Hyperon-nucleon interaction and baryonic contact terms in
SU(3) chiral effective field theory

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In this proceeding we summarize results for baryonic contact terms derived
within SU(3) chiral effective field theory. The four-baryon contact terms, nec-
essary for the description of the hyperon-nucleon interaction, include SU(3)
symmetric and explicit chiral symmetry breaking terms. They also include four-
baryon contact terms involving pseudoscalar mesons, which become important
for three-body forces. Furthermore we derive the leading order six-baryon con-
tact terms in the non-relativistic limit and study their contribution to the ΛNN
three-body contact interaction. These results could play an important role in
studies of hypernuclei or hyperons in nuclear matter.

Keywords: SU(3) chiral effective field theory, two- and three-baryon forces

1. Introduction

The nuclear forces are very well described within the framework of SU(2)
chiral effective field theory.1–3 Therefore it is natural to extend this scheme
to the strangeness sector and use SU(3) chiral effective field theory to de-
scribe the interaction between baryons, as has been done in a recent calcu-
lation of the hyperon-nucleon interaction at next-to-leading order.4 There
the unresolved short-distance dynamics is encoded in four-baryon contact
terms with a priori unknown low-energy constants. These contact terms
are constructed according to the symmetries of QCD.

It is not only interesting to understand baryon-baryon scattering itself,
but these interactions are also input for studies of hypernuclei and hyperons
in nuclear matter, such as exotic neutron star matter. Especially for the few-
and many-body calculations, not only two-baryon interactions, but also
three-baryon interactions will play an important role.5–7 To support the
recently observed two-solar-mass neutron stars,8,9 a very stiff equation of
state and therefore a repulsive hyperon-nucleon force is needed. In order to
achieve enough repulsion, it might be necessary to include hyperon-nucleon
nucleon three-body forces as well. As a first step the leading three-baryon
contact forces have been derived and classified within SU(3) chiral effective
field theory.

2. Four-baryon contact terms

Considering the baryon-baryon interaction, at leading order one has non-
derivative four-baryon contact terms and at next-to-leading order four-
baryon contact terms with two derivatives (Fig. 1), both SU(3) symmetric.
Additionally, at next-to-leading order pure baryon-baryon contact terms
proportional to quark masses arise and lead to explicit SU(3) symmetry
breaking. Furthermore, at next-to-leading order occur four-baryon contact
terms involving one or more pseudoscalar mesons and/or external elec-
troweak fields, cf. Fig. 1. These come into play in the description of chiral
many-body forces and currents relevant for few-baryon systems.

By employing the external fields method,\textsuperscript{10,11} we have constructed a
complete set of terms for the covariant chiral baryon-baryon contact La-
grangian in flavor SU(3) up to order $\mathcal{O}(q^2)$,\textsuperscript{12} which provides the above
mentioned contact terms. The constructed terms are invariant under charge
conjugation, parity transformation, time reversal, Hermitian conjugation
and local chiral transformations and include Goldstone bosons as well as
external fields. In the case of pure baryon-baryon interaction one obtains a
minimal set of 40 terms in the chiral contact Lagrangian up to $\mathcal{O}(q^2)$. After
a non-relativistic reduction and a decomposition into partial waves, 28 of
these contact terms lead to SU(3) symmetric contributions to the potentials
for the channels $^1S_0$, $^3S_1$, $^1P_1$, $^3P_0$, $^3P_1$, $^3P_2$, $^3D_1 \leftrightarrow ^3S_1$ and $^1P_1 \leftrightarrow ^3P_1$. Only one specific term leads to an antisymmetric spin-orbit interaction and
therefore a spin singlet-triplet mixing. Such transitions are not possible in
the $NN$ interaction without SU(2) symmetry breaking. The remaining 12
low-energy constants contribute to the $^1S_0$ and $^3S_1$ partial waves and lead
to SU(3) symmetry breaking contributions linear in the quark masses.
3. Six-baryon contact terms

To describe the effect of three-body forces the full set of the leading three-baryon interactions with a minimal number of low-energy constants, consistent with the symmetries of QCD, is needed. In contrast to phenomenological approaches,\textsuperscript{5,6} we want to construct these three-baryon forces within the framework of SU(3) chiral effective field theory (following the construction of the chiral nuclear forces\textsuperscript{1}). We start this construction by deriving the short-range contact contribution in SU(3) chiral effective field theory in Fig. 2.

The construction of the chiral Lagrangian works analogously to the construction of the four-baryon contact terms. The (approximate) symmetries of QCD have to be fulfilled namely charge conjugation, parity transformation, time reversal, Hermitian conjugation and chiral symmetry. For the construction of the potential it is also important to include the Pauli exclusion principle, since one starts with an overcomplete set of terms in the Lagrangian and wants to obtain the minimal number of low-energy constants. This can be achieved by an antisymmetrization in both the initial and the final state. The Pauli principle is not as restrictive as for the three-nucleon contact interaction, where one ends up with only one low-energy constant, but it is still relevant.

After constructing the pertinent terms in the chiral Lagrangian and performing a non-relativistic reduction, the leading potentials can be expressed through the following operators in spin space

\[ 1, \quad \vec{\sigma}_1 \cdot \vec{\sigma}_2, \quad \vec{\sigma}_1 \cdot \vec{\sigma}_3, \quad \vec{\sigma}_2 \cdot \vec{\sigma}_3, \quad i \vec{\sigma}_1 \times \vec{\sigma}_2 \cdot \vec{\sigma}_3. \]

For each three-baryon channel the prefactors of these spin operators are a combination of SU(3) coefficients and low-energy constants.

As a result we have obtained that the symmetry constraints lead to 18 low-energy constants for the three-baryon contact force. Table 1 gives the number of additional constants that are introduced with increasing strangeness of the three-baryon system. As an explicit example we give the
Table 1. Results for the low-energy constants of the leading three-baryon contact terms.

| strangeness | transitions between | # constants |
|-------------|---------------------|-------------|
| 0           | $NNN$               | 1           |
| −1          | $ΛNN, ΣNN$          | +7          |
| −2          | $ΛΛN, ΛΣN, ΣΣN, ΞNN$| +9          |
| −3          | $ΛΛΣ, ΛΣΣ, ΣΣΣ, ΞΛN, ΞΣN$| +1 |
| −4          | $ΞΝN, ΞΛΛ, ΞΛΣ, ΞΣΣ$| 0           |
| −5          | $ΞΞΛ, ΞΞΣ$         | 0           |
| −6          | $ΞΞΞ$              | 0           |

form of the potentials for the $ΛNN$ interaction with isospin 0 and 1:

$$V_{ΛNN→ΛNN}^{I=0} = e_2(1 + \frac{1}{3} σ_2 · σ_3) + e_3 (σ_1 · σ_2 + σ_1 · σ_3),$$
$$V_{ΛNN→ΛNN}^{I=1} = e_4(1 - σ_2 · σ_3).$$

Note that the low-energy constants for these two isospin channels are independent. The constant $e_1$ (proportional to $c_E$, which is present in the purely nucleonic sector) does not appear in the $ΛNN$ interaction. Therefore the $ΛNN$ contact interaction can not be constrained by the three-nucleon sector.

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