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How Large Are Soft-Pion s-Wave Nonleptonic Hyperon-Decay Amplitudes?

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ABSTRACT

We discuss alternative theoretical schemes for description of the hyperon nonleptonic decays. The soft-pion amplitude $a_{BB'} = \left\langle B' | H_W^{PC} | B \right\rangle$ which enters into the calculation of s-wave (A) and p-wave (B) decay amplitudes can have value $a \sim A_{exp}$ $(B(a) < B_{exp})$ or $a > A_{exp}$ $(B(a) \sim B_{exp})$. Baryon poles ($1/2^+$, $1/2^{+*}$, $1/2^{-*}$, $3/2^{+*}$) might improve the agreement with experimental values.

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Among recent[1-3] theoretical attempts to explain hyperon nonleptonic decays one finds several theoretical schemes. One of them[3] explains major features of the s-wave (A) decay amplitudes by combining soft-pion amplitudes

$$A_c = a_{B'B} = \left\langle B'|H_W^{PC}|B\right\rangle \tag{1}$$

with separable contributions (or vector-meson poles). The QCD corrected electroweak Hamiltonian H_W^{PC} is used as an input for the quark model calculation of matrix element (1). The obtained value is comparable with the experimental value A_{exp}.

$$a_{B'B} \sim A_{exp} \tag{2}$$

This approach tries to avoid any fittings parameters; all quark model parameters are determined from other experimental data (hadron masses, moments, etc.).

The amplitudes $a_{B'B}$ are input for the calculation of the p-wave (B) decay amplitudes. As it is well know, the result (2) makes baryon pole amplitudes $B^P(a)$ too small

$$B^P(a) < B_{exp} \tag{3}$$

by about one-half. These discrepancies with experiment can probably be explained by contributions coming from $1/2^+$ baryon resonances[3].

Two alternative scenarios are possible.[1,2,4] In both $a_{B'B}$ is parametrized in such a way that

$$|a_{B'B}| > |A_{exp}| \tag{4}$$

An agreement with experiment is achieved by introducing $1/2^-$ or $3/2^+$ resonance poles.

References 2 and 4 have $a_{B'B}$ such that

$$B^{P}(a) \sim B_{exp} \tag{5}$$

while $1/2^-$ resonance poles help to explain A_{exp} values.

The other approach[1] uses phenomenological non-static description of $1/2^+$ and $3/2^+$ baryons, which gives nonvanishing matrix elements between different spins

$$\left\langle 1/2^+ | H_W | 3/2^+ \right\rangle \sim \left(p_1^\mu,\ p_2^\mu\right) \quad , \tag{6}$$

proportional to the baryon momenta (such matrix elements vanish in the static quark models). In that approach $3/2^+$ resonance poles contribute to A and B amplitudes. The major features of 14 amplitudes can be explained in terms of five fitted parameters.

Schematical comparison among mentioned theoretical alternatives can be found in Table 1.

Theoretical conclusions are closely connected with the usage made of the experimental data. One might confront theoretical amplitudes directly with their experimental values and aim to reproduce signs and other major features.[1,3] When using sum-rules one sometimes has to judge the reliability of the experimental results and to introduce additional assumptions, as can be illustrated by the Lee-Sugawara relation:

$$\Delta_{LS} = \sqrt{3}A(\Sigma_0^+) + A(\Lambda_-^0) - 2A(\Xi_-^-) \tag{7}$$

Straight introduction of the particle data[6] values gives

$$\Delta_{LS} = -0.05 \pm 0.12 \quad .$$

When the same data are entered into the isospin sum rule

$$\Delta_I = \sqrt{2}A(\Sigma_0^+) + A(\Sigma_+^+) - A(\Sigma_-^-) \tag{8}$$

one finds

$$\Delta_I = 0.22 \pm 0.09 \quad .$$

This indicates a certain amount of the $\Delta I=3/2$ contributions to decay amplitudes. However Δ_I sum rule can be used[2] (with the assumption $A(\Sigma_+^+)=0$) to replace $A(\Sigma_0^+)$ in Δ_{LS} by $A(\Sigma_-^-)$. The modified relation

$$\tilde{\Delta}_{LS} = \sqrt{3/2}\ A(\Sigma_-^-) + A(\Lambda_-^0) - 2A(\Xi_-^-) \tag{9}$$

gives much larger value[2] for the deviation from the Lee-Sugawara sum rule

$$\tilde{\Delta}_{LS} = -0.25 \pm 0.04 \quad .$$

Obviously theoretical conclusions based on Δ_{LS} would differ from those based on $\tilde{\Delta}_{LS}$. (Here we do not attempt to judge which one should be preferable.)

The explanation of the experimental value of $A(\Sigma_+^+)$ might also be a serious test of the theories of hyperon nonleptonic decays. Approach[3,5] has not yet produced a definitive answer. While Pakvasa and Trampetić[5] find the explanation connected with $1/2^-$ resonances, Palle and Tadić[5] are somewhat more pessimistic. It seems that the quark model for resonances is not yet sufficiently developed. It is also possible that quark-antiquark pairs might give an important contribution. The theory with $3/2^+$ resonances[1] predicts a wrong sign for $A(\Sigma^+_+)$. In the light of some theoretical results[5] a large contribution from $1/2^-$ resonances[2,4] would also lead to too large theoretical values for $A(\Sigma^+_+)$.

It is interesting to see how these various theoretical scenarios deal with Ω^- decays. According to reference 3, the amplitude $B(\Omega^- \to \Lambda^0 K^-) = B(\Omega_K)$ is dominated by the baryon pole contribution B^P which is proportional to the amplitude $a_{\Xi^0 \Lambda}$ for $\Xi \to \Lambda\pi$ decay. The calculated value of B^P is almost equal to the experimental value:[7]

$$|B^P(\Omega_K)| = 4.05 \times 10^{-6}\mathrm{GeV}^{-1}$$

$$|B_{exp}(\Omega_K)| = 4.01 \times 10^{-6}\mathrm{GeV}^{-1} \quad .$$

Corrections to $B^P(\Omega_K)$ comes from $3/2^+$ pole term and it is in the wrong direction:[3]

$$|B^P(\Omega_K) + B^{P*}(\Omega_K)| = 4.42 \times 10^{-6}\mathrm{GeV}^{-1} \quad .$$

Other amplitudes $B(\Omega^-_-)$ and $B(\Omega^-_0)$ do not have baryon pole contributions.

Reference 1 has important contributions from $3/2^+$ resonances for all $B(\Omega)$ amplitudes. A prominent role is played by the matrix elements of the type (6). They[1] were able to explain major features of all hyperon decay amplitudes, all $B(\Omega)$ decay amplitudes and all $\Sigma^+ \to p\gamma$ decay amplitudes in terms of five fitted parameters: the measure of $\Delta I=3/2$ contamination, two octet baryon parameters associated with matrix elements of the type (1) and two parameters associated with the matrix elements of the type (6).

If $1/2^-$ resonances play an important role in hyperon nonleptonic decays[2,4] than $3/2^+$ resonances cannot contribute as strongly as needed by Ref. 1. That might lead to difficulties with Ω^- and $\Sigma^+ \to p\gamma$ decays; however such an investigation has got to be carried out.

It seems that at present there is no compelling theoretical argument in favor of any of those schemes. The approach of Ref. 3 ties the description of the hyperon nonleptonic decays to the whole body of the data on the static properties of hadrons which are depicted by quark models. The alternative approaches[1,2,4] use general features of the electroweak and strong interactions in order to select fitted parameters. As long as it can consistently fit[1] the whole range of experimental values, such an approach can be by no means excluded. Quark model results cannot substitute for a rigorous mathematical "proof" which would require an exact solution of the electroweak plus strong dynamical problem. Without such theoretical breakthrough, the understanding of the baryon nonleptonic decays might also be improved by additional experimental information, such as could come from the strangeness violating scattering experiments.[8]

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Table 1. Theoretical schemes.

Theoretical Decay Amplitudes	Remark	References
$A = A_{cc} +$	$A^P(1/2^-)$ too small	
(separable term)	$A(\Sigma_+^+) \sim A^P(1405;1/2^-)$??	3, 5
$B = B^P(A_{cc})+B^P(1/2^+*)$	$B(\Omega)$ explained	
$A = A_{cc} + A^P(1/2^-)$	$\tilde{\Delta}_{LS}$ Eq. (9)	2, 4
$B = B^P(A_{cc})$	$A(\Sigma_+^+) \sim 0$	
$A = A_{cc} + A^P(3/2^+*)$	$A(\Sigma_+^+) \simeq A^P(3/2^+*)$	
	(with wrong sign)	1
$B = B^P(A_{cc})+B^P(3/2^+*)$	$(\Sigma^+ \to P\gamma)$ explained	
	$B(\Omega)$ explained	