Nonleptonic Decays of Hyperons*

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A simple model of the nonleptonic decays of hyperons is discussed, in which weak interactions occur only through the two-baryon vertices. The model is in agreement with the main features of Σ and Λ decays, and leads to pion coupling constants of the same sign and nearly the same magnitude.

I. INTRODUCTION

SEVERAL theoretical models[1-3] for the nonleptonic decays of hyperons have been suggested in recent years. The model of Singh and Udgaonkar[3] has the advantage that it contains only one type of weak vertices, but their approach is too empirical, and the pion coupling constants in their most favorable case do not have the same sign. We shall discuss a model, which also involves only the two-baryon weak vertices, but the relationship between the Σ-N and Λ-N vertices is obtained by theoretical arguments. Our treatment then leads to pion coupling constants with the same sign and nearly the same magnitude, and thus corresponds to approximate global symmetry in pion interactions.

II. MATRIX ELEMENTS FOR Σ AND Λ DECAYS

We assume that the nonleptonic decays of hyperons are dominated by processes, in which a hyperon changes into a nucleon through weak interaction and a pion is created by the hyperon or the nucleon through strong interaction. Thus, the weak vertices in Σ and Λ decays involve the baryon pairs p-Σ^+, n-Σ^0, and n-Λ. According to the $|\Delta I|=\frac{1}{2}$ rule for the nonleptonic decays of strange particles, the effective weak interaction for such vertices is of the form

$$H_w=:[a\bar{p}(1+b\gamma_5)\Sigma^+-(1/\sqrt{2})a\bar{n}(1+b\gamma_5)\Sigma^0 +(1/\sqrt{2})a'\bar{n}(1+b'\gamma_5)\Lambda]:, \quad (1)$$

which transforms like the neutral component of an isospinor.

We also regard all baryons as having the same parity, and write the interaction of pions with N, Σ, and Λ as

$$H_s=:[ig_1(\bar{N}\gamma_5\tau_i N)\pi_i+g_2(\epsilon_{ijk}\bar{\Sigma}_j\gamma_5\Sigma_k)\pi_i +ig_3(\bar{\Lambda}\gamma_5\Sigma_i+\bar{\Sigma}_i\gamma_5\Lambda)\pi_i]:, \quad (2)$$

where the symbols have the usual meaning.

The diagrams for Σ and Λ decays are shown in Fig. 1. Since Λ appears as a virtual particle in Σ decays, one would expect that the matrix elements for such decays are functions of m_Λ. We shall, however, postulate that Σ decays are independent of the mass difference between Σ and Λ, which means that the effects of Σ-Λ mass difference arising from the weak and strong vertices should cancel each other.[4] This postulate will be helpful in choosing suitable relations between the constants a, b, a', and b' appearing in (1).

The S-matrix element S_+ corresponding to the diagrams for $\Sigma^+\to n+\pi^+$ decay, shown in Fig. 1, is given by

$$S_+=(2\pi)^4\delta(p-p'-q)\sqrt{2}\pi^{+*}(q) \times\bar{n}(p')\left[-\frac{ab(g_1+\frac{1}{2}g_2)}{m_\Sigma+m_N}-\frac{\frac{1}{2}a'b'g_3}{m_\Lambda+m_N} +\frac{a(g_1-\frac{1}{2}g_2)}{m_\Sigma-m_N}\gamma_5-\frac{\frac{1}{2}a'g_3}{m_\Lambda-m_N}\gamma_5\right]\Sigma^+(p). \quad (3)$$

If we take $a'=a$ and $b'=b$, S_+ will involve m_Σ as well as m_Λ, and the effect of the mass difference $m_\Sigma-m_\Lambda$ will not be negligible. We, therefore, choose a' and b' such that

$$\frac{a'}{m_\Lambda-m_N}=\frac{a}{m_\Sigma-m_N},\quad \frac{a'b'}{m_\Lambda+m_N}=\frac{ab}{m_\Sigma+m_N}, \quad (4)$$

and thus (3) can be expressed in a form, which is independent of m_Λ, as

$$S_+=(2\pi)^4\delta(p-p'-q)\sqrt{2}\pi^{+*}(q)a \times\bar{n}(p')\left[-\frac{b(g_1+\frac{1}{2}g_2+\frac{1}{2}g_3)}{m_\Sigma+m_N} +\frac{g_1-\frac{1}{2}g_2-\frac{1}{2}g_3}{m_\Sigma-m_N}\gamma_5\right]\Sigma^+(p). \quad (5)$$

Similarly, the S-matrix elements for the decays $\Sigma^-\to n+\pi^-$, $\Sigma^+\to p+\pi^0$, and $\Lambda\to p+\pi^-$, are given by

$$S_-=(2\pi)^4\delta(p-p'-q)\sqrt{2}\pi^{-*}(q)a \times\bar{n}(p')\left[\frac{\frac{1}{2}b(g_2-g_3)}{m_\Sigma+m_N}+\frac{\frac{1}{2}(g_2-g_3)}{m_\Sigma-m_N}\gamma_5\right]\Sigma^-(p), \quad (6)$$

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[4] This postulate has some resemblance with the doublet approximation of A. Pais, Phys. Rev. **122**, 317 (1961); Rev. Mod. Phys. **33**, 493 (1961). It should be noted that while Pais suggests a neglect of the Σ-Λ mass difference, we achieve the same effect by a suitable choice of the coupling constants without neglecting the Σ-Λ mass difference.

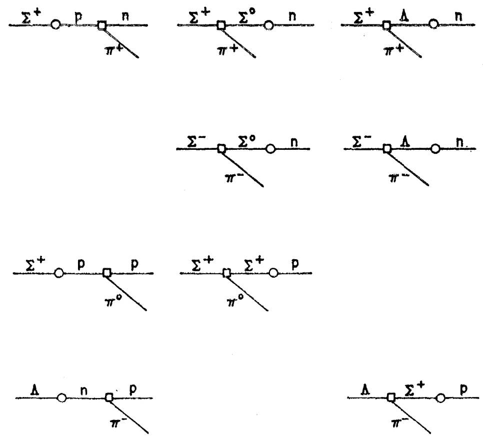

FIG. 1. Diagrams for the decay modes $\Sigma^+ \to n+\pi^+$, $\Sigma^- \to n+{}^-\pi$, $\Sigma^+ \to p+\pi^0$, and $\Lambda \to p+\pi^-$.

$$S_0=(2\pi)^4\delta(p-p'-q)\pi_0(q)a \times\bar{p}(p')\left[-\frac{b(g_1+g_2)}{m_\Sigma+m_N}+\frac{g_1-g_2}{m_\Sigma-m_N}\gamma_5\right]\Sigma^+(p), \quad (7)$$

and

$$S_\Lambda=(2\pi)^4\delta(p-p'-q)\pi^{-*}(q)a \times\bar{p}(p')\left[-\frac{b(g_1+g_3)}{m_\Sigma+m_N}+\frac{g_1-g_3}{m_\Sigma-m_N}\gamma_5\right]\Lambda(p), \quad (8)$$

respectively.

III. ASYMMETRY PARAMETERS IN Σ AND Λ DECAYS

We consider the Σ and Λ decays at rest, and as usual denote the asymmetry parameters in the various decay modes as α_+, α_-, α_0, and α_Λ. Experimental results show that $\alpha_+\approx 0$, $\alpha_-\approx 0$, $\alpha_0\approx 1$, and $\alpha_\Lambda\approx -1$, but the precise values of these parameters are not yet known.

We can obtain $\alpha_+=0$ from (5) by taking

$$2g_1-g_2-g_3=0$$

or

$$g_1-g_2=-(g_1-g_3). \quad (9)$$

In order to obtain $\alpha_0\approx 1$ from (7), we must take

$$-\frac{b(g_1+g_2)}{m_\Sigma+m_N}\approx-\left(\frac{g_1-g_2}{m_\Sigma-m_N}\right)\left(\frac{|\mathbf{p}|}{m_N+E_N}\right)$$

or

$$b\approx\left(\frac{g_1-g_2}{g_1+g_2}\right)\left(\frac{m_\Sigma+m_N}{m_\Sigma-m_N}\right)\left(\frac{|\mathbf{p}|}{m_N+E_N}\right), \quad (10)$$

where $|\mathbf{p}|$ and E_N are the momentum and energy of the final nucleon when Σ decays at rest. Further, assuming that $|\alpha_-|\ll 1$, we find from (6) that

$$\alpha_-\approx-2b\left(\frac{m_\Sigma-m_N}{m_\Sigma+m_N}\right)\left(\frac{m_N+E_N}{|\mathbf{p}|}\right)$$

or

$$b\approx-\frac{\alpha_-}{2}\left(\frac{m_\Sigma+m_N}{m_\Sigma-m_N}\right)\left(\frac{|\mathbf{p}|}{m_N+E_N}\right). \quad (11)$$

Since

$$\left(\frac{m_\Sigma+m_N}{m_\Sigma-m_N}\right)\left(\frac{|\mathbf{p}|}{m_N+E_N}\right)\approx 1, \quad (12)$$

it follows from (10) and (11) that

$$b\approx(g_1-g_2)/(g_1+g_2)\approx-\alpha_-/2. \quad (13)$$

Thus, $|b|$ is small compared with 1, and taking the rough value $\alpha_-\approx 0.16$, obtained by Tripp *et al.*,[5] we get

$$b\approx(g_1-g_2)/(g_1+g_2)\approx-0.08. \quad (14)$$

We observe that $(g_2-g_1)/(g_2+g_1)$ is of the same order as $(m_\Sigma-m_N)/(m_\Sigma+m_N)$, and it is rather satisfying that the g splittings and m splittings for baryons are of the same order, because it suggests the interesting possibility that both splittings are caused by the same agency.

Since our treatment satisfies the $|\Delta I|=\frac{1}{2}$ rule, and $\alpha_+=0$, $|\alpha_-|\ll 1$, $\alpha_0\approx 1$, the decay rates for $\Sigma^+\to n+\pi^+$, $\Sigma^-\to n+\pi^-$, and $\Sigma^+\to p+\pi^0$ are nearly equal. This result can also be derived from the matrix elements (5), (6), and (7).

Finally, the asymmetry parameter in Λ decay, as derived from (8), is $\alpha_\Lambda\approx -1$. The difference in the signs of α_0 and α_Λ, which agrees with the experimental result of Beall *et al.*,[6] is essentially a consequence of the relation (9). The matrix element (8) further shows that the decay rate and the ratio of the P and S amplitudes for $\Lambda\to p+\pi^-$ are appreciably different from those for $\Sigma^+\to p+\pi^0$, and these theoretical results also are in reasonable agreement with experiments.

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