Title

Test of Charge-Conjugation Invariance in Hyperon Decay

Author

Gatto, R

Publication Date

1957-10-01

UCRL 8009

UNIVERSITY OF CALIFORNIA

Radiation Laboratory

BERKELEY, CALIFORNIA

DISCLAIMER

UCRL-8009

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

TEST OF CHARGE-CONJUGATION INVARIANCE IN HYPERON DECAY

R. Gatto

October 6, 1957

Printed for the U. S. Atomic Energy Commission

TEST OF CHARGE-CONJUGATION INVARIANCE IN HYPERON DECAY*

R. Gatto**

Radiation Laboratory
University of California
Berkeley, California

October 6, 1957

The evidence for noninvariance under charge conjugation (C) in β decay and in the π and μ decays was based on a theorem due to Lee, Oehme, and Yang, which states that, in decays where final-state interactions can be neglected, no pseudoscalars of the form $(\vec{\sigma}\cdot\vec{p})$ can appear in the decay distribution if C is conserved.[1] In the decay of hyperons into nucleon + pion a strong final state interaction is present and therefore a quantitative estimate of the limits imposed on the coefficients of the $(\vec{\sigma}\cdot\vec{p})$ terms by C invariance is necessary before one can reach a conclusion on the question of C conservation for such decays. Recent experimental results on up-down asymmetry in $\Lambda\to p+\pi^-$ indicate an asymmetry parameter $|\alpha| > 0.44 \pm 0.11$.[2] From the limitation $|\alpha| \leq 0.18 \pm 0.02$ that we give here for $\Lambda\to p+\pi^-$ under the assumption of C invariance, we can conclude that C is violated in Λ decay. It might be appropriate to remark that the argument is based on the TCP theorem--all evidence so far against C conservation is based on the validity of the TCP theorem.

We write the final amplitude from Λ decay in the form $T\chi_i \mathfrak{J}_i$, where χ_i and $\mathfrak{J}_i$ are the initial spin and i-spin states respectively, and T is a matrix in the spin and i-spin spaces. In the expansion $T = T_{1/2} + T_{3/2} + T_{5/2} + \ldots$, where T_J produces a change $\Delta I = J$ in i spin, only $T_{1/2}$ and $T_{3/2}$ contribute to $\Lambda\to$ nucleon + π. They are of the form $T_{1/2} = g_1 + h_1(\vec{\sigma}\cdot\vec{k})$, $T_{3/2} = g_3 + h_3(\vec{\sigma}\cdot\vec{k})$, where the g's and h's are complex numbers, $\vec{\sigma}$ is the Pauli spin operator, and $\vec{k}$ is a unit vector in the direction of the emitted pion. The decay distribution for $\Lambda\to p+\pi^-$ is given by

$$G_1(\vec{k}) = 1 + \langle\vec{\sigma}\rangle_\Lambda \mathrm{Tr}\left[T_1^\dagger \vec{\sigma} T_1\right]/\mathrm{Tr}\left[T_1^\dagger T_1\right] = 1 + \alpha(\Lambda\to p-)\langle\vec{\sigma}\rangle_\Lambda\cdot\vec{k},$$

---

*This work was done under the auspices of the United States Atomic Energy Commission.

**On leave of absence from Instituto di Fisica dell' Universita' di Roma, Italy.

where $\langle\vec{\sigma}\rangle_\Lambda$ is the Λ polarization vector, T_i is that part of T which contributes to decay into $p + \pi^-$, and $\alpha(\Lambda\to p-)$ is the asymmetry parameter.[3] If C is conserved we can write, using the TCP theorem,

$$g_1 = G_1 e^{i\alpha_1}, g_3 = G_3 e^{i\alpha_3}, h_1 = iH_1 e^{i\alpha_{11}}, h_3 = iH_3 e^{i\alpha_{31}},$$

where the G's and H's are real numbers, and the α's are the relevant nucleon-pion phase shifts for a total kinetic energy in the center-of-mass system equal to the Q value in the decay.[1] With such subtstitutions we can write the asymmetry parameter in the form

$$\alpha(\Lambda\to p-) = f(\Delta)(Av_1v_2 + Bv_1v_4 + Cv_2v_3 + Dv_3v_4),$$

where $f(\Delta) = (1+\frac{\Delta}{3})/(1+\frac{\Delta}{2})$; Δ is defined by (relative frequency of $\Lambda\to p+\pi^-$ to $\Lambda\to n+\pi^0$) = 2 + Δ; A, B, C, and D are parameters proportional to the sines of differences of phase shifts; and the real numbers v_i have to satisfy $\sum v_i^2 = 1$. Defining a vector v with components v_i, one can write this condition $(v,v) = 1$, and $\alpha(\Lambda^0\to p-)$ can be put in the form $f(\Delta)(v, mv)$, where m is the symmetric 4-by-4 matrix associated with the quadratic form in $\alpha(\Lambda\to p-)$. The maximum and the minimum of $\alpha(\Lambda\to p-)$ are therefore given by the maximum and minimum eigenvalue respectively of the matrix $f(\Delta)m$. Two such eigenvalues have the same magnitude, and by direct calculation one finds

$$|\alpha(\Lambda\to p-)| \leq \frac{1}{2\sqrt{2}} f(\Delta)\left[S + (S^2 - P^2)^{1/2}\right]^{1/2},$$ where $S = 4\sin^2(\alpha_1-\alpha_{11}) + 2\sin^2(\alpha_3-\alpha_{11}) + 2\sin^2(\alpha_1-\alpha_{31}) + \sin^2(\alpha_3-\alpha_{31})$, and $P^2 = 16\sin^2(\alpha_1-\alpha_3)\sin^2(\alpha_{11}-\alpha_{31})$.

Taking the value 0.32 ± 0.05 reported by Steinberger's group for the fraction of Λ undergoing neutral decay[4] and for the pion-nucleon phase shifts the values reported by Anderson,[5] we find $|\alpha(\Lambda\to p-)| \leq 0.18 \pm 0.02$ if charge conjugation is satisfied. Similar limitations, under the hypothesis of C conservation, can be given for the asymmetry parameters of Σ decays. We assume spin 1/2 for Σ. The limitation $|\alpha(\Sigma^-\to n-)| \leq |\sin(\alpha_3-\alpha_{31})|$ for Σ^- decay, where only one final i-spin state can occur, is given in the paper quoted in Reference 3. The phase shifts are taken at an energy equal to the decay Q value. We find: $|\alpha(\Sigma^+\to p\,0)| \leq \frac{1}{2\sqrt{2}} g(\Gamma)\left[R + (R^2 - Q^2)^{1/2}\right]^{1/2}$, where $g(\Gamma) = 4/3(1+\frac{\Gamma}{2})$; Γ is defined by:

(relative frequency of $\Sigma^+\to n+\pi^+$ to $\Sigma^+\to p+\pi^0$) = 1 + Γ;

$$R = \sin^2(\alpha_1-\alpha_{11}) + 2\sin^2(\alpha_3-\alpha_{11}) + 2\sin^2(\alpha_1-\alpha_{31}) + 4\sin^2(\alpha_3-\alpha_{31});$$

$Q^2 = 16 \,\mathrm{sen}^2(\alpha_1 - \alpha_3)\,\mathrm{sen}^2(\alpha_{11} - \alpha_{31})$; $|\alpha(\Sigma^+ \rightarrow n+)| \leq \frac{1}{2\sqrt{2}} h(\Gamma)\left[V + (V^2 - Q^2)^{1/2}\right]^{1/2}$;

where $h(\Gamma) = \frac{4}{3}(1 + \frac{\Gamma}{2})/(1+\Gamma)$, and $V = 4\,\mathrm{sen}^2(\alpha_1 - \alpha_{11}) + 2\,\mathrm{sen}^2(\alpha_3 - \alpha_{11})$ $+ 2\,\mathrm{sen}(\alpha_1 - \alpha_{31}) + \mathrm{sen}^2(\alpha_3 - \alpha_{31})$. Taking the value 0.45 ± 0.06 for the ratio $(\Sigma^+ \rightarrow n + \pi^+)$ to the total Σ^+ rate,[6] and the phases from Reference 5, we find

$$|\alpha(\Sigma^- | n-) \leq \sim 0.15,$$

$$|\alpha(\Sigma^+ \rightarrow p0)| \leq \sim 0.27,$$

$$|\alpha(\Sigma^+ \rightarrow n+) \leq \sim 0.37 \quad \text{if C is conserved.}$$

For hyperons with spin 3/2 the decay distributions will not in general be describable with a single parameter α. If C is conserved, the total asymmetry will still be severely limited for Λ decay, but presumably only weakly limited for Σ decay, because of the large α_{33}. One argument for Λ spin 1/2, that based on the ratio of mesonic decay to nonmesonic decay in hyperfragments,[7] may turn out incorrect, if a large p wave is observed in Λ decay. Because of the low final momentum, a large up-down asymmetry in Λ decay could be a severe test for theories which predict the relative amount of parity-conserving and parity-nonconserving interactions on the basis of a universal interaction. The knowledge of the ratio $(\Lambda \rightarrow p0)/(\Lambda \rightarrow n+)$, of $\alpha(\Lambda \rightarrow p-)$, and of $\alpha(\Lambda \rightarrow n0)$ would contribute essential information on the Λ- decay matrix (such data would suffice to determine the decay matrix--in the nonrelativistic approximation--apart from some ambiguities in sign, if time reversal holds). If the present value for the Λ branching ratio is taken as evidence -- in any case incomplete -- in favor of $\Delta I = \frac{1}{2}$[8] in Λ decay, then $\alpha(\Lambda \rightarrow n0)$ is predicted to be equal to $\alpha(\Lambda \rightarrow p-)$.

* * * * * * *

The author is indebted to the members of the Alvarez group, in particular to Frank Crawford, Myron L. Good, Frank Solmitz, and Lynn Stevenson ~~for discussions and for~~ information on their experimental results.

REFERENCES

1. Lee, Oehme, and Yang, Phys. Rev. 106, 340 (1957).
2. Crawford, Cresti, Good, Gottstein, Lyman, Solmitz, Stevenson, and Ticho (preceding letter). The Λ spin is assumed to be 1/2.
3. Here α is the same as in: Lee, Steinberger, Feinberg, Kabir, and Yang. Phys. Rev. 106, 1367 (1957).
4. Eisler, Plano, Samios, Schwartz, and Steinberger, Nuovo Cimento 6, 1700 (1957).
5. H. L. Anderson in Proceedings of the Sixth Annual Rochester Conference on High-Energy Physics, 1956. (Interscience, New York, 1956), I-20. Errors in the phase shifts are estimated from the error matrix given in this reference.
6. Alvarez, Bradner, Falk-Vairant, Gow, Rosenfeld, Solmitz, and Tripp, Interactions of K^- Mesons in Hydrogen, UCRL-3775, July 1957.
7. M. Ruderman and R. Karplus, Phys. Rev. 102, 247 (1956).
8. M. Gell-Mann and A. Pais, in International Conference on Nuclear and Meson Physics, Glasgow, 1954 (Pergamon Press, London 1955), p. 342;
   R. Gatto, Nuovo Cimento 3, 318 (1956);
   G. Wentzel, Phys. Rev. 101, 1215 (1956).