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Sum rules for strange form factors and flavor singlet axial charges

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Abstract

In chiral models with SU(3) group structure, strange form factors of baryon octet are evaluated by constructing their sum rules to yield theoretical predictions comparable to the recent experimental data of the SAMPLE Collaboration. We also study sum rules for the flavor singlet axial currents for the EMC experiment in a modified quark model.

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1. Introduction

There have been many interesting developments concerning the strange flavor structures in the nucleon and the hyperons. Especially, the internal structure of the nucleon is still a subject of great interest to both experimentalists and theorists. In 1933, Frisch and Stern [1] performed the first measurement of the magnetic moment of the proton and obtained the earliest experimental evidence for the internal structure of the nucleon. However, it was not until 40 years later that the quark structure of the nucleon was directly observed in deep inelastic electron scattering experiments and we still lack a quantitative theoretical understanding of these properties including the magnetic moments.

Quite recently, the SAMPLE Collaboration [2] reported the experimental data of the proton strange form factor through parity violating electron scattering [3]. To be more precise, they measured the neutral weak form factors at a small momentum transfer $Q_S^2 = 0.1 \text{ (GeV}/c)^2$ to yield the proton strange magnetic form factor in units of Bohr nuclear magnetons (n.m.) $G_M^s(Q_S^2) = +0.14 \pm 0.29(\text{stat}) \pm 0.31(\text{sys}) \text{ n.m.}$ [2]. This positive experimental value is contrary to the negative values of the proton strange form factor which result from most of the model calculations except the predictions [4,5] based on the SU(3) chiral bag model [6] and the recent predictions of the chiral quark soliton model [7] and the heavy baryon chiral perturbation theory [8]. (See [9] for more details.)

On the other hand, the EMC experiment [10] also reported the highly nontrivial data that less than 30% of the proton spin may be carried by the quark spin, which is quite different from the well-known prediction from

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constituent quark model. To explain this discrepancy, it has been proposed [11] that the experimentally measured quantity is not merely the quark spin polarization $\Delta\Sigma$ but rather the flavor singlet axial current (FSAC) via the axial anomaly mechanism [12]. Recently, at the quark model renormalization scale, the gluon polarization contribution to the FSAC in the chiral bag model has been calculated [13] to yield a significant reduction in the relative fraction of the proton spin carried by the quark spin, consistent with the small FSAC measured in the EMC experiments.

In this Letter, in the chiral models with SU(3) group structure, we will investigate the strange form factors of octet baryons in terms of the sum rules of the baryon octet magnetic moments to predict the proton strange form factor. We will also study the modified quark model with SU(3) group structure to obtain sum rules for the strange flavor singlet axial current of the nucleon in terms of the octet magnetic moments μ_B and the nucleon axial vector coupling constant g_A . In Section 2, we construct the sum rules of the baryon octet magnetic moments in the SU(3) chiral models. In Section 3 we construct the sum rules for the nucleon strange flavor singlet axial current in the modified quark model.

2. Strange form factors

Now we consider the baryon magnetic moments in the chiral models such as skyrmion [14], MIT bag [15] and chiral bag [6] with the general chiral SU(3) group structure. In these models, the EM currents yield the magnetic moment operators $\hat{\mu}^i = \hat{\mu}^{i(3)} + \frac{1}{\sqrt{3}}\hat{\mu}^{i(8)}$ where $\hat{\mu}^{i(a)} = \hat{\mu}_{\text{CS}}^{i(a)} + \hat{\mu}_{\text{FSB}}^{i(a)}$ with

$$\begin{aligned}\hat{\mu}_{\text{CS}}^{i(a)} &= -\mathcal{N}D_{ai}^8 - \mathcal{N}'d_{ipq}D_{ap}^8\hat{T}_q^R + \frac{N_c}{2\sqrt{3}}\mathcal{M}D_{a8}^8\hat{J}_i, \\ \hat{\mu}_{\text{FSB}}^{i(a)} &= -\mathcal{P}D_{ai}^8(1 - D_{88}^8) + \mathcal{Q}\frac{\sqrt{3}}{2}d_{ipq}D_{ap}^8D_{8q}^8 + \mathcal{R}D_{a8}^8D_{8i}^8,\end{aligned}\quad (2.1)$$

where \mathcal{M} , \mathcal{N} , \mathcal{N}' , \mathcal{P} , \mathcal{Q} and \mathcal{R} are the inertia parameters calculable in the chiral models. Note that we include the inertia parameter \mathcal{R} neglected in [5].

In the higher-dimensional irreducible representation of SU(3) group, the baryon wave function is described as [4,16]

$$|B\rangle = |B\rangle_8 - C_{10}^B|B\rangle_{\bar{10}} - C_{27}^B|B\rangle_{27}, \quad (2.2)$$

where the representation mixing coefficients are given by $C_\lambda^B = \lambda\langle B|H_{\text{SB}}|B\rangle_8/(E_\lambda - E_8)$. Here E_λ is the eigenvalue of the eigenequation $H_0|B\rangle_\lambda = E_\lambda|B\rangle_\lambda$. (For explicit expressions for the Hamiltonian $H = H_0 + H_{\text{SB}}$ in the chiral models, see [5].) Using the above baryon wave function, the spectrum of the magnetic moment operator $\hat{\mu}^i$ in (2.1) has the hyperfine structure

$$\begin{aligned}\mu_p &= \frac{1}{10}\mathcal{M} + \frac{4}{15}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) + \frac{8}{45}\mathcal{P} - \frac{2}{45}\mathcal{Q} - \frac{1}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{2}{125}\mathcal{M} + \frac{8}{1125}\mathcal{N} - \frac{16}{1125}\mathcal{N}'\right), \\ \mu_n &= \frac{1}{20}\mathcal{M} - \frac{1}{5}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{1}{9}\mathcal{P} + \frac{7}{90}\mathcal{Q} + \frac{1}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{31}{750}\mathcal{M} - \frac{46}{1125}\mathcal{N} + \frac{42}{1125}\mathcal{N}'\right), \\ \mu_\Lambda &= \frac{1}{40}\mathcal{M} - \frac{1}{10}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{1}{10}\mathcal{P} - \frac{1}{20}\mathcal{Q} + m\mathcal{I}_2\left(\frac{9}{500}\mathcal{M} + \frac{1}{125}\mathcal{N} - \frac{2}{125}\mathcal{N}'\right), \\ \mu_{\Sigma^0} &= \frac{1}{20}\mathcal{M} - \frac{1}{5}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{11}{45}\mathcal{P} - \frac{1}{45}\mathcal{Q} + \frac{1}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{1}{125}\mathcal{M} + \frac{4}{1125}\mathcal{N} - \frac{8}{1125}\mathcal{N}'\right), \\ \mu_{\Sigma^-} &= -\frac{3}{20}\mathcal{M} - \frac{1}{15}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{4}{45}\mathcal{P} - \frac{2}{45}\mathcal{Q} - \frac{4}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{2}{125}\mathcal{M} + \frac{8}{1125}\mathcal{N} - \frac{16}{1125}\mathcal{N}'\right),\end{aligned}$$

$$\begin{aligned}
\mu_{\Sigma^+} &= \frac{1}{10}\mathcal{M} + \frac{4}{15}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) + \frac{13}{45}\mathcal{P} - \frac{1}{45}\mathcal{Q} - \frac{2}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{1}{125}\mathcal{M} + \frac{4}{1125}\mathcal{N} - \frac{8}{1125}\mathcal{N}'\right), \\
\mu_{\Sigma^0} &= -\frac{1}{40}\mathcal{M} + \frac{1}{10}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) + \frac{11}{90}\mathcal{P} + \frac{1}{36}\mathcal{Q} + \frac{1}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{37}{1500}\mathcal{M} - \frac{7}{375}\mathcal{N} + \frac{17}{1125}\mathcal{N}'\right), \\
\mu_{\Sigma^-} &= -\frac{3}{20}\mathcal{M} - \frac{1}{15}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{2}{45}\mathcal{P} + \frac{7}{90}\mathcal{Q} + \frac{4}{45}\mathcal{R} + m\mathcal{I}_2\left(\frac{31}{750}\mathcal{M} - \frac{46}{1125}\mathcal{N} + \frac{14}{375}\mathcal{N}'\right), \quad (2.3)
\end{aligned}$$

where the coefficients are solely given by the SU(3) group structure of the chiral models and the physical informations such as decay constants and masses are included in the above inertia parameters, such as \mathcal{M} , \mathcal{N} and so on. Note that the SU(3) group structure in the coefficients is generic property shared by the chiral models which exploit the hedgehog ansatz solution corresponding to the little group $SU(2) \times \mathbf{Z}_2$ [17]. In the chiral perturbation theory to which the hedgehog ansatz does not apply, one can thus see the coefficients different from those in (2.3) even though the SU(3) flavor group is used in the theory [18].

Now it seems appropriate to comment on the $1/N_c$ expansion [17,19–21]. In the above relations (2.3), the inertia parameters \mathcal{N} , \mathcal{N}' , \mathcal{P} , \mathcal{Q} and \mathcal{R} are of order N_c while \mathcal{M} is of order N_c^{-1} . However, since the inertia parameter \mathcal{M} is multiplied by an explicit factor N_c in (2.1), the terms with \mathcal{M} are of order N_c^0 . Moreover, the inertia parameter m is of order of m_s . (For details of further $1/N_c$ and m_s orders, see [17,21].)

Using the V -spin symmetry sum rules [5], one can obtain the relation

$$\frac{1}{2}\mathcal{M} = \mu_p - \mu_{\Xi^-} - \frac{1}{3}(\mu_{\Sigma^+} - \mu_{\Xi^0}) + \frac{4}{3}(\mu_n - \mu_{\Sigma^-}) \quad (2.4)$$

which will be used later to obtain sum rules of the strange form factors of octet baryons.

Now we consider the form factors of the octet baryons which, in the chiral models, are definitely extended objects with internal structure associated with the electromagnetic (EM) current, to which the photon couples,

$$\hat{V}_\gamma^\mu = \frac{2}{3}\bar{u}\gamma^\mu u - \frac{1}{3}\bar{d}\gamma^\mu d - \frac{1}{3}\bar{s}\gamma^\mu s. \quad (2.5)$$

According to the Feynman rules the matrix element of \hat{V}_γ^μ for the baryon with transition from momentum state p to momentum state $p + q$ is given by the following covariant decomposition

$$\langle p + q | \hat{V}_\gamma^\mu | p \rangle = \bar{u}(p + q) \left[F_{1B}^\gamma(q^2)\gamma^\mu + \frac{i}{2M_B} F_{2B}^\gamma(q^2)\sigma^{\mu\nu}q_\nu \right] u(p), \quad (2.6)$$

where $u(p)$ is the spinor for the baryon states and q is the momentum transfer and $\sigma^{\mu\nu} = \frac{i}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)$ and M_B is the baryon mass and F_1^γ and F_2^γ are the Dirac and Pauli EM form factors, which are Lorentz scalars and $p^2 = (p + q)^2 = M_B^2$ on shell so that they depend only on the Lorentz scalar variable $q^2 (= -Q^2)$. We will also use the Sachs form factors, which are linear combinations of the Dirac and Pauli form factors

$$G_E^\gamma = F_{1B}^\gamma + \frac{q^2}{4M_B^2} F_{2B}^\gamma, \quad G_M^\gamma = F_{1B}^\gamma + F_{2B}^\gamma \quad (2.7)$$

which can be rewritten as

$$G_{E,M}^\gamma = \frac{2}{3}G_{E,M}^u - \frac{1}{3}G_{E,M}^d - \frac{1}{3}G_{E,M}^s. \quad (2.8)$$

On the other hand, the neutral weak current operator is given by an expression analogous to (2.5) but with different coefficients:

$$\hat{V}_Z^\mu = \left(\frac{1}{4} - \frac{2}{3}\sin^2\theta_W\right)\bar{u}\gamma^\mu u + \left(-\frac{1}{4} + \frac{1}{3}\sin^2\theta_W\right)\bar{d}\gamma^\mu d + \left(-\frac{1}{4} + \frac{1}{3}\sin^2\theta_W\right)\bar{s}\gamma^\mu s. \quad (2.9)$$

Here the coefficients depend on the weak mixing angle, which has recently been determined [22] with high precision: $\sin^2 \theta_W = 0.2315 \pm 0.0004$. In direct analogy to (2.8), we have expressions for the neutral weak form factors $G_{E,M}^Z$ in terms of the different quark flavor components:

$$G_{E,M}^Z = \left(\frac{1}{4} - \frac{2}{3} \sin^2 \theta_W \right) G_{E,M}^u + \left(-\frac{1}{4} + \frac{1}{3} \sin^2 \theta_W \right) G_{E,M}^d + \left(-\frac{1}{4} + \frac{1}{3} \sin^2 \theta_W \right) G_{E,M}^s. \quad (2.10)$$

Here one notes that the form factors $G_{E,M}^f$ ($f = u, d, s$) appearing in this expression are exactly the same as those in the EM form factors, as in (2.8).

Utilizing isospin symmetry, one then can eliminate the up and down quark contributions to the neutral weak form factors by using the proton and neutron EM form factors and obtain the expressions

$$G_{E,M}^{Z,p} = \left(\frac{1}{4} - \sin^2 \theta_W \right) G_{E,M}^{\gamma,p} - \frac{1}{4} G_{E,M}^{\gamma,n} - \frac{1}{4} G_{E,M}^s. \quad (2.11)$$

It shows how the neutral weak form factors are related to the EM form factors plus a contribution from the strange (electric or magnetic) form factor. Measurement of the neutral weak form factor will thus allow (after combination with the EM form factors) determination of the strange form factor of interest. It should be mentioned that there are electroweak radiative corrections to the coefficients in (2.10), which are generally small corrections, of order 1–2%, and can be reliably calculated [23].

The EM form factors present in (2.11) are very accurately known (1–2%) for the proton in the momentum transfer region $Q^2 < 1$ (GeV/c)². The neutron form factors are not known as accurately as the proton form factors (the electric form factor G_E^n is at present rather poorly constrained by experiment), although considerable work to improve our knowledge of these quantities is in progress. Thus, the present lack of knowledge of the neutron form factors will significantly hinder the interpretation of the neutral weak form factors.

At zero momentum transfer, one can have the relations between the EM form factors and the static physical quantities of the baryon octet, namely $G_E^\gamma(0) = Q_B$ and $G_M^\gamma(0) = \mu_B$ with the electric charge Q_B and magnetic moment μ_B of the baryon. In the strange flavor sector, the Sachs magnetic form factor in (2.7) yields the strange form factors of baryon octet degenerate in isomultiplets $F_{2B}^s(0) = G_M^s(0) - F_{1B}^s(0)$ where $F_{1B}^s = -3Q_B^s$ with the fractional strange EM charge Q_B^s . Here note that one can express the slope of G_E^s at $Q^2 = 0$ in the usual fashion in terms of a strangeness radius r_s^2 defined as $r_s^2 = -6[dG_E^s/dQ^2]_{Q^2=0}$.

Now we construct model independent sum rules for the strange form factors of baryon octet in the chiral models with the SU(3) flavor group structure. Since the nucleon has no net strangeness the nucleon strange form factor is given by [5]

$$F_{2N}^s(0) = \frac{7}{20} \mathcal{M} - \frac{1}{15} \left(\mathcal{N} + \frac{1}{2} \mathcal{N}' \right) - \frac{1}{15} \mathcal{P} - \frac{1}{30} \mathcal{Q} + m \mathcal{I}_2 \left(-\frac{43}{750} \mathcal{M} + \frac{38}{1125} \mathcal{N} - \frac{26}{1125} \mathcal{N}' \right). \quad (2.12)$$

Substituting (2.4) into the relation $F_{2N}^s(0) + \mu_p + \mu_n - \frac{1}{2} \mathcal{M} = 0$ calculated from (2.3) and (2.12), we obtain the sum rules for the nucleon strange form factor

$$F_{2N}^s(0) = \mu_p - \mu_{\Sigma^-} - (\mu_p + \mu_n) - \frac{1}{3} (\mu_{\Sigma^+} - \mu_{\Sigma^0}) + \frac{4}{3} (\mu_n - \mu_{\Sigma^-}) \quad (2.13)$$

which, at least within the SU(3) flavor chiral models, is independent of the values of the model dependent inertia parameters. Inserting into (2.13) the experimental data for the baryon octet magnetic moments, one can evaluate the nucleon strange form factor

$$F_{2N}^s(0) = G_M^s(0) = 0.32 \text{ n.m.} \quad (2.14)$$

On the other hand, the quantities $G_{E,M}^Z$ in (2.11) for the proton can be determined via elastic parity-violating electron scattering to yield the experimental data $G_M^s(Q_S^2) = +0.14 \pm 0.29(\text{stat}) \pm 0.31(\text{sys}) \text{ n.m.}$ [2] for the

Table 1

The baryon octet strange form factors in units of Bohr nuclear magnetons calculated via model independent relations. For input data for the baryon octet magnetic moments we have used the experimental data (Exp) and the theoretical predictions from the chiral bag model (CBM), skyrmion model (SM) and chiral quark soliton model (CQSM)

Input	$F_{2N}^s(0)$	$F_{2\Lambda}^s(0)$	$F_{2\Sigma}^s(0)$	$F_{2\Sigma}^s(0)$
Exp	0.32	1.42	1.10	-1.10
CBM	0.30	0.49	0.25	-1.54
SM	-0.02	0.51	0.09	-1.75
CQSM	-0.02	1.06	0.86	-1.89

proton strange magnetic form factor. Here one notes that the prediction for the proton strange form factor (2.14) obtained from the sum rule (2.13) is comparable to the SAMPLE data. Moreover, from the relation (2.11) at zero momentum transfer, the neutral weak magnetic moment of the nucleon can be written in terms of the nucleon magnetic moments and the proton strange form factor [24]

$$4\mu_p^Z = \mu_p - \mu_n - 4\sin^2\theta_W\mu_p - F_{2N}^s(0). \quad (2.15)$$

Next, we obtain the other octet baryon strange form factors [5]

$$\begin{aligned} F_{2\Lambda}^s(0) &= \frac{9}{20}\mathcal{M} + \frac{1}{5}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) + \frac{1}{5}\mathcal{P} + \frac{1}{10}\mathcal{Q} + m\mathcal{I}_2\left(-\frac{9}{250}\mathcal{M} - \frac{2}{125}\mathcal{N} + \frac{4}{125}\mathcal{N}'\right) - 1, \\ F_{2\Sigma}^s(0) &= \frac{3}{5}\mathcal{M} + \frac{4}{15}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) + \frac{1}{3}\mathcal{P} + \frac{1}{15}\mathcal{Q} + \frac{1}{15}\mathcal{R} + m\mathcal{I}_2\left(-\frac{3}{125}\mathcal{M} - \frac{4}{375}\mathcal{N} + \frac{8}{375}\mathcal{N}'\right) - 2, \\ F_{2\Sigma}^s(0) &= \frac{11}{20}\mathcal{M} - \frac{1}{5}\left(\mathcal{N} + \frac{1}{2}\mathcal{N}'\right) - \frac{11}{45}\mathcal{P} - \frac{1}{18}\mathcal{Q} - \frac{2}{45}\mathcal{R} + m\mathcal{I}_2\left(-\frac{37}{750}\mathcal{M} + \frac{14}{375}\mathcal{N} - \frac{34}{1125}\mathcal{N}'\right) - 1, \end{aligned} \quad (2.16)$$

which, similarly to the nucleon strange form factors, can be rewritten in terms of the octet magnetic moments to yield the sum rules for the other octet strange form factors

$$\begin{aligned} F_{2\Lambda}^s(0) &= \mu_p - \mu_{\Sigma^-} - 2\mu_{\Lambda} - \frac{1}{3}(\mu_{\Sigma^+} - \mu_{\Sigma^0}) + \frac{4}{3}(\mu_n - \mu_{\Sigma^-}) - 1, \\ F_{2\Sigma}^s(0) &= \mu_p - \mu_{\Sigma^-} - (\mu_{\Sigma^0} + \mu_{\Sigma^-}) - \frac{1}{3}(\mu_{\Sigma^+} - \mu_{\Sigma^0}) + \frac{4}{3}(\mu_n - \mu_{\Sigma^-}) - 2, \\ F_{2\Sigma}^s(0) &= \mu_p - \mu_{\Sigma^-} - (\mu_{\Sigma^+} + \mu_{\Sigma^-}) - \frac{1}{3}(\mu_{\Sigma^+} - \mu_{\Sigma^0}) + \frac{4}{3}(\mu_n - \mu_{\Sigma^-}) - 1. \end{aligned} \quad (2.17)$$

Note that these sum rules (2.13) and (2.17) are extracted only from the intrinsic SU(3) flavor group structures of the octet baryons. Using the experimental data for the known baryon octet magnetic moments, we can predict the octet baryon strange form factors as shown in Table 1. We also evaluate the strange form factors by using the theoretical predictions from the chiral bag model, skyrmion model and chiral quark soliton model as input data of the sum rules (2.13) and (2.17) given in the SU(3) flavor chiral models. Here one notes that, since the values of the magnetic moments used in the theoretical model predictions of the baryon strange form factors have already had discrepancies deviated from the corresponding experimental values of the baryon magnetic moments, the predicted values of the baryon octet strange form factors listed in Table 1 are unreliably sensitive in the strange flavor channel.

3. Strange flavor singlet axial currents

In this section, we consider a modified quark model [25]. In the nonrelativistic quark model, the quarks possess the static properties such as mass, electromagnetic charge and magnetic moments, which are independent of

their surroundings. However this assumption seems to be irrelevant to the realistic experimental situation. In the literature [25], the magnetic moments of the quarks were proposed to be different in the different isomultiplets, but to be the same within an isomultiplet. The magnetic moments are then given by

$$\mu_B = \mu_u^B \Delta u^B + \mu_d^B \Delta d^B + \mu_s^B \Delta s^B, \quad (3.1)$$

where μ_f^B is an effective magnetic moment of the quark of flavor f for the baryon B degenerate in the corresponding baryon isomultiplet, and Δf^B is the spin polarization for the baryon.

Using the SU(3) charge symmetry one can obtain the magnetic moments of the octet baryons as follows [25]¹

$$\begin{aligned} \mu_p &= \mu_u^N \Delta u + \mu_d^N \Delta d + \mu_s^N \Delta s, & \mu_n &= \mu_u^N \Delta d + \mu_d^N \Delta u + \mu_s^N \Delta s, \\ \mu_\Lambda &= \frac{1}{6}(\mu_u^\Lambda + \mu_d^\Lambda)(\Delta u + 4\Delta d + \Delta s) + \frac{1}{3}\mu_s^\Lambda(2\Delta u - \Delta d + 2\Delta s), \\ \mu_{\Sigma^0} &= \mu_u^\Sigma \Delta d + \mu_d^\Sigma \Delta s + \mu_s^\Sigma \Delta u, & \mu_{\Sigma^-} &= \mu_u^\Sigma \Delta s + \mu_d^\Sigma \Delta d + \mu_s^\Sigma \Delta u, \\ \mu_{\Sigma^+} &= \mu_u^\Sigma \Delta u + \mu_d^\Sigma \Delta s + \mu_s^\Sigma \Delta d, & \mu_{\Sigma^0} &= \frac{1}{2}(\mu_u^\Sigma + \mu_d^\Sigma)(\Delta u + \Delta s) + \mu_s^\Sigma \Delta d, \\ \mu_{\Sigma^-} &= \mu_u^\Sigma \Delta s + \mu_d^\Sigma \Delta u + \mu_s^\Sigma \Delta d. \end{aligned} \quad (3.2)$$

Here one notes that it is difficult to figure out which terms are of the order of m_s and whether Δf contain symmetry breaking or whether the symmetry breaking manifests itself only in the fact that the quark magnetic moments are different for different baryons.

After some algebra we obtain the novel sum rules for spin polarizations Δf with the flavor f in terms of the octet magnetic moments μ_B and the nucleon axial vector coupling constant g_A

$$\begin{aligned} \Delta u &= g_A \frac{R_\Sigma - 2R_\Xi + R_S + 3R_\Xi(R_S - R_\Sigma)}{3(R_\Sigma - R_\Xi)(1 - R_S)}, & \Delta d &= g_A \frac{-2R_\Sigma + R_\Xi + R_S + 3R_\Sigma(R_S - R_\Xi)}{3(R_\Sigma - R_\Xi)(1 - R_S)}, \\ \Delta s &= g_A \frac{R_\Sigma + R_\Xi - 2R_S + 3(R_S^2 - R_\Sigma R_\Xi)}{3(R_\Sigma - R_\Xi)(1 - R_S)} \end{aligned} \quad (3.3)$$

with

$$\begin{aligned} R_N &= \frac{\mu_p + \mu_n}{\mu_p - \mu_n}, & R_\Sigma &= \frac{\mu_{\Sigma^+} + \mu_{\Sigma^-}}{\mu_{\Sigma^+} - \mu_{\Sigma^-}}, & R_\Xi &= \frac{\mu_{\Xi^0} + \mu_{\Xi^-}}{\mu_{\Xi^0} - \mu_{\Xi^-}}, \\ R_S &= (R_N R_\Sigma + R_\Sigma R_\Xi - R_\Xi R_N)^{1/2}, \end{aligned} \quad (3.4)$$

where we have assumed the isospin symmetry $\mu_u^B = -2\mu_d^B$. Here one notes that the above sum rules (3.3) are given only in terms of the physical quantities, the coupling constant g_A and baryon octet magnetic moments μ_B , which are independent of details involved in the modified quark model, as in the sum rules in (2.13) and (2.17). Moreover these sum rules are governed only by the SU(3) flavor group structure of the models.

Using the experimental data for g_A and μ_B , we obtain the strange flavor spin polarization Δs

$$\Delta s = -0.20 \quad (3.5)$$

which is comparable to the recent SMC measurement $\Delta s = -0.12 \pm 0.04$ [27] and, together with the other flavor spin polarizations $\Delta u = 0.88$ and $\Delta d = -0.38$, one can arrive at the flavor singlet axial current of the nucleon as follows²

$$\Delta \Sigma = \Delta u + \Delta d + \Delta s = 0.30 \quad (3.6)$$

¹ In the literature [26], the similar equalities are used in connection with the quark-loops.

² In fact, in the literature [25], $\Delta \Sigma$ is evaluated using the sum rule for $\Delta \Sigma$. However, here we have explicitly obtained the sum rules for its flavor components Δf ($f = u, d, s$) and $F_{2N}^{s(0)}$ as shown in (3.3) and (3.8) to predict the values for Δs and $F_{2N}^{s(0)}$ in (3.5) and (3.9).

which is comparable to the recent value $\Delta\Sigma = 0.28$ obtained from the deep inelastic lepton–nucleon scattering experiments [28]. Here note that the strange flavor singlet axial current Δs in (3.5) is significantly noticeable even though the flavor singlet axial current $\Delta\Sigma$ in (3.6) is not quite large. The above predictions are quite consistent with the analysis in the literature [29] where $m_s \ln m_s$ corrections are used to predict $\Delta u = 0.77 \pm 0.04$, $\Delta d = -0.49 \pm 0.04$ and $\Delta s = -0.18 \pm 0.09$.

Now it seems appropriate to discuss the strange form factor in this modified quark model. Exploiting the relations (3.2), together with the isospin symmetry $\mu_u^B = -2\mu_d^B$, one can easily obtain

$$\mu_p + \mu_n = -\mu_d^N (\Delta u + \Delta d) + 2\mu_s^N \Delta s, \quad \mu_p - \mu_n = -3\mu_d^N (\Delta u - \Delta d). \quad (3.7)$$

We thus arrive at the sum rule for the nucleon strange form factor in the modified quark model

$$F_{2N}^{s(0)} = -3\mu_s^N \Delta s = -\frac{3}{2}(\mu_p + \mu_n) + \frac{1}{2}(\mu_p - \mu_n) \frac{\Delta u + \Delta d}{\Delta u - \Delta d}. \quad (3.8)$$

Substituting the experimental values for μ_p and μ_n , and the above predictions $\Delta u = 0.81$ and $\Delta d = -0.44$, we obtain

$$F_{2N}^{s(0)} = -0.39 \text{ n.m.}, \quad (3.9)$$

which reveals the discrepancy from the SAMPLE experimental values, differently from the prediction (2.14) of the SU(3) chiral model case. However, as expected, this result is quite comparable to the prediction in the literature [26] where, similar to (3.2), the SU(3) charge symmetry relations with the quark-loops are used. The difference between the predictions of $F_{2N}^{s(0)}$ in the SU(3) modified quark model and the SU(3) chiral model originates from the assumptions of these models, for instance, those in the SU(3) modified quark model that the magnetic moments of the quarks are different in the different isomultiplets, but do not change within an isomultiplet.

On the other hand, in this modified quark model, Δf are defined through the semileptonic hyperon decays and thus the $\Sigma \rightarrow n$ decay is not well reproduced since $g_A^{\Sigma n} = \Delta d - \Delta s = -0.18$ is quite different from its experimental value $g_A^{\Sigma n} = -0.340 \pm 0.017$ [22]. Moreover, the SU(3) symmetry breaking in the hyperon semileptonic decays can be parameterized by the value of the nonsinglet axial charge $a_8 = \Delta u + \Delta d - 2\Delta s$ in the hyperon β -decay [30]. Exploiting the above values for Δf in the modified quark model, we obtain the prediction $a_8 = 0.90$, which is quite higher than the standard SU(3) value $a_8 = 3F - D = 0.579 \pm 0.025$ [22,30]. Note that the SU(3) skyrmion model [31] and large N_c QCD [21] predict $a_8 = 0.41$ and $a_8 = 0.30$, respectively. It is interesting to see that the large value of a_8 in the modified quark model is incompatible with the SAMPLE experimental values.

4. Conclusions

In summary, we have investigated the strange flavor structure of the octet baryon magnetic moments in the chiral models with SU(3) group structure. The strange form factors of octet baryons are explicitly constructed in terms of the sum rules of the baryon octet magnetic moments to yield the theoretical predictions. Especially in case of using the experimental data for the baryon magnetic moments as input data of the sum rules, the predicted proton strange form factor is comparable to the recent SAMPLE experimental data.

On the other hand, we have studied the modified quark model with SU(3) group structure, where the magnetic moments of the quarks are different in the different isomultiplets, but do not change within an isomultiplet. In this model, we have obtained the sum rules for the spin polarizations Δf with the flavor f ($f = u, d, s$) in terms of the octet magnetic moments μ_B and the nucleon axial vector coupling constant g_A , to yield the flavor singlet axial current of the nucleon, comparable to the recent experimental data. Moreover, the strange flavor spin polarization has been shown to be quite noticeable. However, exploiting the sum rule for the nucleon strange form factor

constructed in the modified quark model, we have obtained the prediction, which shows discrepancy from the SAMPLE experimental values but is comparable to the prediction in the previous literature.

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