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Nonleptonic Decay Modes of the Hyperons

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An attempt is made to correlate the observed asymmetries in hyperon decays and the hyperon decay times using a pole approximation to the decay matrix elements. It is found that a natural correlation is obtained if a near-global relation between pion coupling constants is assumed.

THE relation between the strong pion-nucleon coupling constant, the weak axial vector constant, and the leptonic decay rate of the pion was first obtained by Goldberger and Treiman.[1] This has recently been shown to arise directly from the pole term in the dispersion relation for the appropriate matrix element of the derivative of the axial vector current.[2] The argument can be generalized immediately to the leptonic decay modes of the strange particles.[3] We attempt here an interpretation of the nonleptonic decay modes of the hyperons, on the assumption that these too are dominated by the pole terms. These pole terms arise by considering the matrix elements as functions of the three external masses.

Our procedure is as follows. We assume the $\Delta I=\frac{1}{2}$ rule. We then show that the observed vanishing of the Σ asymmetry parameters α_+ and α_- (see below) strongly suggests global (or near global) symmetry of the pion couplings. With these strong-coupling constants and by choosing essentially one further parameter, we are able to correlate Λ,Σ decay times and asymmetries. Other authors[4] have considered the same problem by making use of specific global Lagrangians. The difference in our work lies in its stress on a "dispersion" rather than a Lagrangian approach and, in particular, in the inclusion of a K-meson pole pictured in Fig. 1(c).

The poles are represented graphically in Fig. 1. The strong-interaction vertex is by definition the corresponding renormalized coupling constant. We assume that the weak vertices satisfy $\Delta I=\frac{1}{2}$. The Y-N vertex is then of form

$$f(a_Y+b_Y\gamma_5), \quad (Y=\Sigma,\Lambda). \tag{1}$$

The K-π vertex is

$$f_K.$$

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[1] M. L. Goldberger and S. B. Treiman, Phys. Rev. **110**, 1478 (1958).

[2] J. Bernstein, S. Fubini, M. Gell-Mann, and W. Thirring (to be published). See also Y. Nambu, Phys. Rev. Letters **4**, 380 (1960).

[3] J. Prentki (private communication).

[4] B. d'Espagnat and J. Prentki, Phys. Rev. **114**, 1366 (1959); R. F. Sawyer, Phys. Rev. **112**, 2135 (1958); S. A. Bludman, Phys. Rev. **115**, 468 (1959); S. B. Treiman, Nuovo cimento **15**, 916 (1960).

Introduce[5]

$$h_Y=fa_Y/(Y-N), \tag{2}$$

$$\sigma^2=\frac{a_\Sigma}{b_\Sigma}\frac{\Sigma+N}{\Sigma-N}, \quad \lambda^2=\frac{a_\Lambda}{b_\Lambda}\frac{\Lambda+N}{\Lambda-N}. \tag{3}$$

The matrix element[6] for $\Sigma^+\rightarrow n+\pi^+$ is

$$T_+=A^++\gamma_5B^+, \tag{4}$$

where

$$A^+=-(2g+g_{\pi\Sigma})\frac{h_\Sigma}{\sigma^2}-g_{\pi\Lambda}\frac{h_\Lambda}{\lambda^2}, \tag{5}$$

$$B^+=(2g-g_{\pi\Sigma})h_\Sigma-g_{\pi\Lambda}h_\Lambda. \tag{6}$$

Similarly for

$$\Sigma^-\rightarrow n+\pi^-,$$

$$A^-=\frac{g_{\pi\Sigma}h_\Sigma}{\sigma^2}-\frac{g_{\pi\Lambda}h_\Lambda}{\lambda^2}, \tag{7}$$

$$B^-=g_{\Sigma\pi}h_\Sigma-g_{\Lambda\pi}h_\Lambda-2F_\Sigma, \tag{8}$$

where

$$F_Y=f_Kg_{KY}/(K^2-\pi^2). \tag{9}$$

The matrix element T_0 for

$$\Sigma^+\rightarrow p+\pi^0$$

is determined by the $\Delta I=\frac{1}{2}$ rule to be

$$T_0=(1/\sqrt{2})(T_+-T_-). \tag{10}$$

If for the moment we neglect Σ,Λ differences (i.e., $\sigma=\lambda$, $h_\Sigma=h_\Lambda$), and assume $g_{\pi\Sigma}=g_{\pi\Lambda}$, then A^- vanishes identically.

If further

$$g=g_{\pi\Sigma}=g_{\pi\Lambda}, \tag{11}$$

then B^+ is also zero, and the corresponding asymmetry parameters α_+ and α_- vanish, in agreement with experiment. Since exact global symmetry is perhaps not realized in nature,[7] we use as exact experimental results $\alpha_+=\alpha_-=0$ to determine the renormalized pion constants. Thus

$$A^-=B^+=0 \tag{12}$$

[5] Σ, Λ, N, K, π denote the masses of the corresponding particles and $g=g_{N\pi}$.

[6] We are assuming the $\Sigma-\Lambda$ parity even and $\Lambda-K$ parity odd.

[7] See A. Salam, Ninth Annual International Conference on High-Energy Physics, Kiev, July, 1959 (unpublished).

TABLE I. Deviations from global symmetry of pion coupling constants.

a_Σ/b_Σ	a_Λ/b_Λ	$g_{\pi\Sigma}/g$	$g_{\pi\Lambda}/g$
$(\Sigma+N)/(\Sigma-N)$	$(\Lambda+N)/(\Lambda-N)$	0.70	0.95
1	1	0.85	0.82
$(\Sigma-N)/(\Sigma+N)$	$(\Lambda-N)/(\Lambda+N)$	1	1

implies

$$g_{\Sigma\pi}=g\frac{2\sigma^2}{\sigma^2+\lambda^2},\quad g_{\Lambda\pi}=g\frac{h_\Sigma}{h_\Lambda}\frac{2\lambda^2}{\sigma^2+\lambda^2}. \tag{13}$$

Although these constants depend on the undetermined parameters a and b [Eq. (1)], nevertheless, they are insensitive to a reasonable range of values of a and b. See Table I.

Using the observed relation of decay rates,[8]

$$w_+=w_-, \tag{14}$$

one can now determine F_Σ, which in contrast to (13), is sensitive to the ratio a/b. Using this and the coupling constants (13), the amplitude for

$$\Lambda\rightarrow p+\pi^-$$

is

$$T_\Lambda=A_\Lambda+\gamma_5 B_\Lambda, \tag{15}$$

where

$$A_\Lambda=-\sqrt{2}\frac{g}{h_\Lambda}\left[\frac{h_\Lambda^2}{\lambda^2}+2h_\Sigma^2\frac{\lambda^2}{\sigma^2(\sigma^2+\lambda^2)}\right], \tag{16}$$

$$B_\Lambda=\sqrt{2}\left\{\frac{g}{h_\Lambda}\left[h_\Lambda^2-2h_\Sigma^2\frac{\lambda^2}{\sigma^2+\lambda^2}\right]+F_\Lambda\right\}. \tag{17}$$

Again some properties of Λ decay turn out to be insensitive to the choice of a and b given in Table I. The s-wave part A_Λ always lies within a few percent of A^0 (the s-wave part of $\Sigma^+\rightarrow p+\pi^0$) and the asymmetry α_Λ is always approximately equal to unity (within 5%) provided we choose F_Λ (i.e., $g_{K\Lambda}/g_{K\Sigma}$) to fit the observed Λ/Σ decay rates. It is remarkable that there exists a solution for F_Λ such that $(g_{K\Lambda}/g_{K\Sigma})^2$ lies consistently between 1 and 3 for all a and b. The value 3 is in agreement with the "pole" approximation to the K^++N elastic scattering data.[9] Also, we find that $\mathrm{sign}(\alpha_\Lambda/\alpha_0)=-\mathrm{sign}(g_{K\Lambda}/g_{K\Sigma})$. See also d'Espagnat and Prentki.[4]

We can state our conclusions as follows. We use the "pole approximation" to the nonleptonic decays and assume a $\Delta I=\frac{1}{2}$ rule in the weak interaction. Then as a consequence of $\alpha_+=\alpha_-=0$ we find an almost global relation [Eq. (13)] amongst the coupling constants. The result is true for all choices of a and b. Next we use $w_+=w_-$ to fit the relative strengths of the weak "vertices" $Y\rightarrow N$ and $K\rightarrow\pi$. This fit is sensitive to the values of a and b appearing in the (Y,N) vertex and presumably should be predicted by some future theory of weak interactions. We still find, however, that for a range of values for a and b the s-wave part of the Λ decay is essentially the same as the s wave in $\Sigma^+\rightarrow p+\pi^0$ decay and thus by choosing $g_{K\Lambda}/g_{K\Sigma}$ to fit w_Λ/w_Σ, almost 100% asymmetry is assured in Λ decay.

[8] It may be remarked that since T_+ is pure s wave and T_- is pure p wave, (14) is equivalent to $|\alpha_0|=1$ from the $\Delta I=\frac{1}{2}$ rule.

[9] P. T. Matthews and A. Salam, Nuovo cimento **7**, 789 (1958).

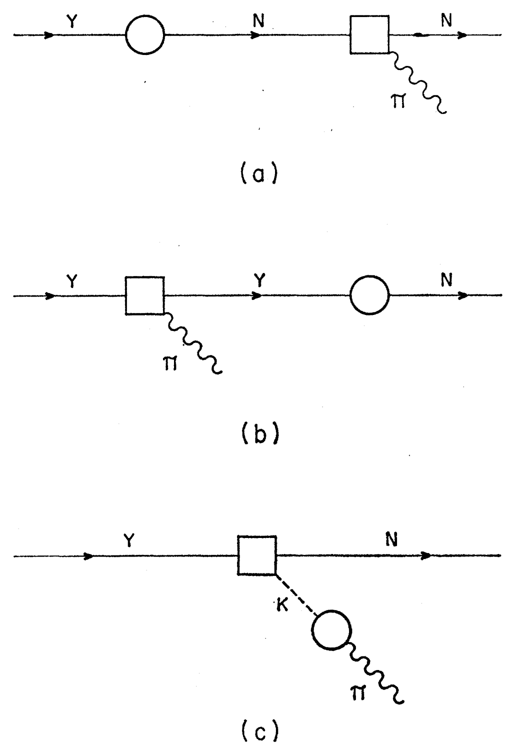

FIG. 1. Graphical representation of the pole terms appearing in hyperon decay into a nucleon and pion. The black box is a purely strong interaction, while the circle involves the weak interaction.

One could now use the same approximation to predict $\Sigma^+\rightarrow p+\gamma$, and $\Lambda\rightarrow n+\gamma$ rates and asymmetries. These rates are proportional to the anomalous moments of the hyperons. However, they are also proportional to the constants a and b which in principle can be determined from the main decay modes.

The remarkable success of the "pole" approximation in predicting the π-decay rate[2] prompts us to believe that the procedure outlined here may provide a reasonable method for determining the magnitudes and signs of the renormalized strong coupling constants, ($g_{\pi\Lambda}$,$g_{\pi\Sigma}$ and $g_{K\Lambda}/g_{K\Sigma}$, as well as the Ξ coupling constants when experimental data becomes available). A further check on the values of $g_{K\Lambda}$, $g_{K\Sigma}$, and $g_{\pi\Lambda}$ would be provided by the leptonic decays

$$Y\rightarrow N+e+\nu,$$
$$\Sigma\rightarrow\Lambda+e+\nu,$$

as discussed in references 2 and 3.