Model of Hyperon Decay

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The vanishing of the asymmetries in the decays $\Sigma^- \to n+\pi^-$ and $\Sigma^+ \to n+\pi^+$ are explained in a model in which all Σ decays occur via virtual K-meson decays. The model then predicts a Λ-decay asymmetry of similar magnitude but opposite sign to that of $\Sigma^+ \to p+\pi^0$. Certain other predictions of this model are discussed.

THE decay of hyperons is described by ten amplitudes $L^{(c)}$, where $L=S$ or P is the outgoing orbital angular momentum and c stands for one of the five decays:

$$\Lambda \to p+\pi^- \quad (\Lambda-),$$
$$\Lambda \to n+\pi^0 \quad (\Lambda 0),$$
$$\Sigma^+ \to p+\pi^0 \quad (\Sigma 0),$$
$$\Sigma^+ \to n+\pi^+ \quad (\Sigma+),$$
$$\Sigma^- \to n+\pi^- \quad (\Sigma-).$$

Experiments[1] indicate there exist simple relations among these amplitudes: Four of these relations are summarized by the $\Delta T=\frac{1}{2}$ rule. In addition it is found that $L^{(\Sigma-)}$ vanishes for either s or p waves and that $L^{(\Sigma+)}$ vanishes for the other. Also the nonvanishing $L^{(\Sigma+)}$ and $L^{(\Sigma-)}$ are equal, and the amplitudes $S^{(\Lambda)}$ and $P^{(\Lambda)}$ are approximately equal. We present here a model of hyperon decays which yields a possible explanation for seven of these eight relationships and which makes some verifiable predictions.

The simplest model of hyperon decays[2] considers only diagram (A) of Fig. 1, where the hyperon-nucleon vertex is given directly by the matrix element of the strangeness-nonconserving weak interaction current. It may be shown[3] using the low rate observed for hyperon β decay that diagram (A) contributes only a small fraction of all the observed hyperon decays. We therefore turn to diagrams (B) through (D) involving virtual K-meson decays. Such diagrams enter in dispersion relation analyses and also enter in a natural way in a theory[4] in which the strangeness-nonconserving weak-interaction current does not explicitly contain (ΣN) or (ΛN) pairs. Diagram (B) might be important because it contains a K-meson pole,[5] and diagrams (C) and (D) may be important because they involve the very strong $K \to 2\pi$ decay vertex. If these diagrams are responsible for hyperon decay we reach the following conclusions:

(1) The $\Delta T=\frac{1}{2}$ rule for hyperon decay follows from the rule for K-meson decay and is not independent evidence of the rule. Of course, here we assume the rule to apply to virtual K-meson decays including the $K \to \pi$ decay.

(2) To obtain parity nonconservation, virtual K-meson decays into both even and odd numbers of pions are needed. If we assume, to be specific, even relative $\Sigma-\Lambda$ parity and odd K parity, then diagram (B) corresponds to p-wave amplitudes while (C) and (D) correspond to s-wave amplitudes.

(3) If we assume that diagram (B) gives all the p-wave amplitudes, then it follows from the YKN vertex that for p waves ΔT_z of the baryons equals $\pm\frac{1}{2}$. Therefore

$$P^{(\Sigma+)}=0. \tag{1}$$

(4) If we assume that diagram (C) gives all the s-wave amplitude, then the final state must have $T=\frac{1}{2}$. This follows from the fact that after the weak vertex there is an intermediate state of two pions with total isotopic spin $T=0$ plus one nucleon. Therefore

$$S^{(\Sigma-)}=0. \tag{2}$$

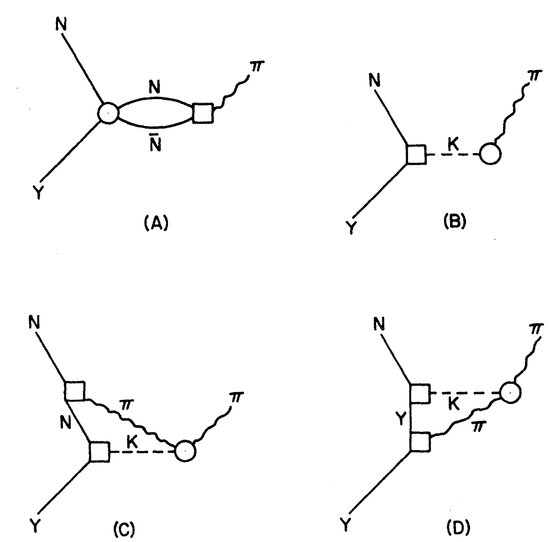

FIG. 1. Diagrams for hyperon decay. Y=hyperon, N=nucleon, $K=\bar{K}$ meson, $\pi=\pi$ meson. Circles denote weak vertices and squares denote strong vertices.

[1] R. L. Cool, B. Cork, J. W. Cronin, and W. A. Wenzel, Phys. Rev. **114**, 912 (1959); J. Cronin, Proceedings of the Tenth Annual International Rochester Conference on High-Energy Nuclear Physics, 1960 (to be published).
[2] S. Okubo, R. E. Marshak, and E. C. G. Sudarshan, Phys. Rev. **113**, 944 (1959).
[3] D. Harrington, Bull. Am. Phys. Soc. **5**, 52 (1960).
[4] L. Wolfenstein, Bull. Am. Phys. Soc. **5**, 51 (1960).
[5] G. Feldman, P. T. Matthews, and A. Salam, Phys. Rev. **121**, 302 (1961), have emphasized the importance of diagram (B). They consider also baryon pole terms, but do not consider diagrams (C) and (D).

For diagram (D) this conclusion would also hold if the Pais "restricted symmetry"[6] were valid. This is easy to see since the virtual $\bar{K}^0$ decays conserve S_1 so that S_1 is a good quantum number; thus, only the (Σ^+,Y^0) doublet can decay via virtual $\bar{K}^0$ decays. A sufficient condition that Eq. (2) holds for diagram (D) is[7]

$$g_{\Lambda\pi}g_{\Lambda K}=g_{\Sigma\pi}g_{\Sigma K}, \tag{3}$$

provided we ignore the mass difference between Σ and Λ.

The experimental requirement that the amplitude $P^{(\Sigma-)}$ arising from diagram (B) alone equal the amplitude $S^{(\Sigma+)}$ coming from diagrams (C) plus (D) appears to be completely accidental in this model.

(5) Applying this model to Λ decays, we find, if we again neglect the $\Sigma-\Lambda$ mass difference and use Eq. (3),

$$S^{(\Lambda-)}=S^{(\Sigma0)}\frac{1+\alpha(g_{N\pi}/g_{\Lambda\pi})(g_{\Sigma\pi}/g_{\Lambda\pi})}{(g_{\Sigma\pi}/g_{\Lambda\pi})+\alpha(g_{N\pi}/g_{\Lambda\pi})},$$

$$P^{(\Lambda-)}=-P^{(\Sigma0)}(g_{\Sigma\pi}/g_{\Lambda\pi}),$$

$$\left(\frac{P}{S}\right)^{(\Lambda-)}=\left(\frac{P}{S}\right)^{(\Lambda0)}=-\left(\frac{P}{S}\right)^{(\Sigma0)}\left[\frac{\alpha g_{N\pi}+g_{\Sigma\pi}}{\alpha g_{N\pi}+g_{\Sigma\pi}(g_{\Lambda\pi}/g_{\Sigma\pi})^2}\right], \tag{4}$$

where α is the ratio of the contribution from the closed loop (C) to that of (D) after factoring out the coupling constants. For the most likely assumptions about the coupling constants and the value of α, the right-hand bracket in Eq. (4) is within a factor two of unity; the approximate equality in magnitude of $P^{(\Lambda)}$ and $S^{(\Lambda)}$ then follows from the known result $(P/S)^{(\Sigma0)}=\pm1$.

The following verifiable predictions can be made on this model:

(1) The asymmetry parameters in Λ decay and $\Sigma^+\rightarrow p+\pi^0$ decay have opposite signs. This may be verified by comparing the longitudinal polarization of the protons for the two cases. No prediction can be made, however, of the absolute sign of the asymmetry parameter for either case.

It may be worth noting that, if restricted symmetry is assumed, the $\Lambda^0\rightarrow\pi^0+n$ asymmetry must be the same as the undetectable $\Sigma^0\rightarrow\pi^0+n$ asymmetry (since these involve virtual $\bar{K}^0$ decays), which from the $\Delta T=\frac{1}{2}$ rule and Eqs. (1) and (2) is opposite to the $\Sigma^+\rightarrow\pi^0+p$ asymmetry.

(2) Assuming that it were definitely known that the K meson is pseudoscalar with respect to the Σ, we could state that the decay $\Sigma^+\rightarrow n+\pi^+$ is pure s-wave while the Σ^- decay is pure p-wave rather than the other way around. This could be verified by measuring the neutron polarization from the decay of Σ^+ and Σ^- with known polarization.

(3) Diagrams in which the final-state pion is replaced by a $(e\nu)$ or $(\mu\nu)$ pair would be expected to provide the major contribution to the leptonic decays of hyperons. The analogs of diagram (B) have been previously considered[8] for leptonic decays and give completely negligible contributions. Thus in the present model all leptonic decays would have to be explained by the analogs of diagrams (C) and (D); this limitation has definite consequences[9] for detailed observations on these decays. In such a model the low ratio of leptonic to nonleptonic decay rates would be related in some way to the low ratio of $K\rightarrow\pi+e+\nu$ to $K_{01}\rightarrow 2\pi$ decay rates; a quantitative relation, however, requires a more detailed model.

ACKNOWLEDGMENT

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[6] A. Pais, Phys. Rev. **110**, 574 (1958).

[7] Our notation for coupling constants is that of M. Gell-Mann, Phys. Rev. **106**, 1296 (1957).

[8] E. M. Ferreira, Nuovo cimento **8**, 359 (1958).

[9] On the assumption of pseudoscalar K meson, we find that the decay appears to be due to the *vector* weak interaction only. Consequences of this may be deduced from the work of C. H. Albright, Phys. Rev. **115**, 750 (1959) and D. Harrington, Phys. Rev. **120**, 1482 (1960). In the notation of Albright we find that only c, d, and d' contribute; in the notation of Harrington, only f_1, f_2, and f_3.