The Isospin strange asymmetry from the chiral effective theory

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Outline

Introduction

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- 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.

The Model

- 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.

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$$\mathcal{L} = -\frac{D}{2}\bar{B}\gamma_\mu\gamma_5\left\{u^\mu, B\right\} - \frac{F}{2}\bar{B}\gamma_\mu\gamma_5 + i\bar{B}\gamma_\mu\left[D^\mu, B\right], \qquad (1)$$

where

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where

$$u_\mu = i\left(u^\dagger\partial_\mu u - u\partial_\mu u^\dagger\right), \tag{2}$$

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

$$u = \exp\left(\frac{i\phi}{\sqrt{2}f_\phi}\right) \tag{3}$$

Review of the Chiral effective Lagrangian

with f_ϕ the pseudoscalar decay constant. The covariant derivative D^μ is defined

$$[D^\mu, B] = \partial_\mu B + [\Gamma_\mu, B] \tag{4}$$

and Γ_μ is the link operator,

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

D and F are constants.

Review of the Chiral effective Lagrangian

- The matrix form for the pseudoscalar field ϕ is given by:

$$\begin{aligned}\phi &= \sum_{a=1}^{8} \frac{\lambda_a}{\sqrt{2}} \phi_a \\ &= \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}\end{aligned} \tag{6}$$

where λ_a are the SU(3) Gell-Mann matrices and the fields ϕ_a are given by $\phi_1 = (\pi^+ + \pi^-)/\sqrt{2}$,$\phi_2 = i(\pi^+ - \pi^-)/\sqrt{2}$, $\phi_3 = \pi^0$, $\phi_4 = (K^+ + K^-)/\sqrt{2}$,$\phi_5 = i(K^+ - K^-)/\sqrt{2}$, $\phi_6 = (K^0 + \overline{K^0})/\sqrt{2}$,$\phi_7 = i(K^0 - \overline{K^0}/\sqrt{2}$, and $\phi_8 = \eta$.

Review of the Chiral effective Lagrangian

- The octet baryon field B can be expressed in terms of the nucleon, the strangeness -1 hyperons Σ and Λ, and the strangeness -2 hyperon Ξ fields as

$$
\begin{aligned}
B &= \Sigma_{a=1}^{8} \frac{\lambda_a}{\sqrt{2}} B_a \\
&= \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}
\end{aligned} \tag{7}
$$

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 $B_8 = \Lambda$.

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$$\mathcal{L}_{\phi BB} = \frac{1}{2f_\phi}\Big\{(D+F)\big[\bar{p}\gamma^\mu\gamma^5 p\partial_\mu\pi^0 - \bar{n}\gamma^\mu\gamma_5 n\partial_\mu\pi^0 + \sqrt{2}$$
$$\big(\bar{n}\gamma^\mu\gamma_5 p\partial_\mu\pi^- + \bar{p}\gamma^\mu\gamma_5 n\partial_\mu\pi^+\big)\big] + (D-F)\big[\bar{\Sigma}^0\gamma^\mu\gamma_5 p\partial_\mu K^-$$
$$+\bar{p}\gamma^\mu\gamma_5\Sigma^0\partial_\mu K^+ + \sqrt{2}\big(\bar{\Sigma}^+\gamma^\mu\gamma_5 p\partial_\mu\bar{K}^0 + \bar{p}\gamma^\mu\gamma_5\Sigma^+\partial_\mu K^0\big)\big]$$
$$-(D-F)\big[\bar{\Sigma}^0\gamma^\mu\gamma_5 n\partial_\mu K^0 + \bar{n}\gamma^\mu\gamma_5\Sigma^0\partial_\mu K^0 - \sqrt{2}$$
$$\big(\bar{\Sigma}^-\gamma^\mu\gamma_5 n\partial_\mu K^- + \bar{n}\gamma^\mu\gamma_5\Sigma^-\partial_\mu K^+\big)\big] - \frac{1}{\sqrt{3}}(D+3F)\big[$$
$$\bar{\Lambda}\gamma^\mu\gamma_5 p\partial_\mu K^- + \bar{p}\gamma^\mu\gamma_5\Lambda\partial_\mu K^+ + \bar{\Lambda}\gamma^\mu\gamma_5 n\partial_\mu\bar{K}^0 +$$
$$\bar{n}\gamma^\mu\gamma_5\Lambda\partial_\mu K^0\big] - \frac{1}{\sqrt{3}}(D-3F)\big[\bar{p}\gamma^\mu\lambda_5 p\partial_\mu\eta + \bar{n}\gamma^\mu\gamma_5 n\partial_\mu\eta\big]\Big\}. \quad (8)$$

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$$\mathcal{L}_{\phi\phi BB} = \frac{i}{2f_\phi}\Big\{\bar{p}\gamma^\mu p\big[\pi^+\partial_\mu\pi^- - \pi^-\partial_\mu\pi^+ + 2\big(K^+\partial_\mu K^- - K^-\partial_\mu K^+\big) + K^0\partial_\mu\bar{K}^0 - \bar{K}^0\partial_\mu K^0\big] + \bar{n}\gamma^\mu n\big[p^-\partial_\mu\pi^+ - \pi^+\partial_\mu\pi^- + K^+\partial_\mu K^- - K^-\partial_\mu K^+ + 2\big(K^0\partial_\mu\bar{K}^0 - \bar{K}^0\partial_\mu K^0\big)\big]\bar{p}\gamma^\mu n\big[\sqrt{2}\big(\pi^0\partial_\mu\pi^+ - \pi^+\partial_\mu\pi^0\big) + K^+\partial_\mu\bar{K}^0 - \bar{K}^0\partial_\mu K^+\big] + \bar{n}\gamma^\mu p\big[\sqrt{2}\big(\pi^-\partial_\mu\pi^0 - \pi^0\partial_\mu\pi^-\big) + K^0\partial_\mu K^- - K^-\partial_\mu K^0\big]\Big\}. \tag{9}$$

The set of Diagrams

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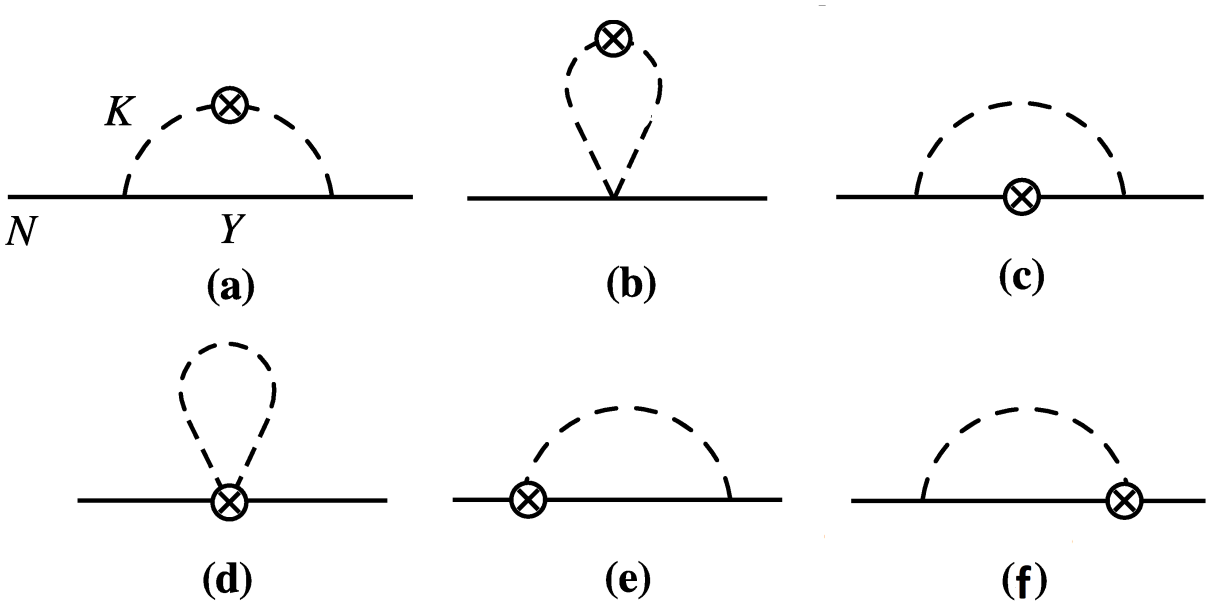

Figure: Loop contributions to the $\bar{s}$ PDF from the (a) kaon rainbow and (b) kaon bubble diagrams, and to the s-quark PDF from (c) hyperon rainbow, (d) tadpole, and (e) and(f) Kroll- Ruderman diagrams. Nucleons N and hyperons $Y = \Lambda; \Sigma$ are denoted by external and internal solid lines,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

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$$\bar{s}(x) = \left(\sum_{KY} f_{KY}^{rbw} + \sum_{K} f_{K}^{bub} \right) \otimes \bar{s}_K. \tag{10}$$

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$$(f \otimes q)(x) = \int_0^1 dy \int_0^1 \delta(x - yz) f(y) q(z) dz. \tag{11}$$

- This is the usual expression for the calculations of the chiral loop corrections in meson cloud models.

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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:

$$q_v(x) = N \cdot x^{(\alpha-1)} \cdot (1-x)^{\beta} \cdot (1+\gamma \cdot x^{\delta}) \tag{14}$$

, where $\alpha = 0.7$,$\beta = 2.03$,$\gamma = 13.8$,$\delta = 2.0$ and $N = 2.8168435$, used to fit data at 4 GeV.

The set of Diagrams

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

$$f_{KY}^{rbw} = \frac{C_{KY}^2 \bar{M}^2}{(4\pi f_K)^2} \left[f_y^{on}(y) + f_K^{\delta}(y) \right], \tag{15}$$

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

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- For the proton fluctuations

$$C_{K^+\Lambda} = \frac{D + 3F}{2\sqrt{3}}, \tag{16}$$

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- For the neutron, the coupling constants are

$$C_{K^0\Lambda} = \frac{D+3F}{2\sqrt{3}}, \tag{18}$$

and

$$C_{K^+\Sigma^-} = \sqrt{2}C_{K^0\Sigma^0} = \frac{D-F}{\sqrt{2}}. \tag{19}$$

The coupling constant and the integrals

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

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

$$a_8 = 3F + D = 0.585 \pm 0.025 \tag{20}$$

where a_3 and a_8 are related to the polarized structure functions

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- By considering the Pauli-Villars regularization method, $F^{(on)}$ is equivalent to

$$F^{(on)} = 1 - \frac{D_{KY}^2}{D_\mu^2} \tag{23}$$

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- 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.

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$$f_{K^+}^{(bub)} = 2 f_{K^0}^{(bub)} = -\frac{\bar{M}^2}{(4\pi f_K)^2} f_K^{(\delta)}. \tag{29}$$

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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 eletromagnetic 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:

$$p \to \Sigma^+ K^0 : 1189.4 + 497.6 = 1687.0$$

$$p \to \Sigma^0 K^+ : 1192.6 + 493.7 = 1686.6$$

$$p \to \Lambda K^+ : 1115.7 + 493.7 = 1609.4$$

$$n \to \Lambda^0 K^0 : 1115.7 + 497.6 = 1613.3$$

$$n \to \Sigma^0 K^0 : 1192.6 + 497.6 = 1690.2$$

$$n \to \Sigma^- K^+ : 1197.4 + 493.7 = 1691.1$$

Result and Conclusion

The amounts $\mathrm{S_p}$ and $\mathrm{S_n}$ 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.

C_{KY}	D=0.806;F=0.464	D=0.80;F=0.46	D=0.83;F=0.4
$C_{K^+\Lambda} = C_{K^0\Lambda}$	0.635	0.629	0.612
$C_{K^0\Sigma^+} = C_{K^+\Sigma^-}$	0.242	0.240	0.283
$C_{K^+\Sigma^0} = C_{K^0\Sigma^0}$	0.171	0.170	0.200
$2\int_0^1 \bar{s}_p(x)dx$	0.1025	0.1009	0.1028
$2\int_0^1 \bar{s}_n(x)dx$	0.0954	0.0939	0.0962
difS	0.0071	0.0070	0.0066

Result and Conclusion

The resulting strange asymmetry with regularization parameters $\mu = 526$ MeV and $\mu_2 = 894$ MeV. The coupling constants are the same of table I.

strange	D=0.806;F=0.464	D=0.80;F=0.46	D=0.83;F=0.43
$2\int_0^1 \bar{s}_p(x)dx$	0.0651	0.0641	0.0653
$2\int_0^1 \bar{s}_n(x)dx$	0.0581	0.0572	0.0587
difS	0.007	0.0069	0.0065

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