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THE SEMILEPTONIC DECAYS OF Λ_c^+ IN CHIRAL THEORY

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Recently the original experimental data on semileptonic decays of charmed baryon Λ_c^+ have been obtained [1]. But the theoretical description of these decays is not yet satisfactory. As far as we know only two works [2,3] devoted to the branching ratio estimations for semileptonic decays of charmed baryons have been published, which are based on SU_4 symmetry and "modified monopole" form-factors including a free parameter. In spite of this it is impossible to satisfy the experimental data if only for $\Lambda_c^+ \to eX$, for example (it should be noted that in the SU_4 symmetry approach there is no transition of Λ_c^+ to $3^+/2$ -spin states).

In this paper we propose to use the phenomenological chiral-Lagrangian method (PLCM) [4,5] for estimating the beta decay branching ratios of Λ_c^+. We shall estimate also the branching ratios for baryon octet semileptonic decays, more exact measurement for which is available.

The PCLM is based on a nonlinear realization of spontaneously broken symmetry $SU_n \times SU_n$ with the vacuum stability group SU_n (where n = 2,3,4,...). In brief, the nonlinear realization means that the Goldstone fields (the π mesons) are identified with the symmetry-group parameters corresponding to the generators which are not bounded by the physical conservation laws. As a rule, PCLM does not contain the phenomenological parameters except the particle mass, decay constants. This method has been successfully used for describing the low-energy physics of the pseudoscalar-meson-octet [4], and later it has been extended to charmed hadron nonleptonic weak interactions [6-8]. The errors of PCLM for decay rates are expected to be (20-30)% for charmless and (40-50)% for charmed hadrons.

Lately the current of works has been published in which the phenomenological chiral Lagrangians are deduced from QCD in low-energy limit [9-11].

The weak interaction Lagrangian has the following universal current-current form:

$$\mathcal{L}_w = \frac{G}{\sqrt{2}} (J^h_\mu \ell_\mu + \text{h.c.})$$

with the Fermi coupling constant, $G \simeq 10^{-5}/M_p^2$. Here ℓ_μ is the leptonic current defined as $\ell_\mu = \bar{\nu}_e \gamma_\mu (I - \gamma_5) e$, and the hadronic current, J^h_μ has the Cabibbo form

$$J^h_\mu = (J^1_\mu + iJ^2_\mu + J^{13}_\mu + iJ^{14}_\mu)\cos\theta_c + (J^4_\mu + iJ^5_\mu - J^{11}_\mu - iJ^{12}_\mu)\sin\theta_c ,$$

where θ_c is the Cabibbo angle. The 15-plet of currents, J^i_μ, has the form

$$J^i_\mu = \frac{1}{2}\bar{B}^k_{[mn]}\gamma_\mu(I - g_A\gamma_5)(\lambda^i/2)^\ell_k B^{[mn]}_\ell -$$

$$- \bar{B}^m_{[\ell n]}\gamma_\mu[I - (2a-1)g_A\gamma_5](\lambda^i/2)^\ell_k B^{[kn]}_m -$$

$$- F_\pi\partial_\mu\phi^i + f^i_{jk}\phi^j\partial_\mu\phi^k + \ldots$$

It is obtained from the $SU_4 \times SU_4$-chiral-invariant Lagrangian of the form[7]

$$\mathcal{L}_s = ig_A\frac{2M_0}{F_\pi}\{\frac{1}{2}\bar{B}^k_{[mn]}\gamma_5(\lambda^i/2)^\ell_k B^{[mn]}_\ell +$$

$$+ (2a-1)\bar{B}^m_{[\ell n]}\gamma_5(\lambda^i/2)^\ell_k B^{[kn]}_m\}\phi_i + \frac{F^2_\pi}{4}\mathrm{Tr}(\partial_\mu U\partial_\mu U^+).$$

Here B and ϕ are fields of the 20-plet of $1/2^+$-baryons and 15-plet of 0^--mesons, respectively, $a = 2/3$ is the F-D coupling constant, $g_A \simeq 1.25$, M_0 is the averaged baryon mass placed equal to M_n for charmless and 2.26 GeV for charmed baryons, λ_i is the Gell-Mann matrix and $U = \exp(\frac{i}{F_\pi}\lambda^k\phi_k)$.

Since the difference of charmless baryon masses is much smaller than the mesonic resonance mass, then the mesonic resonance pole contribution may be neglected. However, for the beta decays of charmed baryons such a contribution must be taken into account. It is clear that the 0^--meson pole contribution is proportional to the lepton-mass, m_e, and therefore, it may be neglected. So, in these approximations for the decay amplitude we have the following expression:

$$M = \frac{G}{\sqrt{2}}\bar{u}(p_2)\gamma_\mu[F_V(q^2) + F_A(q^2)\gamma_5]u(p_1)\cdot\bar{u}(p_\nu)\gamma_\mu(I-\gamma_5)u(p_e),$$

where $F(q^2) = F(0)$ for the charmless, and

$$F_{V,A}(q^2) = F_{V,A}(0)\frac{m^2_{D^*,D_A}}{m^2_{D^*,D_A} - q^2}$$

(if $\Delta S = 0$) or

$$F_{V,A}(q^2) = F_{V,A}(0)\frac{m^2_{F^*,F_A}}{m^2_{F^*,F_A} - q^2}$$

(if $\Delta S = 1$) for charmed baryons, respectively. Here (D^*, F^*) and (D_A, F_A) are charmed vector- and axial-vector-mesonic reso-

nances. The theoretical values of F(0) are listed in the Table. In the Table the PCLM branching ratio estimation results for beta decays of the baryonic octet and Λ^+_c, and the experimental data[12] are presented. The integration of the squared matrix element over phase space was performed by Monte-Carlo method using the Kopylov procedure[13]. Fortran subroutines providing the procedure are contained in the simulation program TWIST[14]. Computer CDC-6500 was used for calculations. Typically, an accuracy about 1% was achieved in 5 minutes of a central processor time.

Table

The values of F(0), decay rates, theoretical and experimental branching ratios of semileptonic decays of usual and Λ_c baryons (when $\tau(\Lambda^+_c) = 2.3\cdot10^{-13}$ sec)

Type of decay	Cabibbo factor	$F_V(0)$	$F_A(0)$	Γ (sec^{-1})	BR^{th}	BR^{exp}
$n \to pe\nu$	$\cos\theta_c$	1	$-g_A$	$0.14\cdot10^{-2}$	1.23	$1.0\pm.002$
$\Xi^- \to \Xi^\circ e\nu$		1	$(2a-1)g_A$	1.47	$2.42\cdot10^{-10}$	$<2.3\cdot10^{-3}$
$\Sigma^- \to \Sigma^\circ e\nu$		2	$\sqrt{2}(a-1)g_A$	0.74	$1.0\cdot10^{-10}$	-
$\Sigma^- \to \Lambda e\nu$		0	$-\frac{2a}{\sqrt{6}}g_A$	$0.39\cdot10^6$	$0.58\cdot10^{-4}$	$(0.57\pm.03)\cdot10^{-4}$
$\Lambda^+_c \to \Lambda e\nu$		-1	$(1-\frac{2a}{3})g_A$	$0.81\cdot10^{11}$	$1.86\cdot10^{-2}$	$(1.1\pm0.8)\%$ *
$\Sigma^- \to ne\nu$	$\sin\theta_c$	-1	$(1-2a)g_A$	$0.52\cdot10^{-7}$	$0.77\cdot10^{-3}$	$(1.02\pm0.03)\times10^{-3}$
$\Xi^- \to \Lambda e\nu$		$-\frac{3}{\sqrt{6}}$	$\frac{3-4a}{\sqrt{6}}g_A$	$0.21\cdot10^7$	$3.28\cdot10^{-4}$	$(5.5\pm0.6)\times10^{-4}$
$\Lambda \to pe\nu$		$-\frac{3}{\sqrt{6}}$	$\frac{3-2a}{\sqrt{6}}g_A$	$0.25\cdot10^7$	$6.45\cdot10^{-4}$	$(8.57\pm0.36)\times10^{-4}$
$\Xi^\circ \to \Sigma^+ e\nu$		1	$-g_A$	$0.76\cdot10^6$	$2.21\cdot10^{-4}$	$<1.1\cdot10^{-3}$
$\Xi^- \to \Sigma^\circ e\nu$		$-\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2}}g_A$	$0.43\cdot10^6$	$0.86\cdot10^{-4}$	$(8.7\pm1.7)\times10^{-5}$
$\Lambda^+_c \to ne\nu$		$-\frac{1}{\sqrt{6}}$	$\frac{1+2a}{\sqrt{6}}g_A$	$33\cdot10^{11}$	$0.76\cdot10^{-2}$	—

* This value corresponds to $\Lambda^+_c \to \Lambda eX$ decay.

One may see from the Table that the PCLM results for charmless baryons, under the above assumptions for mesonic resonance pole contributions, are in agreement with the experimental data.

For the branching ratios of $\Lambda_c^+ \to ne\nu$ and $\Lambda_c^+ \to \Lambda e\nu$, when $\tau(\Lambda_c^+) = 2.3\cdot 10^{-13}$ sec, we have 0.76% and 1.86%, respectively. For the present time the semileptonic branching ratios of Λ_c^+ have been measured in only one experiment /1/, they are $B(\Lambda_c^+) \to e^+X) = (4.5\pm1.7)\%$, $B(\Lambda_c^+ \to \Lambda e^+X) = (1.1\pm0.8)\%$. In view of these data we may conclude that though based on $SU_4\times SU_4$-chiral-symmetry invariance of the strong interactions which are really strongly broken, PCLM leads to reasonable estimations for charm- or strangness-changing processes.

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Полулептонные распады Λ_c^+ в киральной теории

Метод феноменологических киральных лагранжианов применен для описания полулептонных распадов октета барионов и очарованного бариона Λ_c^+. Показано, что относительные вероятности полулептонных распадов барионного октета согласуются с имеющимися данными. Для относительных вероятностей кабиббовски-разрешенного $\Lambda_c^+ \to \Lambda e\nu$, и кабиббовски-запрещенного, $\Lambda_c^+ \to ne\nu$, распадов данный метод /при $\tau(\Lambda_c^+) = 2{,}3\cdot 10^{-13}$ с/ приводит к значениям 1,86 и 0,76%, соответственно. В рамках точности метода они удовлетворяют экспериментальным данным: $B(\Lambda_c^+ \to \Lambda eX) = (1{,}1\pm0{,}8)\%$ и $B(\Lambda_c^+ \to eX) = (4{,}5\pm1{,}7)\%$.

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The Semileptonic Decays of Λ_c^+ in Chiral Theory

The phenomenological chiral Lagrangian method has been applied for describing the semileptonic decays of baryonic octet and charmed baryon, Λ_c^+. It is shown that the calculated decay branching ratios for the baryonic octet are in agreement with available data. For the Cabibbo-favoured, $\Lambda_c^+ \to \Lambda e\nu$, and Cabibbo-suppressed, $\Lambda_c^+ \to ne\nu$, decay branching ratios the calculations by this method (when $\tau(\Lambda_c^+) = 2.3\cdot 10^{-13}$ sec) lead to 1.86 and 0.76%, respectively. Within the accuracy of the method they satisfy the available data, $B(\Lambda_c^+ \to \Lambda eX) = (1.1\pm0.8)\%$ and $B(\Lambda_c^+ \to eX) = (4.5\pm1.7)\%$.

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

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