Spin and flavor strange quark content of the nucleon

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Several spin and flavor dependent parameters characterizing the strangeness content of the nucleon have been calculated 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. In particular, we have calculated the strange spin polarization Δs, the strangeness contribution to the weak axial vector couplings Δ_8 etc., strangeness contribution to the magnetic moments $\mu(p)^s$ etc., the strange quark flavor fraction f_s, the strangeness dependent quark flavor ratios $\frac{2\bar{s}}{u+d}$ and $\frac{2\bar{s}}{\bar{u}+\bar{d}}$ etc. Our results are consistent with the recent experimental observations.

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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. A global fit has also been carried out by including the data from SAMPLE, G0, A4, and HAPPEX and it gives $\mu(p)^s = 0.12 \pm 0.55 \pm 0.07$ [5]. The first lattice calculations by Dong *et al.* give -0.36 ± 0.20 [6], whereas a recent phenomenology study with lattice inputs [7] also predicts a very small value for the strange magnetic moment, $\mu(p)^s = -0.046 \pm 0.19\mu_N$. In the naive constituent quark model (CQM) [8–10], $\mu(p)^s$ is predicted to be zero. The broader question of contribution of strangeness in the nucleon has also been discussed by several authors recently [11]. It is widely recognized that a knowledge about the strangeness content of the nucleon would undoubtedly provide vital clues to the nonperturbative aspects of QCD.

The existence of strangeness in the nucleon has been indicated in the context of low energy experiments [12,13], whereas it has been observed in the deep inelastic scattering (DIS) experiments [14–17]. In the context of DIS, the strange spin polarization of the nucleon [18] looks to be well established through the measurements of polarized structure functions of the nucleon [15–17]. Apart from the observations of DIS data regarding strangeness dependent spin polarization functions, several interesting facts have also been revealed regarding the quark flavor distribution functions in the DIS experiments. In particular, the NuSea Collaboration [19] have given the results for the integrals of $\bar{u} - \bar{d}$ and $\bar{u}/\bar{d}$ asymmetries indicating that the flavor structure of the nucleon is not limited to u and d quarks only. Also the CCFR Collaboration and more recently the NuTeV collaboration [12] have given a fairly good deal of information regarding the integrals of strangeness dependent quark ratios in the nucleon given as $\frac{2\bar{s}}{u+d} = 0.099^{+0.009}_{-0.006}$ and $\frac{2\bar{s}}{\bar{u}+\bar{d}} = 0.477^{+0.063}_{-0.053}$. In the context of low energy experiments, the large pion-nucleon sigma term value [13] indicating nonzero strange quark flavor fraction f_s is also indicative of the presence of strange quarks in the nucleon, although there is no consensus regarding the various mechanisms that can contribute to f_s [20]. Therefore, the indications of the strange quark degree of freedom in DIS, as well as low energy experiments, provide a strong motivation to examine the strangeness contribution to the nucleon, thereby giving vital clues to the nonperturbative effects of QCD.

One may think that the strangeness content of the nucleon perhaps can be obtained through the generation of ''quark sea'' perturbatively from the quark-pair production by gluons. However, this kind of ''sea'' is symmetric w.r.t. $\bar{u}$ and $\bar{d}$ [21], negated by the observed value of $\bar{u} - \bar{d}$ asymmetry [19]. Therefore, one has to consider the ''quark sea'' produced by the nonperturbative mechanism. One such model, which can yield an adequate description of the ''quark sea'' generation through the chiral fluctuations, is the chiral constituent quark model (χCQM) [22], which is not only successful in giving a satisfactory explanation of ''proton spin crisis'' [23] but is also able to account for the violation of the Gottfried sum rule [21,23,24], baryon magnetic moments, and hyperon β-decay parameters [21,25]. Recently, it has been shown that configuration mixing generated by spin-spin forces improves the predictions of χCQM regarding the quark distribution functions and spin polarization functions [26]. Further, the 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 [21] is able to give an excellent fit [27] to the octet magnetic moments. It, therefore, becomes desirable to carry out a detailed analysis in the χCQM$_{\rm config}$ of the strangeness dependent spin polarization functions as well as the quark distribution functions, particularly in light of some recent observations [1–4,12,13,16,28].

The purpose of the present communication is to carry out detailed calculations of the parameters characterizing the strangeness of the nucleon within the χCQM$_{\rm config}$. In particular, we would like to calculate the strange spin polarization Δs, strangeness contribution to the weak axial vector couplings Δ_3, Δ_8, and Δ_0, strangeness contribution to the magnetic moments $\mu(p)^s$ and $\mu(n)^s$, the strange quark flavor fraction f_s, the strangeness dependent quark flavor ratios $\frac{2\bar{s}}{u+d}$ and $\frac{2\bar{s}}{\bar{u}+\bar{d}}$. 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.

To make the manuscript more readable as well as for ready reference, we mention the essentials of χCQM$_{\rm config}$; for details we refer the reader to [21,25,26]. 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, for example,

$$q_\pm \rightarrow {\rm GB}^0 + q'_\mp \rightarrow (q\bar{q}') + q'_\mp, \tag{1}$$

where $q\bar{q}' + q'$ constitute the "quark sea" [21] 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

$$\mathcal{L} = g_8 \bar{\mathbf{q}}\left(\Phi + \zeta\frac{\eta'}{\sqrt{3}}I\right)\mathbf{q} = g_8\bar{\mathbf{q}}(\Phi')\mathbf{q}, \tag{2}$$

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

$$\Phi' = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} & \pi^+ & \alpha K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} & \alpha K^0 \\ \alpha K^- & \alpha\bar{K}^0 & -\beta\frac{2\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} \end{pmatrix} \quad \text{and} \quad q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}. \tag{3}$$

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 $M_{\eta'} > M_{K,\eta}$) [21,25]. 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 $u(d,s) \rightarrow u(d,s) + \eta'$. Further, to make the transition from χCQM to χCQM$_{\rm config}$, the nucleon wave function gets modified because of the configuration mixing generated by the chromodynamic spin-spin forces [8–10,26] as follows,

$$|B\rangle = \cos\phi|56, 0^+\rangle_{N=0} + \sin\phi|70, 0^+\rangle_{N=2}, \tag{4}$$

where ϕ represents the $|56\rangle$–$|70\rangle$ mixing. For details of the spin, isospin, and spatial parts of the wave function, we refer the reader to [29].

Before proceeding further, we briefly discuss the strangeness dependent spin polarization functions, quark distribution functions, and the related quantities of the nucleon. To begin with, we consider the spin structure of a nucleon defined as [21]

$$\hat{B} \equiv \langle B|N|B\rangle, \tag{5}$$

where $|B\rangle$ is the nucleon wave function defined in Eq. (4) and N is the number operator given by

$$N = n_{u_+}u_+ + n_{u_-}u_- + n_{d_+}d_+ + n_{d_-}d_- + n_{s_+}s_+ + n_{s_-}s_-, \tag{6}$$

$n_{q_\pm}$ being the number of $q_\pm$ quarks. Following Ref. [26], the contribution to the proton spin by different quark flavors in χCQM$_{\rm config}$ can be given by the spin polarizations $\Delta q = q_+ - q_-$ expressed as

$$\Delta u = \cos^2\phi\left[\frac{4}{3} - \frac{a}{3}\left(7 + 4\alpha^2 + \frac{4}{3}\beta^2 + \frac{8}{3}\zeta^2\right)\right] + \sin^2\phi\left[\frac{2}{3} - \frac{a}{3}\left(5 + 2\alpha^2 + \frac{2}{3}\beta^2 + \frac{4}{3}\zeta^2\right)\right], \tag{7}$$

$$\Delta d = \cos^2\phi\left[-\frac{1}{3} - \frac{a}{3}\left(2 - \alpha^2 - \frac{1}{3}\beta^2 - \frac{2}{3}\zeta^2\right)\right] + \sin^2\phi\left[\frac{1}{3} - \frac{a}{3}\left(4 + \alpha^2 + \frac{1}{3}\beta^2 + \frac{2}{3}\zeta^2\right)\right], \tag{8}$$

$$\Delta s = \cos^2\phi[-a\alpha^2] + \sin^2\phi[-a\alpha^2]. \tag{9}$$

A closer look at the above equations reveals that ϕ represents the configuration mixing angle, the constant factors represent the CQM results and the factors which are multiple of a represent the contribution from the "quark sea." It is important to mention here that the presence of $s\bar{s}$ in the "quark sea" (Eq. (1)) involves the terms $\alpha^2 a$, $\beta^2 a$, and $\zeta^2 a$ respectively denoting the fluctuations $u(d) \rightarrow s + K^{+(0)}$, $u(d,s) \rightarrow u(d,s) + \eta$, and $u(d,s) \rightarrow u(d,s) + \eta'$. It is clear from the above fluctuations that the strange quarks come from the fluctuations of the u and d quarks as well and therefore, apart from contributing to the strange spin polarization, the strange quarks also contribute to the spin polarizations of u and d quarks. It should also be noted that the $\bar{d}-\bar{u}$ asymmetry in this case can be easily understood in terms of the above fluctuations where the valence u quarks are likely to produce more $\bar{d}$ than the valence d quarks producing $\bar{u}$ in the proton. The spin polarization functions are also related to the axial vector couplings measured in the baryon weak decays [18], for example, the nonsinglet combinations of the quark spin polarizations (Δ_3 and Δ_8) can be expressed as

$$\Delta_3 = \Delta u - \Delta d = F + D, \qquad (10)$$

$$\Delta_8 = \Delta u + \Delta d - 2\Delta s = 3F - D, \qquad (11)$$

where F and D are the usual SU(3) parameters characterizing the weak matrix elements. The flavor singlet combination on the other hand can be related to the total spin carried by the quarks as

$$\Delta_0 = \tfrac{1}{2}\Delta\Sigma = \tfrac{1}{2}(\Delta u + \Delta d + \Delta s). \qquad (12)$$

After discussing the spin polarization functions, we would like to discuss the formalism for the strangeness contribution to the magnetic moments. It would be important to mention here that the predictions for all the octet and decuplet baryon magnetic moments, including the transition magnetic moments, have been discussed in detail in Ref. [27] and have been found to be in good agreement with the recent measurements as well as other theoretical estimates. The magnetic moment of a given baryon in the χCQM can be expressed as

$$\mu(B)_{\rm total} = \mu(B)_{\rm val} + \mu(B)_{\rm sea}, \qquad (13)$$

where $\mu(B)_{\rm val}$ represents the contribution of the valence quarks and $\mu(B)_{\rm sea}$ corresponding to the "quark sea" [Eq. (1)]. Further, $\mu(B)_{\rm sea}$ can be written as

$$\mu(B)_{\rm sea} = \mu(B)_{\rm spin} + \mu(B)_{\rm orbit}, \qquad (14)$$

where the first term is the magnetic moment contribution of the q' in Eq. (1) coming from the spin polarization and the second term is due to the rotational motion of the two bodies, q' and GB, corresponding to the fluctuation given in Eq. (1) and referred to as the orbital angular momentum by Cheng and Li [21].

To find the strangeness contribution to the magnetic moment of the proton $\mu(p)^s$ we should note that there are no "strange" valence quarks, therefore $\mu(p)^s$ receives contributions only from the "quark sea" and is expressed as

$$\mu(p)^s = \mu(p)^s_{\rm spin} + \mu(p)^s_{\rm orbit}. \qquad (15)$$

Following Ref. [27], $\mu(p)^s_{\rm spin}$ in the chiral constituent quark model with configuration mixing can be expressed as

$$\mu(p)^s_{\rm spin} = \sum_{q=u,d,s} \Delta q(p)^s_{\rm sea}\mu_q, \qquad (16)$$

where $\mu_q = \frac{e_q}{2M_q}$ ($q = u, d, s$) is the quark magnetic moment, e_q and M_q are the electric charge and the mass, respectively, for the quark q. The contribution of strangeness to the spin polarization functions is given as

$$\Delta u(p)^s_{\rm sea} = \cos^2\phi\Big[-\frac{a}{3}\Big(4\alpha^2 + \frac{4}{3}\beta^2 + \frac{8}{3}\zeta^2\Big)\Big] + \sin^2\phi\Big[-\frac{a}{3}\Big(2\alpha^2 + \frac{2}{3}\beta^2 + \frac{4}{3}\zeta^2\Big)\Big], \qquad (17)$$

$$\Delta d(p)^s_{\rm sea} = \cos^2\phi\Big[-\frac{a}{3}\Big(-\alpha^2 - \frac{1}{3}\beta^2 - \frac{2}{3}\zeta^2\Big)\Big] + \sin^2\phi\Big[-\frac{a}{3}\Big(\alpha^2 + \frac{1}{3}\beta^2 + \frac{2}{3}\zeta^2\Big)\Big], \qquad (18)$$

$$\Delta s(p)^s_{\rm sea} = \cos^2\phi[-a\alpha^2] + \sin^2\phi[-a\alpha^2]. \qquad (19)$$

Similarly, the contribution of the orbital angular momentum of the "quark sea" to the magnetic moment of a given quark is expressed as

$$\mu(p)^s_{\rm orbit} = \tfrac{4}{3}[\mu(u_+ \to s_-)] - \tfrac{1}{3}[\mu(d_+ \to s_-)], \qquad (20)$$

where

$$\mu(q_+ \to s_-) = \frac{e_s}{2M_q}\langle l_q\rangle + \frac{e_q - e_s}{2M_{GB}}\langle l_{GB}\rangle. \qquad (21)$$

The quantities (l_q, l_{GB}) and (M_q, M_{GB}) are the orbital angular momenta and masses of quark and GB, respectively. The orbital angular momentum contribution to the magnetic moment due to all the fluctuations is then given as

$$\mu(u_+ \to s_-) = a\Big[-\frac{M_\pi^2}{2M_\pi(M_u + M_\pi)} - \frac{\alpha^2(M_K^2 - 3M_u^2)}{2M_K(M_u + M_K)} + \frac{(3 + \beta^2 + 2\zeta^2)M_\eta^2}{6M_\eta(M_u + M_\eta)}\Big]\mu_N, \qquad (22)$$

$$\mu(d_+ \to s_-) = a\frac{M_u}{M_d}\Big[-\frac{\alpha^2 M_K^2}{2M_K(M_d + M_K)} - \frac{(\beta^2 + 2\zeta^2)M_\eta^2}{12M_\eta(M_d + M_\eta)}\Big]\mu_N, \qquad (23)$$

where M_π, M_K, and M_η are the masses of pion, kaon, and η respectively and μ_N is the Bohr magneton. 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.

The integral of the quark distribution functions [30] incorporating the strangeness content in the χCQM are expressed as [21,26]

$$\bar{u} = \frac{1}{12}[(2\zeta + \beta + 1)^2 + 20]a,$$
$$\bar{d} = \frac{1}{12}[(2\zeta + \beta - 1)^2 + 32]a, \quad (24)$$
$$\bar{s} = \frac{1}{3}[(\zeta - \beta)^2 + 9\alpha^2]a,$$

$$u - \bar{u} = 2, \qquad d - \bar{d} = 1, \qquad s - \bar{s} = 0. \quad (25)$$

The integral of the quark distribution functions would henceforth be referred to as "averaged" quark distribution functions.

Similarly, the other important quantities having implications for the strangeness contribution to the nucleon are the averaged quark flavor fractions $f_q = \frac{q+\bar{q}}{\sum_q (q+\bar{q})}$, which are expressed in terms of the χCQM parameters as

$$f_u = \frac{12 + a(21 + \beta^2 + 4\zeta + 4\zeta^2 + \beta(2 + 4\zeta))}{3(6 + a(9 + \beta^2 + 6\alpha^2 + 2\zeta^2))},$$
$$f_d = \frac{6 + a(33 + \beta^2 - 4\zeta + 4\zeta^2 + \beta(-2 + 4\zeta))}{3(6 + a(9 + \beta^2 + 6\alpha^2 + 2\zeta^2))},$$
$$f_s = \frac{4a(\beta^2 + +9\alpha^2 - 2\beta\zeta + \zeta^2)}{3(6 + a(9 + \beta^2 + 6\alpha^2 + 2\zeta^2))}. \quad (26)$$

It is clear from the above expressions that the nonzero value of the parameters a, α, β, and ζ implies $f_s \neq 0$ as well as modify f_u and f_d due to the strangeness contributions coming from the "quark sea." Further, the ratio of the functions

$$f_3 = f_u - f_d, \qquad f_8 = f_u + f_d - 2f_s, \quad (27)$$

and the averaged ratios

$$\frac{2\bar{s}}{(u + d)} = \frac{4a(9\alpha^2 + \beta^2 - 2\beta\zeta + \zeta^2)}{18 + a(27 + \beta^2 + 4\beta\zeta + 4\zeta^2)},$$
$$\frac{2\bar{s}}{(\bar{u} + \bar{d})} = \frac{4(9\alpha^2 + \beta^2 - 2\beta\zeta + \zeta^2)}{27 + \beta^2 + 4\beta\zeta + 4\zeta^2}, \quad (28)$$

TABLE I. The calculated values of the strangeness dependent spin polarization functions and weak axial vector couplings in the CQM and χCQM$_{\rm config}$.

Parameter	Data	CQM	χCQM$_{\rm config}$
Δu [a]	0.85 ± 0.05 [15]	1.333	0.867
Δd	−0.41 ± 0.05 [15]	−0.333	−0.392
Δs	−0.10 ± 0.04 [15]	0	−0.08
	−0.07 ± 0.03 [16]		
Δ_3 [a]	1.267 ± 0.0035 [31]	1.666	1.267
Δ_8	0.58 ± 0.025 [31]	1	0.59
Δ_0	0.19 ± 0.025 [31]	0.50	0.19
F/D	0.575 ± 0.016 [31]	0.673	0.589

[a] Input parameters

have also been measured, therefore providing an opportunity to check the strange quark content of the nucleon.

The χCQM$_{\rm config}$ involves five parameters, four of these a, $a\alpha^2$, $a\beta^2$, $a\zeta^2$ representing, respectively, the probabilities of fluctuations to pions, K, η, η', following the hierarchy $a > \alpha > \beta > \zeta$, while the fifth represents the mixing angle. The mixing angle ϕ is fixed from the consideration of neutron charge radius [10], whereas for the other parameters we would like to update our analysis using the latest data [31]. In this context, we find it convenient to use Δu, Δ_3, $\bar{u} - \bar{d}$, and $\bar{u}/\bar{d}$ as inputs with their latest values given in Tables I and III. Before carrying out the fit to the above-mentioned parameters, we would like to find their ranges by qualitative arguments. To this end, the range of the symmetry breaking parameter a can be easily found by considering the spin polarization function Δu, by giving the full variation to the parameters α, β, and ζ, for example, one finds $0.10 \lesssim a \lesssim 0.14$. The range of the parameter ζ can be found from averaged $\bar{u}/\bar{d}$ using the latest experimental measurement [19] and it comes out to be $-0.70 \lesssim \zeta \lesssim -0.10$. Using the above found ranges of a and ζ as well as the latest measurement of $\bar{u} - \bar{d}$ asym-

TABLE II. The calculated values of the strangeness contribution to the magnetic moment of nucleon and Δ decuplet baryons in the CQM and χCQM$_{\rm config}$.

Parameter	Data	CQM	χCQM$_{\rm config}$
$\mu(p)^s_{\rm spin}$, $\mu(p)^s_{\rm orbit}$	—	0, 0	−0.09, 0.05
$\mu(p)^s$	0.37 ± 0.26 ± 0.20 [1]	0	−0.03
	0.12 ± 0.55 ± 0.07 [5]		
$\mu(n)^s_{\rm spin}$, $\mu(n)^s_{\rm orbit}$	—	0, 0	0.06, −0.09
$\mu(n)^s$	—	0	−0.03
$\mu(\Delta^{++})^s_{\rm spin}$, $\mu(\Delta^{++})^s_{\rm orbit}$	—	0, 0	−0.29, 0.18
$\mu(\Delta^{++})^s$	—	0	−0.11
$\mu(\Delta^{+})^s_{\rm spin}$, $\mu(\Delta^{+})^s_{\rm orbit}$	—	0, 0	−0.14, 0.11
$\mu(\Delta^{+})^s$	—	0	−0.03
$\mu(\Delta^{o})^s_{\rm spin}$, $\mu(\Delta^{o})^s_{\rm orbit}$	—	0, 0	−0.04, −0.03
$\mu(\Delta^{o})^s$	—	0	−0.07
$\mu(\Delta^{-})^s_{\rm spin}$, $\mu(\Delta^{-})^s_{\rm orbit}$	—	0, 0	−0.09, 0.15
$\mu(\Delta^{-})^s$	—	0	0.06

TABLE III. The calculated values of the strangeness dependent averaged quark flavor distribution functions and related parameters in the CQM and χCQM$_{\rm config}$.

Parameter	Data	CQM	χCQM$_{\rm config}$
$\bar{s}$	—	0	0.10
$\bar{u}-\bar{d}$[a]	-0.118 ± 0.015 [19]	0	-0.118
$\bar{u}/\bar{d}$[a]	0.67 ± 0.06 [19]	0	0.66
$\frac{2\bar{s}}{u+d}$	$0.099^{+0.009}_{0.006}$ [12]	0	0.09
$\frac{2\bar{s}}{\bar{u}+\bar{d}}$	$0.477^{+0.063}_{0.053}$ [12]	0	0.44
f_s	0.10 ± 0.06 [12]	—	0.08
f_3	—	—	0.21
f_8	—	—	1.03
f_3/f_8	0.21 ± 0.05 [12]	0.33	0.20

[a]Input parameters

metry [19], β comes out to be in the range $0.2 \lesssim \beta \lesssim 0.7$. Similarly, the range of α can be found by considering the flavor nonsinglet component Δ_3 and it comes out to be $0.2 \lesssim \alpha \lesssim 0.5$. After finding the ranges of the symmetry breaking parameters, we have carried out a fine grained analysis using the above ranges as well as considering $\alpha \approx \beta$ by fitting Δu, Δ_3 [31] as well as $\bar{u}-\bar{d}$, $\bar{u}/\bar{d}$ [19] leading to $a = 0.13$, $\zeta = -0.10$, $\alpha = \beta = 0.45$ as the best fit values. The parameters so obtained have been used to calculate the spin polarization functions and the averaged quark distribution functions. The calculated quantities pertaining to spin polarization functions have been corrected by including the gluon polarization effects [21,32] and symmetry breaking effects [21,25]. Similarly, the averaged quark distribution functions have been corrected by including the symmetry breaking effects. The orbital angular momentum contributions to magnetic moment are characterized by the parameters of χCQM as well as the masses of the GBs. For the u and d quarks, we have used their most widely accepted values in hadron spectroscopy [21,29], for example, $M_u = M_d = 330$ MeV. For evaluating the contribution of GBs, we have used its on mass shell value in accordance with several other similar calculations [33].

In Tables I, II, and III, we have presented the results of our calculations pertaining to the strangeness dependent parameters in χCQM$_{\rm config}$. For comparison sake, we have also given the corresponding quantities in CQM. To begin with, we first discuss the quality of fit pertaining to the spin polarization functions. In Table I, we have presented the strangeness incorporating spin polarization functions and the weak axial vector couplings. Using Δu, Δ_3 along with $\bar{u}-\bar{d}$, $\bar{u}/\bar{d}$ from Table III as inputs, we find that we are able to achieve a fairly good fit in the case of spin polarization functions and the weak axial vector couplings. In particular, the agreement in terms of the magnitude as well as the sign in the case of Δs is in good agreement with the latest data [15,16]. The agreement in the case of Δ_8 and Δ_0, which receives contribution from Δs also, not only justifies the success of χCQM$_{\rm config}$ but also strengthens our conclusion regarding Δs. Similarly, the agreement obtained in the case of the ratio F/D again reinforces our conclusion that χCQM$_{\rm config}$ is able to generate qualitatively as well as quantitatively the requisite amount of strangeness in the nucleon.

In Table II, 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 $\mu(p)^s$ [1,5–7]. 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 [27]; 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 [21] but would also suggest that the chiral fluctuations are 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.

After finding that the χCQM$_{\rm config}$ is able to give a fairly good account of the spin dependent polarization functions, in Table III, we have presented the results of averaged quark distribution functions having implications for strangeness in the nucleon. In line with the success of χCQM$_{\rm config}$ in describing the spin dependent polarization functions, in this case also we are able to give a fairly good account of most of the measured values. The agreement in the case of $\frac{2s}{u+d}$ and $\frac{f_3}{f_8}$ indicates that, in the χCQM, we are able to generate the right amount of strange quarks through chiral fluctuation. A refinement in the case of the strangeness dependent quark ratio $\frac{2s}{\bar{u}+\bar{d}}$ would have important implications for the basic tenets of χCQM. The observed result for the case of f_s in the present case also indicates that the strange sea quarks play a significant role in the nucleon. This is in agreement with the observations of other authors [20,21].

To summarize, the χCQM$_{\rm config}$ is able to provide a fairly good description of the spin dependent polarization functions as well as the averaged quark distribution functions having implications for strangeness in the nucleon. It is able to give a quantitative description of the important parameters such as Δs, the weak axial vector couplings Δ_8 and Δ_0, strangeness contribution to the magnetic moment $\mu(p)^s$, the strange quark flavor fraction f_s, the strangeness dependent ratios $\frac{2\bar{s}}{u+d}$ and $\frac{f_3}{f_8}$ etc. In the case of $\mu(p)^s$, our result is consistent with the latest experimental measurements as well as with the other calculations. In conclusion, we would like to state that at the leading order 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 in the χCQM$_{\rm config}$ through the chiral fluctuation is the key in understanding the strangeness content of the nucleon.

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[1] D. T. Spayde *et al.* (SAMPLE Collaboration), Phys. Lett. B **583**, 79 (2004).
[2] D. Armstrong *et al.* (G0 Collaboration), Phys. Rev. Lett. **95**, 092001 (2005).
[3] F. E. Maas *et al.* (A4 Collaboration), Phys. Rev. Lett. **94**, 152001 (2005).
[4] K. A. Aniol *et al.* (HAPPEX Collaboration), Phys. Rev. Lett. **98**, 032301 (2007); Eur. Phys. J. A **31**, 597 (2007).
[5] R. D. Young *et al.*, Phys. Rev. Lett. **97**, 102002 (2006).
[6] S. J. Dong, K. F. Liu, and A. G. Williams, Phys. Rev. D **58**, 074504 (1998); N. Mathur and Shao-Jing Dong, Nucl. Phys. B, Proc. Suppl. **94**, 311 (2001); R. Lewis, W. Wilcox, and R. M. Woloshyn, Phys. Rev. D **67**, 013003 (2003).
[7] D. B. Leinweber, S. Boinepalli, I. C. Cloet, A. W. Thomas, A. G. Williams, R. D. Young, J. B. Zhang, J. M. Zanotti, and J. B. Zhang, Eur. Phys. J. A **24S2**, 79 (2005); Phys. Rev. Lett. **94**, 212001 (2005).
[8] A. De Rujula, H. Georgi, and S. L. Glashow, Phys. Rev. D **12**, 147 (1975).
[9] N. Isgur and G. Karl, Phys. Rev. D **21**, 3175 (1980); P. Geiger and N. Isgur, Phys. Rev. D **55**, 299 (1997).
[10] A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Rev. D **15**, 844 (1977); M. Gupta and A. N. Mitra, Phys. Rev. D **18**, 1585 (1978).
[11] R. D. McKeown, Phys. Lett. B **219**, 140 (1989); L. Hannelius, D. O. Riska, and L. Ya. Glozman, Nucl. Phys. **A665**, 353 (2000); K. F. Liu, J. Phys. G **27**, 511 (2001); J. Ellis, Eur. Phys. J. A **24S2**, 3 (2005); G. Dillon and G. Morpurgo, Phys. Rev. D **75**, 073007 (2007).
[12] A. O. Bazarko *et al.* (CCFR Collaboration and NuTeV Collaboration), Z. Phys. C **65**, 189 (1995).
[13] R. Koch, Z. Phys. C **15**, 161 (1982); M. M. Pavan, I. I. Strakovsky, R. L. Workman, and R. A. Arndt, PiN Newslett. **16**, 110 (2002); hep-ph/0111066; P. Schweitzer, Eur. Phys. J. A **22**, 89 (2004).
[14] J. Ashman *et al.* (EMC Collaboration), Phys. Lett. B **206**, 364 (1988); Nucl. Phys. **B328**, 1 (1989).
[15] B. Adeva *et al.* (SMC Collaboration), Phys. Rev. D **58**, 112001 (1998).
[16] P. Adams *et al.*, Phys. Rev. D **56**, 5330 (1997); P. L. Anthony *et al.* (E142 Collaboration), Phys. Rev. Lett. **71**, 959 (1993); K. Abe *et al.* (E143 Collaboration), Phys. Rev. Lett. **74**, 346 (1995); Phys. Rev. Lett. **79**, 26 (1997).
[17] A. Airapetian *et al.* (HERMES Collaboration), Phys. Rev. D **71**, 012003 (2005).
[18] J. Ellis and M. Karliner, Phys. Lett. B **341**, 397 (1995).
[19] J. C. Peng *et al.* (E866/NuSea Collaboration), Phys. Rev. D **58**, 092004 (1998); R. S. Towell *et al.*, *ibid.* **64**, 052002 (2001).
[20] J. Gasser and H. Leutwyler, Phys. Rep. **87**, 77 (1982); M. E. Saino, PiN Newslett. **16**, 138 (2002); hep-ph/0110413; M. Nagy, M. D. Scadron, and G. E. Hite, Acta Phys. Slovaca **54**, 427 (2003); hep-ph/0406009; M. D. Scadron, F. Kleefeld, and G. Rupp, arXiv:hep-ph/0609024.
[21] T. P. Cheng and Ling Fong Li, Phys. Rev. Lett. **74**, 2872 (1995); Phys. Rev. D **57**, 344 (1998); Phys. Rev. Lett. **80**, 2789 (1998); X. Song, Phys. Rev. D **57**, 4114 (1998).
[22] S. Weinberg, Physica A (Amsterdam) **96**, 327 (1979); A. Manohar and H. Georgi, Nucl. Phys. **B234**, 189 (1984).
[23] E. J. Eichten, I. Hinchliffe, and C. Quigg, Phys. Rev. D **45**, 2269 (1992).
[24] K. Gottfried, Phys. Rev. Lett. **18**, 1174 (1967).
[25] J. Linde, T. Ohlsson, and Hakan Snellman, Phys. Rev. D **57**, 452 (1998).
[26] H. Dahiya and M. Gupta, Phys. Rev. D **64**, 014013 (2001); **67**, 074001 (2003).
[27] H. Dahiya and M. Gupta, Phys. Rev. D **66**, 051501(R) (2002); **67**, 114015 (2003).
[28] Steven D. Bass, Phys. Lett. B **463**, 286 (1999); Czech. J. Phys. **50**, 109 (2000); Nucl. Phys. B, Proc. Suppl. **105**, 56 (2002); Rev. Mod. Phys. **77**, 1257 (2005).
[29] A. Le Yaouanc *et al.*, *Hadron Transitions in the Quark Model* (Gordon and Breach, New York, 1988).
[30] H. Dahiya and M. Gupta, Eur. Phys. J. C **52**, 571 (2007).
[31] W.-M. Yao *et al.*, J. Phys. G **33**, 1 (2006).
[32] A. V. Efremov and O. V. Teryaev, JINR Report No. E2-88-287 1988; G. Igo, Phys. Rev. D **63**, 057501 (2001); H. Dahiya and M. Gupta, Int. J. Mod. Phys. A **19**, 5027 (2004).
[33] V. Elias, Mong Tong, and M. D. Scadron, Phys. Rev. D **40**, 3670 (1989); D. A. Dicus, D. Minic, U. van Klock, and R. Vega, Phys. Lett. B **284**, 384 (1992); Y. B. Dong, K. Shimizu, A. Faessler, and A. J. Buchmann, J. Phys. G **25**, 1115 (1999).