

Hyperon–nucleon interactions—a chiral effective field theory approach

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Abstract

We construct the leading order hyperon–nucleon potential in chiral effective field theory. We show that a good description of the available data is possible and discuss briefly further improvements of this scheme.
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1. Introduction

The derivation of nuclear interactions from chiral effective field theory (EFT) has been discussed extensively in the literature since the work of Weinberg [1,2]. For reviews we refer to [3,4]. The main advantages of this scheme are the possibilities to derive two- and three-nucleon forces as well as external current operators in a consistent way and to improve calculations systematically by going to higher orders in the power counting.

Recently the nucleon–nucleon (NN) interaction has been described to a high precision using chiral EFT [5] (see also [6]). In this reference, the power counting is applied to the NN potential, as originally proposed in [1,2]. The NN potential consists of pion-exchanges and a series of contact interactions with an increasing number of derivatives to parameterize the shorter ranged part of the NN force. A regularized Lippmann–Schwinger equation is solved to calculate ob-

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servable quantities. Note that in contrast to the original Weinberg scheme, the effective potential is made explicitly energy-independent as it is important for applications in few-nucleon systems (for details, see [7]).

The hyperon–nucleon (YN) interaction has not been investigated using EFT as extensively as the NN interaction. Hyperon and nucleon mass shifts in nuclear matter, using chiral perturbation theory, have been studied in [8]. These authors used a chiral interaction containing four-baryon contact terms and pseudoscalar-meson exchanges. Recently, the hypertriton and Λd scattering were investigated in the framework of an EFT with contact interactions [9]. Korpa et al. [10] performed a next-to-leading order (NLO) EFT analysis of YN scattering and hyperon mass shifts in nuclear matter. Their tree-level amplitude contains four-baryon contact terms; pseudoscalar-meson exchanges were not considered explicitly, but $SU(3)_f$ breaking by meson masses was modeled by incorporating dimension-two terms coming from one-pion exchange. The full scattering amplitude was calculated using the Kaplan–Savage–Wise resummation scheme [11]. The hyperon–nucleon scattering data were described successfully for laboratory momenta below 200 MeV, using 12 free parameters. Some aspects of strong ΛN scattering in effective field theory and its relation to various formulations of lattice QCD are discussed in [12].

In this work we apply the scheme used in [5] to the YN interaction. Analogous to the NN potential, at leading order in the power counting, the YN potential consists of pseudoscalar-meson (Goldstone boson) exchanges and four-baryon contact terms, related via $SU(3)_f$ symmetry. We solve a regularized coupled channels Lippmann–Schwinger equation for the leading-order (LO) YN potential, including non-derivative contact terms and one-pseudoscalar-meson exchange, and fit to the low-energy cross sections, which are dominated by S -waves. Contrary to the NN case, it is not possible to fit to partial waves, since they cannot be extracted from the incomplete and low-precision YN scattering data. We remark that our approach is quite different from [10].

The contents of this paper are as follows. The effective potential is developed in Section 2. In Section 2.1, we first give a brief recollection of the underlying power counting for the effective potential. We then investigate the $SU(3)_f$ structure of the four-baryon contact interactions in leading order. This is done in Section 2.2. The lowest order $SU(3)_f$ -invariant four-baryon contact interactions are given and the corresponding potentials are derived. Similar to pion-exchanges in the NN case, the YN potential contains the exchanges of pseudoscalar mesons in general. The lowest order $SU(3)_f$ -invariant interactions are given in Section 2.3. Here also the one pseudoscalar meson-exchange potential is derived. The coupled channels Lippmann–Schwinger equation is solved for the partial-wave projected potential. This integral equation is solved in the LSJ basis. The Lippmann–Schwinger equation and the calculation of observable quantities are discussed in Section 3. Results of the fit to the low-energy YN cross sections are presented in Section 4. We show the empirical and calculated total cross sections, differential cross sections and give the values for the scattering lengths. Also, predictions for some YN phase shifts are presented and results for the hypertriton binding energy are listed. Finally, the summary gives an overview of the research in this work and an outlook for future investigations. Some technical details can be found in the appendices.

2. The effective potential

In this section, we construct in some detail the effective chiral hyperon–nucleon potential at leading order in the (modified) Weinberg power counting. This power counting is briefly recalled first. Then, we construct the minimal set of non-derivative four-baryon interactions and derive the formulae for the one-Goldstone-boson-exchange contributions.

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