

Model of Pionic Hyperon Decay*

JUGORO IZUKA AND REINHARD OEHME

Enrico Fermi Institute for Nuclear Studies and Department of Physics, University of Chicago, Chicago, Illinois

(Received November 29, 1961)

Using a phenomenological $V+A$ coupling for the weak vertex $\Lambda \rightarrow N+\pi$, a simple model of the decays $\Sigma \rightarrow N+\pi$ is constructed under the assumption of odd $\Sigma\Lambda$ parity. The model predicts that $\alpha_0 \approx -\alpha_\Lambda$ and that the decay $\Sigma^- \rightarrow n+\pi^-$ ($\Sigma^+ \rightarrow n+\pi^+$) is essentially pure s wave (p wave).

IT is the purpose of this note to point out that the remarkable regularities of the decays¹ $\Lambda \rightarrow p+\pi^-$, $\Sigma^+ \rightarrow p+\pi^0$, and $\Sigma^+ \rightarrow n+\pi^+$ can be described as well in a scheme with odd $\Sigma\Lambda$ parity as in one with even parity. This applies especially to the recent experimental results concerning the sign of the asymmetry parameter α_0 for $\Sigma^+ \rightarrow p+\pi^0$ and the sign of the parameter α_Λ for $\Lambda \rightarrow p+\pi^-$.²⁻⁴

For even $\Sigma\Lambda$ parity the relation $\alpha_0 = -\alpha_\Lambda$ is a direct consequence of the Pais doublet approximation⁵ in conjunction with the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule⁶; It also follows from more specific dynamical models.⁷

For odd $\Sigma\Lambda$ parity⁸ we propose the following simple model which relates the transition amplitude for Σ decays to that of the Λ decay. We assume that the Σ hyperon first dissociates into a Λ and a pion via a strong scalar $\Sigma\Lambda\pi$ vertex.⁹ Then we consider two possible sequences:

(1) The Λ and the pion recombine weakly to give a nucleon which finally emits a pion.

(2) The initial pion is emitted as a real particle, and the Λ decays into a pion and a nucleon which finally recombine to form a neutron.

The corresponding graphs G_1 and G_2 are shown in Fig. 1. We note that both graphs have an intermediate state corresponding to a single particle which is connected to a physical initial or final single particle state via a weak vertex. This situation should be understood in connection with our phenomenological treatment of the $\Lambda N\pi$ vertex. Furthermore, the final pion is always created strongly and correspondingly the pion asso-

ciated with the weak vertex never comes out. This is our model, but it is not complete without a specific form for the weak $\Lambda N\pi$ vertex. Here we use a phenomenological $V+A$ coupling which, in momentum space, may be written in the form

$$(\bar{N}\boldsymbol{\tau}s) \cdot \boldsymbol{\pi}\gamma(p_\Lambda - p_N)(1 - \gamma_5)\Lambda, \quad (1)$$

where s describes the spurion.¹⁰ With the vertex (1) our model satisfies the selection rule $|\Delta\mathbf{T}| = \frac{1}{2}$ and gives $\alpha_\Lambda = -0.9$. Note that it is the experimental result²⁻⁴ sign $\alpha_\Lambda = -1$ which requires a coupling of the form $V+A$ instead of $V-A$. This, in itself, may be an important hint, because on the basis of weak four-fermion interactions one would have expected a $V-A$ form of the effective coupling.¹¹

The computation of the Σ -decay amplitudes is straightforward. We obtain the relations

$$\begin{aligned} T_0 &= \sqrt{2}G_1, \\ T_+ &= 2G_1 + 3G_2, \\ T_- &= 3G_2, \end{aligned} \quad (2)$$

which satisfy the equation $\sqrt{2}T_0 = T_+ - T_-$ as a consequence of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule. Here G_1 and G_2 are amplitudes corresponding to the individual graphs with isotopic factors omitted. We have

$$\begin{aligned} G_1 &= C_1 \frac{g_{NN\pi}g_{\Sigma\Lambda\pi}}{m_\Sigma^2 - m_N^2} \bar{u}_N(p) \\ &\quad \times [(m_\Sigma - m_N) - (m_\Sigma + m_N)\gamma_5] u_\Sigma(q), \\ G_2 &= C_2 \frac{g_{NN\pi}g_{\Sigma\Lambda\pi}}{m_\Lambda^2 - m_N^2} \bar{u}_N(p) \\ &\quad \times [(m_\Lambda + m_N) - (m_\Lambda - m_N)\gamma_5] u_\Sigma(q), \end{aligned} \quad (3)$$

where the coefficients C_1 and C_2 contain both linearly and logarithmically divergent integrals. In a dispersion approach the constants C_1 and C_2 should be considered as subtraction terms which must be determined empirically.

¹⁰ G. Wentzel, *Proceedings of the Sixth Annual Rochester Conference on High-Energy Nuclear Physics* (Interscience Publishers, Inc., New York, 1956); B. d'Espagnat and J. Prentki, *Nuovo cimento* **10**, 1045 (1956).

¹¹ S. Okubo, R. E. Marshak, and E. C. G. Sudarshan, *Phys. Rev.* **113**, 944 (1959); A. Fujii and M. Kawaguchi, *Phys. Rev.* **113**, 1156 (1959); S. Oneda, T. C. Pati, and B. Sakita, *Phys. Rev.* **119**, 482 (1960); Z. Maki and Y. Ohnuki, *Progr. Theoret. Phys.* (Kyoto) **25**, 353 (1961).

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

¹ For reviews see: M. Schwartz, *Proceedings of the 1960 International Conference on High-Energy Physics at Rochester* (Interscience Publishers, Inc., New York, 1960), p. 721; M. Gell-Mann and A. Rosenfeld, *Ann. Rev. Nuclear Sci.* **7**, 454 (1957); A. Pais, *Revs. Modern Phys.* **33**, 471 (1961).

² R. W. Birge and W. B. Fowler, *Phys. Rev. Letters* **5**, 254 (1960).

³ E. F. Beall, Bruce Cork, D. Keefe, P. G. Murphy, and W. A. Wenzel, *Phys. Rev. Letters* **7**, 285 (1961).

⁴ T. Leitner *et al.*, *Phys. Rev. Letters* **7**, 264 (1961).

⁵ A. Pais, *Phys. Rev.* **110**, 1480 (1958).

⁶ B. d'Espagnat and J. Prentki, *Phys. Rev.* **114**, 1366 (1959); S. Treiman, *Nuovo cimento* **15**, 916 (1960); A. Pais, *Nuovo cimento* **18**, 1003 (1960); *Phys. Rev.* **122**, 317 (1961).

⁷ G. Feldman, P. Matthews, and A. Salam, *Phys. Rev.* **121**, 302 (1961); and L. Wolfenstein, *Phys. Rev.* **121**, 1245 (1961).

⁸ S. Barshay, *Phys. Rev. Letters* **1**, 97 (1958); S. Barshay and M. Schwartz, *Phys. Rev. Letters* **4**, 618 (1960).

⁹ J. Bernstein and R. Oehme, *Phys. Rev. Letters* **6**, 639 (1961).

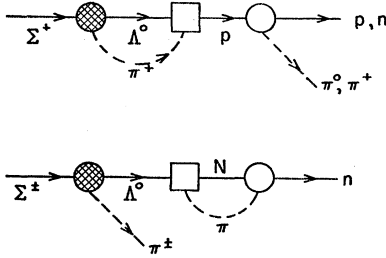


FIG. 1. The graphs G_1 and G_2 which characterize the model of the decay $\Sigma \rightarrow N + \pi$.

Independent of C_1 and C_2 we can draw the following conclusions:

(a) Since $T_0 = s_0 + p_0 \sigma \cdot \hat{k}_\pi$ is given by G_1 alone, we find

$$p_0/s_0 = \frac{m_\Sigma + m_N}{m_\Sigma - m_N} \frac{|p_N|}{p_{0N} + m_N} \approx 0.83,$$

where p_N is the four-momentum of the nucleon in the decay $\Sigma^+ \rightarrow p + \pi^0$. The corresponding asymmetry parameter α_0 is then given by

$$\alpha_0 = 2s_0 p_0 / (s_0^2 + p_0^2) \approx +0.98,$$

and hence we have $\alpha_0 \approx -\alpha_\Lambda$.

(b) The amplitude $T_- = s_- + p_- \sigma \cdot \hat{k}_\pi$ is proportional to G_2 and we have

$$p_-/s_- = \frac{m_\Lambda - m_N}{m_\Lambda + m_N} \frac{|p_N|}{p_{0N} + m_N} \approx 0.008.$$

The decay $\Sigma^- \rightarrow n + \pi^-$ is essentially pure s -wave.

The properties of T_+ depend upon the ratio C_1/C_2 , which we simply take as an adjustable parameter in the sense of a subtraction in dispersion theory. Then we can make the decay amplitude for $\Sigma^+ \rightarrow n + \pi^+$ to be predominantly p wave in agreement with the observed small value of α_+ . [If one takes the perturbation

theoretic expressions for the graphs G_1 and G_2 and evaluates the cutoff-dependent integrals, then one finds that, for large values of the cutoff, the ratio C_1/C_2 tends to a constant which has the wrong sign and magnitude. But in view of the quadratic divergence and the phenomenological character of our model we do not think that this high cutoff limit is relevant.] It is clear from the relation $\sqrt{2}T_0 = T_+ - T_-$ that, with the above choice of C_1/C_2 , the amplitudes T_0 , T_+ , and T_- all have essentially the same magnitude. In addition we may choose C_1 such that the magnitude of these amplitudes agrees with that of T_Λ , as indicated by experiments.¹

We note that our model has been constructed in the spirit of a pole approximation and with the assumption that the final pion is created strongly. In this framework we have ignored a graph G_3 where the final pion is created weakly at the vertex $\Lambda N \pi$ while the pion originating in the dissociation $\Sigma \rightarrow \Lambda + \pi$ is absorbed by the final nucleon.¹²

Let us finally summarize the essential predictions of the model: The decay $\Sigma^+ \rightarrow p + \pi^0$ proceeds with near maximal parity violation resulting in an asymmetry parameter $\alpha_0 \approx -\alpha_\Lambda$. In the reactions $\Sigma^- \rightarrow n + \pi^-$ and $\Sigma^+ \rightarrow n + \pi^+$ parity is essentially conserved, the Σ^- decay corresponding to an s -wave transition and the Σ^+ decay to a p -wave transition. This assignment could be tested experimentally by a measurement of the neutron polarization in the decay of Σ hyperons with known polarization. We note that in several other models the situation is just reversed.

It is a pleasure to thank Y. Nambu for stimulating conversations.

¹² S. Barshay and M. Schwartz in reference 8 have outlined a model of Σ decay for odd $\Sigma\Lambda$ parity which may perhaps be realized by the graphs G_2 and G_3 . Unfortunately, the asymmetry parameter α_0 for the decay $\Sigma^+ \rightarrow p + \pi^0$ depends upon the details of the graph G_3 . If we choose for the logarithmic cutoff a value $\lambda \gtrsim m_N$ we obtain $\text{sign } \alpha_0 = -\text{sign } \alpha_\Lambda$. This holds for weak $\Lambda N \pi$ couplings of the form $V + A$ as well as $S + P$.