Charm baryon magnetic moments in $\chi\mathrm{CQM}_{\mathrm{config}}$

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During the last few years, there have been a revival of interest in charm baryon spectroscopy with more than a dozen new states being identified and several new theoretical investigations being undertaken. The CLEO, BABAR and Belle Collaborations [1] observed Λ_c^+, Ξ_c and Ω_c excited charmed baryons states. These experiments have inspired new investigations in the heavy flavor sector. One of the important parameters in the heavy baryons spectroscopy is their magnetic moment, which gives valuable information about the internal structure of hadrons.

Recently, it has been shown that χCQM [2] with spin-spin generated configuration mixing ($\chi\mathrm{CQM}_{\mathrm{config}}$) [3, 4] is able to give a satisfactory explanation of the various low energy phenomenon [5–8]. Also, $\chi\mathrm{CQM}_{\mathrm{config}}$ when coupled with the "quark sea" polarization and orbit angular momentum of the "quark sea" (referred as Cheng and Li Mechanism) [5] is able to give a fit to the baryon magnetic moments and gives a satisfactory explanation of the Coleman Glashow sum rule [9]. In this paper, we extend the Cheng and Li mechanism to the charmed baryons in the $\chi\mathrm{CQM}_{\mathrm{config}}$.

The basic process in the χCQM is the internal emission of a Goldstone Boson (GB) by a constituent quark, which further splits into a $q\bar{q}$ pair as $q_\pm \rightarrow \mathrm{GB} + q'_\mp \rightarrow (q\bar{q}^{'}) + q'_\mp$, where $q\bar{q}^{'} + q^{'}$ constitute the "quark sea" [4, 5, 8]. The effective Lagrangian describing interaction between quarks and GBs can be expressed as $\mathcal{L} = g_{15}\bar{\mathbf{q}}\,(\Phi)\,\mathbf{q}$, where the field Φ includes the GBs and g_{15} is the coupling constant. In χCQM, the magnetic moment of a baryon receives contribution from the valence quarks, "quark sea" and its orbital angular momentum and can be written as

$$\mu(B)_{\mathrm{total}} = \mu(B)_{\mathrm{val}} + \mu(B)_{\mathrm{sea}} + \mu(B)_{\mathrm{orbit}}, \quad (1)$$

where $\mu(B)_{\mathrm{val}}$ and $\mu(B)_{\mathrm{sea}}$ represent the the contribution of the valence quark and contribution due to the chiral fluctuation of constituent quark q' in the "quark sea', whereas the term $\mu(B)_{\mathrm{orbit}}$ correspond to the contribution due to the orbital angular momentum of the "quark sea".

The valence quark and the sea quark contributions, in terms of quarks magnetic moments and spin polarizations, can be written as

$$\mu(B)_{\mathrm{val}} = \sum_{q=u,d,s,c} \Delta q_{\mathrm{val}} \mu_q \,, \quad (2)$$

$$\mu(B)_{\mathrm{sea}} = \sum_{q=u,d,s,c} \Delta q_{\mathrm{sea}} \mu_q \,, \quad (3)$$

where, $\mu_q = \frac{e_q}{2M_q}$ $(q = u, d, s, c)$ is the quark magnetic moment, with e_q and M_q as the electric charge and the mass for the quark q, respectively. The valence quark spin polarizations Δq_{val}, following references [3–5] are defined as $\Delta q_{\mathrm{val}} = q_+ - q_-$, where $q_\pm$ are the number of valence quarks, obtained from the spin structure of a baryon. The sea quark spin polarization Δq_{sea} can be evaluated by considering the effect of change in spin structure and making substitution for every valence quark by $q_\pm \rightarrow \sum P_q q_\pm + |\psi(q_\pm)|^2$,where $\sum P_q$ is the probability of emission of GBs from a q quark and $|\psi(q_\pm)|^2$ is the probability of transforming a $q_\pm$ quark [3].

The contribution of the orbital angular momentum $\mu(B)_{\mathrm{orbit}}$ of the "quark sea" to the magnetic moment of the baryon expressed in terms of the valence quark polarizations and contribution of the magnetic moment of the spin flip process ($q_\pm \rightarrow q'_\mp + \mathrm{GB}$), following Cheng and Li [3, 5], is defined by

$$\mu(B)_{\mathrm{orbit}} = \sum_{q=u,d,s,c} \Delta q_{\mathrm{val}} \; \mu(q_+ \rightarrow q^{'}_-), \quad (4)$$

where

$$\mu(q_+ \rightarrow q^{'}_-) = \frac{e_{q'}}{2M_q}\langle l_q \rangle + \frac{e_q - e_{q'}}{2M_{\rm GB}}\langle l_{\rm GB} \rangle \,.$$

Here, $\langle l_q \rangle = \frac{M_{\rm GB}}{M_q + M_{\rm GB}}$ and $\langle l_{\rm GB} \rangle = \frac{M_q}{M_q + M_{\rm GB}}$, $(l_q, l_{\rm GB})$ and $(M_q, M_{\rm GB})$ are the orbital angular momenta and masses of quark and GBs, respectively. The orbital magnetic moment of each process is then multiplied by the probability of such a process to take place to yield the magnetic moment due to all the transitions.

The χCQM$_{\rm config}$ involves five parameters a, $a\alpha^2$, $a\beta^2$, $a\zeta^2$, $a\gamma^2$ representing the probabilities of fluctuations to pions, K, η, $\eta^{'}$, η_c, respectively, following the hierarchy $a > \alpha > \beta > \zeta > \gamma$. These parameters are fixed by using the spin polarizations and quark distribution functions as input with their latest values [1]. The best fit parameters are $a = 0.12, \alpha \simeq \beta = 0.45, \zeta = -0.21$ and $\gamma = 0.11$. For evaluating the contribution of GBs masses, we have used their on shell mass value in accordance with several other similar calculations.

The results for magnetic moments of charmed baryons with the explicit values for the valence, sea and orbit contributions are presented in Table I. It has been observed that the orbital part contributes with the same sign as valence quark distribution, while the sea part contribute with the opposite sign. The sea quark and orbital contributions are quite large in magnitude except for the case of Λ_c^+, $\Xi_c^{'+}$ and $\Xi_c^{'0}$. However, their contributions cancel each other to a large extent. Thus the sum of residual sea quark contribution and valence quark contribution seems to give the magnetic moment of baryons. Since experimental results for the magnetic moments of the spin $1/2^+$ charmed baryons are still awaited, we compare our predictions with the QCD Sum Rules method [10].

In conclusion, our results for the magnetic moments of charmed baryons are consistent with the other approaches existing in the literature. The success of χCQM with the configuration mixing and Cheng and Li mechanism in achieving a fit to the magnetic moments suggest that constituent quarks and weakly interacting goldstone bosons provide the appropriate degree of freedom in the in the non perturbative regime of QCD.

TABLE I: The magnetic moments of the charmed baryons spin $1/2^+$ in units of nucleon magneton.

	NRQM	QCDSR[10]	VAL	SEA	ORBIT	Total
$\mu_{\Sigma_c^{++}}$	2.52	2.1± 0.3	2.07	−0.47	0.40	2.00
$\mu_{\Sigma_c^+}$	0.52	0.6 ±0.1	0.44	−0.20	0.02	0.26
$\mu_{\Sigma_c^0}$	−1.48	−1.6 ± 0.2	−1.18	0.06	−0.37	−1.49
$\mu_{\Xi_c^+}$	0.76	...	0.70	−0.19	0.19	0.70
$\mu_{\Xi_c^0}$	−1.24	...	−1.08	0.03	−0.19	−1.24
$\mu_{\Omega_c^0}$	−1.01	...	−0.87	0.04	−0.01	−0.84
$\mu_{\Lambda_c^+}$	0.44	0.40± 0.05	0.42	−0.02	0.002	0.402
$\mu_{\Xi_c^{'+}}$	0.44	0.50 ±0.05	0.41	−0.01	0.01	0.41
$\mu_{\Xi_c^{'0}}$	0.44	0.35± 0.05	0.31	−0.001	−0.01	0.299

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