Nucleon spin-flavor structure in the SU(3)-breaking chiral quark model

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(Received 21 June 1996; revised manuscript received 19 November 1996)

The SU(3) symmetric chiral quark model, which describes interactions between quarks, gluons, and the Goldstone bosons, explains reasonably well many aspects of the flavor and spin structure of the proton, except for the values of f_3/f_8 and Δ_3/Δ_8. Introducing the SU(3)-breaking effect suggested by the mass difference between the strange and nonstrange quarks, we find that this discrepancy can be removed and better overall agreement obtained. [S0556-2821(97)07205-6]

PACS number(s): 12.39.Fe, 11.30.Rd, 14.20.Dh

I. INTRODUCTION

One of the important goals in high energy physics is to reveal the internal structure of the nucleon. This includes the study of the flavor and spin contents of the quark and gluon constituents in the nucleon and how these are related to the nucleon properties: spin, magnetic moment, elastic form factors, and deep inelastic structure functions. In the late 1980s, the polarized deep inelastic lepton nucleon scattering experiments [1] surprisingly indicated that only a small portion of the proton spin is carried by the quark and antiquarks, and a significant negative strange quark polarization in the proton sea. Since then, a tremendous effort has been made for solving this puzzle both theoretically and experimentally (recent review see [2–5]). According to the most recent result [6,7], the quarks contribute about one third of proton's spin, which is only one half of the spin expected from the hyperon decay data ($\Delta\Sigma \simeq 0.6$) and the strange quark polarization is about -0.10, which deviates significantly from the naive quark model expectation. On the other hand, the baryon magnetic moments can be reasonably well described by the spin-flavor structure in the nonrelativistic constituent quark model.

Most recently, the New Muon Collaboration (NMC) experiments [8] have shown that the Gottfried sum rule [9] is violated, which indicates that the $\bar{d}$ density is larger than the $\bar{u}$ density in the nucleon sea. This asymmetry has been confirmed by the NA51 Collaboration experiment [10], which shows that $\bar{u}/\bar{d} \simeq 0.51$ at $x=0.18$. From the perturbative QCD motivated quark model of the nucleon, the density of $\bar{u}$ would be almost the same as that of $\bar{d}$ if the sea quark pairs are produced by the flavor-independent gluons ($\bar{s}$ could be different because of $m_s \gg m_{u,d}$).

Many theoretical works, trying to solve these puzzles, have been published. Among these, the application of the chiral quark model, suggested by Eichten, Hinchliffe, and Quigg [11], and then extended by Cheng and Li [12], seems to be more promising. The chiral quark model was originated by Weinberg [13] and then developed by Manohar and Georgi [14]. In this model, they introduced an effective Lagrangian for quarks, gluons and Goldstone bosons in the region between the chiral symmetry-breaking scale ($\Lambda_{\chi\mathrm{SB}} \simeq 1$ GeV) and the confinement scale ($\Lambda_{\mathrm{QCD}} \simeq 0.1-0.3$ GeV). The great success of the constituent quark model in low energy hadron physics can be well understood in this framework. In the chiral quark model the effective strong coupling constant α_s could be as small as 0.2–0.3, which implies that the hadrons can be treated as weakly bound states of effective constituent quarks. The model gave a correct value for $(G_A/G_V)_{n\to p} = (5/3)g_A \simeq 1.25$, with $g_A \simeq 0.75$, and a fairly good prediction for baryon magnetic moments.

The extended description given in [12] can solve many puzzles related to the proton flavor and spin structures: a significant strange quark presence in the nucleon indicated in the low energy pion nucleon sigma term $\sigma_{\pi N}$, the asymmetry between $\bar{u}$ and $\bar{d}$ densities, the total net quark spin $\Delta\Sigma \simeq 1/3$ and nonzero negative strange polarization $\Delta s \simeq -0.10$. However, the SU(3) symmetry description yields $f_3/f_8 = 1/3$ and $\Delta_3/\Delta_8 = 5/3$ (the definitions of $f_{3,8}$ and $\Delta_{3,8}$ are given in Sec. II; also see [12]), which are inconsistent with the experimental values. In this paper, we introduce an SU(3) symmetry-breaking effect that arises from the mass difference between the strange and nonstrange quarks, which results in a suppressed amplitude for producing the "kaons." The result shows that not only the above discrepancy can be removed but also better agreement between some other theoretical predictions and experimental results is obtained. The η meson is not included in the SU(3) breaking here despite its strange quark contents because it is not well established as a Goldstone boson. An investigation in this direction is underway and the result will be presented elsewhere. Our limited goal in this work is to look at the SU(3) breaking by first introducing the suppression of kaon fluctuations.

II. SU(3) SYMMETRY BREAKING

In the scale range between $\Lambda_{\chi\mathrm{SB}}$ and Λ_{QCD} in the chiral quark model, the relevant degrees of freedom are the quasiparticles of quarks, gluons and the Goldstone bosons associated with the spontaneous breaking of the SU(3)×SU(3) chiral symmetry. In this quasiparticle description, the effective gluon coupling is small and the important interaction is taken to be the coupling among quarks and Goldstone bosons, which may be treated as an excitation of $q\bar{q}$ pair produced in the interaction between the constituent quark and the quark condensate. Note that these Goldstone bosons can be *identified, in quantum numbers, with the usual pseudoscalar mesons, but they* propagate inside the nucleon and *are not free on-shell mesons.*

The sea quark-antiquark pairs could also be created by the gluons. Since the gluon is flavor independent, a valence quark cannot change its flavor by emitting a gluon. Also the spin cannot be changed due to the vector coupling nature between the quarks and gluons. On the other hand, emitting a Goldstone boson a valence quark could change its flavor and certainly change its spin because of pseudoscalar coupling between the quarks and Goldstone bosons. The presence of Goldstone bosons in the nucleon causes quite a different sea quark flavor-spin content from that given by emitting gluons from the quarks. Hence the chiral quark model may provide a better understanding to the above puzzles.

The effective Lagrangian describing interaction between quarks and Goldstone bosons can be written [12]

$$L_I = g_8 \bar{q} \vec{\phi} q + \sqrt{1/3}\, g_0 \bar{q} \eta' q, \quad q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}, \tag{2.1}$$

where

$$\hat{\phi} = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^o + \frac{1}{\sqrt{6}}\eta^o & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^o + \frac{1}{\sqrt{6}}\eta^o & K^o \\ K^- & \overline{K^o} & -\frac{2}{\sqrt{6}}\eta^o \end{pmatrix} \tag{2.2}$$

and λ_i ($i=1,2,\ldots,8$) are the Gell-Mann matrices. If the singlet Yukawa coupling is equal to zero, $g_0=0$, the quark sea created by emitting 0^- meson octet would contain more $\bar{d}$ quarks than $\bar{u}$ quarks (and less $\bar{s}$ quarks). The resulting $\bar{u}$-$\bar{d}$ asymmetry seems to be consistent with $\bar{u}$-$\bar{d}<0$ indicated by the NMC data which show a significant violation of the Gottfried sum rule. However, if the singlet is as important as the octet in the quark meson interactions and its Yukawa coupling is equal to the octet coupling, $g_0=g_8$, then the flavor asymmetry in the sea disappears and the numbers of $u\bar{u}$, $d\bar{d}$, and $s\bar{s}$ are equal. Cheng and Li suggested an unequal singlet and octet coupling, $g_0/g_8 \equiv \zeta \neq 1$ [see discussion below Eq. (2.12)]. Taking $a=|g_8|^2=0.1$ and $\zeta=-1.2$, they obtained

$$\bar{u}/\bar{d} = 0.53(\text{expt}: 0.51 \pm 0.04 \pm 0.05), \tag{2.3}$$

$$I_G = \int_0^1 dx \frac{F_2^p(x) - F_2^n(x)}{x} = 0.236(\text{expt}: 0.235 \pm 0.026), \tag{2.4}$$

$$f_s \equiv \frac{2\bar{s}}{3 + 2(\bar{u} + \bar{d} + \bar{s})} = 0.19(\text{expt}: 0.18 \pm 0.03), \tag{2.5}$$

where $f_q = (q + \bar{q})/[\Sigma(q + \bar{q})]$ $(q = u,d,s)$. Using the same parameters, the quark spin polarizations are also consistent with the data (see [12]).

Defining $f_3 = f_u - f_d$, $f_8 = f_u + f_d - 2f_s$, $\Delta_3 = \Delta u - \Delta d$, and $\Delta_8 = \Delta u + \Delta d - 2\Delta s$, the SU(3) symmetry description yields

$$f_3/f_8 = 1/3(\text{expt}: 0.23), \quad \Delta_3/\Delta_8 = 5/3(\text{expt}: 2.1). \tag{2.6}$$

In Ref. [12], Cheng and Li suggested that this inconsistency between theoretical prediction and data could be attributed to some SU(3)-breaking effects.

We assume that the breaking of SU(3)-flavor symmetry arises from a mass difference between the strange and nonstrange light quarks. Since the $m_s > m_{u,d}$ the breaking would cause a suppressed amplitude, and thus a smaller probability, for a u quark to fluctuate into a $K^+ = (u\bar{s})$ plus a strange quark than fluctuate into a *pion* and a nonstrange light quark. Defining $\Psi(u \to \pi^+ d)$ as the probability amplitude of a π^+ meson emission from a u quark, etc., we have

$$|\Psi(u \to \pi^+ d)|^2 = |\Psi(d \to \pi^- u)|^2 = |g_8|^2 \equiv a, \text{ etc.} \tag{2.7}$$

for pion emission, and

$$|\Psi(u \to K^+ s)|^2 = |\Psi(d \to K^0 s)|^2 \equiv \epsilon a \tag{2.8}$$

for kaon emission. The new parameter ϵ denotes the ratio of the probability of emitting a kaon to that of a pion from the quarks, and we expect $0 < \epsilon \leqslant 1$. In the following, we will show that a reasonable value $\epsilon \simeq 0.5 - 0.6$ gives a good fit to the data.

It is easy to see that the nonstrange quark numbers, thus $\bar{d} - \bar{u}$ and $\bar{d}/\bar{u}$ would not be affected by the SU(3)-breaking effect arising from suppression of kaon production, but the strange quark number $\bar{s}$ and f_s would be reduced. A straightforward calculation yields the results

$$\bar{u} = \frac{a}{3}(\zeta^2 + 2\zeta + 6), \tag{2.9}$$

$$\bar{d} = \frac{a}{3}(\zeta^2 + 8), \tag{2.10}$$

$$\bar{s} = \frac{a}{3}(\zeta^2 - 2\zeta + 10) - 3a(1 - \epsilon), \tag{2.11}$$

which reduce to the SU(3) results [12] when $\epsilon \to 1$. From Eqs. (2.9)–(2.11), we obtain

$$\bar{d} - \bar{u} = \frac{2a}{3}(1 - \zeta), \quad \frac{\bar{u}}{\bar{d}} = 1 - 2\left(\frac{1 - \zeta}{\zeta^2 + 8}\right) \tag{2.12}$$

since data shows $\bar{d} > \bar{u}$ and $a > 0$, hence $\zeta < 1$. From the data, $\bar{u}/\bar{d} \simeq 0.51$, which leads to $(1-\zeta)/(\zeta^2+8) \simeq 0.24$, and $\zeta \simeq -1.2$. The explanation for $\zeta \neq 1$ in [12] was that the nonplanar contributions [15] in the $1/N_c$ expansion break the U(3) symmetry. A study given in [16] shows that the singlet and nonsinglet couplings are renormalized differently in the chiral quark model since they receive different contributions from the loops of Goldstone bosons. A detail model calculation in [16] gave $\zeta \simeq -2$. But it still needs further study.

For the spin contents of the proton, the SU(3)-breaking results are

$$\Delta u = \frac{4}{3} - \frac{a}{9}(8\zeta^2 + 37) + \frac{4a}{3}(1-\epsilon), \tag{2.13}$$

$$\Delta d = -\frac{1}{3} + \frac{2a}{9}(\zeta^2 - 1) - \frac{a}{3}(1-\epsilon), \tag{2.14}$$

$$\Delta s = -a + a(1-\epsilon). \tag{2.15}$$

One can see that with the SU(3)-breaking effect arising from the kaon suppression, Δu would be *more positive*, Δd *more negative* and Δs *less negative*. Compared to the results without SU(3) breaking,

$$\Delta s - (\Delta s)_{\mathrm{SU}(3)} = a(1-\epsilon), \quad \Delta\Sigma - (\Delta\Sigma)_{\mathrm{SU}(3)} = 2a(1-\epsilon). \tag{2.16}$$

Hence a consequence of this breaking is that the strange sea polarization is reduced (less negative) and the total quark spin would slightly increase.

From Eqs. (2.9)–(2.11), we have

$$f_3/f_8 = \frac{1}{3}\left(\frac{1}{1 + \dfrac{4a(1-\epsilon)}{1 + (4a/3)(\zeta - 1)}}\right). \tag{2.17}$$

For the nonsinglet axial charges, one obtains

$$\Delta_3 = \frac{5}{3}\left[1 - \frac{a}{3}(2\zeta^2 + 4 + 3\epsilon)\right], \tag{2.18}$$

$$\Delta_8 = 1 - \frac{a}{3}(2\zeta^2 + 10 - 3\epsilon), \tag{2.19}$$

and

$$\Delta_3/\Delta_8 = \frac{5}{3}\left(\frac{1 - \dfrac{a}{3}(2\zeta^2 + 7) + a(1-\epsilon)}{1 - \dfrac{a}{3}(2\zeta^2 + 7) - a(1-\epsilon)}\right). \tag{2.20}$$

It is obvious that the correction factors, appearing in Eqs. (2.17) and (2.20), due to the SU(3) breaking, are in the right direction, i.e., f_3/f_8 decreases [provided that $1 + (4a/3)(\zeta - 1) > 0$ and $\epsilon < 1$] and Δ_3/Δ_8 increases. The SU(3) results can be recovered by taking $\epsilon \to 1$.

III. NUMERICAL RESULTS AND DISCUSSION

To maintain the agreement obtained in the SU(3) symmetry description, we choose $a = 0.1$ and $\zeta = -1.2$ used in Ref. [12] (one can see from Eq. (2.12) that a and ζ are completely determined by fitting data $\bar{d}/\bar{u}$ and $\bar{d} - \bar{u}$. Two remarks should be made. First, data $\bar{d} - \bar{u}$ is obtained from the measurement of the Gottfried sum I_G by assuming there is no charge symmetry breaking in the sea [17]. Second, "data" $\bar{d}/\bar{u}$ are measured only at one particular x point). For the SU(3)-breaking parameter ϵ, we choose $\epsilon = 0.5 - 0.6$, which is quite a reasonable value if we assume that ϵ is proportional to the ratio $m_{u,d}/m_s$, where $m_{u,d}$ and m_s are the constituent quark masses of nonstrange and strange quarks. Having three parameters a, ζ, and ϵ in the SU(3)-breaking description, one obtains

$$f_3/f_8 = 0.26(\mathrm{expt}{:}\,0.23), \quad \Delta_3/\Delta_8 = 1.94(\mathrm{expt}{:}\,2.10); \tag{3.1}$$

the theoretical predictions are now much closer to the data than those from SU(3) description and the inconsistency shown in [12] is removed. The results for the quark flavor and spin contents in the proton are listed in Tables I and II, respectively. Comparison with Cheng and Li's SU(3) symmetry prediction and data are shown. For comparison, the experimental results from the analysis given by Ellis and Karliner [18] are also shown.

Several remarks are in order.

(1) According to the analysis given in [19,20], the hyperon β decay data can be well accommodated within the framework of Cabbibo's SU(3) symmetry description. For example, Ref. [19] shows that the use of SU(3) symmetry with a small SU(3) breaking proportional to the mass difference between strange and nonstrange quarks allows a very satisfactory description of the hyperon β decay data and leaves little room for any further SU(3)-breaking contributions. Similar conclusion has been reached in [20]. Hence as a good approximation, one can write

$$\Delta_3 = \Delta u - \Delta d = F + D, \quad \Delta_8 = \Delta u + \Delta d - 2\Delta s = 3F - D. \tag{3.2}$$

TABLE I. Quark flavor contents for the proton in the chiral quark model ($a = 0.1$, $\zeta = -1.2$) with ($\epsilon = 0.5$ and 0.6) and without ($\epsilon = 1.0$) SU(3) breaking.

Quantity	Data	$\epsilon=0.5$	$\epsilon=0.6$	$\epsilon=1.0$
$\bar{u}/\bar{d}$	0.51 ± 0.09	0.53	0.53	0.53
I_G	0.235 ± 0.026	0.236	0.236	0.236
f_u		0.51	0.50	0.48
f_d		0.35	0.35	0.33
f_s	0.18 ± 0.03	0.15	0.15	0.19
f_3/f_8	0.23 ± 0.05	0.26	0.27	0.33

TABLE II. Quark spin contents for the proton in the chiral quark model ($a = 0.1$, $\zeta = -1.2$) with ($\epsilon = 0.5$, 0.6) and without ($\epsilon = 1.0$) SU(3) breaking.

Quantity	Data	$\epsilon=0.5$	$\epsilon=0.6$	$\epsilon=1.0$
Δu	0.84 ± 0.05 (E143)	0.86	0.85	0.79
	0.83 ± 0.05 (SMC)			
	0.85 ± 0.03 (E-K)			
Δd	-0.43 ± 0.05 (E143)	-0.34	-0.34	-0.32
	-0.44 ± 0.05 (SMC)			
	-0.41 ± 0.03 (E-K)			
Δs	-0.08 ± 0.05 (E143)	-0.05	-0.06	-0.10
	-0.09 ± 0.05 (SMC)			
	-0.06 ± 0.04 (E142)			
	-0.08 ± 0.03 (E-K)			
$\Delta\Sigma$	0.30 ± 0.06 (E143)	0.47	0.45	0.37
	0.20 ± 0.11 (SMC)			
	0.39 ± 0.10 (E142)			
	0.37 ± 0.07 (E-K)			

TABLE III. Hyperon β-decay constants in the chiral quark model ($a=0.1$, $\zeta=-1.2$) with ($\epsilon=0.5$ and 0.6) and without ($\epsilon=1.0$) SU(3) breaking.

Quantity	Data	$\epsilon=0.5$	$\epsilon=0.6$	$\epsilon=1.0$
$F-D$	1.2573 ± 0.0028	1.20	1.19	1.11
$F+D/3$	0.718 ± 0.015	0.70	0.70	0.67
$F-D$	-0.340 ± 0.017	-0.29	-0.28	-0.22
$F-D/3$	0.25 ± 0.05	0.21	0.21	0.22
F/D	0.575 ± 0.016	0.61	0.62	0.67
Δ_3/Δ_8	2.09 ± 0.13	1.94	1.88	1.67

From the spin contents shown in Table II, we can calculate F/D and other weak axial couplings. The results are listed in Table III. It shows that our description gives better agreement with the hyperon β decay data [21,22] as well.

(2) The first moments of g_1^p and g_1^n including QCD corrections can be written as

$$I^p=\int_0^1 dx g_1^p(x)=\frac{C_{\rm NS}}{6}\Delta u+\frac{1}{18}(2C_S-C_{\rm NS})\Delta\Sigma, \tag{3.3}$$

$$I^d=\int_0^1 dx g_1^d(x)=\eta\left[-\frac{C_{\rm NS}}{6}\Delta s+\frac{1}{18}(4C_S+C_{\rm NS})\Delta\Sigma\right], \tag{3.4}$$

where $\eta=0.4565$ and $C_S(Q^2)$, $C_{\rm NS}(Q^2)$ are the QCD radiative correction factors given in Ref. [23]. Taking $\alpha_s=0.35$ at $Q^2=3.0$ GeV^2 and using the spin contents in Table II, the first moments I^p and I^d are evaluated and listed in Table IV.

One can see that the SU(3)-breaking results are also better than those without SU(3) breaking except for the moment of g_1^d. Our prediction of I^d is higher than both spin muon collaboration (SMC) and E143 data. In addition, our I^p value is closer to the SMC data, while the SU(3) symmetry prediction is closer to the E143 data.

(3) For comparison, we also evaluated a quantity defined as

$$\langle A_1^p\rangle=2\langle x\rangle\frac{\Sigma e_q^2\Delta q}{\Sigma e_q^2 q}, \tag{3.5}$$

which is a crude approximation of the asymmetry A_1^p measured in deep inelastic lepton proton scattering, where $\langle x\rangle$ is the average value of the Bjorken variable x and can be taken as 0.5–0.7. Taking the q's from Eqs. (2.9)–(2.11) and Δq's from Eqs. (2.13)–(2.15), and using $\alpha_s=0.35$ at $Q^2=3.0$ GeV^2, we obtain

$$\langle A_1^p\rangle=0.24-0.34\ \ (\epsilon=0.5),\quad 0.20-0.30\ \ (\epsilon=1.0); \tag{3.6}$$

the data from E143

$$\int_0^1 A_1^p(x)dx=0.40\pm0.10 \tag{3.7}$$

seems to favor the symmetry-breaking description.

(4) We decompose the valence and sea contributions for the flavor contents in the proton. Neglecting the antisymmetrization effect of the u and d sea quarks with the valence quarks (u, d in the nucleon), we may assume $u_{\rm val}=2$ and $d_{\rm val}=1$, since $s_{\rm val}=0$, and obtain

$$u_{\rm sea}=\bar{u}=\frac{a}{3}(\zeta^2+2\zeta+6), \tag{3.8}$$

$$d_{\rm sea}=\bar{d}=\frac{a}{3}(\zeta^2+8), \tag{3.9}$$

$$s_{\rm sea}=\bar{s}=\frac{a}{3}(\zeta-1)^2+3\epsilon a; \tag{3.10}$$

here the equality of the sea quark number and the antiquark number is because the sea must be flavorless. From Eqs. (3.8)–(3.10), the sea not only violates SU(3) flavor symmetry but also violates SU(2) symmetry; i.e.,

$$\bar{s}<\bar{u}<\bar{d}. \tag{3.11}$$

However, for a special case $\zeta=1$ and $\epsilon=1$, one obtains a complete SU(3) symmetric sea: $\bar{s}=\bar{u}=\bar{d}$, which was discussed in [11].

(5) For sea quark spin contents, we have to be careful in defining the sea quark polarizations. Unlike the equality $q^{\rm sea}=\bar{q}$ holds in the unpolarized case, we do not have similar equality for sea quark polarization and corresponding antiquark polarization in general [24,29]. As an example, the chiral quark model [SU(3) symmetry or SU(3)-breaking descriptions] gives that all antiquark polarizations are zero

$$\Delta\bar{u}=\Delta\bar{d}=\Delta\bar{s}=0. \tag{3.12}$$

The smallness of antiquark polarizations was discussed in [25] and seems to be consistent with the most recent SMC

TABLE IV. The first moments of $g_1^{p,n}$ and g_1^d in the chiral quark model ($a=0.1$, $\zeta=-1.2$) with ($\epsilon=0.5$, 0.6) and without ($\epsilon=1.0$) SU(3) breaking.

Quantity	Data	$\epsilon=0.5$	$\epsilon=0.6$	$\epsilon=1.0$
I^p	0.136 ± 0.016 (SMC)	0.137	0.136	0.128
	0.127 ± 0.011 (E143)			
I^n	-0.031 ± 0.011 (E142)	-0.021	-0.022	-0.021
	-0.037 ± 0.014 (E143)			
I^d	0.034 ± 0.011 (SMC)	0.053	0.052	0.049
	0.042 ± 0.005 (E143)			

experiment [26]. It is obvious from Eq. (2.15) and Eq. (3.12) that *at least* for the *strange quark* sea polarization the equality $\Delta q_{\rm sea}=\Delta\overline{q}$ does not hold; i.e.,

$$\Delta s_{\rm sea}\neq\Delta\overline{s}. \tag{3.13}$$

If we neglect the antisymmetrization effect of the u and d sea quarks with the valence quarks as before, we may assume $\Delta u_v=\frac{4}{3}$ and $\Delta d_v=-\frac{1}{3}$, since no valence strange quarks $\Delta s_v=0$, and obtain

$$\Delta u_{\rm sea}=-\frac{a}{9}(8\zeta^2+37)+\frac{4a}{3}(1-\epsilon), \tag{3.14}$$

$$\Delta d_{\rm sea}=+\frac{2a}{9}(\zeta^2-1)-\frac{a}{3}(1-\epsilon), \tag{3.15}$$

$$\Delta s_{\rm sea}=-a\epsilon. \tag{3.16}$$

For the SU(3) symmetric case in [12], one has $(\epsilon=1)$

$$\Delta u_{\rm sea}<0,\quad \Delta d_{\rm sea}>0,\quad \Delta s_{\rm sea}<0. \tag{3.17}$$

It implies that the sea quark of each flavor is polarized in the direction opposite to the valence quark of the same flavor. However, in the SU(3)-breaking description, $\Delta d_{\rm sea}$ could be negative if $1-\epsilon>\frac{2}{3}(\zeta^2-1)\simeq 0.3$, or $\epsilon<0.7$. In this case, all sea quarks are spinning in the opposite direction with respect to the proton spin. This includes the cases ($\epsilon=0.5$ or 0.6) discussed in this work. A set of negative flavor asymmetric sea polarizations ($|\Delta s|<|\Delta u|<|\Delta d|$ and $\Delta q<0$ for $q=u,d,s$) has been used in [27]. The result shows that a set of valence quark helicity distributions, given by the c.m. bag model, and a set of negative sea helicity distributions can well describe the spin-dependent structure functions $g_1^p(x)$, $g_1^n(x)$, and $g_1^d(x)$ measured in deep inelastic scattering (DIS).

(6) If the gluon axial-anomaly contribution [28] is taken into account (in the chiral-invariant factorization scheme), then one should use $\Delta\tilde{q}=\Delta q-(\alpha_s/2\pi)\Delta G$, not the Δq, to compare with the DIS data. Taking $(\alpha_s/2\pi)\Delta G\simeq 0.04$ (this implies $\Delta G\simeq 0.7$ at $\alpha_s=0.35$), one has (for $\epsilon=0.6$)

$$\Delta\tilde{u}=0.81,\quad \Delta\tilde{d}=-0.38,\quad \Delta\tilde{s}=-0.10,\quad \Delta\tilde{\Sigma}=0.33 \tag{3.18}$$

and

$$I^p=0.125,\quad I^n=-0.033,\quad I^d=0.042, \tag{3.19}$$

which seem to be in better agreement with the DIS data listed in Tables II and IV. Note that the prediction for hyperon β decay constants, Δ_3, Δ_8 and thus Δ_3/Δ_8 listed in Table III are not affected.

Finally, we have

$$\frac{\mu_p}{\mu_n}=\left(-\frac{3}{2}\right)\left[1-\frac{5a}{6}\,\frac{1-r\epsilon}{1-\frac{2a}{3}\left(\zeta^2+\frac{11}{4}\right)+a(1-\epsilon)}\right], \tag{3.20}$$

where $m_u=m_d$ and $r=m_{u,d}/m_s$ are assumed. It is not necessary to require r to be equal to the suppression parameter ϵ. Assuming $r=\epsilon=0.6$ and using the numbers given in Table II, one obtains $\mu_p/\mu_n\simeq 1.40$, which can be compared to the data $(\mu_p/\mu_n)_{\rm expt}=1.46$. A more detail discussion on the octet baryon magnetic moments will be given elsewhere.

IV. SUMMARY

In this paper we introduced an SU(3)-breaking effect into the SU(3) symmetric chiral quark model. A breaking parameter $\epsilon\equiv|\Psi(u\to K^+s)|^2/|\Psi(u\to\pi^+d)|^2<1$ is suggested. The new parameter denotes a smaller probability of the kaon emission from a quark than that of emitting pions. Taking $\epsilon\simeq 0.5-0.6$, the f_3/f_8 and Δ_3/Δ_8 values are much closer to the data. With the breaking effect, some other theoretical predictions are also in better agreement with the experiments. The simple model suggested in this work does not have power to predict the flavor and spin distributions in the nucleon. Furthermore, no Q^2 dependence can be discussed in this simple calculation. However, the success of explaining many puzzles by using only a few parameters encourages us to present this work and to study it further.

ACKNOWLEDGMENTS

One of us (X.S.) would like to thank L. F. Li for useful comments and thank X. Ji for helpful discussions. The authors thank P. K. Kabir for reading the manuscript and suggestions. We also thank D. Crabb and O. Rondon for providing the new E142 and E143 data. This work was supported in part by the U.S. Department of Energy and by the Commonwealth of Virginia, the Institute of Nuclear and Particle Physics, University of Virginia.

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[24] The equality $q_{\rm sea}=\overline{q}$ is usually taken as the *definition* of $q_{\rm sea}$, but it is more appropriate to say that the equality is required by the *flavorlessness of the sea.* For the sea polarization, we do not have a similar requirement in general. If one *defines*

$$\Delta q_{\rm sea}=\Delta\overline{q},$$

it implies $(q_{\rm sea})_\uparrow-(q_{\rm sea})_\downarrow=\overline{q_\uparrow}-\overline{q_\downarrow}$. Considering the equality $q_{\rm sea}=\overline{q}$, which gives $(q_{\rm sea})_\uparrow+(q_{\rm sea})_\downarrow=\overline{q_\uparrow}+\overline{q_\downarrow}$, we immediately find that

$$(q_{\rm sea})_\uparrow=\overline{q_\uparrow},\quad (q_{\rm sea})_\downarrow=\overline{q_\downarrow}\ \ (q=u,d,s,\ldots);$$

these are very strong constraints imposed on the sea spin components. It may be true for the quark-antiquark pair produced from gluons but not necessarily true in general case. For example, in the chiral quark model, one has $\Delta q_{\rm sea}\neq 0$ and $\Delta\overline{q}=0$. After completion of this paper, we have seen a paper [29] which reached a similar conclusion in their light-cone meson-baryon fluctuation model.

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