

## Decay of the Cascade Particles\*

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(Received December 16, 1958)

A phenomenological investigation of the decay of the cascade particles is presented. Several possible correlation measurements, which exploit the large asymmetry in  $\Lambda^0$  decay as an analyzer of  $\Xi$ , are suggested. One of these experiments does not require polarized  $\Xi$ 's. The relation to the theory of universal weak interactions is briefly discussed.

### INTRODUCTION

THE chirality-invariant  $V-A$  theory<sup>1</sup> of four-fermion couplings provides a satisfactory framework to correlate the data on various weak interactions. It has been shown that the large pseudoscalar parameter observed in  $\Lambda^0$  decay<sup>2</sup> can be understood on the basis of this theory which lends additional support to the postulate of a universal  $V-A$  coupling, even when the pion-nucleon interactions in the final state are considered.<sup>3</sup> It would be interesting to see if this postulate is consistent with other strangeness-nonconserving processes; and perhaps the most fruitful further experimental study of hyperon decay is that of the cascade particle.

It appears that in the near future cascade particles will be made, for example, via the reactions

$$K^- + p \rightarrow \begin{cases} \Xi^- + K^+ \\ \Xi^0 + K^0. \end{cases}$$

It is to be expected that the cascade particles so produced will be partially polarized in the plane of production, making possible the observation of an up-down asymmetry in the subsequent decay

$$\Xi^{-,0} \rightarrow \Lambda^0 + \pi^{-,0}.$$

Because of the large known asymmetry in the  $\Lambda^0$  decay,<sup>2</sup> the spin direction of the  $\Lambda^0$  should be relatively easy to measure. This makes possible a complete measurement of decay parameters of the cascade particles.

A comparison of the results for the  $\Xi^-$  with those for the  $\Xi^0$ , and those for the  $\Lambda^0$  should provide useful information on the universality of the weak interactions.

\* Work supported in part by the U. S. Atomic Energy Commission.

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<sup>1</sup> E. C. G. Sudarshan and R. E. Marshak, Proceedings of the Padua-Venice Conference on Fundamental Particles, September, 1957 [Suppl. Nuovo cimento (to be published)]; Phys. Rev. **109**, 1860 (1958); see also, R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

<sup>2</sup> Eisler, Plano, Prodell, Samios, Schwartz, Steinberger, Bassi, Borelli, Puppi, Tanaka, Waloschek, Zoboli, Conversi, Franzini, Manelli, Santangelo, Silvestrini, Glaser, Graves, and Perl, Phys. Rev. **108**, 1353 (1957); Crawford, Cresti, Good, Gottstein, Lyman, Solmitz, Stevenson, and Ticho, Phys. Rev. **108**, 1102 (1957).

<sup>3</sup> Okubo, Marshak, and Sudarshan, Phys. Rev. **113**, 944 (1959).

### PHENOMENOLOGICAL ANALYSIS OF $\Xi$ DECAY

The general considerations<sup>4</sup> which have been used to discuss the decay of the  $\Lambda^0$  may be applied in a straightforward fashion to the analysis of the  $\Xi$  decay. If the  $\Lambda^0$  has spin  $\frac{1}{2}$ , the final state in the decay of the  $\Xi$  will be a coherent linear combination of at most two states of opposite parity (differing in the orbital angular momentum by one unit). The entire decay process can then be described in terms of 3 real parameters: the amplitude of each component state and their relative phase.

If we assume that the  $\Xi$  also has spin  $\frac{1}{2}$ , the decay  $\Lambda^0$  can only be in a  $S_{\frac{1}{2}}$  or  $P_{\frac{1}{2}}$  state in the coordinate system in which the  $\Xi$  was at rest. Let  $A$  and  $B$  be the amplitude of the  $S_{\frac{1}{2}}$  and  $P_{\frac{1}{2}}$  state, respectively. One of the three parameters which characterize the decay may be taken to be  $|A|^2 + |B|^2$ , which is proportional to the decay probability; the other two may be given in terms of

$$\begin{aligned} \alpha &= 2 \operatorname{Re}[A^*B/(|A|^2 + |B|^2)], \\ \beta &= 2 \operatorname{Im}[A^*B/(|A|^2 + |B|^2)], \\ \gamma &= (|A|^2 - |B|^2)/( |A|^2 + |B|^2), \end{aligned}$$

which satisfy

$$\alpha^2 + \beta^2 + \gamma^2 = 1.$$

The parameters  $\alpha$ ,  $\beta$ , and  $\gamma$  are directly connected to the longitudinal and transverse polarization of the  $\Lambda^0$ 's produced in the decay of the  $\Xi$ 's.

Consider the decay of  $\Xi$ 's completely polarized in the direction  $\hat{n}$ . Let  $\hat{p}_\Lambda$  be the direction of motion of the  $\Lambda^0$  in the rest system of the  $\Xi$ , and let  $\hat{y}$  be the direction of  $\hat{n} \times \hat{p}_\Lambda$ . The angular distribution of the decay  $\Lambda^0$ 's is given by  $1 + \alpha \cos\theta$ , where  $\cos\theta = \hat{p}_\Lambda \cdot \hat{n}$ . The direction of polarization of the decay  $\Lambda^0$ 's is

$$[(\alpha + \cos\theta)\hat{p}_\Lambda + \beta \sin\theta \hat{y} + \gamma \sin\theta (\hat{p}_\Lambda \times \hat{y})]/(1 + \alpha \cos\theta),$$

in the rest system of the  $\Lambda^0$ .

Suppose we choose a sample of  $\Xi$ 's with a spin density matrix of the form  $\frac{1}{2}(1 + P_s \sigma \cdot \hat{n})$ . It is possible to select for measurement several correlations all of the form  $1 + a \cos\theta$ , where the values of  $a$  for each of the experiments is given in Table I. Here  $\hat{p}_\Lambda$  is the direction

<sup>4</sup> Lee, Steinberger, Feinberg, Kabir, and Yang, Phys. Rev. **106**, 1367 (1957); T. D. Lee and C. N. Yang, Phys. Rev. **108**, 1645 (1957).

of motion of the proton from the  $\Lambda^0$  decay in the  $\Lambda^0$  rest system, and  $\alpha_\Lambda$  is the asymmetry parameter in the  $\Lambda^0$  decay.<sup>5</sup>

In case the spin  $J$  of the  $\Xi$  is greater than  $\frac{1}{2}$ , but the spin of the  $\Lambda^0$  is  $\frac{1}{2}$ , all but the correlation between  $\hat{n}$  and  $\hat{p}_\Lambda$  are still of the form  $1+a \cos\theta$ . The quantities  $\alpha, \beta$ , and  $\gamma$  are defined as before in terms of  $A$  and  $B$ , which now represent the amplitudes of the angular momentum states  $J-\frac{1}{2}$  and  $J+\frac{1}{2}$  of the final  $\Lambda^0$ -pion system. In the last two expressions,  $\frac{1}{4}\pi P_s$  is to be replaced by

$$-\sum_{m=-J}^J \frac{[I_m - I_{-m}]}{[I_m + I_{-m}]} \frac{(J-m)!}{(J+m-1)!} \times \int_{-1}^1 dx P_{J-\frac{1}{2}}^{m-\frac{1}{2}}(x) P_{J+\frac{1}{2}}^{m+\frac{1}{2}}(x), \ddagger$$

where  $I_m$  is the statistical weight factor of the initial  $\Xi$  belonging to the magnetic quantum number  $m$ , so that

$$\sum_{M=-J}^J I_M = 1, \quad I_M \geq 0.$$

Lee and Yang have given a beautiful analysis<sup>6</sup> of the decay of a hyperon of arbitrary spin into a nucleon and a pion. Their considerations apply equally well to the decay of a  $\Xi$  into a  $\Lambda^0$  and a pion, provided the spin of the  $\Lambda^0$  is  $\frac{1}{2}$ . Thus, the possible complexity of the correlation between  $\hat{n}$  and  $\hat{p}_\Lambda$  is determined by the spin of the  $\Xi$ . The longitudinal polarization of the decay  $\Lambda^0$ 's from unpolarized  $\Xi$ 's is  $\alpha$ . Of course, the average longitudinal polarization of *all* the  $\Lambda^0$ 's from a sample of polarized  $\Xi$ 's will also be  $\alpha$ . If  $\alpha$  is known, as will be very likely for the  $\Xi$ 's, the inequalities of Lee and Yang can be improved somewhat. For example, their Theorem 1 becomes

$$-|\alpha|/(2J+2) \leq \langle \hat{n} \cdot \hat{p}_\Lambda \rangle \leq |\alpha|/(2J+2).$$

#### DISCUSSION

The measurement of the correlation between the direction of motion  $\hat{p}_\Lambda$  of the  $\Lambda^0$  and the direction of

<sup>5</sup> The asymmetry factors  $\alpha$  and  $\alpha_\Lambda$  given here are referred to the  $\Lambda^0$  and the proton, respectively, but not to the pions.

<sup>‡</sup> Note added in proof.— $P_l^m$  is defined by

$$P_l^m(x) = (-1)^m \cdot 2^{-i} \cdot (l!)^{-1} (1-x^2)^{m/2} (d^{l+m}/dx^{l+m})(x^2-1)^l.$$

<sup>6</sup> T. D. Lee and C. N. Yang, Phys. Rev. **109**, 1755 (1958).

TABLE I.

$\cos\theta$	$a$
$\hat{n} \cdot \hat{p}_\Lambda$	$P_s \alpha$
$\hat{p}_\Lambda \cdot \hat{p}_p$	$\alpha \alpha_\Lambda$
$\hat{y} \cdot \hat{p}_p$	$(\pi/4) P_s \beta \alpha_\Lambda$
$\hat{p}_\Lambda \times \hat{y} \cdot \hat{p}_p$	$(\pi/4) P_s \gamma \alpha_\Lambda$

motion  $\hat{p}_p$  of the proton, each measured in the rest system of its parent particle, determines  $\alpha \alpha_\Lambda$ , the product of the asymmetry parameters of the  $\Xi$ -decay and the  $\Lambda^0$ -decay. Since this correlation is independent of the initial polarization of the  $\Xi$ 's, *all* observed  $\Xi$  decay sequences can be used to obtain data. A nonzero value for  $\alpha \alpha_\Lambda$  of course implies that parity is not conserved in the  $\Xi$ -decay, as well as in the  $\Lambda^0$ -decay. A large value would indicate that roughly equal amounts of vector and axial vector contributions are contained in the decay matrix element of the  $\Xi$ , if the spin of the  $\Xi$  is  $\frac{1}{2}$ . In the latter case, the sign of  $\alpha \alpha_\Lambda$  would determine whether the cascade particle enters into the universal weak interaction in the same fashion as the other baryons. A positive sign is to be expected according to the choice previously made.<sup>1,3,7</sup>

The parameter  $\beta$  will be small if the decay process is invariant under time reversal and if final state interactions are negligible.

The possibility of observing  $\Xi^0$  as well as  $\Xi^-$  invites a comparison of their decay parameters. The  $\Delta I = \frac{1}{2}$  selection rule makes definite predictions; namely the decay rate of the  $\Xi^-$  is twice that of the  $\Xi^0$ , while the other parameters are the same for both. In general  $\Delta I = \frac{1}{2}$  and  $\Delta I = \frac{3}{2}$  parts would both be expected to contribute<sup>7,3</sup> and to lead to results which differ from the predictions of the  $\Delta I = \frac{1}{2}$  selection rule.

#### ACKNOWLEDGMENTS

We would like to express our thanks to Professor R. E. Marshak for his encouragement, and two of us (W.B.T. and E.C.G.S.) are grateful for his hospitality at the University of Rochester. We wish to thank Dr. A. Gamba, Dr. C. J. Goebel, and Dr. S. Weinberg for useful discussions related to the subject of this paper.

<sup>7</sup> Okubo, Marshak, Sudarshan, Teutsch, and Weinberg, Phys. Rev. **112**, 665 (1958).