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Detection of Parity Nonconservation in Λ Decay[†]

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The recent discovery of parity nonconservation in β -decay, n -decay, and μ -decay has made it extremely important to find out whether parity is also violated in hyperon decay.

In order to study hyperon production and decay we have exposed a 10-inch hydrogen bubble chamber to a beam of 1.12 Bev/c π^- . Hyperons are produced according to the reactions



We have established the following facts about the decay $\Lambda \rightarrow p + \pi^-$:

1. The degree of parity violation is very large.
2. Charge conjugation invariance is also violated.

We have found no statistically significant evidence of parity violation in a sample of 122 Σ^- decays. This may be due to lack of polarization or lack of parity violation in Σ^- decay, or both. (The findings of emulsion workers suggest that parity violation in Σ^- decay may be small. ⁽²⁾)

Also, of all the hyperons, the Λ hyperon is the only one for which the decay is not isotropic in zero field. The spin is 1/2. We follow the usual practice and write

B
In nuclear emulsion many K^- have been brought to rest and captured from atomic orbits according to the reaction $K^- + p \rightarrow \Sigma^+ + \pi^-$, where p represents a proton which is part of a nucleus. The Σ and π tracks are in general not collinear, so one can define a "production plane," and look for an up-down asymmetry in Σ decay. Compiling the emulsion data and using the notation of this letter, one finds for the mode $\Sigma^+ \rightarrow p + \pi^0$, $\alpha_{\bar{p}} = -0.37 \pm 0.19$, for $\Sigma^+ \rightarrow n + \pi^+$, $\alpha_{\bar{p}} = -0.36 \pm 0.21$, but for $\Sigma^- \rightarrow n + \pi^-$, $\alpha_{\bar{p}} = -.13 \pm .26$. We wish to thank the Berkeley, Göttingen, Livermore, and NRL emulsion groups for their private communications.

Lee, et al ¹ have given a phenomenological discussion of hyperon production and decay, assuming that the K^0 spin is zero and the Λ spin is $1/2$. We follow their notation and write

\vec{p}_{in} = c.m. momentum of the incoming π^- .

\vec{p}_{Λ} = c.m. momentum of the Λ produced.

θ = hyperon production angle (between \vec{p}_{in} and \vec{p}_{Λ})

R = projection of the c.m. momentum of the decay π^- in the direction of $\vec{p}_{in} \times \vec{p}_{\Lambda}$.

\bar{R} = R /(maximum value of R)

$P(\theta)$ = the polarization of the Λ produced at the angle θ

= the expectation value of the spin of the Λ in the direction of $\vec{p}_{in} \times \vec{p}_{\Lambda}$, in units of $1/2\hbar$.

$I(\theta)$ = the c.m. differential production cross section.

The decay distribution function for ξ is given by

$$W(\theta, \xi) d\Omega d\xi = I(\theta) d\Omega [1 + \alpha P(\theta)\xi] \frac{d\xi}{2}, \quad (4)$$

where the asymmetry coefficient α must lie between -1 and 1. The existence of a nonvanishing α constitutes an unambiguous proof of parity nonconservation in Λ decay.

Integration of Eq. (4) over all production angles θ yields

$$\bar{W}(\xi) d\xi = \left[\int I(\theta) d\Omega \right] (1 + \alpha \bar{P}\xi) \frac{d\xi}{2}. \quad (5)$$

If we designate by N_{up} the number of decays having $\xi > 0$, then integration of Eq. (5) over ξ yields

$$\alpha \bar{P} = \frac{N_{up} - N_{down}}{(1/2)(N_{up} + N_{down})}. \quad (6)$$

Our photographs for $\Lambda \rightarrow p + \pi^-$ fall into two categories:

1. 76 double \checkmark° events, where both the Λ and K° decays are observed.
2. 277 single \checkmark° events, where only the Λ decay is observed. (In both categories the disappearance of the incident π^- is of course observed.)

We have analyzed 76 double \checkmark° events corresponding to reaction (1). In addition we have performed a preliminary analysis on the 277 single \checkmark° events, which include Λ 's from reaction (1) and secondary Λ 's from reaction (3). No attempt has yet been made to separate out those single \checkmark° 's which are secondary Λ 's from Σ° decay. \checkmark In this preliminary analysis

\checkmark Analysis of the double \checkmark° 's shows that reaction (1) is about three times as common as reaction (3). R. Gatto has shown (private communication) that the magnitude of the polarization of such secondary Λ 's (averaged over the Σ° decay solid angle) is 1/3 that of the Σ° 's. Thus even if the Σ° 's were highly polarized their contribution would have a very small effect on our result.

a single $\sqrt{0}$ event is called a \wedge decay (i.e. rather than a K^0 decay) provided that a) the laboratory angle between the momentum of the positive decay fragment and that of the neutral parent is $< 25^\circ$, and b) the negative decay fragment makes a larger laboratory angle than does the positive fragment, with respect to the momentum of the neutral parent. \checkmark

\checkmark We estimate that in our sample the contamination of $K^0 \rightarrow 2\pi$ decays allowed by this criterion is about 15 %. We are indebted to Dr. Melvin Schwartz for pointing out this simple way of eliminating most of the K^0 s from the single $\sqrt{0}$ s.

Our total sample of $76 + 277 = 353 \wedge$ decays yields

$$N_{up} = 48 + 167 = 215, \quad (7)$$

$$N_{down} = 28 + 110 = 138, \quad (8)$$

from which according to (6)

$$\alpha \bar{P} = 0.44 \pm 0.11. \quad \checkmark \quad (8)$$

\checkmark This result is in excellent agreement with results of similar experiments performed at Brookhaven and analyzed by the Bologna, Columbia, Michigan, and Pisa groups. Those data were compiled at the recent Venice-Padova conference (1957); they are $N_{up} = 129$, $N_{down} = 81$, so $\alpha \bar{P} = 0.46 \pm 0.14$. Their asymmetry for $\sum \pi^- \rightarrow n + \pi^-$ are much smaller, also in agreement with our result and those for emulsion.

If parity were conserved, and hence $\alpha = 0$ were the true value, we would have $N_{up} = N_{down}$, on the average. The odds against a statistical fluctuation as large or larger than that which would be needed to give our result (7) are

better than 10^4 to 1. We conclude that parity invariance is violated in Λ decay.

We can compare our value of $|\alpha|$ with the maximum value of $|\alpha|$ allowed by invariance under charge conjugation. Using the TCP theorem, Gatto ¹² has calculated this maximum value and finds $|\alpha| \leq 0.18 \pm 0.02$, which is inconsistent with our result (8) (since $|\bar{P}| \leq 1$). We conclude that the Λ decay interaction violates charge conjugation as well as parity invariance.

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- ∇ R. Gatto, Phys. Rev. (to be published) and private communications.

Footnotes

* This work has been performed under the auspices of the U. S. Atomic Energy Commission.

† A preliminary account of this work was reported in an invited paper by H. K. Ticho at the Boulder meeting of the American Physical Society, Sept 5 - 7, 1957 (Bull. A. Phys. Soc. II, 2, No. 6 (1957)).

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