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ISOSPIN VIOLATION IN THE TWO-NUCLEON SYSTEM *

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In this contribution violation of isospin symmetry of the nuclear forces is investigated using the effective field theory of the Standard Model, Chiral Perturbation Theory (χPT). Without going into details of the underlying Nuclear χPT, we concentrate on the construction of a systematic expansion of isospin breaking effects (electromagnetic interaction and quark mass difference) at the level of a chiral Lagrangian. First results especially for the $^1S_0$ threshold paramters are shown.

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1. Introduction

Connecting the symmetries of QCD

$$\mathrm{SU}(2)_A \otimes \mathrm{SU}(2)_V \otimes \mathrm{U}(1)_V \tag{1}$$

(restricted to two flavours) to the hadronic spectrum, the pattern of a spontaneous breakdown of the $\mathrm{SU}(2)_A$ (leading to χPT (for a review see Ref. [1]) and an explicit breaking of $\mathrm{SU}(2)_V$ due to the mass term

$$L_{\mathrm{mass}} = \frac{1}{2}\bar{q}(m_u + m_d)(1 + \varepsilon\tau_3)q \tag{2}$$

with $\varepsilon = (m_d - m_u)/(m_d - m_u)$ and the electromagnetic interaction is observed. Here we are going to show how these symmetry considerations provide us with a systematic expansion of isospin breaking in the nuclear forces on the basis of Nuclear χPT. Particulary we demonstrate how the charge independence breaking (CIB) in the $^1S_0$ threshold parameters [2]

$$\Delta a_{\mathrm{CIB}} = a_{np} - \frac{a_{pp} + a_{nn}}{2} = (5.7 \pm 0.5)\,\mathrm{fm} \tag{3}$$

can be understood.

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2. Nuclear χPT

Based on earlier works by Weinberg [3] and van Kolck *et al.* [4] a nuclear χPT has been constructed by Epelbaoum and coworkers [5] using the projection formalism proposed by Okubo [6]. The incorporation of an explicit isospin dependence of the potentials constructed in that way is the subject of this investigation.

3. Incorporation of isospin breaking

Now we show how to implement the different mechanisms of isopin violation (quark mass difference and electromagnetic interaction) at the level of the effective Lagrangian: while soft photons were treated with a particular momentum-space technique for the Coulomb potential [7], hard photons and the mass difference were incorporated using the technique of external sources, a standard method of χPT. Therefore we define two scalar fields

$$\chi = 2B(m_u + m_d)(1 + \varepsilon\tau_3)\,, \tag{4}$$

$$Q = \frac{e}{2}(1 + \tau_3)\,, \tag{5}$$

(B is proportional to the scalar quark condensate in the chiral limit) with a well defined counting and coupling to the nucleonic and pionic fields [8]. Instead of writing down all the $\pi\pi$, πN and NN contributions (as already constructed in [8]), we only show one example, the second order $\pi\pi$ Lagrangian,

$$L^{(2)}_{\pi\pi} = \frac{f_\pi^2}{4}\langle \nabla_\mu U \nabla^\mu U + \chi^\dagger U + \chi U^\dagger\rangle + C\langle QUQU^\dagger\rangle \tag{6}$$

(f_π is the pion decay constant in the chiral limit). The last term is the Leading Order (LO) contribution to the pion mass difference (πmd),

$$\frac{8\pi\alpha C}{f_\pi^2} = \delta m_\pi^2 = (m^2_{\pi_+} - m^2_{\pi_0})\,. \tag{7}$$

Therefore we count the πmd proportional to α. Notice further that the special form of (4) and (5) allows us to rewrite all nucleonic contact terms with insertions of external fields at a given chiral order as the sum of isospin symmetric contact structures and

$$V_{\mathrm{CSB}} = (N^\dagger\tau_3 N)(N^\dagger N)\,, \tag{8}$$

$$V_{\mathrm{CIB}} = (N^\dagger\tau_3 N)^2\,, \tag{9}$$

which parametrize the non-pionic CSB and CIB-effects[1]. Analyzing the Lagrangians constructed in that way, one is able to establish the following expansion in α and ε [8] (O(T)PE abbreviating One(Two)-Pion-Exchange):

Chiral order	Expansion-parameter	Contribution
LO	α	Coulomb potential
	α	πmd in OPE
	α	$\propto (N^\dagger QN)^2$
	ε	$\propto (N^\dagger \chi N)(N^\dagger N)$
NLO	α	πmd in TPE
	α	$\propto (\nabla_\mu \nabla^\mu N^\dagger QN)^2 \ldots$
	ε	$\propto (\nabla_\mu \nabla^\mu N^\dagger \chi N)(N^\dagger N) \ldots$
	α	$\pi\gamma$ exchanges

The dots in the Next to Leading Order (NLO) contact interaction represent the other possible combinations of derivatives on the nucleonic fields.

4. First results

To work out the connection between πmd in OPE and CIB, we only incorporate the leading order effects into our calculation. After adjusting

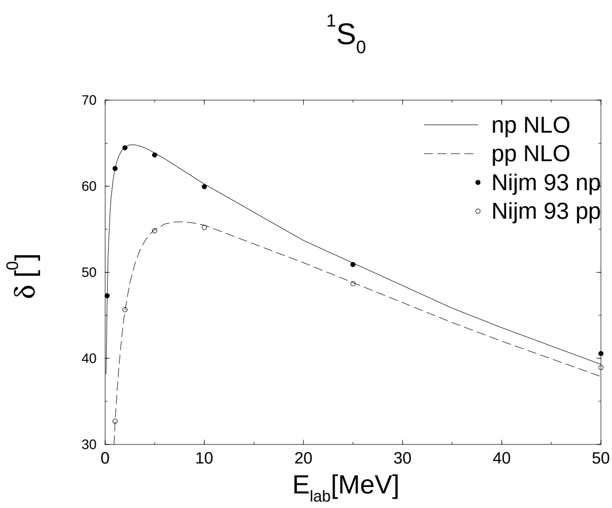

Fig. 1. Phase shifts for pp and np scattering in $^1S_0$

[1] CSB is the charge symmetry breaking *e.g.* $\Delta a_{\rm CSB} = a_{pp} - a_{np} = (1.5 \pm 0.1)\,$fm.

the two contact interactions of every partial wave in NLO separatly for the different isospin channels, the phase shifts can be determined[2] (see Fig. 1). The phase shift for various partial waves as well as a more detailed documentation of our method will be published elsewhere [10]. In this contribution we will concentrate on the threshold parameters determined with the contact terms matched to the phase shifts:

		a[fm]	r[fm]	process	a[fm]	r[fm]
Exp.	np	-23.75 ± 0.01	2.68 ± 0.05	pp	-17.3 ± 0.4	2.85 ± 0.04
χPT	np	-23.562	2.64	pp	-16.638	2.79

Performing only NLO considerations, we are a little bit off in the absolute value (*cf.* [5]), while the CIB of the scattering length in ${}^1S_0$ is very well described. By switching the pion mass difference on and off, we are able to determine the effect of OPE.

	$\Delta a_{\rm CIB}$[fm]	$\Delta r_{\rm CIB}$[fm]	$\Delta a_{\rm CIB}^{\rm OPE}$[fm]	$\Delta r_{\rm CIB}^{\rm OPE}$[fm]
Exp.	5.7 ± 0.5	0.05 ± 0.13		
χPT	6.174	0.10	2.83	0.05

5. Conclusion

Even in this preliminary stage of investigation, we are able to show how powerful an effective field theory approach is in order to describe the elastic scattering of nucleons in all isospin channels simultaneously (nn scattering can be investigated by adjusting the contact terms to the effective range expansion). Just performing a next-to-leading order calculation in χPT and incorporating leading-order isospin breaking, the experimentally observed CIB has been worked out. To allow predictions at higher energies, a NNLO-calculation is necessary. An investigation of the influence of pion mass difference in two-pion-exchange and a fresh look at the pion-photon-loops will follow.

[2] Data taken from the Nijmwegen partial wave analysis [9].

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