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POSSIBLE EXPERIMENTS ON THE BEHAVIOR
OF THE WEAK HYPERON DECAY INTERACTIONS UNDER P, C, AND T

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ABSTRACT

Various experimental possibilities for detecting the transformation properties of the weak hyperon decay interactions under P, C, and T are discussed.

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INTRODUCTION

The possibility of detecting parity nonconservation in hyperon decay has been discussed recently.^{1, 2} In this note we treat briefly of some further experimental possibilities for detecting the transformation properties of the weak hyperon decay interactions under P, C, and T. The experiments proposed here are in general more difficult than the detection of the up-down asymmetries suggested by Lee and Yang;^{1, 2} however, they will give more complete information.

HYPERON PRODUCTION FROM THE K⁻ BEAM

The reaction $K^- + p \rightarrow Y + \pi$ (and similar reactions on complex nuclei)³ will presumably be the most useful way of producing hyperons. If we assume spin zero for K and 1/2 for Y and denote the initial and final center-of-mass momenta by \vec{p} and \vec{p}' , the transition matrix for this reaction has the form $M = A + B \vec{\sigma} \cdot \vec{n}$, where A and B are functions of p and $\vec{p} \cdot \vec{p}' = pp' \cos \theta$, and \vec{n} is a unit vector normal to the production plane. The amplitudes A and B are further restricted by the requirement of containing \vec{p} and \vec{p}' only up to some powers, corresponding to the maximum values of the orbital angular momenta for the initial and final state respectively. Explicit expressions in terms of the reaction matrix elements are given by Spitzer and Stapp in a paper in preparation. The differential cross section is given by

$$\sigma = \frac{1}{2} \text{Tr}[MM^\dagger] = |A|^2 + |B|^2$$

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and the polarization of the produced Y by

$$\langle \vec{\sigma} \rangle_Y = \frac{\text{Tr} [MM^\dagger \vec{\sigma}]}{\text{Tr} [MM^\dagger]} = \frac{2 \text{Re}(AB^*)}{|A|^2 + |B|^2} \vec{n} \quad (1)$$

Note that if perturbation theory were applicable, we would have $\langle \vec{\sigma} \rangle_Y = 0$. The transition matrix for the decay $Y \rightarrow N + \pi$ in center-of-mass is $T = g + h \vec{\sigma} \cdot \vec{K}$ where g and h are complex numbers and \vec{K} is a unit vector in the direction of the emitted N . The distribution of \vec{K} is given by

$$G = \frac{1}{2} \left\{ \text{Tr} [TT^\dagger] + \langle \vec{\sigma} \rangle_Y \text{Tr} [T\vec{\sigma}T^\dagger] \right\} \\ \propto 1 + \frac{2 \text{Re}(gh^*)}{|g|^2 + |h|^2} \frac{2 \text{Re}(AB^*)}{|A|^2 + |B|^2} (\vec{n} \cdot \vec{K}) \quad (2)$$

showing the up-down asymmetry (term proportional to $\vec{n} \cdot \vec{K}$) pointed out by Lee and Yang.^{1, 2} We write $g = g_3 + g_1$ and $h = h_3 + h_1$, where g_3 and h_3 are the amplitudes corresponding to $N + \pi$ in the s and p states respectively with $I = 3/2$, and g_1 and h_1 are corresponding amplitudes for $I = 1/2$. If time reversal is satisfied, these amplitudes can be written in the form $\rho e^{i\alpha}$ where the ρ 's are real numbers (positive or negative) and the α 's are the relevant $N + \pi$ phase shifts taken at the hyperon decay energy. If charge conjugation is satisfied, the amplitudes can still be written in the form $\rho e^{i\alpha}$, where the α 's are the phase shifts; however, the ρ 's are real for the two g amplitudes and pure imaginary for the h amplitudes (or vice versa).² Because the relevant phase shifts are small for spin $1/2$ of Y , if C is satisfied g is essentially real and h essentially pure imaginary, and the up-down asymmetry would be small. Observation of a large $(\vec{n} \cdot \vec{K})$ term in (1) would therefore essentially imply both P and C nonconservation--but it would, of course, provide no information on T . Unfortunately, the coefficient of such term could also be small because of $\langle \vec{\sigma} \rangle_Y$ being small. A measurement of the polarization of the emitted nucleon would provide direct information on the question of P and C nonconservation and, if $\langle \vec{\sigma} \rangle_Y$ is not very small, also on the question of T invariance. The polarization of the emitted nucleon in the hyperon decay will be given by

$$\begin{aligned}
 G \langle \vec{\sigma} \rangle_N &= \frac{1}{2} \left\{ \text{Tr} [T T^\dagger \vec{\sigma}] + \langle \vec{\sigma} \rangle_Y \text{Tr} [T \vec{\sigma} T^\dagger \vec{\sigma}] \right\} \\
 &= 2 \text{Re} (gh^*) \vec{k} + (|g|^2 - |h|^2) \langle \vec{\sigma} \rangle_Y \\
 &+ 2i \text{Im} (gh^*) \langle \vec{\sigma} \rangle_Y \wedge \vec{k} + 2|h|^2 (\langle \vec{\sigma} \rangle_Y \cdot \vec{k}) \vec{k}. \quad (3)
 \end{aligned}$$

Taking hyperons from any origin, independently of their production process, one is left only with a longitudinal polarization for the emitted nucleon, which is given by

$$\langle \vec{\sigma} \rangle_N = \frac{2 \text{Re} (gh^*)}{|g|^2 + |h|^2} \vec{k}. \quad (4)$$

Such longitudinal polarization could be detected by bending it into a transverse one with a magnetic field, or by successive scatterings, or by utilizing the transverse component that originates from the transformation from the Y rest frame to the laboratory system. The detection of a large longitudinal polarization would imply violation not only of P but also of C, and vice versa, if P is violated, such polarization must always be different from zero but very small if C is conserved. To illustrate the quantitative argument, let us consider, as Lee and Yang do, the simple case of Σ^- decay for which only the final $I = 3/2$ is possible. (A corresponding simple situation perhaps holds for the Λ^0 decay for which, according to the latest measurements, only the final $I = 1/2$ seems to contribute.) In the case of Σ^- decay, the coefficient of \vec{k} in (4) is $\pm \sin(\alpha_3 - \alpha_{31}) \cdot 2x/(1+x^2)$, with $x = |g/h|$ if C is satisfied, and $\pm \cos(\alpha_3 - \alpha_{31}) \cdot 2x/(1+x^2)$, if T is satisfied. If the production planes are also observed, the polarization will be given by the full expression (3), and we note that the observation of the third term proportional to $\text{Im}(gh^*)$ may give information on T conservation by the same arguments used before. Experiments to measure $\langle \vec{\sigma} \rangle_N$ are being planned in Berkeley.

PRODUCTION AND DECAY OF Ξ^-

In the reaction $K^- + p \rightarrow \Xi^- + K^+$ with observation of the subsequent cascade decay of Ξ^- (which will be investigated in Berkeley by Alvarez and collaborators), the decay of the emitted Λ^0 could serve as an analyzer of the possible polarization of

the Λ^0 itself. If we assume spin 1/2 for the hyperons, the polarization of the Ξ^- will be given by an expression like (1), where A and B refer to the above production reaction. The polarization of the Λ^0 from the decay of Ξ^- will similarly be described by (3), where g and h refer to $\Xi^- \rightarrow \Lambda^0 + \pi^-$. Such polarization is directly observed in the subsequent Λ^0 decay for which the distribution of $\vec{\chi}$, the unit vector in the direction of emission of the nucleon, will be given by

$$W \propto 1 + \frac{2 \operatorname{Re}(pq^*)}{|p|^2 + |q|^2} \langle \vec{\sigma} \rangle \cdot \vec{\chi} \quad (5)$$

where we have written the transition matrix for $\Lambda^0 \rightarrow N + \pi$ in the form $p + q \vec{\sigma} \cdot \vec{\chi}$. If Ξ^- particles from any origin are considered independent of the production reaction, observation of a large $\vec{\chi}$ dependence (forward-backward asymmetry) in (5) would imply not only violation of P in both Ξ^- and Λ^0 decay but also violation of C, unless the relevant $\Lambda^0 - \pi^-$ phase shift is large. If the production plane in $K^- + p \rightarrow \Xi^- + K^+$ is observed, observation of a large term proportional to $n_{\Lambda} K \cdot \vec{\chi}$ in (5) would imply violation of T invariance.

DECAY OF HYPERFRAGMENTS

The possibility of observing P nonconservation essentially depends on the s-p interference in the final state. Especially in Λ^0 decay, p-wave emission could be rather infrequent because of the angular-momentum barrier which is more efficient due to the low Q value. We might ask whether any possibility exists of enhancing this p-wave amplitude in hope of obtaining larger interference effects. A possibility presents itself in the nonmesonic decay of hyperfragments for which the angular momentum barrier for larger orbital angular momenta is less disfavored with respect to the case of free Λ^0 decay because of the larger momentum transfer. If we write the transition matrix for $\Lambda^0 \rightarrow N + \pi$ as $T = g + i \vec{\sigma} \cdot \vec{j}$, where \vec{j} is the momentum of π , the transition matrix for $\Lambda^0 + N \rightarrow N + N$ in perturbation theory is essentially of the form $i(g + i \vec{\sigma}_1 \cdot \vec{p}_{N1}) (i \vec{\sigma}_2 \cdot \vec{p}_{N2})$, where i is a constant and \vec{p}_N is the momentum of each final N in the center-of-mass system. The p amplitude of Λ^0 decay does appear to be enhanced by a factor $\sim p_{N1}/R_1 \sim 4$

with respect to the case of free Λ^0 decay if we assume, as Ruderman and Karplus do, that the energy dependence of g and l can be neglected.⁵ The above factor is expected to increase if the Λ^0 - N correlation and the effect of the exclusion principle for the final nucleons in heavy fragments are taken into account. For the detection of P nonconservation, a measurement of the angular correlations in the decay of simpler hyperfragments could be useful. Such correlations must not necessarily depend on the polarization of the hyperfragment. In a four-body decay with final momenta \vec{p}_1 , \vec{p}_2 , \vec{p}_3 , and \vec{p}_4 of an unpolarized hyperfragment, $\langle \vec{p}_1 \wedge \vec{p}_2 \cdot \vec{p}_3 \rangle$ is a pseudoscalar, and its detection would imply parity nonconservation. Moreover, a careful examination of the decay distributions of the different decay modes of the same hyperfragment could also give information on the possible existence of final amplitudes of opposite parity. Such study would be of interest in any case for the theory of hyperfragments.

REFERENCES AND FOOTNOTES

1. T. D. Lee and C. N. Yang, *Phys. Rev.* 104, 254 (1954).
2. Lee, Steinberger, Feinberg, Kabir, and Yang. (to be published).
3. The hyperon in $K^- + p \rightarrow Y + \pi$ is polarized only if the K^- is absorbed in flight. Unfortunately only a few cases of $K^- + p \rightarrow Y + \pi$ in flight have been reported so far. On the other hand, a large number of cases of K^- absorption at rest from emulsion nuclei are now available. The absorbing nucleon has, however, a Fermi momentum inside the nucleus. By choosing only those events for which the emitted Σ and π have not suffered appreciable scattering inside the nucleus (almost all energy taken by the Σ and the π), it might be possible to detect an up-down asymmetry in the Σ decay with respect to the plane defined by the direction of emission of the Σ and of the π , if p-wave absorption is efficient at such low relative energies.
4. See E. Fermi, *Supplemento Nuovo Cimento* 1, 62 (1955).
5. M. Ruderman and R. Karplus, *Phys. Rev.* 102, 247 (1956).

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