Strangeness magnetic moments of N and Δ

Harleen Dahiya[1] and Neetika Sharma
Department of Physics, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar-144011, India

We have calculated the strangeness contribution to the magnetic moments of the nucleon and Δ decuplet baryons in the chiral constituent quark model with configuration mixing (χCQM$_{\rm config}$) which is known to provide a satisfactory explanation of the proton spin crisis and related issues. Our results are consistent with the recent experimental observations.

1 Introduction

The recent measurements by several groups SAMPLE at MIT-Bates [1], G0 at JLab [2], A4 at MAMI [3] and by HAPPEX at JLab [4] regarding the contribution of strangeness to the electromagnetic form factors of the nucleon have triggered a great deal of interest in finding the strangeness magnetic moment of the proton ($\mu(p)^s$). The SAMPLE experiment has observed $\mu(p)^s$ to be $0.37 \pm 0.26 \pm 0.20$ [1] whereas G0 [2], A4 [3] and HAPPEX [4] have observed the combination of electric and magnetic form factors. It is widely recognized that a knowledge about the strangeness content of the nucleon would undoubtedly provide vital clues to the non-perturbative aspects of QCD.

Chiral constituent quark model (χCQM) [6] can yield an adequate description of the quark sea generation through the chiral fluctuations and is also successful in giving a satisfactory explanation of proton spin crisis [7]. Recently, it has been shown chiral constituent quark model with configuration mixing (χCQM$_{\rm config}$) when coupled with the quark sea polarization and orbital angular momentum through the Cheng-Li mechansim [8] is able to give an excellent fit [9] to the octet and decuplet magnetic moments. It, therefore, becomes desirable to carry out the calculations of the strangeness contribution to the magnetic moments of nucleon in the χCQM$_{\rm config}$ in the light of some recent observations [1–5]. For the sake of completeness, we would also like to calculate the strangeness contribution to the magnetic moments of decuplet baryons $\mu(\Delta^{++})^s$, $\mu(\Delta^{+})^s$, $\mu(\Delta^{o})^s$ and $\mu(\Delta^{-})^s$ which have not been observed experimentally.

[1] dahiyah@nitj.ac.in

2 Chiral Constituent Quark Model

The basic process in the χCQM formalism is the emission of a Goldstone boson (GB) by a constituent quark which further splits into a $q\bar{q}$ pair [8, 10, 11], for example, $q_{\pm} \rightarrow \mathrm{GB}^0 + q^{'}_{\mp} \rightarrow (q\bar{q}^{'}) + q^{'}_{\mp}$, where $q\bar{q}^{'} + q^{'}$ constitute the quark sea [8] and the $\pm$ signs refer to the quark helicities. The effective Lagrangian describing interaction between quarks and a nonet of GBs, consisting of octet and a singlet, can be expressed as $\mathcal{L} = g_8 \bar{\mathbf{q}} \left(\Phi + \zeta \frac{\eta'}{\sqrt{3}} I \right) \mathbf{q} = g_8 \bar{\mathbf{q}} \left(\Phi' \right) \mathbf{q}$, where $\zeta = g_1/g_8$, g_1 and g_8 are the coupling constants for the singlet and octet GBs, respectively, I is the 3×3 identity matrix. The GB field which includes the octet and the singlet GBs is written as

$$(1)\ \Phi' = \left(\begin{array}{ccc} \frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta^{'}}{\sqrt{3}} & \pi^+ & \alpha K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta^{'}}{\sqrt{3}} & \alpha K^0 \\ \alpha K^- & \alpha \bar{K}^0 & -\beta\frac{2\eta}{\sqrt{6}} + \zeta\frac{\eta^{'}}{\sqrt{3}} \end{array} \right) \text{and } q = \left(\begin{array}{c} u \\ d \\ s \end{array} \right).$$

SU(3) symmetry breaking is introduced by considering $M_s > M_{u,d}$ as well as by considering the masses of GBs to be nondegenerate ($M_{K,\eta} > M_\pi$ and $M_{\eta'} > M_{K,\eta}$) [8,10]. The parameter $a (= |g_8|^2)$ denotes the probability of chiral fluctuation $u(d) \rightarrow d(u) + \pi^{+(-)}$, $\alpha^2 a$, $\beta^2 a$ and $\zeta^2 a$ respectively denote the probabilities of fluctuations $u(d) \rightarrow s + K^{-(0)}$, $u(d,s) \rightarrow u(d,s) + \eta$ and $u(d,s) \rightarrow u(d,s) + \eta^{'}$.

3 Magnetic moment

The magnetic moment of a given baryon in the χCQM can be expressed as $\mu(B)_{\mathrm{total}} = \mu(B)_{\mathrm{val}} + \mu(B)_{\mathrm{sea}}$, where $\mu(B)_{\mathrm{val}}$ represents the contribution of the valence quarks and $\mu(B)_{\mathrm{sea}}$ corresponding to the quark sea. Further, $\mu(B)_{\mathrm{sea}}$ can be written as $\mu(B)_{\mathrm{sea}} = \mu(B)_{\mathrm{spin}} + \mu(B)_{\mathrm{orbit}}$, where the first term is the magnetic moment contribution of the $q^{'}$ coming from the spin polarization and the second term is due to the rotational motion of the two bodies, $q^{'}$ and GB and referred to as the orbital angular momentum by Cheng and Li [8].

The strangeness contribution to the magnetic moment of the proton $\mu(p)^s$ receives contributions only from the quark sea and is expressed as $\mu(p)^s = \mu(p)^s_{\mathrm{spin}} + \mu(p)^s_{\mathrm{orbit}}$ where $\mu(p)^s_{\mathrm{spin}} = \sum_{q=u,d,s} \Delta q(p)^s_{\mathrm{sea}} \mu_q$ and $\mu(p)^s_{\mathrm{orbit}} = \frac{4}{3}[\mu(u_+ \rightarrow s_-)] - \frac{1}{3}[\mu(d_+ \rightarrow s_-)]$. Here, $\mu_q = \frac{e_q}{2M_q}$ $(q = u, d, s)$ is the quark magnetic moment, e_q and M_q are the electric charge and the mass respectively for the quark q and $\mu(q_+ \rightarrow s_-) = \frac{e_s}{2M_q}\langle l_q \rangle + \frac{e_q - e_s}{2M_{GB}}\langle l_{GB} \rangle$. The quantities (l_q, l_{GB}) and (M_q, M_{GB}) are the orbital angular momenta and masses of quark and GB, respectively. The strangeness contribution to the magnetic moments of the neutron $n(ddu)$ as well as the decuplet baryons $\Delta^{++}(uuu)$, $\Delta^+(uud)$, $\Delta^o(udd)$ and $\Delta^-(ddd)$ can be calculated similarly.

Baryon	Data	$\mu(B)^s_{\text{spin}}$	$\mu(B)^s_{\text{orbit}}$	$\mu(B)^s$
p	$0.37 \pm 0.26 \pm 0.20$ [1]	-0.09	0.06	-0.03
n	–	0.06	-0.09	-0.03
Δ^{++}	–	-0.29	0.18	-0.11
Δ^{+}	–	-0.14	0.11	-0.03
Δ^{o}	–	-0.04	-0.03	-0.07
Δ^{-}	–	-0.09	0.15	0.06

Table 1: The calculated values of the strangeness contribution to the magnetic moment of nucleon and Δ decuplet baryons in the χCQM$_{\text{config}}$.

4 Results and Discussion

In Table 1, we have presented the spin and orbital contributions pertaining to the strangeness magnetic moment of the nucleon and Δ baryons. From the Table one finds that the present result for the strangeness contribution to the magnetic moment of proton looks to be in agreement with the most recent results available for $\mu(p)^s$. On closer examination of the results, several interesting points emerge. The strangeness contribution to the magnetic moment is coming from spin and orbital angular momentum of the quark sea with opposite signs. These contributions are fairly significant and they cancel in the right direction to give the right magnitude to $\mu(p)^s$, For example, the spin contribution in this case is $-0.09\mu_N$ and the contribution coming from the orbital angular momentum is $0.05\mu_N$. These contributions cancel to give a small value for $\mu(p)^s$ $-0.03\mu_N$ which is consistent with the other observed results. Interestingly, in the case of $\mu(n)^s$, the magnetic moment is dominated by the orbital part as was observed in the case of the total magnetic moments [9] however, the total strangeness magnetic moment is same as that of the proton. Therefore, an experimental observation of this would not only justify the Cheng-Li mechanism [8] but would also suggest that the chiral fluctuations is able to generate the appropriate amount of strangeness in the nucleon. For the sake of completeness, we have also presented the results of $\mu(\Delta^{++})^s$, $\mu(\Delta^{+})^s$, $\mu(\Delta^{o})^s$, $\mu(\Delta^{-})^s$ and here also we find that there is a substantial contribution from spin and orbital angular momentum. In general, one can find that whenever there is an excess of d quarks the orbital part dominates, whereas when we have an excess of u quarks, the spin polarization dominates.

In conclusion, χCQM$_{\text{config}}$ is able to provide a fairly good description of the strangeness contribution to the magnetic moment $\mu(p)^s$ and our result is consistent with the latest experimental measurements as well as with the other calculations. The constituent quarks and the weakly interacting Goldstone bosons constitute the appropriate degrees of freedom in the nonperturbative regime of QCD and the quark sea generation through the chiral fluctuation is the key in understanding the strangeness content of the nucleon.

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