in Ref. 1; by this convention the helicity of the decay nucleon has the same sign as α. The new values listed in Table I are consistent with the $\Delta I = \frac{1}{2}$ rule.

In the experiment the Lawrence Radiation Laboratory's 25-inch hydrogen bubble chamber was exposed to a beam of K^- mesons. About 15 000 examples of the reactions $K^- + p \to \Sigma^\pm + \pi^\mp$ have been analyzed 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

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

	This experiment	Other experiments	Combined	Least-squares $\Delta I = \frac{1}{2}$ 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
$\dfrac{\Sigma_+^+}{\Sigma_+^+ + \Sigma_0^+}$		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

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 1(a) shows the measured product $-\alpha_0 P(\theta)$ for the decay $\Sigma_0{}^+ \to p + \pi^0$. 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. 1(a), the new polarization data which represent a twenty-fold 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 evaluate α_0 quantitatively, 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. 1(a). 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 $\Sigma_+{}^+ \to n + \pi^+$ was handled in two ways. One was to compare directly the small asymmetry in this mode with that for $\Sigma_0{}^+ \to p + \pi^0$ 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 $\alpha_+ P$ with the new best-fit polarization curves of Fig. 1(a). 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

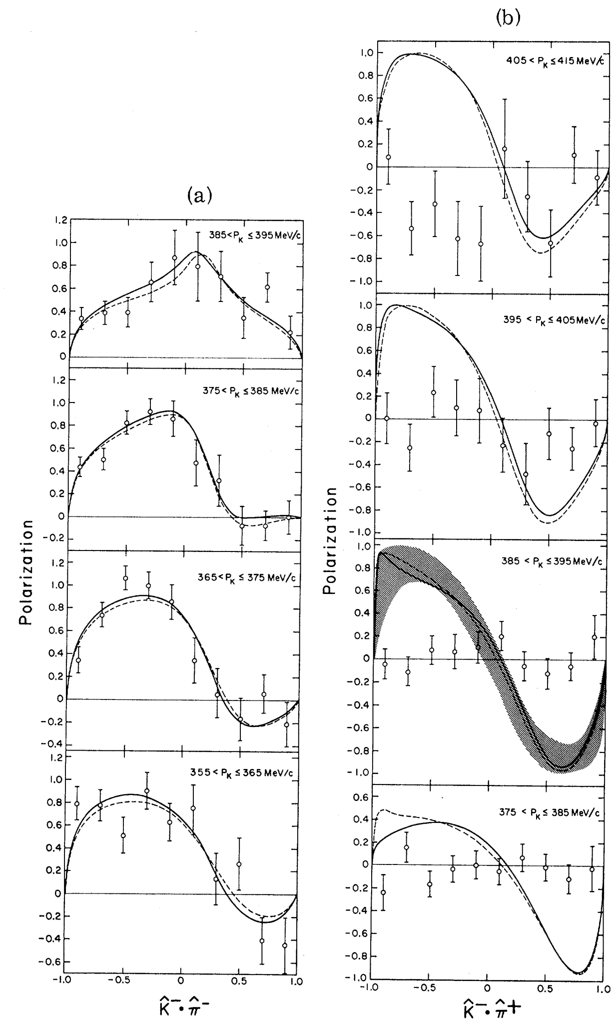

FIG. 1. Measured product $-\alpha P$ plotted as a function of the c.m. production angle θ in four momentum intervals for the reaction sequences (a) $K^- + p \to \Sigma_0{}^+ + \pi^-$ and $\Sigma_0{}^+ \to p + \pi^0$; and (b) $K^- + p \to \Sigma^- + \pi^+$ and $\Sigma^- \to n + \pi^-$. The dotted curves 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. 1(a) as well as those 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.

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, the interference manifesting 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 or charge independence, there cannot be gross uncertainty in the predicted polarization.

Figure 1(b) 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 selection rule $\Delta I = \frac{1}{2}$—the measured Σ^- and Σ^+ lifetimes and the branching fraction $\Sigma_+^+/(\Sigma_+^+ + \Sigma_0^+)$. The selection rule $\Delta I = \frac{1}{2}$ 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 selection rule $\Delta I = \frac{1}{2}$ is well satisfied.

Figure 2 illustrates the sensitivity of the various measurements to the $\Delta I = \frac{1}{2}$ test. Here we compare the best fit (dashed lines) with the combined values for the experimentally

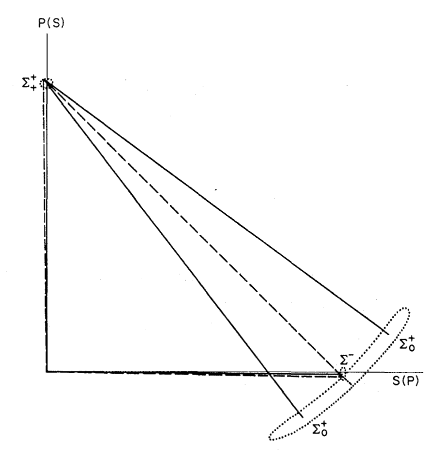

FIG. 2. Measured amplitudes for Σ^-, Σ_+^+, and Σ_0^+ (solid lines) with their associated uncertainties (dotted lines) plotted on the S-P plane. The best fit of these six measurements to the selection rule $\Delta I = \frac{1}{2}$ is indicated by the dotted triangle, which is evidently an adequate fit.

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 1. 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 with that of Σ_+^+ and Σ^- would require, in our experiment, 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-inch 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 Professor Luis W. Alvarez.

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

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EXCHANGE OF EVEN- AND ODD-PARITY BARYON-MESON RESONANCES AND BACKWARD ELASTIC SCATTERING*

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If there are two meson-baryon resonances or bound states with opposite parities but with the same remaining internal quantum numbers including signature, one at c.m. energy W_1 with $l = J - \frac{1}{2}$ and the other at W_2 with $l = J + \frac{1}{2}$, then the residue of the Regge trajectory on which they lie must change sign between W_1 and $-W_2$. Consequences of the exchange of such a trajectory to backward elastic scattering are discussed.

According to the MacDowell symmetry,[1] the πN amplitudes for orbital angular momenta $l = J \pm \frac{1}{2}$ for a given total angular momentum, J, and isotopic spin, I, are related as follows:

$$h_{J+\frac{1}{2}}^{J}(W+i\epsilon) = -h_{J-\frac{1}{2}}^{J}(-W-i\epsilon), \qquad (1)$$

where W is the total c.m. energy, and for $W \geqslant m + m_\pi$,

$$h_{J-\frac{1}{2}}^{J}(W+i\epsilon) = \frac{W}{E+m}\,\frac{\exp[i\delta_{J-\frac{1}{2}}(W)]\sin\delta_{J-\frac{1}{2}}(W)}{k}, \qquad (2)$$