Title

A SELF-CONSISTENT MODEL FOR NONLEPTONIC DECAYS OF u AND-A HYPERONS

Authors

Singh, Virenda
Udgaonkar, Bhalchandra M.

Publication Date

1961-09-20

UCRL-9863
Limited distribution

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

A SELF-CONSISTENT MODEL FOR NONLEPTONIC DECAYS OF Σ AND Λ HYPERONS

Virendra Singh and Bhalchandra M. Udgaonkar

September 20, 1961

UCRL-9863

A SELF-CONSISTENT MODEL FOR NONLEPTONIC DECAYS OF Σ AND Λ HYPERONS

Virendra Singh and Bhalchandra M. Udgaonkar

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 20, 1961

ABSTRACT

A self-consistent calculation of pionic Σ and Λ decays has been carried out in the pole approximation of an S-matrix approach in order to get information on (a) the angular momentum in which the decay $\Sigma^+ \rightarrow n\pi^+$ takes place, (b) the relative $(\Sigma\Lambda)$ parity, (c) the possible existence of other than global symmetric solutions. On the basis of existing experimental data the model predicts that $\Sigma^+ \rightarrow n\pi^+$ decay must occur in the S-wave, and, somewhat less definitely, that $(\Sigma\Lambda)$ parity is even. It is interesting that even though the model does not start from the global-symmetry hypothesis, it indicates the global-symmetric solutions be to the most reasonable.

A SELF-CONSISTENT MODEL FOR NONLEPTONIC DECAYS OF Σ AND Λ HYPERONS*

Virendra Singh† and Bhalchandra M. Udgaonkar§

Lawrence Radiation Laboratory
University of California
Berkeley, California

September 20, 1961

INTRODUCTION

Recently, Beall et al. have established that the helicities of the protons in the nonleptonic decays of Σ^+ and Λ^o are opposite.[1] This result, while confirming an important prediction of the global-symmetry hypothesis, contradicts the predictions of several other models of hyperon decay. In particular, it disagrees with the bound-pion model of Barshay and Schwartz,[2] in which the Λ decay is taken as the primary decay, and thus invalidates one of the arguments used by Nambu and Sakurai in favor of odd Σ-Λ parity.[3] We have, therefore, considered a simple self-consistent model in which both these decays are treated as equally fundamental, with parameters to be determined by requirements of consistency. We have then tried to seek answers to the following questions: (1) Are there solutions other than the global-symmetric one that fit the experimental data? (2) Does odd Σ-Λ parity fit the data better, or vice versa? (3) Can one predict which of the two decays--$\Sigma^+ \rightarrow n\pi^+$ or $\Sigma^- \rightarrow n\pi^-$--goes into s-wave and which into p-wave? With regard to the last question, it has been well known for some time, from the experimental data on the Σ triangle of Gell-Mann and Rosenfeld,[4,5] that one of these decays must go into s-wave and the other into p-wave, but

THE MODEL

Ours is essentially an S-matrix approach carried out in the pole approximation which has given reasonable results in the theory of strong interactions and also been successful in the treatment of the π decay. The diagrams considered are shown in Fig. 1. The contributions of the black boxes to the matrix elements are shown in the figure.[6] Here g_N, g_Λ, g_Σ are coupling constants; a_Λ, a_Σ, b_Λ, b_Σ (as also g_Λ, g_Σ) are to be fitted from experiment;[10] and Γ takes the value γ_5 or 1 according as the relative $\Sigma\Lambda$ parity is even or odd. Time-reversal invariance implies that b_Λ and b_Σ are real. Then the matrix elements for $\Sigma^+ \to p\pi^0$, $\Sigma^+ \to n\pi^+$, and $\Sigma^- \to n\pi^-$ respectively are given by

$$M_0 = \sqrt{2}\ \left\{ B_\Sigma (g_\Sigma + g_N) + i\,\gamma_5\, A_\Sigma (g_\Sigma - g_N)\right\} ,$$

$$M_+ = \left\{ B_\Lambda g_\Lambda - B_\Sigma (g_\Sigma + 2g_N) + i\,\gamma_5 \left[A_\Lambda g_\Lambda - A_\Sigma (g_\Sigma - 2g_N)\right]\right\} ,$$

and

$$M_- = \left\{ B_\Lambda g_\Lambda + B_\Sigma g_\Sigma + i\,\gamma_5 \,(A_\Lambda g_\Lambda + A_\Sigma g_\Sigma)\right\} .$$

Here we define

$$B_\Sigma = (a_\Sigma b_\Sigma)/(m_\Sigma + m_N) \quad \text{and} \quad A_\Sigma = a_\Sigma/(m_\Sigma - m_N) ,$$

$$B_\Lambda = a_\Lambda b_\Lambda/ (m_\Lambda + m_N) \quad \text{and} \quad A_\Lambda = a_\Lambda/(m_\Lambda - m_N)$$

for $\Gamma = \gamma_5$, and

$$B_\Lambda = i\, a_\Lambda/(m_\Lambda - m_N) \quad \text{and} \quad A_\Lambda = i\, a_\Lambda b_\Lambda/(m_\Lambda + m_N)$$

for $\Gamma = 1$. Also, we have

$$M_\Lambda = \sqrt{2} \left\{ (B_\Lambda g_N - B_\Sigma g_\Lambda) - i\gamma_5 (A_\Lambda g_N + A_\Sigma g_\Lambda) \right\}$$

for $\Gamma = \gamma_5$, and

$$M_\Lambda = - \sqrt{2}\ i \left\{ (A_\Lambda g_N + A_\Sigma g_\Lambda) - i\gamma_5 (B_\Lambda g_N - B_\Sigma g_\Lambda) \right\}$$

for $\Gamma = 1$. Introducing the conditions that the asymmetries in $\Sigma^+ \rightarrow n\pi^+$ and $\Sigma^- \rightarrow n\pi^-$ are zero, and that the s/p ratios in $\Sigma^+ \rightarrow p\pi^0$ and $\Lambda \rightarrow p\pi^-$ decays have values x_0 and x_Λ, respectively, we can eliminate the A_Λ, A_Σ, B_Λ, and B_Σ and get a relation between the various strong-coupling constants. Another relation between the coupling constants is given by the ratio $|M_\Lambda| / |M_0|$, which is known from the measured life-times of Σ and Λ.[11] We now have four cases to consider: $\Gamma = 1$ or γ_5; and pure s-wave or pure p-wave in $\Sigma^+ \rightarrow n\pi^+$. The corresponding relations between the coupling constants are given below:

Case I. $\Gamma = \gamma_5$; $\Sigma^+ \to n\pi^+$ s-wave

$$\frac{(g_\Sigma - g_N)(g_\Lambda^2 + g_\Sigma g_N)}{(g_\Sigma + g_N)(g_\Lambda^2 + g_\Sigma g_N - 2g_N^2)} = \frac{x_\Lambda \mu_\Lambda}{x_0 \mu_\Sigma}$$

$$\frac{g_\Lambda^2 + g_\Sigma g_N}{g_\Lambda (g_\Sigma + g_N)} = \pm \frac{|M_\Lambda|}{|M_0|} \left(\frac{1+x_0^2}{1+x_\Lambda^2} \cdot \frac{x_\Lambda^2}{x_0^2} \right)^{1/2}$$

Case II. $\Gamma = \gamma_5$; $\Sigma^+ \to n\pi^+$ p-wave

$$\frac{(g_\Sigma - g_N)\ (g_\Lambda^2 - g_\Sigma g_N - 2g_N^2)}{(g_\Sigma + g_N)(g_\Lambda^2 - g_\Sigma g_N)} = \frac{x_\Lambda \mu_\Lambda}{x_0 \mu_\Sigma}$$

$$\frac{g_\Lambda^2 - g_\Sigma g_N}{g_\Lambda\ (g_\Sigma - g_N)} = \pm \frac{|M_\Lambda|}{|M_0|} \left(\frac{1 + x_0^2}{1 + x_\Lambda^2} \cdot \frac{\mu_\Sigma^2}{\mu_\Lambda^2} \right)^{1/2}$$

Case III. $\Gamma = 1$; $\Sigma^+ \to n\pi^+$ s-wave

$$\frac{(g_\Sigma - g_N)(g_\Lambda{}^2 + g_\Sigma g_N)}{(g_\Sigma + g_N)(g_\Lambda{}^2 + g_\Sigma g_N - 2g_N{}^2)} = \frac{1}{x_0 \, x_\Lambda \, \mu_\Sigma \, \mu_\Lambda}$$

$$\frac{g_\Lambda{}^2 + g_\Sigma g_N}{g_\Lambda (g_\Sigma + g_N)} = \pm \frac{|M_\Lambda|}{|M_0|} \left(\frac{1+x_0{}^2}{1+x_\Lambda{}^2} \right)^{1/2} \frac{1}{x_0 \, \mu_\Lambda}$$

Case IV. $\Gamma = 1$, $\Sigma^+ \to n\pi^+$ p-wave

$$\frac{(g_\Sigma - g_N)(g_\Lambda{}^2 - g_\Sigma g_N - 2g_N{}^2)}{(g_\Sigma + g_N)(g_\Lambda{}^2 - g_\Sigma g_N)} = \frac{1}{x_0 \, x_\Lambda \, \mu_\Sigma \, \mu_\Lambda}$$

$$\frac{g_\Lambda{}^2 - g_\Sigma g_N}{g_\Lambda (g_\Sigma - g_N)} = \pm \frac{|M_\Lambda|}{|M_0|} \cdot x_\Lambda \, \mu_\Sigma \left(\frac{1+x_0{}^2}{1+x_\Lambda{}^2} \right)^{1/2} .$$

Here μ_Λ and μ_Σ...kinematical factors for Λ and Σ decays, respectively--are given by

$$\mu_\Lambda = \frac{q_\Lambda}{E_\Lambda + m_N} \simeq 0.053$$

and

$$\mu_\Sigma = \frac{q_\Sigma}{E_\Sigma + m_N} \simeq 0.10 ,$$

where q_Λ and q_Σ are the momenta, and E_Λ and E_Σ, the energies of the proton in the decays at rest of Λ and Σ, respectively. When the $|\Delta T| = 1/2$ rule is assumed in the analysis of experimental data, x_0 is known to be[5] very nearly -1, while x_Λ has a greater uncertainty attached to it. For further discussion, we shall take $x_0 = - x_\Lambda = -1$, and $|M_\Lambda|/|M_0| = 1$ which values are consistent with the experimental data. To simplify the calculations, we will also take $\mu_\Lambda/\mu_\Sigma = 1/2$ (instead of the actual value of ~ 0.53). We then get the following solutions for the coupling constants.

Case I. $\Gamma = \gamma_5$, $\Sigma^+ \to n\pi^+$ s-wave

$$g_\Sigma = -\frac{2}{3} g_N$$

$$g_\Lambda{}^2 = g_\Sigma{}^2 = \frac{4}{9} g_N{}^2$$

Case II. $\Gamma = \gamma_5$, $\Sigma^+ \to n\pi^+$ p-wave

$$g_\Sigma = -\frac{5}{3} g_N$$

$$g_\Lambda{}^2 = \frac{g_\Sigma{}^2}{25} = \frac{g_N{}^2}{9}$$

Case III. $\Gamma = 1$, $\Sigma^+ \to n\pi^+$ s-wave

$$g_\Sigma \simeq -g_N$$

$$g_\Lambda{}^2 \simeq 3g_N{}^2$$

Case IV. $\Gamma = 1$, $\Sigma^+ \to n\pi^+$ p-wave

$$g_\Sigma \simeq 0.02\, g_N$$

$$g_\Lambda{}^2 \simeq 100 g_\Sigma{}^2 \simeq 0.04 g_N{}^2$$

DISCUSSION

In the absence of definite knowledge of any of the strong strange-particle coupling constants, it is impossible to make a clear choice between the four cases considered. It appears, however, to be a reasonable demand that g_Λ^2 and g_Σ^2 be comparable with each other and be roughly of the same order as the πN coupling constant g_N^2. In that case our results above may be regarded as an indication that the decay $\Sigma^+ \to n\pi^+$ takes place in the s-wave. If it took place in the p-wave, one would have $g_\Sigma^2 \simeq 25 g_\Lambda^2$ for the case of even Σ-Λ parity, and $g_\Lambda^2 \simeq 100 \ g_\Sigma^2 \simeq 0.04 g_N^2$ for the case of odd Σ-Λ parity. The question of relative Σ-Λ parity is more difficult to decide. But if g_Λ^2 and g_Σ^2 are to be $\simeq g_N^2$, we are left with $\Gamma = \gamma_5$, i.e. even Σ-Λ parity. It may be noticed that this is just the global-symmetry case $(g_\Sigma^2 = g_\Lambda^2)$, and it is interesting that our model, which starts off on quite different premises, ends up by excluding almost every other possibility except global symmetry, particularly if one assumes that Σ Λ parity is even.[12]

Once we have thus chosen the g's, the parameters a_Λ, a_Σ, b_Λ, and b_Σ are completely determined in this self-consistent model. We will not, however, give expressions for them since we have no way of deciding what should be the reasonable values for them until we have analyzed the weak boxes further. When that is done, we hope we can make more definite statements about all these questions and about the relative Σ-Λ parity in particular. It may also be remarked that in the above calculation, only the relative sign of x_0 and x_Λ has been used, and not the absolute sign of either. The latter affects only the signs of a's and b's.

We would like to remark upon the relation of our model to the similar models of Feldman et al.[13], and of Wolfenstein.[14] Feldman et al. take

K poles also into account, in the spirit of a completely dispersion theoretical approach, where no particles are to be regarded as more fundamental than others. In doing so, however, they introduce two additional parameters-- $(g_{K\Lambda}\, f_K)$, $(g_{K\Sigma}\, f_K)$, where f_K is the strength of the $K\pi$ vertex--into a problem in which there are already a large number of parameters. It is then impossible to make a definite statement on any of the questions to which we have sought answers. In fact, it is impossible even to predict the relative helicity of the protons in the Σ^+ and Λ decays, which depends on the sign $(g_{K\Sigma}/g_{K\Lambda})$ in the case considered by them in detail. In our model, on the other hand, the same helicity for the proton is almost definitely ruled out if the relative Σ-Λ parity is even, since a fit requires $g_\Sigma = 2g_N$, $g_\Lambda = \pm 2g_N$ for $\Sigma^+ \to n\pi^+$ going in s-wave, and $g_\Sigma^2 = (8.5 \pm 2.9)\, g_N^2$, $g_\Lambda^2 = (g_\Sigma + 2g_N)^2$, for $\Sigma^+ \to n\pi^+$ going in p-wave. The choice is more difficult in the case of odd Σ-Λ parity, since the values of the coupling constants turn out to be practically the same as those which give rise to opposite proton helicities in the two decays.

Wolfenstein's model assumes that K decay is the more fundamental decay and that Σ and Λ decays are secondary. He therefore neglects baryon poles completely, but has to include two-particle intermediate states. His model, like that of Feldman et al., also has (KYN) vertices, and his prediction regarding the angular-momentum states involved in $\Sigma^\pm$ decays into a neutron depends on the (KYN) and $(\Sigma\Lambda)$ particles assumed. Further, while in our model the fact that $\Sigma^+ \to n\pi^+$ goes into s-wave and $\Sigma^- \to n\pi^-$ into p-wave is due to a dynamical concellation between various diagrams, in the model of Wolfenstein, the Σ^+ goes into s-wave only because a certain parity is assumed for the K meson and for $(\Sigma\Lambda)$, so that only a single diagram (K-pole diagram) contributes to it.[15]

A word about our omission of other diagrams which would be included in a complete S-matrix approach. The lowest mass two-particle diagram has a pion and a nucleon in the intermediate state. Because the $J = 1/2\,\pi N$ interaction is known to be small at the relevant energies, the contribution of this diagram may be expected to be small. The πY intermediate-state diagrams would be expected to make an even smaller contribution. As for the K-pole diagrams, it has often been conjectured that the K couplings are weak compared to the π couplings, and the fact that we are able to fit experimental data without the inclusion of these diagrams may be regarded as an a posteriori indication that K couplings are indeed small.

ACKNOWLEDGMENTS

We wish to thank Dr. O. W. Greenberg for an interesting discussion. One of us(B.M.U.) wishes to thank Dr. David L. Judd for his hospitality at the Lawrence Radiation Laboratory.

REFERENCES AND FOOTNOTES

* This work was done under the auspices of the U. S. Atomic Energy Commission.

† On deputation from Tata Institute of Fundamental Research, Bombay, India.

§ On deputation from Atomic Energy Establishment Trombay, Bombay, India.

1. E. F. Beall, B. Cork, D. Keefe, P. G. Murphy, and W. A. Wenzel, Asymmetry Parameters in the Decays $\Sigma^+ \rightarrow p + \pi^0$ and $\Lambda \rightarrow p + \pi^-$, Lawrence Radiation Laboratory Report UCRL-9820, Aug. 22, 1961 (unpublished).
2. S. Barshay and M. Schwartz, Phys. Rev. Letters 4, 618 (1960).
3. Y. Nambu and J. J. Sakurai, Phys. Rev. Letters 6, 377 (1961).
4. M. Gell-Mann and A. H. Rosenfeld, in Annual Reviews of Nuclear Science (Annual Review, Inc., Palo Alto, Calif.) 1957, Vol. 7, p. 407.
5. B. Cork, L. Kerth, W. A. Wenzel, J. W. Cronin, and R. L. Cool, Phys. Rev. 120, 100 (1960).
6. We have used the $|\Delta T| = 1/2$ rule in writing these contributions. Until the recent experimental results of Beal et al., (Ref. 3), Fowler et al., (Ref. 7), and Leitner et al., (Ref. 8), there has always been the possibility, emphasized by Okubo, Marshak, and Sudarshan (Ref. 9) that the $|\Delta T| = 1/2$ rule for Λ decays could be accidental, since the same branching ratio in Λ decay is also predicted by the current-current form of the universal Fermi interaction which violates the $|\Delta T| = 1/2$ rule. However, the prediction of the latter theory that the proton helicity in Λ decay must be negative is contradicted by these experiments, and one is now left with the $|\Delta T| = 1/2$ rule as the only explanation of the observed branching ratio in Λ decay.
7. W. B. Fowler, R. W. Birge, P. Eberhard, R. Ely, M. L. Good, W. M. Powell, and H. K. Ticho, Phys. Rev. Letters 6, 134 (1961).

8. J. Leitner, L. Gray, E. Harth, S. Lichtman, M.Block, B. Brucker, A. Engler, R. Gessaroli, A. Kovacs, T. Kikuchi, C. Meltzer, H. O. Cohn, W. Bugg, A. Pevsner, P. Schein, M. Meer, N. T. Grinellini, L. Lendinara, L. Monari, and G. Puppi, Office of Naval Research Report ONRL-61-4, July 1, 1961(unpublished).

9. S. Okubo, R. E. Marshak, and E. C. G. Sudarshan, Phys. Rev. 113, 944(1959).

10. These six parameters have to fit six experimental numbers--four decay asymmetries and two lifetimes. However, it is not obvious that a fit will be obtainable with reasonable values of the coupling constants.

11. For recent measurements of the lifetimes, see William E. Humphrey, Hyperon Production by K^- Mesons Incident on Hydrogen, Lawrence Radiation Laboratory Report UCRL-9752 (June 12, 1961).

12. Note that our result $g_\Sigma^2 = g_\Lambda^2$ refers to the renormalized coupling constants of conventional field theory, and not to bare coupling constants as in the usual symmetry schemes based on Lagrangians.

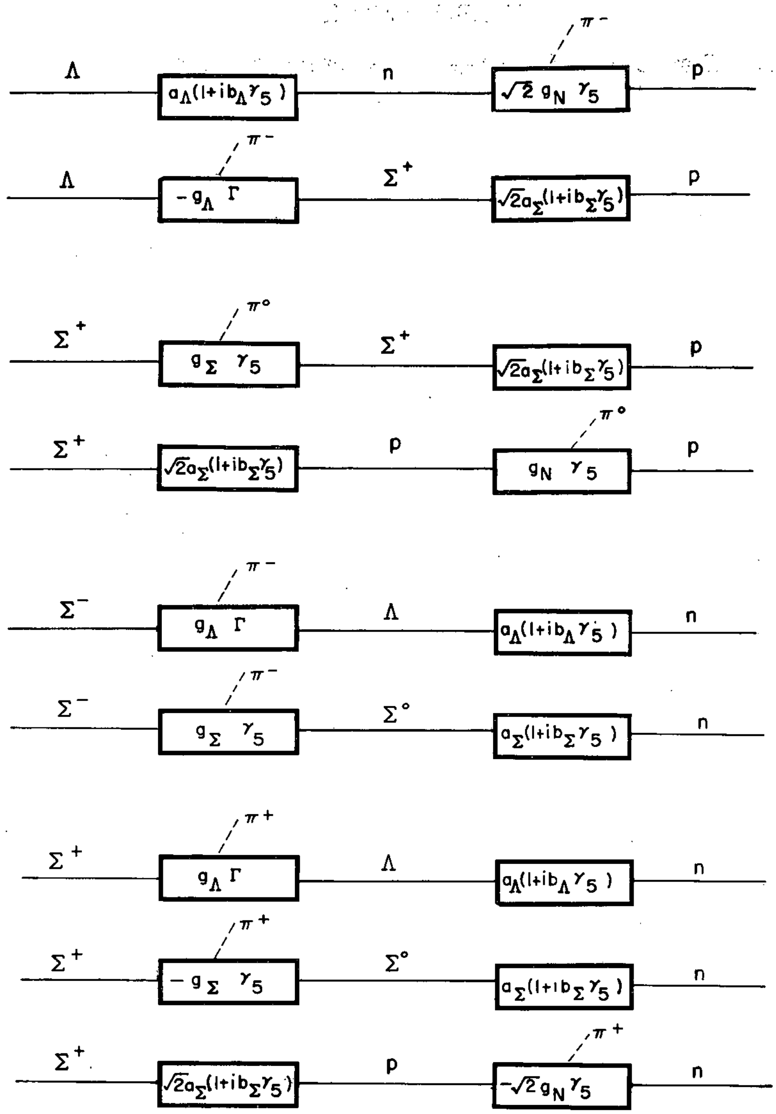
13. G. Feldman, P. T. Mathews, and A. Salam, Phys. Rev. 121 , 302 (1961).

14. L. Wolfenstein, Phys. Rev. 121 , 1245 (1961).

15. Wolfenstein's expressions could be used to evaluate g_Σ/g_Λ from his model in the way we have done. In the case considered by him, if one assumes $x_0 = -x_\Lambda$ and $|M_\Lambda| = |M_0|$, one is led to $g_\Lambda = g_\Sigma$ in his model too. It is curious that with both our model, which includes only baryon poles and excludes K poles, and Wolfenstein's model, which excludes baryon poles, one is led to a global-symmetric solution.

FIGURE LEGEND

Fig. 1. Diagrams for Σ and Λ decays via baryon poles.



MU-24797

Fig. 1.