The Isospin strange asymmetry from the chiral effective theory

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Outline

Introduction

The model
  Review of the Chiral effective Lagrangian
  The set of Diagrams
  The coupling constant and the integrals

Result and Conclusion
Introduction

- Following the model of Effective Chiral theory Ref.[1,2] this paper estimates the total amount of strange quarks-antiquarks, in the proton and in the neutron.
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- Following the model of Effective Chiral theory Ref.[1,2] this paper estimates the total amount of strange quarks-antiquarks, in the proton and in the neutron.
- Due to the small mass difference involved, mainly among the kaons and hyperons, it is obtained an asymmetry in these quantities; that is, an isospin strange asymmetry.
In this section, we review the model presented in Ref. [2], where the chiral effective theory is used to obtain the strange quark asymmetry in the proton.
Introduction

The model
- Review of the Chiral effective Lagrangian
- The set of Diagrams
- The coupling constant and the integrals

Result and Conclusion
Some review of SU(3) theory is needed to explain and justify the basic features of the model
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The Lagrangian has the SU(3) symmetry:

\[
L = -D_{\mu}^2 \bar{B} \gamma^\mu \gamma^5 \{u_\mu, B\} - F_{\mu}^2 \bar{B} \gamma^\mu \gamma^5 + i \bar{B} \gamma^\mu [D_{\mu}, B],
\]

where

\[
u_\mu = i (\nu^\dagger \partial_\mu \nu - \nu \partial_\mu \nu^\dagger),
\]

and the operator \(u\) is given in terms of the pseudoscalar fields by

\[
u = \exp (i \varphi \sqrt{2} f \varphi).
\]
Review of the Chiral effective Lagrangian

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- The Lagrangian has the SU(3) symmetry:

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where

\[ u^\mu = i(\bar{u} \partial_\mu u - u \partial_\mu \bar{u}). \quad (2) \]
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(1)

where

\[ u_\mu = i \left( u^{\dagger} \partial_\mu u - u \partial_\mu u^{\dagger} \right) , \]  

(2)

and the operator \( u \) is given in terms of the pseudoscalar fields by

\[ u = \exp \left( \frac{i \phi}{\sqrt{2} f_\phi} \right) \]  

(3)
with $f_\phi$ the pseudoscalar decay constant. The covariant derivative $D^\mu$ is defined

\[ [D^\mu, B] = \partial_\mu B + [\Gamma_\mu, B] \] (4)

and $\Gamma_\mu$ is the link operator,

\[ \Gamma_\mu = \frac{1}{2} \left[ u^\dagger, \partial_\mu u \right] . \] (5)

$D$ and $F$ are constants.
Review of the Chiral effective Lagrangian

The matrix form for the pseudoscalar field $\phi$ is given by:

$$
\phi = \sum_{a=1}^{8} \frac{\lambda_a}{\sqrt{2}} \phi_a
$$

$$
= \begin{pmatrix}
\frac{1}{\sqrt{2}} \pi^0 + \frac{1}{\sqrt{6}} \eta & \pi^+ & K^+ \\
\pi^- & -\frac{1}{\sqrt{2}} \pi^0 + \frac{1}{\sqrt{6}} \eta & K^0 \\
K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}} \eta \\
\end{pmatrix}
$$

(6)

where $\lambda_a$ are the SU(3) Gell-Mann matrices and the fields $\phi_a$ are given by $\phi_1 = (\pi^+ + \pi^-)/\sqrt{2}, \phi_2 = i(\pi^+ - \pi^-)/\sqrt{2}, \phi_3 = \pi^0, \phi_4 = (K^+ + K^-)/\sqrt{2}, \phi_5 = i(K^+ - K^-)/\sqrt{2}, \phi_6 = (K^0 + \bar{K}^0)/\sqrt{2}, \phi_7 = i(K^0 - \bar{K}^0)/\sqrt{2},$ and $\phi_8 = \eta.$
The octet baryon field $B$ can be expressed in terms of the nucleon, the strangeness -1 hyperons $\Sigma$ and $\Lambda$, and the strangeness -2 hyperon $\Xi$ fields as

$$B = \sum_{a=1}^{8} \frac{\lambda_a}{\sqrt{2}} B_a$$

$$= \begin{pmatrix}
\frac{1}{\sqrt{2}} \Sigma^0 + \frac{1}{\sqrt{6}} \Lambda \\
\Sigma^- \\
\Xi^- \\
\Xi^0 \\
p \\
n \\
-\frac{2}{\sqrt{6}} \Lambda
\end{pmatrix}$$

where the individual baryon fields $B_a$ are $B_1 = (\Sigma^+ + \Sigma^-)/\sqrt{2}$, $B_2 = (\Sigma^+ - \Sigma^-)/\sqrt{2}$, $B_3 = \Sigma^0$, $B_4 = (p + \Xi^-)/\sqrt{2}$, $B_5 = i(p - \Xi^-)/\sqrt{2}$, $B_6 = (n + \Xi^0)/\sqrt{2}$, $B_7 = i(n - \Xi^0)/\sqrt{2}$, and $B_8 = \Lambda$. 

\[ (7) \]
Review of the Chiral effective Lagrangian

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\[
\mathcal{L}_{\phi BB} = \frac{1}{2f_\phi} \left\{ (D + F) \left[ \bar{p} \gamma^\mu \gamma^5 p \partial_\mu \pi^0 - \bar{n} \gamma^\mu \gamma^5 n \partial_\mu \pi^0 + \sqrt{2} \right.ight.
\]
\[
\left. \left( \bar{n} \gamma^\mu \gamma^5 p \partial_\mu \pi^- + \bar{p} \gamma^\mu \gamma^5 n \partial_\mu \pi^+ \right) \right] + (D - F) \left[ \bar{\Sigma}^0 \gamma^\mu \gamma^5 p \partial_\mu K^- + \bar{p} \gamma^\mu \gamma^5 \Sigma^0 \partial_\mu K^+ + \sqrt{2} \left( \bar{\Sigma}^+ \gamma^\mu \gamma^5 p \partial_\mu \bar{K}^0 + \bar{p} \gamma^\mu \gamma^5 \Sigma^+ \partial_\mu K^0 \right) \right]
\]
\[
\left. - (D - F) \left[ \bar{\Sigma}^- \gamma^\mu \gamma^5 n \partial_\mu K^- + \bar{n} \gamma^\mu \gamma^5 \Sigma^- \partial_\mu K^+ \right] \right] - \frac{1}{\sqrt{3}} (D + 3F) \left[ \bar{\Lambda} \gamma^\mu \gamma^5 p \partial_\mu K^- + \bar{p} \gamma^\mu \gamma^5 \Lambda \partial_\mu K^+ + \bar{\Lambda} \gamma^\mu \gamma^5 n \partial_\mu \bar{K}^0 + \bar{n} \gamma^\mu \gamma^5 \Lambda \partial_\mu K^0 \right] - \frac{1}{\sqrt{3}} (D - 3F) \left[ \bar{p} \gamma^\mu \lambda_5 p \partial_\mu \eta + \bar{n} \gamma^\mu \gamma^5 n \partial_\mu \eta \right] \right\}. \quad (8)
\]
Review of the Chiral effective Lagrangian

- The second term is a Weinberg-Tomozowa term, $\mathcal{L}_{\phi \phi BB}$, in which pseudoscalar mesons couple to the Baryon at same point.

\[
\mathcal{L}_{\phi \phi BB} = \frac{i}{2} f_{\phi} \left\{ \bar{p} \gamma^\mu p \left[ \pi + \partial^\mu \pi - \pi - \partial^\mu \pi + 2 \left( K + \partial^\mu K - K - \partial^\mu K \right) \right] + \bar{n} \gamma^\mu n \left[ p - \partial^\mu \pi + \pi + \partial^\mu \pi - K + \partial^\mu K - K - \partial^\mu K \right] \right\}.
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Result and Conclusion
The set of Diagrams

- The chiral SU(3) Lagrangian is expanded to the lowest order.
The set of Diagrams

The chiral SU(3) Lagrangian is expanded to the lowest order.
This leads to diagrams with hadron-meson fluctuations

Figure: Loop contributions to the $\bar{s}$ PDF from the (a) kaon rainbow and (b) kaon bubble diagrams, and to the s-quark PDF from (c) hyperon rainbow, (d) tadpole, and (e) and(f) Kroll- Ruderman diagrams. Nucleons $N$ and hyperons $Y = \Lambda; \Sigma$ are denoted by external and internal solid lines, respectively, and kaons $K$ by dashed lines, with crosses representing insertions of the vector current.
The set of Diagrams

▶ The rainbow Fig. 1(a) and the bubble diagrams can be written in the form of convolutions of the nucleon $\rightarrow$ hyperon + kaon splitting function and the $\bar{s}$ PDF in the Kaon:

\[
\bar{s}(x) = \left( \sum_{KY} f_{rbw}^{KY} \right) \otimes \bar{s}_K.
\] (10)

▶ The convolution integral in eq.(10) is defined as:

\[
(f \otimes q)(x) = \int_0^1 dy \int_0^1 \delta(x-yz) f(y) q(z) \, dz.
\] (11)

▶ This is the usual expression for the calculations of the chiral loop corrections in meson cloud models.
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Without consider isospin symmetry violating effects, the antistrange PDFs in the kaon is given by

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\bar{s}_K = \bar{s}_0 + \bar{K} = \bar{s}_0 K,
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The present work uses the recent fit by from Aicher et al. ([?]) to the PDF of valence quarks in the meson:

\[ q_v(x) = N \cdot x^{(\alpha-1)} \cdot (1 - x)^\beta \cdot (1 + \gamma \cdot x^\delta) \]  \hspace{1cm} (14)

\( \alpha = 0.7, \beta = 2.03, \gamma = 13.8, \delta = 2.0 \) and \( N = 2.8168435 \), used to fit data at 4 GeV.
The set of Diagrams

The splitting function $f_{K_Y}^{rbw}$ is the sum of two terms,

$$f_{K_Y}^{rbw} = \frac{C_{K_Y}^2 \tilde{M}^2}{(4\pi f_K)^2} \left[ f_Y^{on}(y) + f_K^{\delta}(y) \right], \quad (15)$$

where $f_Y^{on}$ and $f_K^{\delta}$ are the on-shell and $\delta$-function contributions, $M$ is the nucleon mass, $M_Y$ is the hyperon mass and $\tilde{M} = M + M_Y$ and $f_K = 113$ MeV is the kaon decay constant.
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The coupling constant and the integrals

- The couplings $C_{KY}$ defines the strength of the NKY interaction

For the proton fluctuations

\[ C_{K0} + \Lambda = D + 3F^2 \sqrt{3}, \quad (16) \]

and

\[ C_{K+} + \Sigma = \sqrt{2} C_{K0} + \Sigma = D - F \sqrt{2}, \quad (17) \]

For the neutron, the coupling constants are

\[ C_{K0} \Lambda = D + 3F^2 \sqrt{3}, \quad (18) \]

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\[ C_{K+} - \Sigma = \sqrt{2} C_{K0} - \Sigma = D - F \sqrt{2}. \quad (19) \]
The coupling constant and the integrals

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\[ C_{K+\Lambda} = \frac{D + 3F}{2\sqrt{3}}, \quad (16) \]

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The coupling constant and the integrals

From Ref. [?], we can fix the parameters $F = 0.464$ and $D = 0.806$ by sum rules:

$$a_3 = g_A = F + D = 1.269 \pm 0.003$$

$$a_8 = 3F + D = 0.585 \pm 0.025 \quad (20)$$

where $a_3$ and $a_8$ are related to the polarized structure functions
The coupling constant and the integrals

- The on shell hyperon piece,

\[ f_{\text{on}}(Y) = Y \int \text{dk}^2 \perp k^2 + \left[ M_Y - (1 - Y)M \right]^2 \left( 1 - Y \right)^2 + D^2_{KY} F_{\text{on}}(21) \]

contributes at \( y > 0 \).

\[ D_{KY} = k^2 - m^2_K = - \left[ k^2 \perp + yM^2 \right] + (1 - y)m^2_K - y(1 - y)M^2 \] \( (22) \)

\[ F_{\text{on}} \] is the kaon virtuality for an on-shell hyperon intermediate state, given by

\[ F_{\text{on}} = 1 - D^2_{KY} D^2_{\mu} (23) \]

where \( \mu \) is a cutoff mass.
The coupling constant and the integrals

The on shell hyperon piece,

\[
f_Y^{(on)}(y) = y \int dk_\perp^2 \frac{k_\perp^2 + [M_y - (1 - y)M]^2}{(1 - y)^2 + D_{KY}^2} F^{(on)} \tag{21}
\]

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The coupling constant and the integrals

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\[ (1 - y)^2 \]  

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The coupling constant and the integrals

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- \( F^{(on)} \) is a regulating function that regularizes the ultraviolet divergence of the \( k_\perp^2 \) integration.
The coupling constant and the integrals

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- \( F^{(on)} \) is a regulating function that regularizes the ultraviolet divergence of the \( k_\perp^2 \) integration.
- By considering the Pauli-Villars regularization method, \( F^{(on)} \) is equivalent to

\[ F^{(on)} = 1 - \frac{D_{KY}^2}{D_\mu^2} \]  \hspace{1cm} (23)
The coupling constant and the integrals

- The $f^K_\delta$ arises from kaons with zero light-cone momentum,
The coupling constant and the integrals

- The $f_K^\delta$ arises from kaons with zero light-cone momentum,

$$f_K^\delta(y) = \frac{1}{\bar{M}^2} \int dk^2_{\perp} \log \Omega_K \delta(y) F^\delta,$$

where

$$\Omega_K = k^2_{\perp} + m^2_K$$

- $F^{(\delta)}$ is the corresponding regulating function.
The coupling constant and the integrals

- The $f_K^\delta$ arises from kaons with zero light-cone momentum,

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- By applying the Pauli-Villars regularization method twice: 
The coupling constant and the integrals

- The $f_\delta^K$ arises from kaons with zero light-cone momentum,

$$f_\delta^K(y) = \frac{1}{M^2} \int dk^2_\perp \log \Omega_K \delta(y) F_\delta,$$  \hspace{1cm} (24)

where

$$\Omega_K = k^2_\perp + m^2_K$$ \hspace{1cm} (25)

- $F^{(\delta)}$ is the corresponding regulating function.

- By applying the Pauli-Villars regularization method twice:

$$F^{(\delta)} = 1 - \frac{a_1 \log(\Omega_{\mu_1}) + a_2 \log(\Omega_{\mu_2})}{\log(\Omega_K)},$$ \hspace{1cm} (26)

where $\mu_1$ and $\mu_2$ are cutoff mass and
The coupling constant and the integrals

- The $f^\delta_K$ arises from kaons with zero light-cone momentum,

\[ f^\delta_K(y) = \frac{1}{M^2} \int dk^2_\perp \log \Omega_K \delta(y) F^\delta, \quad (24) \]

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\[ \Omega_{\mu_i} = k^2_\perp + \mu_i^2. \quad (27) \]
The coupling constant and the integrals

- The constants $a_1$ and $a_2$ are calculated as follows:

\[
\begin{align*}
    a_1 &= \mu_2^2 - m_2 K \mu_1^2 - \mu_1, \\
    a_2 &= -\mu_1 - m_2 K \mu_1^2 - \mu_1.
\end{align*}
\]

(28)

Refs. [2,3] gives the following values for $\mu = \mu_1 = 545$ MeV and $\mu_2 = 600$ MeV. With the experimental uncertainty, considering two standard deviations, we may take $\mu = 526$ MeV and $\mu_2 = 894$ MeV.

The bubble diagram fig (1b) contributes to $\bar{s}$ amount Ref[2,3]f (bub)$K + = 2 f (bub)$K_0 = - \bar{M}_2 \left( \frac{4 \pi}{f K} \right)^2 f (\delta K)$.

(29)
The coupling constant and the integrals

The constants $a_1$ and $a_2$ are calculated as follows:

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- The bubble diagram fig (1b) contributes to $\bar{s}$ amount Ref[2,3]

\[
f_{K^+}^{(bub)} = 2f_{K^0}^{(bub)} = -\frac{\bar{M}^2}{(4\pi f_K)^2} f_{K}^{(\delta)}.
\] (29)
The main point of this work is to calculate the difference in the amount of strange quarks of the proton to the neutron, through the effective chiral theory.
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- The main point of this work is to calculate the difference in the amount of strange quarks of the proton to the neutron, through the effective chiral theory.
- To this end, it is interesting to recall the mass of the Kaons and the hyperons involved.
- The electromagnetic interaction are one of the reasons of this difference.
The coupling constant and the integrals

The total mass (in MeV) for each fluctuation is given below:

\[ p \rightarrow \Sigma^+ K^0 : 1189.4 + 497.6 = 1687.0 \]
\[ p \rightarrow \Sigma^0 K^+ : 1192.6 + 493.7 = 1686.6 \]
\[ p \rightarrow \Lambda K^+ : 1115.7 + 493.7 = 1609.4 \]
\[ n \rightarrow \Lambda^0 K^0 : 1115.7 + 497.6 = 1613.3 \]
\[ n \rightarrow \Sigma^0 K^0 : 1192.6 + 497.6 = 1690.2 \]
\[ n \rightarrow \Sigma^- K^+ : 1197.4 + 493.7 = 1691.1 \]
The amounts $S_p$ and $S_n$ are given in table I; for the case $\mu = 545$ MeV and $\mu_2 = 600$ MeV.

Coupling constants with different values for D and F and the resulting strange asymmetry. The regularization parameters are $\mu = 545$ MeV and $\mu_2 = 600$ MeV.

<table>
<thead>
<tr>
<th>$C_{KY}$</th>
<th>$C_{K^+\Lambda} = C_{K^0\Lambda}$</th>
<th>$D=0.806;F=0.464$</th>
<th>$D=0.80;F=0.46$</th>
<th>$D=0.83;F=0.46$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.635</td>
<td>0.629</td>
<td>0.612</td>
<td></td>
</tr>
<tr>
<td>$C_{K^0\Sigma^+} = C_{K^+\Sigma^-}$</td>
<td>0.242</td>
<td>0.240</td>
<td>0.283</td>
<td></td>
</tr>
<tr>
<td>$C_{K^+\Sigma^0} = C_{K^0\Sigma^0}$</td>
<td>0.171</td>
<td>0.170</td>
<td>0.200</td>
<td></td>
</tr>
<tr>
<td>$2 \int_0^1 \bar{s}_p(x) dx$</td>
<td>0.1025</td>
<td>0.1009</td>
<td>0.1028</td>
<td></td>
</tr>
<tr>
<td>$2 \int_0^1 \bar{s}_n(x) dx$</td>
<td>0.0954</td>
<td>0.0939</td>
<td>0.0962</td>
<td></td>
</tr>
<tr>
<td>$\text{dif}S$</td>
<td>0.0071</td>
<td>0.0070</td>
<td>0.0066</td>
<td></td>
</tr>
</tbody>
</table>
The resulting strange asymmetry with regularization parameters $\mu = 526$ MeV and $\mu_2 = 894$ MeV. The coupling constants are the same of table I.

<table>
<thead>
<tr>
<th>Strange</th>
<th>2 $\int_0^1 \bar{s}_p(x)dx$</th>
<th>2 $\int_0^1 \bar{s}_n(x)dx$</th>
<th>difS</th>
</tr>
</thead>
<tbody>
<tr>
<td>D=0.806;F=0.464</td>
<td>0.0651</td>
<td>0.0581</td>
<td>0.007</td>
</tr>
<tr>
<td>D=0.80;F=0.46</td>
<td>0.0641</td>
<td>0.0572</td>
<td>0.0069</td>
</tr>
<tr>
<td>D=0.83;F=0.43</td>
<td>0.0653</td>
<td>0.0587</td>
<td>0.0065</td>
</tr>
</tbody>
</table>
Summary

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- Thanks.


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