Determination of sea-quark polarization in the proton

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We show that there exists nonzero antiquark polarization in a proton. In order to get this result we have used the experimental numbers of octet-particle magnetic moments. Assuming that the sea is polarized in the SU(2)-symmetric way we show that it is not SU(3) symmetric. With the help of a few simplifying assumptions we get for a polarization of nonstrange and strange antiquarks: $\Delta\bar{u}^{\text{sea}}=\Delta\bar{d}^{\text{sea}}=-0.17\pm0.03$ and $\Delta\bar{s}^{\text{sea}}=-0.09\pm0.04$, respectively. The ratio of these numbers is the same as the one for the spin-averaged densities.

The data from the European Muon Collaboration[1] (EMC) on the spin asymmetry in deep-inelastic electron-proton scattering and its theoretical interpretation[2] gave rise to several papers[3] which deal with the answer to the open question: how is the proton spin distributed among constituents? The theoretical interpretation of the above-mentioned experimental results leads to the conclusion that the contribution to a nucleon spin coming from valence and sea quarks add up approximately to zero.

In this paper we should like to show how much of the proton spin is carried by the valence quarks of both flavors u and d and how the sea quarks share the parts of it. In a previous analysis the determination of sea-quark polarization was not obtainable on general grounds.[4] One was able to get the numbers only when a specific phenomenological model was applied (see, e.g., Ref. 5). In our paper we propose to get these quantities using, in addition to a well-known technique (i.e., making use of F and D which describe β decays of octet baryons), values of baryonic octet magnetic moments. To present an ability of taking off the information from these moments let us consider the nonrelativistic formulas for the weak axial-vector coupling constant g_A [equal to $F+D$ in the SU(3)-symmetric Cabibbo model] and μ_B (B stands for a name of a particle or a quark flavor). If one tries to calculate g_A for $n\to p$ β decay one deals with nondiagonal matrix elements; but using the Wigner-Eckart theorem [for the SU(2) isospin symmetry group] one is able to express g_A in terms of quantities which are some distribution densities of a proton solely. Thus we have

$$g_A=(\Delta n_u-\Delta n_d+\Delta n_{\bar{u}}-\Delta n_{\bar{d}})g_0\ , \tag{1}$$

where $g_0=1$ for structureless current quarks and where

$$\Delta n_q\equiv n_{q\uparrow}-n_{q\downarrow}\ . \tag{2}$$

The subscript q ($q=u,d,s,\ldots$) stands for a flavor of a corresponding quark whereas the arrows indicate whether the spin of a quark is parallel ($\uparrow$) or antiparallel ($\downarrow$) to the spin of a proton. The quantities $n_{q\uparrow(\downarrow)}$ are the average numbers of q-flavored quarks inside a proton. They are, e.g., for SU(6)-symmetric spin-isospin wave function as

$$n_{u\uparrow}=\tfrac{5}{3},\quad n_{u\downarrow}=\tfrac{1}{3},\quad n_{d\uparrow}=\tfrac{1}{3},\quad n_{d\downarrow}=\tfrac{2}{3}$$

(hence, $\Delta n_u=\frac{4}{3}$ and $\Delta n_d=-\frac{1}{3}$) and all the other modes are zero since we have no strange constituents quarks nor antiquarks in a nonrelativistic description. Inserting these numbers into Eq. (1) we get the famous value $\frac{5}{3}$ for the ratio g_A/g_V in nucleon β decay (the vector coupling constant is $g_V=n_{u\uparrow}+n_{u\downarrow}-n_{d\uparrow}-n_{d\downarrow}=1$ and $g_0=1$). Usually one rewrites Eq. (1) as

$$(g_A/g_V)_{n\to p}=\Delta u-\Delta d\ , \tag{3}$$

where

$$\Delta q\equiv\Delta n_q+\Delta n_{\bar{q}} \tag{4}$$

is connected with matrix element of the J_5 current.

For the magnetic moment of a proton one can get the formula in terms of already introduced quantities. We have

$$\mu_p=\sum_q\mu_q(\Delta n_q-\Delta n_{\bar{q}}) \tag{5}$$

and we see that the sign is negative for the antiquark contribution (the magnetic moment for an antiquark is opposite to such moment of the corresponding quark) on the contrary to the one in Eq. (4). Hence, we introduce the new quantity

$$\delta_q\equiv\Delta n_q-\Delta n_{\bar{q}}\ . \tag{6}$$

If we consider the relativized quark model (as the bag model,[6] e.g.) the numbers Δq from Eq. (4) become spin-weighted constituent distribution functions (integrated over the x variable) introduced elsewhere. Considering β decays of octet baryons [and making use of Wigner-Eckart theorem for the SU(3) flavor-symmetry group] and ignoring the possible SU(3)-breaking effects (see however the discussion in Ref. 7) we end up with the following formulas for several combinations of Δu, Δd, and Δs:

$$\Delta N_3 \equiv \Delta u - \Delta d = F + D \ ,$$
$$\Delta N_8 \equiv \Delta u + \Delta d - 2\Delta s = 3F - D \ , \tag{7}$$

where we have used the F- and D-invariant matrix elements, the parametrization which is valid in the limit where the SU(3) symmetry is unbroken. We shall use the following numbers[8,9] gotten from the analysis of experimental data:

$$\begin{aligned} \Delta N_3 &= F + D = (g_A/g_V)_{n\to p} = 1.259\pm0.004 \ , \\ \Delta N_8 &= 3F - D = 2(g_A/g_V)_{\Sigma^-\to n} + (g_A/g_V)_{n\to p} \\ &= 0.60\pm0.04\pm0.15 \ , \end{aligned} \tag{8}$$

where we have added to the second number an artificial theoretical error which accounts for the possible SU(3)-symmetry breaking[10] (we agree with Lipkin's objections formulated in Ref. 7).

Now we should like to extend our discussion on the magnetic moments. The first step in this direction was made by Sehgal[11] and we would like to get the relativistic formulas for magnetic moments which depend on the relativistic extensions of the quantities δq introduced in Eq. (6). There the problem with the orbital angular momentum, which is important when we are dealing with fast moving quarks, comes into game. The connection between average values of spin and orbital angular momentum contributions to magnetic moments can be parametrized, using the notion of the Landé factor (g) known from atomic physics. Thus we have

$$\langle L_z \rangle = \frac{2-g}{g-1} \langle S_z \rangle \ . \tag{9}$$

If the Landé factor will be the same for all octet states and for all quark species we can express the magnetic moments in terms of δq. In order to gain some intuition how big is the value of this factor let us calculate it in a relativistic model, as the MIT bag model[6] really is. We get, for massless quarks (in the case $x_0 = 2.04\ldots$),

$$g_{\text{bag}} = \frac{4x_0 - 3}{3(x_0 - 1)} \simeq 1.65 \ . \tag{10}$$

This quantity does not depend on the bag radius (i.e., on the state) and we are able to get a similar formula for a strange quark which does not differ too much numerically. So if we ignore SU(3)-breaking effects (i.e., the mass of a strange quark) we have the unique Landé factor. Moreover, as we shall see later we do not need the value of such a factor for the s-flavored quark. Hence, we assume that we have only one Landé factor for all baryonic octet states and quark flavors and this gives us the opportunity to write the following expressions for magnetic moments:

$$\begin{aligned} \mu_p &= \mu_\mu \delta m + \mu_d \delta d + \mu_s \delta s \ , \\ \mu_n &= \mu_u \delta d + \mu_d \delta u + \mu_s \delta s \ , \\ \mu_\Lambda &= \tfrac{1}{6}\mu_u(\delta u + 4\delta d + \delta s) + \tfrac{1}{6}\mu_d(\delta u + 4\delta d + \delta s) \\ &\quad + \tfrac{1}{3}\mu_s(2\delta u - \delta d + 2\delta s) \ , \\ \mu_{\Sigma^+} &= \mu_u \delta u + \mu_d \delta s + \mu_s \delta d \ , \\ \mu_{\Sigma^-} &= \mu_u \delta s + \mu_d \delta u + \mu_s \delta d \ , \\ \mu_{\Xi^0} &= \mu_u \delta d + \mu_d \delta s + \mu_s \delta u \ , \\ \mu_{\Xi^-} &= \mu_u \delta s + \mu_d \delta d + \mu_s \delta u \ . \end{aligned} \tag{11}$$

If we put $\delta u = \Delta n_u = \frac{4}{3}$, $\delta d = \Delta n_d = -\frac{1}{3}$, $\delta s = \Delta n_s = 0$ we get the known formulas[12] for magnetic moments of baryons in a quark model [with an SU(6)-symmetric spin-isospin wave function]. All moments are expressed in terms of spin distributions for a proton due to the SU(3)-symmetry demand. We have seven measured moments and six parameters but not all of them are independent. We have only as many as four independent parameters and hence we get three already known sum rules:[13–15]

$$\begin{aligned} &[(-1.84\pm0.01)\mu_N] \leftarrow 3\mu_\Lambda = (\mu_p + \mu_n) - \tfrac{1}{2}(\mu_{\Sigma^+} + \mu_{\Sigma^-}) + (\mu_{\Xi^0} + \mu_{\Xi^-}) \rightarrow [(-1.69\pm0.05)\mu_N] \ , \\ &[(0.57\pm0.07)\mu_N] \leftarrow (\mu_p - \mu_n) - (\mu_{\Sigma^+} - \mu_{\Sigma^-}) + (\mu_{\Xi^0} - \mu_{\Xi^-}) = \rightarrow [(0)\mu_N] \ , \\ &[(3.43\pm0.26)\mu_N^2] \leftarrow (\mu_{\Sigma^+}^2 - \mu_{\Sigma^-}^2) - (\mu_{\Xi^0}^2 - \mu_{\Xi^-}^2) = (\mu_p + \mu_n)[(\mu_{\Sigma^+} - \mu_{\Sigma^-}) - (\mu_{\Xi^0} - \mu_{\Xi^-})] \rightarrow [(3.64\pm0.07)\mu_N^2] \ , \end{aligned} \tag{12}$$

where in square brackets we quote the experimental numbers[8] in nuclear magneton (μ_N) units.

The failure of the first sum rule is understood if one takes into account that on the left-hand side we quote the experimental results for the *physical* Λ state. Because of the mixing with Σ^0 we get, for a pure SU(3) Λ state (see, e.g., Ref. 16),

$$\mu_{\Lambda^{\text{SU(3)}}} \simeq \mu_{\Lambda^{\text{phys}}} + 0.027|\mu_{\Sigma^0\to\Lambda}| = -0.570\pm0.005 \ , \tag{13}$$

where we have used for the transition moment the value $|\mu_{\Sigma^0\to\Lambda}| = 1.61\pm0.08$ (Ref. 8). Hence, the corrected left-hand side number for the first sum rule should read $3\mu_{\Lambda^{\text{SU(3)}}} \rightarrow [(-1.71\pm0.02)\mu_N]$. The failure of the second *isovector* sum rule can be interpreted as noninclusion of the pionic cloud contribution which is important for nucleon moments only (such contributions to other octet particles can be absorbed into a redefinition of μ_q, see Ref. 15). It was shown in this reference that only nondiagonal pion exchanges (i.e., between different nonstrange valence quarks) give a contribution to baryon magnetic moments. The diagonal ones redefine the quark moments. The nondiagonal terms are present for nucleons only, because the Σ^0 and Λ^0 hyperons are isospin states with $I_3=0$ and hence do not get pionic corrections. Hence adding the new, isovector component to the nucleon moments: i.e.,

$$\begin{aligned} \mu_p &= \mu_u \delta u + \mu_d \delta d + \mu_s \delta s + \mu_\pi \ , \\ \mu_n &= \mu_u \delta d + \mu_d \delta u + \mu_s \delta s - \mu_\pi \ , \end{aligned} \tag{14}$$

we can save our sum rule.

In order to determine the unknown parameters let us rewrite Eqs. (11) and (14) using the quantities

$$\begin{aligned} \delta n_3 &\equiv \delta u - \delta d \ , \\ \delta n_8 &\equiv \delta u + \delta d - 2\delta s \ , \\ \delta \Sigma &\equiv \delta u + \delta d + \delta s \ , \end{aligned} \tag{15}$$

and

$$\begin{aligned} \mu_3 &\equiv \mu_u - \mu_d \ , \\ \mu_8 &\equiv \mu_u + \mu_d - 2\mu_s \ , \\ \mu_0 &\equiv \mu_u + \mu_d + \mu_s \ . \end{aligned} \tag{16}$$

Then we get

$$\begin{aligned} \mu_p &= \tfrac{1}{3}\mu_0 \delta\Sigma + \tfrac{1}{2}\mu_3 \delta n_3 + \tfrac{1}{6}\mu_8 \delta n_8 + \mu_\pi \ , \\ \mu_n &= \tfrac{1}{3}\mu_0 \delta\Sigma - \tfrac{1}{2}\mu_3 \delta n_3 + \tfrac{1}{6}\mu_8 \delta n_8 - \mu_\pi \ , \\ \mu_\Lambda &= \tfrac{1}{3}\mu_0 \delta\Sigma - \tfrac{1}{4}\mu_8 \delta n_3 + \tfrac{1}{12}\mu_8 \delta n_8 \ , \\ \mu_{\Sigma^+} &= \tfrac{1}{3}\mu_0 \delta\Sigma + \tfrac{1}{4}\mu_3 \delta n_3 + \tfrac{1}{4}\mu_3 \delta n_8 + \tfrac{1}{4}\mu_8 \delta n_3 \\ &\quad - \tfrac{1}{12}\mu_8 \delta n_8 \ , \\ \mu_{\Sigma^-} &= \tfrac{1}{3}\mu_0 \delta\Sigma - \tfrac{1}{4}\mu_3 \delta n_3 - \tfrac{1}{4}\mu_3 \delta n_8 + \tfrac{1}{4}\mu_8 \delta n_3 - \tfrac{1}{12}\mu_8 \delta n_8 \ , \\ \mu_{\Xi^0} &= \tfrac{1}{3}\mu_0 \delta\Sigma - \tfrac{1}{4}\mu_3 \delta n_3 + \tfrac{1}{4}\mu_3 \delta n_8 - \tfrac{1}{4}\mu_8 \delta n_3 - \tfrac{1}{12}\mu_8 \delta n_8 \ , \\ \mu_{\Xi^-} &= \tfrac{1}{3}\mu_0 \delta\Sigma + \tfrac{1}{4}\mu_3 \delta n_3 - \tfrac{1}{4}\mu_3 \delta n_8 - \tfrac{1}{4}\mu_8 \delta n_3 - \tfrac{1}{12}\mu_8 \delta n_8 \ . \end{aligned} \tag{17}$$

Because of the above-mentioned theoretical uncertainties with the magnetic moments of nucleons and Λ hyperon we do not make the overall fit but we just extract the values of four independent parameters from the experimental values of Σ's and Ξ's magnetic moments.[8] It is rather the matter of convenience than the way to avoid the theoretical problem. We get

$$\begin{aligned} \mu_3 \delta n_3 &= (\mu_{\Sigma^+} - \mu_{\Sigma^-}) - (\mu_{\Xi^0} - \mu_{\Xi^-}) = (4.14 \pm 0.07)\mu_N \ , \\ \mu_3 \delta n_8 &= (\mu_{\Sigma^+} - \mu_{\Sigma^-}) + (\mu_{\Xi^0} - \mu_{\Xi^-}) \\ &= (3.02 \pm 0.07)\mu_N \ , \\ \mu_8 \delta n_3 &= (\mu_{\Sigma^+} + \mu_{\Sigma^-}) - (\mu_{\Xi^0} + \mu_{\Xi^-}) = (3.20 \pm 0.07)\mu_N \ , \\ 4\mu_0 \delta\Sigma - \mu_8 \delta n_8 &= 3[(\mu_{\Sigma^+} + \mu_{\Sigma^-}) + (\mu_{\Xi^0} + \mu_{\Xi^-})] \\ &= -(2.03 \pm 0.07)\mu_N \ . \end{aligned} \tag{18}$$

As a check of our parametrization we can calculate the magnetic moments for p, n, and $\Lambda^{SU(3)}$. We have, using $\mu_\pi = [(\mu_p - \mu_n) - (\mu_{\Sigma^+} - \mu_{\Sigma^-}) + (\mu_{\Xi^0} - \mu_{\Xi^-})]/2 = (0.28 \pm 0.07)\mu_N$,

$$\begin{aligned} \mu_p &= (2.77 \pm 0.02)\mu_N \quad (2.79) \ , \\ \mu_n &= -(1.94 \pm 0.02)\mu_N \quad (-1.91) \ , \\ \mu_{\Lambda^{SU(3)}} &= -(0.58 \pm 0.01)\mu_N \quad (-0.57) \ , \end{aligned} \tag{19}$$

where in parentheses we give the experimental results, which agree satisfactorily with our predictions.[17] The good agreement with experimental numbers obtained in Eqs. (19) confirms *a posteriori* our assumptions about the proportionality of orbital angular momentum to the spin angular momentum for all quark species and about the inclusion of the isovector contribution to nucleon moments.

The most interesting result for us in Eqs. (18) is in fact the ratio $\delta n_8 / \delta n_3$ which can be extracted and which is equal to

$$\delta n_8 / \delta n_3 = 0.73 \pm 0.02 \ . \tag{20}$$

This should be compared with a ratio gotten from the analysis of β decays of neutrons and hyperons: i.e.,

$$\Delta N_8 / \Delta N_3 = (3F - D)/(F + D) = 0.48 \pm 0.12 \ ; \tag{21}$$

hence we see the substantial difference which in our picture is due to a nonzero sea-antiquark polarization. We would like to emphasize that this statement is a consequence of the analysis of the baryon's static properties only, without referring to the EMC result for the first moment of the spin-dependent structure function $g_1^p(x)$ (Ref. 1).

In order to get further results we need just a few new assumptions. Let us remind that for q-flavored quarks the following formulas hold:[4]

$$\begin{aligned} \Delta q &= \Delta q^{\text{val}} + \Delta q^{\text{sea}} + \Delta \bar{q}^{\text{sea}} \ , \\ \delta q &= \Delta q^{\text{val}} + \Delta q^{\text{sea}} - \Delta \bar{q}^{\text{sea}} \ . \end{aligned} \tag{22}$$

The minimal assumption we can make is that the sea of quarks inside a proton is SU(2) symmetric, which means that

$$\Delta u^{\text{sea}} = \Delta d^{\text{sea}}$$

and (23)

$$\Delta \bar{u}^{\text{sea}} = \Delta \bar{d}^{\text{sea}} \ .$$

This gives us immediately

$$\delta n_3 \equiv \delta u - \delta d = \Delta u^{\text{val}} - \Delta d^{\text{val}} = \Delta u - \Delta d \equiv \Delta N_3 = 1.259 \pm 0.004 \quad (24)$$

and, hence, combining Eqs. (20) and (24) one gets

$$\delta n_8 = 0.92 \pm 0.02 \ . \quad (25)$$

This number is quite different from $\Delta N_8 = 0.60 \pm 0.15$; hence the quark sea cannot be SU(3) symmetric; otherwise, $\delta n_8 = \Delta N_8$. To illustrate this, one can get from Eqs. (7), (8), (15), (22), and (25) the estimate

$$\Delta \bar{u}^{\text{sea}} - \Delta \bar{s}^{\text{sea}} = \tfrac{1}{4}(\Delta N_8 - \delta n_8) = -0.08 \pm 0.04 \ , \quad (26)$$

a result which is indeed independent of the value $\Delta I^p = \int_0^1 g_1^p(x)dx$ but certainly depends on an assumption about the SU(2) symmetry of the sea.

In order to get the values of valence-quark contributions to the proton spin and also to get the strength of a polarization of quarks and antiquarks in the sea we have to add to our analysis the EMC result:[1] namely,

$$\Delta I^p = \tfrac{1}{2}(\tfrac{4}{9}\Delta u + \tfrac{1}{9}\Delta d + \tfrac{1}{9}\Delta s) = 0.126 \pm 0.010 \pm 0.015 \ . \quad (27)$$

This equation together with Eqs. (7) and (8) give us the well-known predictions (see, e.g., Ref. 2) for quantities defined in Eq. (4):

$$\begin{aligned} \Delta u &= 0.74 \pm 0.05 \ , \\ \Delta d &= -0.52 \pm 0.05 \ , \\ \Delta s &= -0.19 \pm 0.08 \ , \end{aligned} \quad (28)$$

and, for the quark contribution to a proton spin (i.e., $\frac{1}{2}\Delta\Sigma$),

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.04 \pm 0.17 \ . \quad (29)$$

As stated elsewhere the spin of the proton gets nearly no contribution from the spins of quarks and antiquarks. In our scheme the contribution coming from the orbital angular momenta of quarks and antiquarks is also negligible because of our assumption about a proportionality of $\langle L_z \rangle$ and $\langle S_z \rangle$ for quarks.

In order to obtain the values of Δq^{val}, Δq^{sea}, and $\Delta \bar{q}^{\text{sea}}$ separately we need additional assumptions. One set of possible ones is $\Delta q^{\text{sea}} = \Delta \bar{q}^{\text{sea}}$ (i.e., that the polarization of sea quarks and antiquarks of the same flavor is the same), the result which emerges from the naive picture of spin-1 gluon producing spin-$\frac{1}{2}$ quark and antiquark in pair with zero orbital angular momentum. This gives $\delta u = \Delta u^{\text{val}}$, $\delta d = \Delta d^{\text{val}}$, and $\delta s = 0$, which enable us to get the valence and sea quarks polarization separately. In the case of the quantity δn_8 in Eq. (25), also gives the percentage of the proton spin carried by the valence quarks, since $\delta s = 0$ [$\delta n_8 = \delta\Sigma = \Delta\Sigma^{\text{val}}$, see Eqs. (15)]. So far we get finally (the quantities are defined at $Q^2 = \langle Q^2_{\text{EMC}} \rangle$)

$$\begin{aligned} \Delta u^{\text{val}} &= \Delta N_3(\mu_{\Sigma^+} - \mu_{\Sigma^-})/[(\mu_{\Sigma^+} - \mu_{\Sigma^-}) - (\mu_{\Xi^0} - \mu_{\Xi^-})] = 1.09 \pm 0.01 \ , \\ \Delta d^{\text{val}} &= \Delta N_3(\mu_{\Xi^0} - \mu_{\Xi^-})/[(\mu_{\Sigma^+} - \mu_{\Sigma^-}) - (\mu_{\Xi^0} - \mu_{\Xi^-})] = -0.17 \pm 0.01 \ , \\ \Delta u^{\text{sea}} &= \Delta \bar{u}^{\text{sea}} = \Delta d^{\text{sea}} = \Delta \bar{d}^{\text{sea}} = \tfrac{1}{4}(\Delta u + \Delta d) - \tfrac{1}{4}(\Delta u^{\text{val}} + \Delta d^{\text{val}}) = -0.17 \pm 0.03 \ , \\ \Delta s^{\text{sea}} &= \Delta \bar{s}^{\text{sea}} = \tfrac{1}{2}\Delta s = -0.09 \pm 0.04 \ . \end{aligned} \quad (30)$$

As we can see from Eqs. (30) the s-quark polarization in the sea is two times smaller than that one of u and d sea quarks. This result, which is consistent with existing model parametrizations[5] means that possibly the polarization densities can be, at least averaged, proportional to the spin-averaged densities (U,D,S, etc.). We recall here the CERN-Dortmund-Heidelberg-Saclay Collaboration (CDHS) figure:[18] $2s/(\bar{U}+\bar{D}) = 0.52 \pm 0.09$, which should be compared with the one we get:

$$2\Delta s^{\text{sea}}/(\Delta \bar{u}^{\text{sea}} + \Delta \bar{d}^{\text{sea}}) = 0.54 \pm 0.21 \ . \quad (31)$$

Concluding, we would like to stress that we have shown that (i) the polarization of antiquarks is nonzero and (ii) the polarization of s-flavored quarks and antiquarks is different from u- and d-flavored quarks and antiquarks in the sea. These results were obtained without any use of the EMC value for ΔI^p. Adding new possible assumptions: $\Delta q^{\text{sea}} = \Delta \bar{q}^{\text{sea}}$ and introducing ΔI^p we were able to give the final answer to the question: how big are the polarizations of the valence quarks and of different quark species in the sea? The results presented in Eqs. (30) and (31) are in some sense expected (see, e.g., Ref. 5), but changing the assumption $\Delta q^{\text{sea}} = \Delta \bar{q}^{\text{sea}}$ we can obtain different numerical results. However, some plausible assumptions are in fact excluded by the existing data. For example, $\Delta \bar{q}^{\text{sea}} = 0$ is not possible since it gives $\Delta N_8 = \delta n_8$ which is not the case. The assumption $\Delta q^{\text{sea}} = -\Delta \bar{q}^{\text{sea}}$ is also nontruthful because it demands $\Delta s = 0$. The consideration of other probable assumptions: e.g., $\Delta q^{\text{sea}} = 0$ gives slightly different numerical results [$\delta\Sigma^{\text{val}} = 0.76 \pm 0.08$, $2\Delta \bar{s}^{\text{sea}}/(\Delta \bar{u}^{\text{sea}} + \Delta \bar{d}^{\text{sea}}) = 0.70 \pm 0.18$] but also gives rather big antiquark polarizations ($\Delta \bar{u}^{\text{sea}} = -0.27 \pm 0.06$ and $\Delta \bar{s}^{\text{sea}} = -0.19 \pm 0.08$).

We do not touch in this paper other questions as, e.g., how big are orbital angular momentum and glue contributions to the proton spin? Also we do not consider the probable mechanism which would be responsible for a polarization of the sea so substantially that it reduces the whole valence contribution. The answers to such problems remain open.

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[17]Inserting into Eq. (19) the newest value for the Σ^+ magnetic moment, $\mu_{\Sigma^+} = (2.479 \pm 0.012 \pm 0.022)\mu_N$ [C. Wilkinson *et al.*, Phys. Rev. Lett. **58**, 855 (1987)], instead of the averaged value given in Ref. 8, the agreement is even better because then we obtain 2.80, -1.91, and -0.57 μ_N for the magnetic moments of proton, neutron, and Λ hyperon, respectively.

[18]H. Abramowicz *et al.*, Z. Phys. C **15**, 19 (1982).