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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 $\Lambda \rightarrow p + \pi^-$ indicate an asymmetry parameter $|\alpha| > 0.44 \pm 0.11$.[2] From the limitation $|\alpha| \leqslant 0.18 \pm 0.02$ that we give here for $\Lambda \rightarrow p + \pi^-$ 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 $T\chi_i \zeta_i$, where χ_i and ζ_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 $\Lambda \rightarrow$ 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 $\Lambda \rightarrow p + \pi^-$ is given by

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

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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 substitutions we can write the asymmetry parameter in the form

$$\alpha(\Lambda\to p-) = f(\Delta)(A v_1 v_2 + B v_1 v_4 + C v_2 v_3 + D v_3 v_4),$$

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: $|\alpha(\Sigma^+\to p0)| \leq \frac{1}{2\sqrt{2}} g(\Gamma)\left[R + (R^2 - Q^2)^{1/2}\right]^{1/2}$, 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;

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

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

where $h(\Gamma) = 4/3(1 + \frac{\Gamma}{2})/(1 + \Gamma)$, and $V = 4 \sin^2(\alpha_1 - \alpha_{11}) + 2 \sin^2(\alpha_3 - \alpha_{11})$

$+ 2 \sin(\alpha_1 - \alpha_{31}) + \sin^2(\alpha_3 - \alpha_{31})$. Taking the value 0.45 ± 0.06 for the ratio $(\Sigma^+ \to n + \pi^+)$ to the total Σ^+ rate,[6] and the phases from Reference 5, we find

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

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

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

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 $(\Lambda \to p0)/(\Lambda \to n+)$, of $\alpha(\Lambda \to p-)$, and of $\alpha(\Lambda \to n0)$ 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 $\Delta I = 1/2$[8] in Λ decay, then $\alpha(\Lambda \to n0)$ is predicted to be equal to $\alpha(\Lambda \to p-)$.

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