# Model of Pionic Hyperon Decay*

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

It is the purpose of this note to point out that the remarkable regularities of the decays[1] $\Lambda \to p+\pi^-$, $\Sigma^+ - p+\pi^0$, and $\Sigma^+ \to n+\pi^+$ 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 $\alpha_0$ for $\Sigma^+ \to p+\pi^0$ and the sign of the parameter $\alpha_\Lambda$ for $\Lambda \to p+\pi^-$.[2–4]

For even $\Sigma\Lambda$ parity the relation $\alpha_0 = -\alpha_\Lambda$ is a direct consequence of the Pais doublet approximation[5] in conjunction with the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule[6]; It also follows from more specific dynamical models.[7]

For odd $\Sigma\Lambda$ parity[8] we propose the following simple model which relates the transition amplitude for $\Sigma$ decays to that of the $\Lambda$ decay. We assume that the $\Sigma$ hyperon first dissociates into a $\Lambda$ and a pion via a strong scalar $\Sigma\Lambda\pi$ vertex.[9] Then we consider two possible sequences:

(1) The $\Lambda$ 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 $\Lambda$ 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 associated 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

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

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 result[2–4] $\operatorname{sign}\alpha_\Lambda = -1$ 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 $\Sigma$-decay amplitudes is straightforward. We obtain the relations

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

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

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

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.

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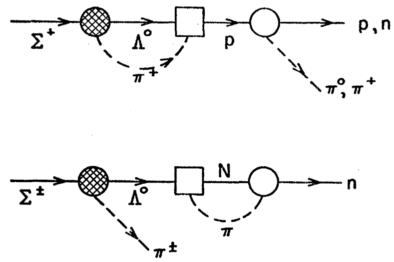


FIG. 1. The graphs $G_1$ and $G_2$ which characterize the model of the decay $\Sigma \to N+\pi$.

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

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

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

where $p_N$ is the four-momentum of the nucleon in the decay $\Sigma^+ \to p+\pi^0$. The corresponding asymmetry parameter $\alpha_0$ is then given by

$$\alpha_0 = 2s_0p_0/(s_0^2+p_0^2) \approx +0.98,$$

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

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

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

The decay $\Sigma^- \to n+\pi^-$ 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 $\Sigma^+ \to n+\pi^+$ to be predominantly $p$ wave in agreement with the observed small value of $\alpha_+$. [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 $T_\Lambda$, 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 $\Sigma \to \Lambda+\pi$ is absorbed by the final nucleon.[12]

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

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