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SEMILEPTONIC DECAYS OF ORDINARY AND CHARMED Λ_c^+ BARYONS IN CHIRAL THEORY

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Recently the original experimental data on the semileptonic decays of charmed baryon Λ_c^+ have been obtained [1]. However, there is no satisfactory theoretical description of these data. For example, in ref. [2] total semileptonic decay width of the charmed particles has only been calculated within QCD: there are also rather rough estimations [3] based on SU_4 symmetry.

In this paper, we have calculated the partial widths for semileptonic decays of ordinary and charmed, Λ_c^+, baryons using the phenomenological chiral Lagrangian method [4,5] (PCLM). Today a significant progress is achieved in substantiation of the chiral Lagrangians from QCD [6]. At first we considered the charmless baryons for testing the currents and predicting the branching ratios for the decays, for which only experimental limitations are available. Then we calculated the partial widths for the decays $\Lambda_c^+ \to Be\nu$, $\Lambda_c^+ \to BMe\nu$, where B and M are the $1/2^+$-baryon and the 0^--meson, respectively (as it has been shown in ref. [3], there are no $\Lambda_c^+ \to 3/2^+$-baryon transitions).

According to PCLM the strong interactions of pseudoscalar mesons and baryons are described by the $SU_4 \times SU_4$-chiral invariant Lagrangian [5]

$$\begin{aligned}
L_S = {} & \frac{F_\pi^2}{4}\,\mathrm{tr}\,[\partial_\mu \exp(i\pi/F_\pi)\,\partial_\mu \exp(-i\pi/F_\pi)] + \\
& \bar{B}^{a}_{[mn]}(i\gamma_\mu\partial_\mu - M_0)\,B_a^{[mn]} + \frac{i}{2}(\bar{B}\gamma_\mu V_i B)_f \times \\
& \mathrm{tr}\,[V_i \exp(-i\pi\cdot A/F_\pi)\,\partial_\mu \exp(i\pi\cdot A/F_\pi)] + \\
& \frac{i}{2} g_A [\alpha(\bar{B}\gamma_\mu A_i B)_d + (1-\alpha)(\bar{B}\gamma_\mu A_i B)_f] \times \\
& \mathrm{tr}\,[A_i \exp(-i\pi\cdot A/F_\pi)\,\partial_\mu \exp(i\pi\cdot A/F_\pi)],
\end{aligned} \qquad /1/$$

where $g_A = 1.25$ is the renormalization constant of axial-vector current, $F_\pi = 93$ MeV is the pion leptonic decay constant, M_0 is the averaged mass of baryonic multiplet ($= M_n$ for charmless and $= 2.69$ GeV for charmed baryons, respectively), $V_i = \lambda_i/2I$,

$A_i = V_i \gamma_5$, $\pi = \lambda_i \pi^i$ (λ_i is the Gell-Mann matrix). We suppose that the mixing parameter of f- and d-couples, α , defined as

$$(\bar{B}V_i B)_{d(f)} = \frac{1}{2} \bar{B}^a_{[mn]} (V_i)^b_a B^{[mn]}_b + (-) \bar{B}^m_{[bn]} (V_i)^b_a B^{[an]}_m .$$

has the same value, 2/3, both for usual and charmed baryons. $B^{[jk]}_i$ and π_i are the fields of 20-plet of $1/2^+$ -baryons and 15-plet of 0^- -mesons, respectively.

From the Lagrangian (1) for the 15-plet of hadronic currents, we obtained

$$J^i_\mu = \frac{1}{2} \bar{B}^a_{[mn]} (V^i)^b_a \gamma_\mu B^{[mn]}_b - \bar{B}^m_{[bn]} (V^i)^b_a \gamma_\mu B^{[an]}_m +$$

$$g_A [\alpha (\bar{B}A^i \gamma_\mu B)_d + (1-\alpha)(\bar{B}A^i \gamma_\mu B)_f] - F_\pi \partial_\mu \pi^i +$$

$$f^i_{jk} \pi^j \partial_\mu \pi^k + O(F_\pi^{-1}) .$$

The week interaction Lagrangian has the usual current-current form,

$$L_W = \frac{G}{\sqrt{2}} (J_\mu \ell^+_\mu + \text{h.c.}) , \qquad /2/$$

with the universal Fermi constant $G = 10^{-5}/M_n^2$. Here ℓ_μ is the leptonic current and J_μ has the Cabibbo form

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

θ_c is the Cabibbo angle ($\sin \theta_c$ =0.23).

Assuming the absence of second-class currents and neglecting the lepton mass (m_e), we arrive at the matrix elements of beta decay

$$M = \frac{G}{\sqrt{2}} \bar{u}(p_2) [f_1(q^2) \gamma_\mu - f_2(q^2) \sigma_{\mu\nu} q_\nu +$$

$$g(q^2) \gamma_\mu \gamma_5] \bar{u}(p_1) u_e(k_2) \gamma_\mu (1+\gamma_5) u_\nu(k_1) .$$

where $q = k_1 + k_2$, p_1, p_2 and k_1, k_2 are the four-momenta of baryons and leptons. For the case of ordinary baryons, since q is small compared to the masses of baryons, the approximations: $f_1 = f_1(0)$, $g_1 = g_1(0)$ and $f_2 = 0$ can be used. The form factors, partial widths and branching ratios for beta decays charmless baryons are listed in table 1. They are in good agreement with the available data /7/ . For the case of Λ_c^+, q-dependence of the form factors must be taken into account; using (axial-) vector-dominance hypothesis we have

Table 1

Form factors, partial widths, theoretical and experimental /7/ branching ratios for ordinary baryons (the above section contains Cabibbo-favored decays and the lower of Cabibbo-suppressed ones), where $f_2 = 0$, $\alpha = 2/3$, $g_A = 1.25$, $B^{th} = \Gamma \cdot \tau^{exp}$.

decay	$f_1(0)$	$g(0)$	(sec^{-1})	B^{th}	B^{exp}
$n \to pe\nu$	1	g_A	$1.1 \cdot 10^{-3}$	0.99	1.0
$\Xi^- \to \Xi^0 e\nu$	1	$(1-2\alpha) g_A$	1.7	$3 \cdot 10^{-10}$	$< 2.3 \cdot 10^{-3}$
$\Sigma^- \to \Sigma^0 e\nu$	2	$\sqrt{2}(1-\alpha) g_A$	0.8	10^{-10}	-
$\Sigma^- \to \Lambda e\nu$	0	$2\alpha g_A/\sqrt{6}$	$4.8 \cdot 10^5$	$0.71 \cdot 10^{-4}$	$(0.57 \pm 0.03) \cdot 10^{-4}$
$\Sigma^- \to ne\nu$	-1	$(2\alpha-1) g_A$	$7.3 \cdot 10^6$	$1.08 \cdot 10^{-3}$	$(1.08 \pm 0.04) \cdot 10^{-3}$
$\Xi^- \to \Lambda e\nu$	$-3/\sqrt{6}$	$(4\alpha-3) g_A/\sqrt{6}$	$2.7 \cdot 10^6$	$4.4 \cdot 10^{-4}$	$(2.8 \pm 1.2) \cdot 10^{-4}$
$\Lambda \to pe\nu$	$-3/\sqrt{6}$	$(2\alpha-3) g_A/\sqrt{6}$	$2.9 \cdot 10^6$	$7.6 \cdot 10^{-4}$	$(8.07 \pm 0.28) \cdot 10^{-4}$
$\Xi^0 \to \Sigma^+ e\nu$	1	g_A	$9.0 \cdot 10^5$	$2.6 \cdot 10^{-4}$	$< 1.1 \cdot 10^{-3}$
$\Xi^- \to \Sigma^0 e\nu$	$-1/\sqrt{2}$	$-g_A/\sqrt{2}$	$5.1 \cdot 10^5$	$8.4 \cdot 10^{-5}$	$(8.7 \pm 1.7) \cdot 10^{-5}$

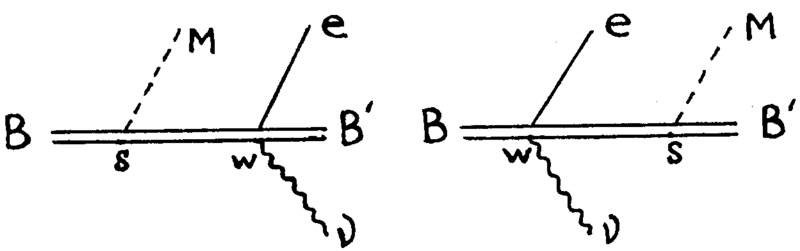
$$f(q^2) = f(0)\, m_V^2/(m_V^2 - q^2),$$

$$g(q^2) = g(0)\, m_A^2/(m_A^2 - q^2), \qquad /3/$$

where $m_{V,A}$ are the masses of D^*, D_A (if $\Delta S = 0$) or F^*, F_A (if $|\Delta S| = 1$) which, except for D^*, are not available, and we supposed $m_{F^*} = m_{F_A} = m_{D_A} = m_{D^*} = 2.01$ GeV /7/. We must also know the magnetic form factor $f_2(0)$; from SU_4 symmetry we have $f_2(0) = (f^n - 4f^p)/\sqrt{6}$ and $f_2(0) = -f^n$ for Cabibbo-favoured ($\Lambda_c^+ \to \Lambda e\nu$) and Cabibbo-suppressed ($\Lambda_c^+ \to ne\nu$) decays, respectively. Here $f^n = \mu_n/2M_n$, $f^p = \mu_p/2M_p$. μ_n and μ_p are the nucleon magnetic moments. The form factors, partial widths, theoretical and experimental branching ratios for ordinary baryons are listed in table I. Agreement with the experiment is obvious. As one sees from the table decays $\Sigma^- \to \Sigma^0 e\nu$ and $\Xi^- \to \Xi^0 e\nu$ must be suppressed and $B^{th}(\Xi^0 \to \Sigma^+ e\nu) = 2.6\cdot 10^{-4}$ (whereas $B^{exp} < 1.1\cdot 10^{-3}$).

Beta decay of Λ_c^+ have been calculated in the cases: (A) $f_2 = 0$; (B) $f_1(q) = f_1(0)$, $g(q) = g(0)$; and (C) when $f(q), g(q)$ are defined by (3), the results are collected in table II.

Four-body semileptonic decays of Λ_c^+ when $m_e \sim 0$ are described by the diagrams shown in fig.1. For virtual charmed baryons, the masses of which are not yet known, we have used the mass estimations from ref./5/.



Three-approximation diagram. (s) *and* (w) *correspond to strong and weak interactions.*

Partial widths have been calculated by the integration of squared matrix elements over phase space by using the Monte-Carlo method and Kopylov's procedure/8/. Fortran subroutines for the procedure are contained in the simulation program TWIST /9/.

Table II

Partial widths and branching ratios corresponding to $\tau_{\Lambda_c^+} = 2.3\cdot 10^{-13}$ sec for $\Lambda_c^+ \to Be\nu$ and $\Lambda_c^+ \to BMe\nu$ decays. For the $\Lambda_c^+ \to \Lambda e\nu$ and $\Lambda_c^+ \to ne\nu$ decays $f_1(0) = -1$, $g(0) = (2\alpha/3 - 1)g_A$, $f_2(0) = (f - 4f)/\sqrt{6}$ and $f_1(0) = -1/\sqrt{6}$, $g(0) = -(1+2\alpha)g_A/\sqrt{6}$, $f_2(0) = -f^n$, respectively. (About A-C see the text).

Cabibbo-favored decays				Cabibbo-suppressed decays			
decay		Γ (sec^{-1})	B^{th}(%)	decay		Γ (sec^{-1})	B^{th}(%)
	(A)	$2.9\cdot 10^{11}$	6.7		(A)	$5.7\cdot 10^{10}$	1.3
$\Lambda_c^+ \to \Lambda e\nu$	(B)	$2.0\cdot 10^{11}$	4.6	$\Lambda_c^+ \to ne\nu$	(B)	$0.3\cdot 10^{11}$	0.6
	(C)	$1.7\cdot 10^{13}$	~400		(C)	$1.5\cdot 10^{12}$	34.5
$\Lambda_c^+ \to \Xi^- K^+ e\nu$		$5\cdot 10^{6}$	$1.2\cdot 10^{-4}$	$\Lambda_c^+ \to p\pi^- e\nu$		$1.2\cdot 10^{9}$	$2.8\cdot 10^{-2}$
$\Lambda_c^+ \to \Xi^0 K^0 e\nu$		$1.1\cdot 10^{7}$	$2.5\cdot 10^{-4}$	$\Lambda_c^+ \to n\pi^0 e\nu$		$5.8\cdot 10^{8}$	$1.3\cdot 10^{-2}$
$\Lambda_c^+ \to \Lambda\eta e\nu$		$1.4\cdot 10^{8}$	$3.2\cdot 10^{-3}$	$\Lambda_c^+ \to n\eta e\nu$		$9.5\cdot 10^{6}$	$2.2\cdot 10^{-4}$
$\Lambda_c^+ \to pK^- e\nu$		$2.3\cdot 10^{9}$	$5.3\cdot 10^{-2}$	$\Lambda_c^+ \to \Sigma^0 K^0 e\nu$		$1.6\cdot 10^{6}$	$3.7\cdot 10^{-5}$
$\Lambda_c^+ \to \Sigma^+\pi^- e\nu$		$3.1\cdot 10^{8}$	$7.1\cdot 10^{-3}$	$\Lambda_c^+ \to \Lambda K^0 e\nu$		$3\cdot 10^{8}$	$6.9\cdot 10^{-3}$
$\Lambda_c^+ \to \Sigma^0\pi^0 e\nu$		$2.8\cdot 10^{8}$	$6.4\cdot 10^{-3}$	$\Lambda_c^+ \to \Sigma^- K^+ e\nu$		$1.1\cdot 10^{6}$	$1.5\cdot 10^{-5}$
$\Lambda_c^+ \to \Sigma^-\pi^+ e\nu$		$2.5\cdot 10^{8}$	$5.8\cdot 10^{-3}$	$\Lambda_c^+ \to \Sigma^+ K^- e\nu$		$1.3\cdot 10^{6}$	$3\cdot 10^{-5}$
$\Lambda_c^+ \to n\bar{K}^0 e\nu$		$2.1\cdot 10^{9}$	$4.8\cdot 10^{-2}$	–		–	–

The data [1] available on semileptonic decays of Λ_c^+ are

$$B(\Lambda_c^+ \to \Lambda e X) = (1.1 \pm 0.8)\%, \quad \text{(i)}$$

$$B(\Lambda_c^+ \to p e X) = (1.8 \pm 0.9)\%, \quad \text{(ii)}$$

$$B(\Lambda_c \to e X) = (4.5 \pm 1.7)\%. \quad \text{(iii)}$$

One sees from table II that the branching ratio of $\Lambda_c^+ \to \Lambda e\nu$ is in a reasonable accord with (i)in (B) case.It follows that the $\Lambda_c^+ \to B$-transition magnetic moment must indeed be too small. For decays $\Lambda_c^+ \to pe\nu X$ from the table we have B^{th} =0.08%, much smaller than (ii). Summing the partial widths of all decays (further everywhere we use the results for (B)) we have obtained $\Gamma sl = 2.3 \cdot 10^{11}$ sec.$^{-1}$ whereas the QCD predictions [2] are $(1.9 \pm \pm 0.5) \cdot 10^{11}$ sec^{-1}. Using Γsl and (iii) we have estimated the Λ_c^+ lifetime, $\tau_{\Lambda_c} = (2.0 \pm 0.7) \cdot 10^{-13}$ sec.

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Калиновский Ю.Л., Сариков Н.А., Тахтамышев Г.Г. E2-85-737

Полулептонные распады обычных и очарованных Λ_c^+ барионов в киральной теории

Метод феноменологических киральных лагранжианов применяется для описания полулептонных распадов обычных и очарованного Λ_c^+ барионов. Вычисленные парциальные ширины /или относительные вероятности/ распадов обычных барионов согласуются с имеющимися экспериментальными данными, что подтверждает теорию Кабиббо с киральными токами и позволяет предсказать вероятности тех распадов ($\Xi^- \to \Xi^0 e\nu$, $\Sigma^- \to \Sigma^0 e\nu$, $\Xi^0 \to \Sigma^+ e\nu$), которые еще точно не измерены. Для Λ_c^+ вычислены трех- и четырехчастичные полулептонные распады. Вероятность кабиббовски-разрешенного распада $\Lambda_c^+ \to \Lambda e\nu$ согласуется с экспериментальным результатом для $\Lambda_c^+ \to \Lambda eX$, в то время как вероятность распадов $\Lambda_c^+ \to p\pi e\nu$ и $\Lambda_c^+ \to pKe\nu$ значительно меньше экспериментального значения для $\Lambda_c^+ \to peX$. Сделана оценка времени жизни Λ_c^+, которая равна $(2,0 \pm 0,7)\cdot 10^{-13}$ с.

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Semileptonic Decays of Ordinary and Charmed Λ_c^+ Baryons in Chiral Theory

The phenomenological chiral Lagrangian method is applied for describing the semileptonic decays of ordinary and charmed Λ_c^+ baryons. The calculated branching ratios of ordinary baryon decays agree with the experimental data available. That confirms the Cabibbo theory with chiral currents and permits to predict the branching ratios of such decays /$\Xi^- \to \Xi^0 e\nu$, $\Sigma^- \to \Sigma^0 e\nu$, $\Xi^0 \to \Sigma^+ e\nu$/not yet measured. For Λ_c^+ three- and four-body decays are calculated. Branching ratio of $\Lambda_c^+ \to \Lambda e\nu$ is in agreement with the data on $\Lambda_c^+ \to \Lambda eX$, whereas for $\Lambda_c^+ \to p\pi e\nu$ and $\Lambda_c^+ \to pKe\nu$ calculated branching ratio value is smaller as compared to the experimental one for $\Lambda_c^+ \to peX$. The lifetime of Λ_c^+ is estimated to be equal to $\tau_{\Lambda_c^+} = (2.0 \pm 0.7)\cdot 10^{-13}$s.

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

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