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STRONG DECAYS OF CHARMED 3/2$^+$ - AND 1/2$^+$-BARYONS

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1. INTRODUCTION

The construction of the standard theory of strong, weak and electromagnetic interactions leads to a substantial progress in the elementary particle physics. This theory very well describes the high energy physics and is an important step to build a unified theory.

However, the problem of the low-energy description of hadrons within this theory is not completely solved yet. There are open questions in the foundation of confinement, the computation of hadron spectrum, the explanation of the selection rules for the nonleptonic weak decays of hadrons, the description of strong and radiative decays of baryons, the deduction of the spontaneous chiral-symmetry-breaking Lagrangians, etc.

In phenomenological approaches, e.g. for nonleptonic weak decays of charmed baryons, usually the PCAC hypothesis and factorization of the amplitudes are used. In this approach the "hard" component of gluon corrections is taken into account by the effective Hamiltonian and the "soft" gluon corrections are "absorbed" by the wave functions of the baryon-ground states. As a result, the knowledge of the wave functions becomes very important.

To find the latter, quark (nonrelativistic) models, bag models[2], etc. are used. The approaches based on these models to two-body nonleptonic weak decays of the Λ_c^+-baryon lead to discrepant results. Additionally, they are characterized by a large number of parameters and complicated calculations, which practically makes impossible the calculation of many-body decays.

Nevertheless, it is useful to have reliable though rough branching ratio estimates for a more effective measurement and analysis of the experiment.

For this aim, in works[3] the phenomenological chiral lagrangian method (PCLM) was proposed, which gives reasonable results for low-energy hadron processes. Recently, the PCLM has attracted attention of physicists in view of the low-energy limit of QCD and of that it takes effectively into account the quark-gluon interactions at large distances. The PCLM contains a minimal number of phenomenological parameters and in the "tree" approximation reproduces the current algebra results.

In the present work the PCLM, including the strong interactions of pseudoscalar mesons and $\frac{3}{2}^+$-, $\frac{1}{2}^+$-baryons, is used to describe strong decays of these baryons.

2. THE $\frac{3}{2}^+ \to \frac{1}{2}^+ + 0^-$ DECAYS

The strong interactions of the 15-plet of pseudoscalar mesons with the 20-plets of $\frac{3}{2}^+$- and $\frac{1}{2}^+$-baryons are given by the SU(4) x SU(4)-chiral invariant lagrangian

$$L_s = g_s \epsilon^{abcf} \bar{B}^m_{[ab]} \Delta^\mu_{\{mcd\}} D_\mu \Phi^d_f , \qquad (1)$$

where $B^{[ab]}_m$ denotes the 20_m - plet of the $\frac{1}{2}^+$-baryons and $\Delta^\mu_{\{mcd\}}$ - the 20_m - plet of $\frac{3}{2}^+$-baryons.

$$D_\mu \Phi^d_f = -\frac{i}{2}\{tr[A^k e^{-i(\xi A)} \partial_\mu e^{i(\xi A)}]\}(\lambda_k)^d_f ,$$

$$(\xi A) = \frac{1}{F_\pi} \sum_{i=1}^{15} \gamma_5 \left(\frac{\lambda_i \Phi_i}{2}\right), \qquad A_i = \frac{\lambda_i}{2}\gamma_5 .$$

Here λ^i are the Gell-Mann matrices, Φ_i describes the 15-plet of pseudoscalar mesons, ϵ^{abcf} is the fully antisymmetric tensor, F_π = 93 MeV and g_s correspond to the pion decay and strong coupling constants, respectively.

The matrix element of the $\frac{3}{2}^+ \to \frac{1}{2}^+ + 0^-$ has the following form

$$A_i = \left(\frac{g_s C_i}{F_\pi}\right) u(p) u^\mu(k) q_\mu , \qquad (2)$$

where $u^\mu(k)$ is the Rarita - Schwinger spinor, $u(p)$ is the Dirac spinor; k, p, q are momenta of the $\frac{3}{2}^+$-, $\frac{1}{2}^+$-baryons and 0^--mesons, respectively. Only decays with one final pion are energetically allowed and the coefficients C_i come out from the group structure of the Lagrangian (1) (see Table 1).

The partial widths for the $\frac{3}{2}^+ \to \frac{1}{2}^+ + 0^-$ decays are defined by

Table 1. Strong decays $\frac{3}{2}^+ \to \frac{1}{2}^+ + 0^-$. All widths are given in MeV. a) All kinematically allowed decays are listed, b) partial widths (theoretical values), c) total widths (experimental data /5/), d) experimental data are not available yet.

Decay mode a)	C_i	Γ_{th} b)	Γ_{exp} c)
$\Delta^{++} \to p\pi^+$	1	102.1	111.8 ± 0.6
$\Delta^+ \to n\pi^+$	$-1/\sqrt{3}$	34.4	117.7 ± 2.4
$\to p\pi^0$	$\sqrt{2/3}$	70.9	
$\Delta^0 \to p\pi^-$	$1/\sqrt{3}$	34.8	117.4 ± 1
$\to n\pi^0$	$\sqrt{2/3}$	70.7	
$\Delta^- \to n\pi^-$	1	104.3	118 ± 3
$\Sigma^{*+} \to \Lambda\pi^+$	$1/\sqrt{2}$	31.9	35.80 ± 0.75
$\to \Sigma^0\pi^+$	$1/\sqrt{6}$	2.27	
$\to \Sigma^+\pi^0$	$-1/\sqrt{6}$	2.74	
$\Sigma^{*0} \to \Lambda\pi^0$	$-1/\sqrt{2}$	33.46	35.8 ± 4.9
$\to \Sigma^-\pi^+$	$1/\sqrt{6}$	1.98	
$\to \Sigma^+\pi^-$	$-1/\sqrt{6}$	2.54	
$\Sigma^{*-} \to \Lambda\pi^-$	$-1/\sqrt{2}$	33.66	39.4 ± 2.1
$\to \Sigma^-\pi^0$	$-1/\sqrt{6}$	2.48	
$\to \Sigma^0\pi^-$	$1/\sqrt{6}$	2.59	
$\Xi^{*0} \to \Xi^0\pi^0$	$-1/\sqrt{6}$	4.14	9.14 ± 0.48
$\to \Xi^-\pi^+$	$1/\sqrt{3}$	6.69	
$\Xi^{*-} \to \Xi^0\pi^-$	$-1/\sqrt{3}$	8.26	10.1 ± 1.9
$\to \Xi^-\pi^0$	$1/\sqrt{6}$	3.59	

Decay mode	C_i	Γ_{th} d)
$\Sigma^{*++}_c \to \Lambda^+_c \pi^+$	$-1/\sqrt{2}$	13.11
$\Sigma^{*+}_c \to \Lambda^+_c \pi^0$	$1/\sqrt{2}$	13.91
$\Sigma^{*0}_c \to \Lambda^+_c \pi^-$	$1/\sqrt{2}$	14.08
$\Xi^{*+}_c \to \Xi^0_c \pi^+$	$-1/2$	1.21
$\to \Xi^+_c \pi^0$	$-1/2\sqrt{2}$	0.81
$\Xi^{*0}_c \to \Xi^+_c \pi^-$	$-1/2$	1.52
$\to \Xi^0_c \pi^0$	$1/2\sqrt{2}$	0.69

$$\Gamma_i = \frac{\alpha_s(M)}{3}\left(\frac{M}{4F_\pi}\right)^2 C_i^2 M \left[\frac{(M+m)^2-\mu^2}{M^2}\right]^{\frac{5}{2}}\left[\frac{(M-m)^2-\mu^2}{M^2}\right]^{\frac{3}{2}}, \qquad (3)$$

where $\alpha_s(M) = \frac{g_s(M)}{4\pi}$; M, m, μ are the masses of the $\frac{3}{2}^+$-, $\frac{1}{2}^+$- and 0^--hadrons. The dependence of $\alpha_s(M)$ on the mass M reflects the breaking of the symmetry of strong interactions.

The mass values are the experimental ones [5], for the undiscovered the values are taken from [6].

The experimental data for the known decays of the resonance baryons are satisfactorily reproduced by using the "universal" constant

$$\alpha_s = \frac{\alpha_s(M)}{3}\left(\frac{M}{4F_\pi}\right)^2 = 0{,}54. \qquad (4)$$

This means the following phenomenological dependence of the initial coupling constant $g_s = g_s(M)$

$$\alpha_s(M) = \frac{26F_\pi^2}{M^2}. \qquad (5)$$

The tendency of $\alpha_s(M)$ to decrease for heavier resonances agrees with the behaviour of $\alpha_s(M)$ arising in other approaches used to describe the strong interactions of $\frac{3}{2}^+$- and $\frac{1}{2}^+$-baryons by means of 0^--mesons [7].

The calculated widths are given in Table 1.

3. THE $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ DECAYS

The SU(4) x SU(4) - chiral invariant lagrangian describing strong interactions of $\frac{1}{2}^+$-baryons and 0^--mesons has the form

$$L_s = g_A[\alpha(\bar{B}\gamma_\mu A^i B)_d + (1-\alpha)(\bar{B}\gamma_\mu A^i B)_f]D^\mu\Phi_i, \qquad (6)$$

where α is the mixing parameter of the d- and f-couplings defined by

$$(\bar{B}A^iB)_{d(f)} = \frac{1}{2}\bar{B}^a_{[mn]}\left(\frac{\lambda_i\gamma_5}{2}\right)^b_a B^{[mn]}_b + (-)\bar{B}^m_{[bn]}\left(\frac{\lambda_i\gamma_5}{2}\right)^b_a B^{[an]}_m,$$

and the chosen value $\alpha = \frac{2}{3}$ satisfactorily describes the semileptonic decays of usual and charmed baryons.

The matrix element for $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ can be parametrized as follows:

$$A_\ell = -ig_A\left(\frac{M+m}{F_\pi}\right)C_\ell\,\bar{u}(p)\gamma_5 u(k), \qquad (7)$$

where k, p, q are the corresponding momenta of the initial, final baryons and of the pion. There allowed are only one-pion decays [6] and the C_ℓ reflects the group structure of the Lagrangian (6) with respect to the d- and f-couplings (see Table 2); $g_A = 1.25$.

The partial widths for the $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ case have the following form

$$\Gamma_i = \alpha_s(M)\left(\frac{C_i}{4}\right) M \left[\frac{(M-m)^2-\mu^2}{M^2}\right]^{\frac{3}{2}}\left[\frac{(M+m)^2-\mu^2}{M^2}\right]^{\frac{1}{2}}, \qquad (8)$$

$$g_s = g_A\left(\frac{M+m}{F_\pi}\right). \qquad (9)$$

The dependence of $g_s = g_s(M)$ (9) on the baryon masses results from the breaking of the chiral symmetry and is analogous to that in other approaches [7].

The results for the widths of strong $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$ decays are listed in Table 2.

4. THE PRESENT PAPER YIELDS THE FOLLOWING RESULTS

i) the phenomenological chiral lagrangian method is proposed for the description of strong decays of $\frac{3}{2}^+$- and $\frac{1}{2}^+$-baryons; ii) the corresponding widths are calculated; iii) it is shown that one has the satisfactory agreement for the availab-

Table 2. Strong decays $\frac{1}{2}^+ \to \frac{1}{2}^+ + 0^-$.
The widths are given in MeV

Decay mode	C_i	Γ_{th}
$\Sigma_c^{++} \to \Lambda_c^+ \pi^+$	$2/3\sqrt{3}$	3.29
$\Sigma_c^{+} \to \Lambda_c^+ \pi^0$	$2/3\sqrt{3}$	4.78
$\Sigma_c^{0} \to \Lambda_c^+ \pi^-$	$2/3\sqrt{3}$	4.85
$\Xi_c^{\prime +} \to \Xi_c^0 \pi^+$	$1/3\sqrt{2/3}$	0.09
$\to \Xi_c^+ \pi^0$	$-1/3\sqrt{3}$	0.30
$\Xi_c^{\prime 0} \to \Xi_c^0 \pi^0$	$-1/3\sqrt{3}$	0.20
$\to \Xi_c^+ \pi^-$	$1/3\sqrt{2/3}$	0.53

le experimental data (in the case $\frac{3}{2}^+ \to \frac{1}{2}^+ + 0^-$) when the strong coupling constant $\alpha_s(M)$ depends on the initial baryon mass through (5).

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Калиновский Ю.Л. и др. E2-87-906

Сильные распады $\frac{3}{2}^{+}$ – и $\frac{1}{2}^{+}$ –очарованных барионов

В рамках нарушенной киральной SU(4)xSU(4)–теории рассмотрены сильные распады $\frac{3}{2}^{+}$ – и $\frac{1}{2}^{+}$ –барионов. При расчете вероятностей распадов $\frac{3}{2}^{+}$ –барионов предполагается уменьшение константы распада $\frac{3}{2}^{+}$ –барионов с ростом массы распадающегося резонанса. Полученные результаты /в рамках точности киральной SU(4)xSU(4)–теории/ удовлетворительно воспроизводят имеющиеся экспериментальные данные.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Strong Decays of Charmed $\frac{3}{2}^{+}$ – and $\frac{1}{2}^{+}$ –Baryons

In the framework of the broken chiral SU(4)xSU(4) symmetry strong decays of $\frac{3}{2}^{+}$ – and $\frac{1}{2}^{+}$ –baryons are considered. To calculate the decay probabilities of the $\frac{3}{2}^{+}$ –baryons, the decrease of the decay constant with increasing masses of the decaying baryons is assumed. The obtained results within the expected accuracy of the chiral lagrangian method satisfactorily reproduce the available experimental data.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

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