SPIN CONTENT OF THE Λ HYPERON

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Using the known experimental data for the hyperon semileptonic decay constants, we calculate integrated polarized quark densities Δq_Λ and $\Delta\Sigma_\Lambda$ for the hyperon Λ with flavor SU(3) symmetry breaking taken into account. Symmetry breaking is implemented with the help of the chiral quark-soliton model in such a way that the dynamical parameters in the model are fixed by the experimental data for six hyperon semileptonic decay constants. This parametrization allows us to reproduce the first moment of the $g_1^p(x)$ of the proton. For the Λ we obtain: $\Delta u_\Lambda = \Delta d_\Lambda \approx 0$ and Δs_Λ of the order of 1. Unfortunately large experimental uncertainties of the Ξ^- decays propagate in our analysis, in particular, in the case of $\Delta\Sigma_\Lambda$ and Δs_Λ, where they amount in the end to the errors of more than 50%. Only if the errors for these decays are reduced, accurate theoretical predictions for $\Delta\Sigma_\Lambda$ and Δs_Λ will be possible.

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1. Introduction

The spin and flavor content of the nucleon has been an extensively studied issue for well over a decade, since the first EMC [1] measurement in 1988. One of the possible interpretations of the EMC data was that the strange quark was strongly polarized opposite to the valence quarks, indicating that quarks carried only a small fraction of the nucleon spin. In contrast to the Ellis–Jaffe sum rule [2], the polarization of the strange quark turned out to be nonnegligible. A series of following experiments confirmed the EMC result [3–6]. Hence, it is also natural to investigate the structure of other baryons. In particular, the Λ hyperon is interesting, since Δq_Λ are related to the fragmentation functions which can be measured experimentally [7]. According to the naive quark model the spin of Λ comes solely from the strange quark, while the up and down quarks form the spin singlet, so that they make no contribution. However, an analysis based on the data of hyperon semileptonic decays and lepton-nucleon deep-inelastic scattering [7–9] predicts $\Delta s_\Lambda \simeq 0.6$ and $\Delta u_\Lambda = \Delta d_\Lambda \simeq -0.2$. This analysis assumes, however, the flavor SU(3) symmetry, *i.e.* it uses the relations: $\Delta u = \Delta d = \frac{1}{3}(\Delta\Sigma - D)$ and $\Delta s = \frac{1}{3}(\Delta\Sigma + 2D)$, with $\Delta\Sigma$ identical for all octet baryons. It implies that the Λ spin is not completely carried by the strange quark. While the above analysis shows a discrepancy with the naive quark model, one should note that the effect of SU(3) symmetry breaking was not taken into account.

Recently, we have investigated hyperon semileptonic decays and the spin content of the nucleon with SU(3) flavor symmetry breaking taken into account [10]. The SU(3) symmetry breaking was implemented via the Chiral Quark-Soliton Model (χQSM) in such a way that all dynamical variables in the model were fixed by the experimental data for the semileptonic decay constants. The results for the proton were: $\Delta u_p = 0.72 \pm 0.07$, $\Delta d_p = -0.54 \pm 0.07$, $\Delta s_p = 0.33 \pm 0.51$, and $\Delta\Sigma_p = 0.51 \pm 0.41$. The large errors in Δs_p and $\Delta\Sigma_p$ are due to the large experimental uncertainties of the Ξ^- decay constants. The conclusion in that work was as follows: First, statements concerning Δs_p and $\Delta\Sigma_p$ based on SU(3) flavor symmetry are premature. Second, accurate results can be obtained only by reducing the experimental uncertainty for Ξ decays. It is of great interest to study the spin content of the Λ, using the same framework as in Ref. [10]. The aim of this paper is thus to find out what we can reliably conclude on the spin structure of the Λ, based on hyperon semileptonic decays.

Let us first briefly recall how the standard analysis is carried out. Three diagonal axial-vector coupling constants define integrated polarized quark densities for a given baryon B:

$$\begin{aligned} g_A^{(3)}(B) &= \Delta u_B - \Delta d_B, \\ \sqrt{3}g_A^{(8)}(B) &= \Delta u_B + \Delta d_B - 2\Delta s_B, \\ g_A^{(0)}(B) &= \Delta u_B + \Delta d_B + \Delta s_B. \end{aligned} \tag{1}$$

Note that in our normalization $g_A^{(0)}(\mathrm{B}) = \Delta\Sigma_B$.

Assuming SU(3) symmetry, one can calculate $g_A^{(3,8)}(B)$ in terms of the reduced matrix elements F and D. For the proton and Λ one gets:

$$g_A^{(3)}(p) = F + D, \qquad \sqrt{3}g_A^{(8)}(p) = 3F - D,$$
$$g_A^{(3)}(\Lambda) = 0, \qquad \sqrt{3}g_A^{(8)}(\Lambda) = -2D. \tag{2}$$

The constants F and D can be in principle extracted from the hyperon semileptonic decays. For example:

$$A_1 \;=\; \left(\frac{g_1}{f_1}\right)^{(n\to p)} = F + D\,, \quad A_4 \;=\; \left(\frac{g_1}{f_1}\right)^{(\Sigma^-\to n)} = F - D\,. \tag{3}$$

For convenience, we denote the ratios of axial-vector to vector decay constants by A_i (see Table I). Taking for these decays experimental values (see Table I), one gets $F = 0.46$ and $D = 0.80$.

TABLE I

The parameters $r, \ldots, q'$ fixed to the experimental data of the semileptonic decays [26, 27] $A_1 - A_6$. The entries for $A_1 - A_6$ for the full fit (last column) correspond to the experimental data.

		chiral limit	with m_s	
	r	-0.0892	-0.0892	
	s	0.0113	0.0113	
	x'	0	-0.0055	
	y	0	0.0080	
	z	0	-0.0038	
	q'	0	-0.0140	
A_1	$(g_1/f_1)^{n\to p}$	1.271 ± 0.11	1.2573 ± 0.0028	(Input)
A_2	$(g_1/f_1)^{\Sigma^+\to\Lambda}$	0.769 ± 0.04	0.742 ± 0.018	(Input)
A_3	$(g_1/f_1)^{\Lambda\to p}$	0.758 ± 0.08	0.718 ± 0.015	(Input)
A_4	$(g_1/f_1)^{\Sigma^-\to n}$	-0.267 ± 0.04	-0.340 ± 0.017	(Input)
A_5	$(g_1/f_1)^{\Xi^-\to\Lambda}$	0.246 ± 0.07	0.25 ± 0.05	(Input)
A_6	$(g_1/f_1)^{\Xi^-\to\Sigma^0}$	1.271 ± 0.11	1.278 ± 0.158	(Input)

Since $g_A^{(0)}(B)$ does not correspond to the SU(3) current, it cannot be expressed in terms of F and D without further assumptions. Thus, in order to extract all Δq_p separately, one needs some additional information. Either another experimental input is needed, or a model which predicts $g_A^{(0)}(B)$ in terms of the F and D.

The first possibility can be realized by taking the experimental result for the first moment of the spin structure function $g_1^p(x)$ of the proton:

$$I_p = \int_0^1 dx\, g_1^p(x) = \frac{1}{18}\left(4\Delta u_p + \Delta d_p + \Delta s_p\right)\left(1 - \frac{\alpha_s}{\pi} + \ldots\right). \tag{4}$$

Recent analysis [13] implies $I_p = 0.124 \pm 0.011$ which translates into:

$$\Gamma_p \equiv 4\Delta u_p + \Delta d_p + \Delta s_p = 2.56 \pm 0.23 \tag{5}$$

if $\alpha_s(Q^2 = 3\ (\mathrm{GeV}/c)^2) = 0.4$ is assumed. Taking for $F = 0.46$ and for $D = 0.80$ together with Eq. (5), one gets for the nucleon: $\Delta u_p = 0.79$, $\Delta d_p = -0.47$ and $\Delta s_p = -0.13$, which implies $\Delta\Sigma_p = 0.19$, a fairly small number as compared with the naive expectation from the quark model: $\Delta\Sigma_p = 1$.

It is important to realize that $\Delta\Sigma_p$ is not directly measured; it is extracted from the data through some theoretical model. In the above example we have assumed the SU(3) symmetry and used two arbitrarily chosen hyperon decays (3). One could, however, use any two A_i's out of 6 known hyperon decays to extract F and D. The number of combinations which one can form to extract F and D is 14 (actually 15, but two conditions are linearly dependent). Taking these 14 combinations into account, one gets:

$$F = 0.40 \div 0.55, \quad D = 0.70 \div 0.89\,. \tag{6}$$

These are the uncertainties of the *central values* due to the theoretical error caused by using the exact SU(3) symmetry to describe the hyperon semileptonic decays. These uncertainties are further increased by the experimental errors of all individual decays.

Looking at Eq. (6), one might get an impression that a typical error associated with using SU(3) symmetry in analyzing the hyperon decays is of the order of 15 % or so. While this is true for the hyperon decays, the values of Δq_B and $\Delta\Sigma_B$ of the various baryons might be much more affected by the symmetry breaking. Indeed for F and D corresponding to (6) and Γ_p as given by Eq. (5) $\Delta\Sigma_p = 0.02 \div 0.30$.

As will be shown in the following, the χQSM predicts in the chiral limit [11]:

$$g_A^{(0)}(B) = 9F - 5D \tag{7}$$

for any baryon B. Here $g_A^{(0)}$ is very sensitive to small variations of F and D, since it is a difference of the two, with relatively large prefactors. Indeed, for the 14 fits mentioned above the central value for $g_A^{(0)}$ of the nucleon varies between -0.25 to approximately 1 and a similar feature is expected for any baryon, particularly for the Λ. Thus, despite the fact that hyperon semileptonic decays are relatively well described by the model in the chiral limit, the singlet axial-vector constant is basically undetermined. This is a clear signal of the importance of the symmetry breaking for this quantity.

One could argue that this kind of behavior is just an artifact of the χQSM. However, the scenario of a rotating soliton (which is by the way used also in the Skyrme-type models) is very plausible and cannot be *a priori* discarded on the basis of first principles. The χQSM is a particular realization of this scenario and we use it as a tool to investigate the sensitivity of the singlet axial-vector current to the symmetry breaking effects in hyperon semileptonic decays. In fact, conclusions similar to ours have been obtained in chiral perturbation theory in Ref. [12].

In Ref. [10] we have at length discussed the properties of the model formula for $g_A^{(0)}$ in two limiting cases, *i.e.* large (Skyrme model limit) and small (quark model limit) soliton sizes. In the Skyrme model the ratio $F/D = 5/9$ and $\Delta\Sigma_p$ vanishes. In the quark model $F/D = 2/3$ and $F+D = 5/3$, and therefore $\Delta\Sigma_p = 1$. We also gave numerical arguments in support of our approach: namely releasing the model assumptions concerning $g_A^{(0)}$ and using Γ_p as an additional input one arrives at almost identical numerical results as using Eq. (7).

It is virtually impossible to analyze the symmetry breaking in weak decays without resorting to some specific model [13]. In this paper, following Ref. [10], we will implement the symmetry breaking for the hyperon decays using the χQSM (see Ref. [14] for review) which satisfactorily describes the axial-vector properties of hyperons [15–18].

The model provides a link between the matrix elements of the octet of the axial-vector currents, responsible for hyperon decays, and the matrix elements of the singlet axial-vector current. In the present work we will study the relation between hyperon semileptonic decays and integrated polarized quark distributions for the Λ hyperon. We will use the χQSM only to identify the algebraic structure of the symmetry breaking (m_s corrections). The dynamical quantities, so called inertia parameters which are in principle calculable within the model [15], will be treated as free parameters. By adjusting them to the experimentally known semileptonic decays we allow not only for maximal phenomenological input but also for minimal model dependence. In Ref. [19,20] we have already studied the magnetic moments of the octet and decuplet in this way.

Such a "model-independent" approach — used for example by Adkins and Nappi [21] in the context of the Skyrme model — is of interest for at least two reasons. First, it can be considered as a QCD-motivated tool to analyze and classify (in terms of powers of m_s and $1/N_c$) the symmetry-breaking terms for a given observable. For nontrivial operators such as axial-vector form factors a general analysis, without referring to some specific model, is virtually impossible. Second, this "model-independent" analysis provides an information for the model builders as well. It tells us what are the best predictions the model can ever produce. Indeed, model calculations in the framework of the χQSM are not as unique as one might think: They depend on adopted regularizations, cutoff parameter, or the constituent quark mass. Moreover, in the SU(3) version of the χQSM a quantization ambiguity appears [22]. Therefore, if the "model-independent" analysis would have failed to describe the data, that would mean that the model did not correctly include all necessary physics relevant for a given observable. On the other hand, the success of such an analysis gives a strong hint for the model builders that the model is correct and worth exploring.

As far as the symmetry breaking is concerned, our results are identical to the ones obtained in Refs. [23] within QCD in the large N_c limit. Indeed, the χQSM is a specific realization of the large N_c limit. The truly new ingredient of our analysis is the model formula for the singlet axial-vector constant $g_A^{(0)}$, *i.e.* Eq. (7), which we use to calculate quantities relevant for polarized high energy experiments.

2. Hyperon decays in the Chrial Quark Soliton Model

The discussion in this section follows closely Ref. [10]. The transition matrix elements of the hadronic axial-vector current $\langle B_2|A_\mu^X|B_1\rangle$ can be expressed in terms of three independent form factors:

$$\Big\langle B_2|A_\mu^X|B_1\Big\rangle = \bar{u}_{B_2}(p_2) \times\left[\left\{ g_1^{B_1\to B_2}(q^2)\Gamma_\mu - \frac{ig_2^{B_1\to B_2}(q^2)}{M_1}\Sigma_{\mu\nu}q^\nu + \frac{g_3^{B_1\to B_2}(q^2)}{M_1}q_\mu \right\}\Gamma_5\right] u_{B_1}(p_1)\,, \tag{8}$$

where the axial-vector current is defined as

$$A_\mu^X \;=\; \bar{\psi}(x)\Gamma_\mu\Gamma_5\Lambda_X\psi(x) \tag{9}$$

with $X = \frac{1}{2}(1\pm i2)$ for strangeness conserving $\Delta S = 0$ currents and $X = \frac{1}{2}(4\pm i5)$ for $|\Delta S| = 1$. Similar expressions hold for the hadronic vector current, where the g_i are replaced by f_i ($i = 1,2,3$) and Γ_5 by $\mathbf{1}$.

Hadronic matrix elements such as $\langle B_2|A_\mu^X|B_1\rangle$ can be easily evaluated within the χQSM [14]. Taking into account the $1/N_c$ rotational and m_s corrections, we can write the resulting axial-vector constants $g_1^{B_1\to B_2}(0)$ in the following form[1]:

$$\begin{aligned} g_1^{(B_1\to B_2)} = {} & a_1\langle B_2|D^{(8)}_{X3}|B_1\rangle + a_2 d_{pq3}\langle B_2|D^{(8)}_{Xp}\,\hat{S}_q|B_1\rangle + \frac{a_3}{\sqrt{3}}\langle B_2|D^{(8)}_{X8}\hat{S}_3|B_1\rangle \\ & + m_s\left[\frac{a_4}{\sqrt{3}} d_{pq3}\langle B_2|D^{(8)}_{Xp}D^{(8)}_{8q}|B_1\rangle + a_5\langle B_2|\left(D^{(8)}_{X3}D^{(8)}_{88} + D^{(8)}_{X8}D^{(8)}_{83}\right)|B_1\rangle \right. \\ & \left. + a_6\langle B_2|\left(D^{(8)}_{X3}D^{(8)}_{88} - D^{(8)}_{X8}D^{(8)}_{83}\right)|B_1\rangle\right]. \end{aligned} \tag{10}$$

$\hat{S}_q$ ($\hat{S}_3$) stand for the q-th (third) component of the spin operator of the baryons. The $D^{(\mathcal{R})}_{ab}$ denote the SU(3) Wigner matrices in representation $\mathcal{R}$. The a_i denote parameters depending on the specific dynamics of the chiral soliton model (see for example Refs. [14, 24] and references therein). Their explicit form in terms of a Goldstone mean field can be found in Ref. [15]. As mentioned already, in the present approach we will not calculate this mean field but treat a_i as free parameters to be adjusted to experimentally known semileptonic hyperon decays.

Because of the SU(3) symmetry breaking due to the strange quark mass m_s, the collective baryon Hamiltonian is no more SU(3)-symmetric. The octet states are mixed with the higher representations such as antidecuplet $\overline{\mathbf{10}}$ and eikosiheptaplet $\mathbf{27}$ [19]. In the linear order in m_s the wave function of a state $B=(Y,I,I_3)$ of spin S_3 is given as:

$$\psi_{B,S_3} = (-)^{\frac{1}{2}-S_3}\left(\sqrt{8}\,D^{(8)}_{B\,S} + c_B^{(\overline{10})}\sqrt{10}\,D^{(\overline{10})}_{B\,S} + c_B^{(27)}\sqrt{27}\,D^{(27)}_{B\,S}\right), \tag{11}$$

where $S=(-1,\frac{1}{2},S_3)$. Mixing parameters $c_B^{(\mathcal{R})}$ can be found for example in Ref. [15]. They are given as products of a numerical constant $N_B^{(\mathcal{R})}$ depending on the quantum numbers of the baryonic state B and a dynamical parameter $c_{\mathcal{R}}$ depending linearly on m_s (which we assume to be 180 MeV) and the model parameter I_2, which is responsible for the splitting between the octet and higher exotic multiplets [11, 25].

Analogously to Eq. (10), one obtains in the χQSM diagonal axial-vector coupling constants. In that case X can take two values: $X=3$ and $X=8$. For $X=0$ (singlet axial-vector current) we have the following expression [15, 16]:

$$\tfrac{1}{2}\,g_A^{(0)}(B) = \tfrac{1}{2}a_3 + \sqrt{3}\,m_s\,(a_5-a_6)\left\langle B\middle|D^{(8)}_{83}\middle|B\right\rangle. \tag{12}$$

[1] In the following we will assume that the baryons involved have $S_3=+\frac{1}{2}$.

This equation is remarkable, since it provides a link between an octet and singlet axial-vector current. It is the most important model input in our analysis. Pure QCD-arguments based on the large N_c expansion [23] do not provide such a link. Moreover, due to the structure of the matrix element $\langle B|D^{(8)}_{83}|B\rangle$, the $g_A^{(0)}(B)$ are identical inside the isospin multiplets. We predict much stronger symmetry breaking for the Λ than for the proton, since

$$\sqrt{3}\langle p|D^{(8)}_{83}|p\rangle = -\frac{1}{10}, \quad \sqrt{3}\langle \Lambda|D^{(8)}_{83}|\Lambda\rangle = \frac{3}{10}\,, \tag{13}$$

for spin $S_3 = +1/2$.

Instead of calculating 7 dynamical parameters $a_i (i = 1,\cdots,6)$ and I_2 (which enters into $c_{\overline{10}}$ and c_{27}) within the χQSM, we shall fit them from the hyperon semileptonic decays data. It is convenient to introduce the following set of 7 new parameters:

$$\begin{aligned}
r &= \frac{1}{30}\left(a_1 - \frac{1}{2}a_2\right), \quad s = \frac{1}{60}a_3, \quad x = \frac{1}{540}m_s a_4\,, \quad y = \frac{1}{90}m_s a_5\,,\\
z &= \frac{1}{30}m_s a_6\,, \quad p = \frac{1}{6}m_s c_{\overline{10}}\left(a_1 + a_2 + \frac{1}{2}a_3\right),\\
q &= -\frac{1}{90}m_s c_{27}\left(a_1 + 2a_2 - \frac{3}{2}a_3\right).
\end{aligned}\tag{14}$$

Employing this new set of parameters, we can express all possible semi-leptonic decays of the octet baryons:

$$\begin{aligned}
A_1 &= \left(\frac{g_1}{f_1}\right)^{(n\to p)} = -14r + 2s - 44x - 20y - 4z - 4p + 8q\,,\\
A_2 &= \left(\frac{g_1}{f_1}\right)^{(\Sigma^+\to \Lambda)} = -9r - 3s - 42x - 6y - 3p + 15q\,,\\
A_3 &= \left(\frac{g_1}{f_1}\right)^{(\Lambda\to p)} = -8r + 4s + 24x - 2z + 2p - 6q\,,\\
A_4 &= \left(\frac{g_1}{f_1}\right)^{(\Sigma^-\to n)} = 4r + 8s - 4x - 4y + 2z + 4q\,,\\
A_5 &= \left(\frac{g_1}{f_1}\right)^{(\Xi^-\to \Lambda)} = -2r + 6s - 6x + 6y - 2z + 6q\,,\\
A_6 &= \left(\frac{g_1}{f_1}\right)^{(\Xi^-\to \Sigma^0)} = -14r + 2s + 22x + 10y + 2z + 2p - 4q\,.
\end{aligned}\tag{15}$$

The U(1) and SU(3) axial-vector constants $g_A^{(0,3,8)}$ can be also expressed in terms of the new set of parameters (14). In the case of the proton and the

Λ we have the singlet axial-vector constants:

$$g_A^{(0)}(p) = 60s - 18y + 6z, \quad g_A^{(0)}(\Lambda) = 60s + 54y - 18z, \tag{16}$$

for the triplet ones, we write[2]:

$$g_A^{(3)}(p) = -14r + 2s - 44x - 20y - 4z - 4p + 8q, \quad g_A^{(3)}(\Lambda) = 0, \tag{17}$$

and for the octet one, we obtain:

$$\begin{aligned} g_A^{(8)}(p) &= \sqrt{3}(-2r + 6s + 12x + 4p + 24q)\,, \\ g_A^{(8)}(\Lambda) &= \sqrt{3}(6r + 2s - 36x + 36q)\,. \end{aligned} \tag{18}$$

Let us finally note that there is certain redundancy in Eq. (15)–(18), namely by redefinition of q and x we can get rid of the variable p:

$$x' = x - \frac{1}{9}p\,, \quad q' = q - \frac{1}{9}p\,. \tag{19}$$

3. Spin content of Λ hyperon

As shown in the last section there are 6 free parameters which have to be fitted from the data. There are 2 *chiral* parameters: r and s, related closely to F and D:

$$F = 5(s - r), \quad D = -3(s + 3r). \tag{20}$$

and 4 proportional to m_s: x', y, z, and q'. Since there are six known hyperon semileptonic decays, we can express all model parameters as linear combinations of these decay constants, and subsequently all quantities of interest can be expressed in terms of the input amplitudes. In the following we will use the experimental values of Refs. [26, 27], which are presented in Table I.

Before doing this, let us, however, observe that there exist two linear combinations A_i's which within the model are free of the m_s corrections:

$$\begin{aligned} -42r + 6s &= A_1 + 2A_6\,, \\ 90r + 90s &= 3A_1 - 8A_2 - 6A_3 + 6A_4 + 6A_5\,. \end{aligned} \tag{21}$$

Solving Eq. (21) for r and s, we obtain the *chiral-limit* expressions for hyperon semileptonic decays and integrated quark densities (*i.e.* with $x' = y =$

[2] Triplet $g_A^{(3)}$'s are proportional to I_3, formulae in Eq. (17) correspond to the highest isospin state.

$z = q' = 0$). The corresponding F and D take the following form:

$$
\begin{aligned}
F &= \frac{1}{12}(4A_1 - 4A_2 - 3A_3 + 3A_4 + 3A_5 + 5A_6), \\
D &= \frac{1}{12}(4A_2 + 3A_3 - 3A_4 - 3A_5 + 3A_6).
\end{aligned} \tag{22}
$$

Numerically:

$$
F = 0.50 \pm 0.07, \quad D = 0.77 \pm 0.04. \tag{23}
$$

With these values for F and D together with Eq. (5) one gets: $\Delta u_p = 0.81$, $\Delta d_p = -0.47$ and $\Delta s_p = -0.20$, which implies $\Delta\Sigma_p = 0.15$. The advantage of using Eq. (22) consists in the fact that F and D do not need to be refitted when m_s corrections are added.

Another important point is, that Eq. (22) is more general than the model considered here. In fact they follow from the large N_c QCD, as discussed in Ref. [23]. The errors come from the experimental errors of the decay amplitudes and are dominated by the errors of the Ξ^- decays. It is of utmost importance to reduce the errors of these decays in order to get better accuracy for F and D.

In the case of the Λ Eq. (2) implies that $\Delta u_\Lambda = \Delta d_\Lambda$ and one has in the chiral limit:

$$
\begin{aligned}
\Delta u_\Lambda^{(0)} &= 3F - 2D = A_1 - \frac{5}{3}A_2 - \frac{5}{4}A_3 + \frac{5}{4}A_4 + \frac{5}{4}A_5 + \frac{3}{4}A_6\,, \\
\Delta s_\Lambda^{(0)} &= 3F - D = A_1 - \frac{4}{3}A_2 - A_3 + A_4 + A_5 + A_6\,.
\end{aligned} \tag{24}
$$

Numerical values $\Delta u_\Lambda^{(0)} = \Delta d_\Lambda^{(0)} = -0.03 \pm 0.14$ and $\Delta s_\Lambda^{(0)} = 0.74 \pm 0.17$ (see Table II) are closer to the naive quark model expectations: $\Delta u_\Lambda = \Delta d_\Lambda = 0$ and $\Delta s_\Lambda = 1$, than to the numbers quoted in Ref. [7, 8]: $\Delta u_\Lambda = \Delta d_\Lambda = -0.23 \pm 0.06$ and $\Delta s_\Lambda = 0.58 \pm 0.07$. This is reflected in the fact that

$$
\Delta\Sigma^{(0)} = 9F - 5D = 3A_1 - \frac{14}{3}A_2 - \frac{7}{2}A_3 + \frac{7}{2}A_4 + \frac{7}{2}A_5 + \frac{5}{2}A_6\,. \tag{25}
$$

(which is identical to all hadrons) reads: $\Delta\Sigma^{(0)} = 0.68 \pm 0.44$ and is much larger than the value required by using Γ_p as an additional input. Indeed, as explained in Ref. [10], in the chiral limit one is not able to reproduce the value of Γ_p (see Table II).

The two least known amplitudes A_5 and A_6 are almost entirely responsible for the errors of Δq_Λ. However, since the coefficients which enter into Eqs.(24),(25) are not too large, the absolute errors are relatively small.

TABLE II

Integrated polarized quark densities Δq and $\Delta\Sigma$ for the nucleon (Ref. [10]) and for Λ

	chiral limit	with m_s
Δu_p	0.98 ± 0.23	0.72 ± 0.07
Δd_p	-0.29 ± 0.13	-0.54 ± 0.07
Δs_p	-0.02 ± 0.09	0.33 ± 0.51
$\Delta\Sigma_p$	0.68 ± 0.44	0.51 ± 0.41
Γ_p	3.63 ± 1.12	2.67 ± 0.33
Δu_Λ	-0.03 ± 0.14	-0.02 ± 0.17
Δs_Λ	0.74 ± 0.17	1.21 ± 0.54
$\Delta\Sigma_\Lambda$	0.68 ± 0.44	1.17 ± 0.65

The full expressions are obtained by solving the remaining 4 equations for m_s dependent parameters x', y, z and q'. Also in this case we are able to link integrated quark densities Δq to the hyperon decays:

$$\begin{aligned}
\Delta u_\Lambda &= \Delta d_\Lambda = -\frac{A_2}{3} - \frac{A_3}{4} + \frac{A_4}{4} + \frac{13A_5}{4} - \frac{A_6}{4}, \\
\Delta s_\Lambda &= \frac{15\,A_1}{4} - \frac{13\,A_2}{2} - \frac{87\,A_3}{16} - \frac{21\,A_4}{16} + \frac{45\,A_5}{16} + \frac{51\,A_6}{16} \\
\Delta\Sigma_\Lambda &= \frac{15\,A_1}{4} - \frac{46A_2}{6} - \frac{95\,A_3}{16} - \frac{13\,A_4}{16} + \frac{149\,A_5}{16} + \frac{46\,A_6}{16}\,. \qquad (26)
\end{aligned}$$

To guide the eye it is convenient to restore the linear m_s dependence for the quark densities in the following way:

$$\Delta q = \Delta q^{(0)} + \frac{m_s}{180\,MeV}\left(\Delta q - \Delta q^{(0)}\right),$$

and similarly for $\Delta\Sigma$. This dependence is explicitly shown in Fig. 1, where we plot the central values and "experimental" error bars (shaded areas) of Δq_Λ's.

In Fig. 2 we plot m_s dependence of $\Delta\Sigma$ both for the proton and for the Λ. In order to make the plot readable we have denoted theoretical errors as error bars around the black dots which correspond to the chiral limit and full theoretical prediction. The splitting between the proton and the Λ is caused by the term proportional to $a_5 - a_6$ in Eq. (12). Numerical values can be found in Table II. We see that for $m_s = 180$ MeV apart from fitting all hyperon semileptonic decays (which is our input) we reproduce Γ_p with relatively small error. The errors of $\Delta\Sigma$ and Δs are much bigger. The central values, however, differ from the "standard" ones. Interestingly Δs_p in proton is rather large and positive, however, the error bars are so large that the quark model value $\Delta s_p = 0$ is not excluded. In the Λ the Δs_Λ is

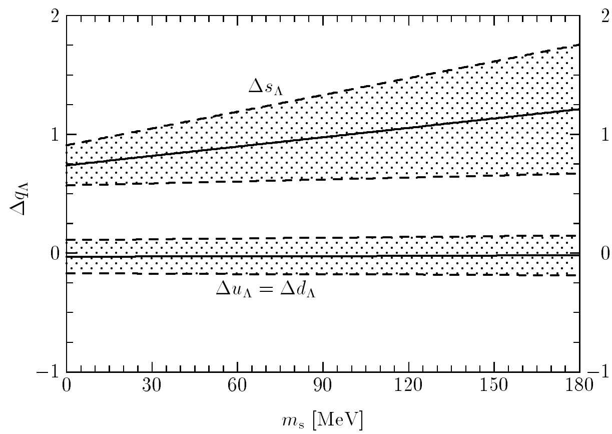

Fig. 1. Δq_Λ as functions of m_s

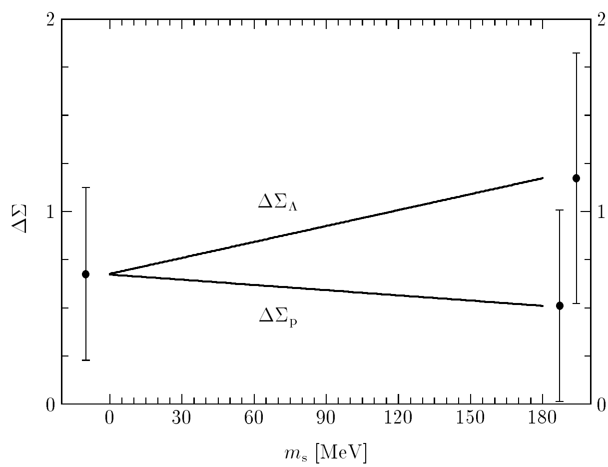

Fig. 2. $\Delta\Sigma_p$ and $\Delta\Sigma_\Lambda$ as functions of m_s

larger than 1, but again the errors are large. The errors for Δu and Δd both in the proton and in the Λ are much smaller. For the Λ we get that the non-strange quarks almost do not carry spin in surprising accordance with the expectations of the naive quark model.

As already discussed, the errors on for Δq's and $\Delta\Sigma$ come almost entirely from the large errors of the Ξ^- decays (A_5 and A_6). Instead of using these two hyperon semileptonic decays A_5 and A_6 as input, we can use the experimental value for Γ_p as given by Eq. (5) and $\Delta\Sigma_p$, which we vary in the range from 0 to 1. In Fig. 3 we plot our predictions for A_5 and A_6 (solid lines), together with the experimental error bands for these two decays. It is clearly seen from Fig. 3 that the allowed region for $\Delta\Sigma_p$, in which the theoretical prediction falls within the experimental error bars amounts to $\Delta\Sigma_p = 0.20 \div 0.45$.

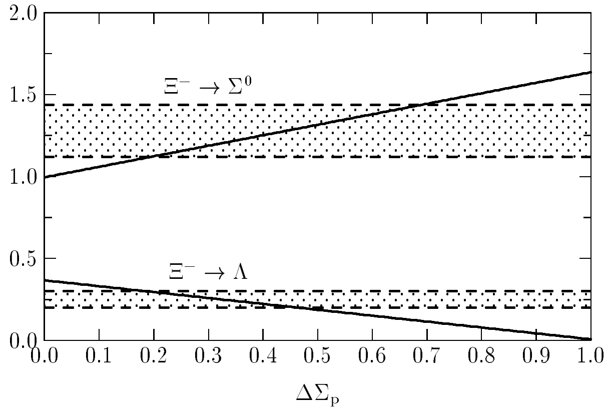

Fig. 3. A_5 (lower line) and A_6 (upper line) as functions of $\Delta\Sigma_p$.

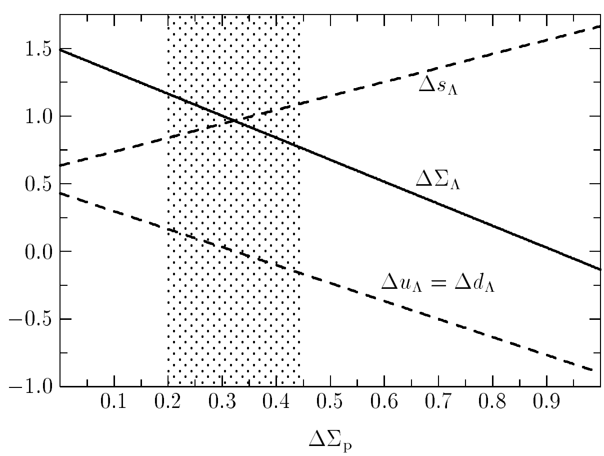

Fig. 4. Δq_Λ's and $\Delta\Sigma_\Lambda$ as functions of $\Delta\Sigma_p$.

In Fig. 4 we plot the dependence of Δq_Λ's and $\Delta\Sigma_\Lambda$ upon $\Delta\Sigma_p$ (with Γ_p fixed by Eq. (5)). We see rather strong correlation of these quantities with $\Delta\Sigma_p$. Within the allowed region $0.20 < \Delta\Sigma_p < 0.45$ the strange quark density Δs_Λ varies from 0.84 to 1.10. Interestingly, in the central region around $\Delta\Sigma_p \approx 0.35$ the strange quark density in Λ is close to 1 in accordance with an intuitive assumptions of the naive quark model. Nonstrange quarks contribute to the spin of the Lambda at the level of -0.04, and $\Delta\Sigma_\Lambda = 0.92$.

4. Summary

In this paper we studied the influence of the SU(3) symmetry breaking in hyperon semileptonic decays on the determination of the integrated polarized quark densities Δq_Λ in the Λ. Using the Chiral Quark-Soliton Model we have obtained a satisfactory parametrization of all available experimental data on semileptonic decays. In this respect our analysis is identical to QCD analysis in the large N_c of Ref. [23].

The new ingredient of our analysis consists in using the model formula for the singlet axial-vector current in order to make contact with the high energy polarization experiments.

The model contains 6 free parameters which can be fixed by 6 known hyperon decays. Unfortunately g_1/f_1 for the two known decays of Ξ^- have large experimental errors, which influence our predictions for Δq_Λ. Our strategy was very simple: using model parametrization we expressed Δq_Λ's and $\Delta \Sigma_\Lambda$ in terms of the six known hyperon decays. Errors were added in quadrature.

There are two points which have to be stressed here. Our fit respects chiral symmetry in a sense that the leading order parameters r and s (or equivalently F and D) are fitted to the linear combinations of the hyperon decays which are free from m_s corrections. As discussed in Ref. [10] it is impossible to use the SU(3) symmetric parametrization as given by Eq. (21) and reproduce Γ_p (as far as the central values are concerned) . With m_s corrections turned on one hits the experimental value for Γ_p (see Table II), however, the value of $\Delta\Sigma_p$ is practically undetermined, due the the experimental error of Ξ^- decays.

The nature of the m_s is such that the central value of $\Delta\Sigma_p$ is relatively large, whereas Δs_p is positive, however, still compatible with 0 within large errors. So one can accommodate all existing data with Δq_p much closer to the expectations of the naive quark model than in the standard, SU(3) symmetric approach. This trend is even stronger in the case of the Λ, where $\Delta u_\Lambda = \Delta d_\Lambda \approx 0$ and $\Delta s_\Lambda \approx 1$. SU(3) symmetry breaking effects cause $\Delta\Sigma_\Lambda > \Delta\Sigma_p$, so that the Λ is in a sense more nonrelativistic than the nucleon.

Our analysis shows clearly that if one wants to link hyperon semileptonic decays with high-energy polarized experiments, one cannot neglect SU(3) symmetry breaking for the former. In this respect our conclusion agrees with Refs. [12, 28]. Similarly to Ref. [28] we see that $\Delta s_p = 0$ is not ruled out by present experiments. Therefore, the commonly quoted results for Δs_Λ and $\Delta\Sigma_\Lambda$ based on assuming exact SU(3) symmetry are in our opinion premature.

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