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BREAKDOWN OF CHIRAL SU(4) x SU(4)-SYMMETRY AND MASSES OF CHARMED BARYONS

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1. At present, known is a large number of experimental values of masses and branching ratios for charmed baryons [1]. But the up-to-date QCD cannot give a satisfactory description of these data. The potential (nonrelativistic) quark models, bag models and others contain a large number of parameters and are characterized by complicated calculations.

In this paper, we use, within the framework of phenomenological chiral Lagrangians [2] a simple scheme to calculate the mass spectrum of the $\frac{1}{2}^+$ - and $\frac{3}{2}^+$ -baryons.

To break the symmetry, we consider a symmetry-breaking mass term which preserves $SU(2)\times SU(2)$ symmetry. The remaining $SU(2)\times SU(2)$-symmetry will be broken, too, by rotating the baryon fields arround the 7th and 10th axis in SU(4)-space. In the following, we are looking only for $\Delta S = \Delta C = 0$ contributions.

2. $\frac{1}{2}^+$ -baryons masses. To get baryon mass formulae, let us choose the following $SU(4)\times SU(4)$ symmetry-breaking mass term in the Lagrangian

$$L_M = L_M(0,0) + \Delta L_M(\theta_7, \theta_{10}), \tag{1}$$

where

$$L_M(0,0) = \bar{B} M_0 B. \quad M_0 = m_0 \cdot 1;$$

$$\Delta L_M(\theta_7, \theta_{10}) = \frac{1}{2} \tilde{\bar{B}}^i_{[mn]} \begin{pmatrix} bs'^2 & & & \\ & as^2 & & \\ & & ac^2 & \\ & & & bc'^2 \end{pmatrix}^j_i \tilde{B}^{[mn]}_j + \tag{2}$$

$$+ \tilde{\bar{B}}^m_{[jn]} \begin{pmatrix} ds'^2 & & & \\ & ks^2 & & \\ & & kc^2 & \\ & & & dc'^2 \end{pmatrix}^j_i \tilde{B}^{[in]}_m .$$

Here $\tilde{B}_\ell^{[mn]} = (U^+)^m_i (U^+)^n_j U^k_\ell B^{[ij]}_k$ are the "physical" baryon fields, $U = \exp(-i\lambda_7\theta_7)\cdot\exp(-i\lambda_{10}\theta_{10})$ corresponds to the rotations around the 7th and 10th axis in SU(4)-space, $s = \sin\theta_7$, $c = \cos\theta_7$, $s' = \sin\theta_{10}$ and $c' = \cos\theta_{10}$.

Formula (2) is a direct generalization of the mass term of the works [3] with the help of an additional rotation around the 10th axis, which on the quark level means a u- and c-quark mixing.

Eq.(2) describing the breakdown of the chiral symmetry yields the following mass formulae:

$$
\begin{aligned}
m_P &= m_0 - \ell_1 - \ell_7 - \ell_8, & m_{\Sigma_c^{++}} &= m_0 - \ell_1 - \ell_6 - \ell_7, \\
m_N &= m_0 - \ell_2 - \ell_7 - \ell_8, & m_{\Sigma_c^{0}} &= m_0 - \ell_1 - \ell_5 - \ell_7, \\
m_{\Sigma^+} &= m_0 - \ell_1 - \ell_6 - \ell_8, & m_{\Omega_c^{0}} &= m_0 - \ell_3 - \ell_5 - \ell_6, \\
m_{\Sigma^-} &= m_0 - \ell_2 - \ell_5 - \ell_8, & m_{\Xi_{cc}^{++}} &= m_0 - \ell_4 - \ell_6 - \ell_8, \\
m_{\Xi^0} &= m_0 - \ell_3 - \ell_6 - \ell_8, & m_{\Xi_{cc}^{+}} &= m_0 - \ell_4 - \ell_5 - \ell_7, \\
m_{\Xi^-} &= m_0 - \ell_3 - \ell_5 - \ell_8, & m_{\Omega_{cc}^{+}} &= m_0 - \ell_4 - \ell_5 - \ell_6.
\end{aligned}
\tag{3}
$$

Here and in the following the symbols of the particles represent their masses. To find the masses of the rest of the baryons (Λ, Σ^0), $(\Lambda_c^+, \Sigma_c^+)$, $(\Xi_c^+, \Xi_c'^+)$ and $(\Xi_c^0, \Xi_c'^0)$ it is necessary to diagonalize the corresponding contributions. The coefficients $\ell_1, \ell_2 \ldots \ell_8$ are equal to $b\sin^2\theta_{10}$, $a\sin^2\theta_7$, $a\cos^2\theta_7$, ..., $d\cos^2\theta_{10}$, respectively.

The mass formulae (3) give the well-known mass relations of Coleman - Glashow [4] and Gell-Mann - Okubo [5] for the uncharmed baryons and analogous relations in the charmed sector:

$$
\begin{aligned}
& P + \Sigma^- + \Xi^0 = N + \Sigma^+ + \Xi^-, \\
& N + \Sigma^+ + \Omega_c^0 = \Sigma^- + \Xi^0 + \Sigma_c^{++}, \\
& P + \Sigma_c^0 + \Xi_{cc}^{++} = N + \Sigma_c^{++} + \Xi_{cc}^{+}, \\
& \Sigma^+ + \Omega_c^0 + \Xi_{cc}^{++} = \Xi^0 + \Sigma_c^{++} + \Omega_{cc}^{+}, \\
& \Sigma^- + \Omega_c^0 + \Xi_{cc}^{+} = \Xi^- + \Sigma_c^0 + \Omega_{cc}^{+},
\end{aligned}
\tag{4}
$$

and

$$
\begin{aligned}
& P + \Sigma^- + \Xi^0 = \frac{3}{2}(\Lambda + \Sigma^0), \\
& \Sigma^+ + \Omega_c^0 + \Xi_{cc}^{++} = \frac{3}{2}(\Xi_c^+ + \Xi_c'^+), \\
& P + \Sigma_c^0 + \Xi_{cc}^{++} = \frac{3}{2}(\Lambda_c^+ + \Sigma_c^+), \\
& \Sigma^- + \Omega_c^0 + \Xi_{cc}^{+} = \frac{3}{2}(\Xi_c^0 + \Xi'^0).
\end{aligned}
\tag{5}
$$

For the numerical analysis the masses of P, N, Σ^+, Σ^-, Ξ^- and Λ_c^+ are used [1]. The values of the angles θ_7 and θ_{10} are obtained by

$$
\theta_{7(10)} = \arctan\sqrt{\frac{\ell_{1(5)}}{\ell_{4(8)}}}. \tag{6}
$$

The results for the masses of the $\frac{1}{2}^+$-baryons, the parameters m_0, a, b, k, d and the angles are listed in Table 1.

3. $\frac{3}{2}^+$-baryons masses. To get the mass formulae for the $\frac{3}{2}^+$-baryons we can use the more simple term

$$
L_M = m_0 \bar{\tilde{D}}^{\{\alpha\beta\gamma\}} \tilde{D}_{\{\alpha\beta\gamma\}} + \bar{\tilde{D}}^{\{\alpha\beta\delta\}} \begin{pmatrix} ds'^2 & & & \\ & bs^2 & & \\ & & bc^2 & \\ & & & dc'^2 \end{pmatrix}^{\rho}_{\delta} \tilde{D}_{\{\alpha\beta\rho\}}, \tag{7}
$$

where m_0, b and d differ from the corresponding parameters of the $\frac{1}{2}^+$-baryon case, but the angles θ_7 and θ_{10} are the same. The mass relations, obtained by (7), reproduce the equal-spacing rules, including charmed baryons now,

$$
\begin{aligned}
& \Delta^{++} - \overset{*}{\Sigma}{}^{+} = \overset{*}{\Sigma}{}^{+} - \overset{*}{\Xi}{}^{0} = \overset{*}{\Xi}{}^{0} - \Omega^- = \overset{*}{\Sigma}{}_c^{++} - \overset{*}{\Xi}{}_c^{+} = \overset{*}{\Xi}{}_c^{+} - \overset{*}{\Omega}{}_c^{0} = \\
& = \overset{*}{\Xi}{}_{cc}^{++} - \overset{*}{\Omega}{}_{cc}^{+} = \Delta^{++} - \overset{*}{\Sigma}{}_c^{++} = \overset{*}{\Sigma}{}_c^{++} - \overset{*}{\Xi}{}_{cc}^{++} = \overset{*}{\Xi}{}_{cc}^{++} - \Omega_{ccc}^{++},
\end{aligned}
\tag{8}
$$

the decuplet splitting, predicted by Thirring [6], extended to the charm case

$$
\Delta^0 - \Delta^+ = \overset{*}{\Sigma}{}^{0} - \overset{*}{\Sigma}{}^{+} = \overset{*}{\Xi}{}^{-} - \overset{*}{\Xi}{}^{0} = \overset{*}{\Sigma}{}_c^{0} - \overset{*}{\Sigma}{}_c^{+} = \overset{*}{\Xi}{}_c^{0} - \overset{*}{\Xi}{}_c^{+} = \overset{*}{\Xi}{}_{cc}^{+} - \overset{*}{\Xi}{}_{cc}^{++} \tag{9}
$$

Table 1

The masses of $\frac{1}{2}^{+}$*-baryons are listed. The used values of the parameters (in MeV) are:* **a** *=135.7,* **b** *= -1266.9,* **d** *= 1528.7,* **k** *= 275.0 and* **m** *= = 2702.1; for the angles we have:* $\sin\theta_7$ *=0.2080 and* $\sin\theta_{10}$ *= 0.0594*

notation	mass (MeV)	
	experiment	theory
P	938.3	938.3
N	939.6	939.6
Λ	1115.6	1106.8
Σ^{+}	1189.4	1189.4
Σ^{0}	1192.5	1193.4
Σ^{-}	1197.3	1197.3
Ξ^{0}	1314.9	1314.8
Ξ^{-}	1321.3	1321.3
Λ_c^{+}	2281.2	2281.9
Σ_c^{++}	2450 /8/	2449.6
Σ_c^{+}	-	2453.6
Σ_c^{0}	-	2457.5
Ξ_c^{+}	2460	2501.0
Ξ_c^{0}	-	2507.8
$\Xi_c^{\prime +}$	-	2652.1
$\Xi_c^{\prime 0}$	-	2654.9
Ω_c^{0}	2740	2832.7
Ξ_{cc}^{++}	-	3707.5
Ξ_{cc}^{+}	-	3714.0
Ω_{cc}^{+}	-	3965.2

Table 2

The masses of $\frac{3}{2}^{+}$*-baryons;* **a** *= 1214,* **b** *=479,* **d** *= 4002 (all are given in MeV). The angles* θ_7 *and* θ_{10} *are the same as in the* $\frac{1}{2}^{+}$*-baryon case*

notation	mass (MeV)	
	experiment	theory
Δ^{++}	1231	1228
Δ^{+}	1230	1230
Δ^{0}	1232	1232
Δ^{-}	1236	1235
$\dot{\Sigma}^{+}$	1383	1376
$\dot{\Sigma}^{0}$	1384	1378
$\dot{\Sigma}^{-}$	1387	1381
$\dot{\Xi}^{0}$	1532	1524
$\dot{\Xi}^{-}$	1535	1526
Ω^{-}	1672	1672
$\dot{\Sigma}_c^{++}$	2510 /8/	2555
$\dot{\Sigma}_c^{+}$	-	2557
$\dot{\Sigma}_c^{0}$	-	2558
$\dot{\Xi}_c^{+}$	-	2702
$\dot{\Xi}_c^{0}$	-	2703
$\dot{\Omega}_c^{0}$	-	2849
$\dot{\Xi}_{cc}^{++}$	-	3878
$\dot{\Xi}_{cc}^{+}$	-	3879
$\dot{\Omega}_{cc}^{+}$	-	4025
Ω_{ccc}^{++}	-	5202

and some others

$$\Delta^{+} = \frac{1}{3}(2\Delta^{++} + \Delta^{-}), \qquad \overset{*}{\Xi}{}^{+}_{c} = \frac{1}{3}(\Delta^{++} + \Omega^{-} + \Omega^{++}_{ccc}),$$
$$\overset{*}{\Sigma} = \frac{1}{3}(2\Delta^{++} + \Omega^{-}), \qquad \overset{*}{\Xi}{}^{++}_{cc} = \frac{1}{3}(\Delta^{++} + 2\Omega^{++}_{ccc}), \tag{10}$$
$$\overset{*}{\Xi}{}^{\circ} = \frac{1}{3}(\Delta^{++} + 2\Omega^{-}), \qquad \Omega^{+}_{cc} = \frac{1}{3}(\Omega^{-} + 2\Omega^{++}_{ccc}).$$
$$\overset{*}{\Sigma}{}^{+}_{c} = \frac{1}{3}(\Delta^{++} + \Delta^{-} + \Omega^{++}_{ccc})$$

The numerical results are given in Table 2 together with the parameter values. The input masses are Δ^{+}, Δ° and Ω^{-} /1/ .

4. Conclusion. The comparatively good agreement with the available experimental data for $\frac{1}{2}^{+}$- and $\frac{3}{2}^{+}$-baryons, reproduction of a series of well-known mass relations and the possibility of principle to enhance the $K^{+}K^{-}$ decay mode of D°-mesons relative to the mode $\pi^{+}\pi^{-}$ /7/ may be interpreted as a first signal that this breaking scheme can have a reasonable physical meaning.

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Калиновский Ю.Л. и др. E2-87-897

Нарушенная киральная SU(4)xSU(4)-симметрия и массы очарованных барионов

Для описания спектра масс $\frac{1}{2}^+$- и $\frac{3}{2}^+$-барионов используется обобщение схемы Оакса. Схема Оакса расширена на случай SU(4)xSU(4)-симметрии при помощи дополнительного поворота вокруг 10-й оси в SU(4)-пространстве. Получены массовые формулы и массы для $\frac{1}{2}^+$ - и $\frac{3}{2}^+$ - двадцатиплетов барионов. Полученные результаты удовлетворительно описывают имеющиеся экспериментальные данные.

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Breakdown of Chiral SU(4)xSU(4)-Symmetry and Masses of Charmed Baryons

For the description of the mass spectrum of $\frac{1}{2}^+$ and $\frac{3}{2}^+$ baryons generalized scheme of Oakes is used. The Oakes scheme is extended to the SU(4)xSU(4) symmetry violation case with the help of an additional rotation around the 10th axis in SU(4)-space. Mass formulae and mass values are obtained for the $\frac{1}{2}^+$ - and $\frac{3}{2}^+$ -baryons. The latter are in good agreement with the available experimental mass data.

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

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