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Nucleon-Nucleon Potential from an Effective Chiral Lagrangian

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An effective chiral Lagrangian for a system of low momentum pions and nonrelativistic nucleons developed in earlier works has been extended to include Δ isobar fields. The nucleon-nucleon potential obtained from this Lagrangian is consistently expanded in powers of momentum divided by a QCD mass scale and includes all one-loop, two pion exchange diagrams. Several of the loop diagrams are a direct consequence of chiral symmetry. The parameters of the potential were adjusted to reproduce the low energy nucleon-nucleon scattering phase shifts as well as the properties of the deuteron. Reasonable fits are obtained in this first application of a nucleon-nucleon potential based on chiral symmetry.

Theoretical efforts to account for the nucleon-nucleon (NN) interaction have been underway for many decades. Early field theoretical approaches¹ in the 1950s were generally unsuccessful. These eventually gave way to more phenomenological treatments² which provided a pragmatic way to describe the abundant NN scattering and bound state (deuteron) data. Beginning in the 1970s theoretical models emerged which were more successful than in earlier attempts. These were based on one-pion exchange (OPE), heavy meson exchange, and multi-meson exchange plus short range phenomenology.³⁻⁵ The Paris,³ Nijmegen,⁴ and Bonn⁵ models are representative of these more recent efforts. The Paris model includes OPE and single ω -meson exchange along with two-pion exchange (TPE) contributions calculated using π N phase shifts, $\pi\pi$ interactions and dispersion relations, plus short range phenomenological potentials. Regge pole theory was used by the Nijmegen group to obtain a NN interaction model which includes numerous one-boson exchange terms with exponential form factors and repulsive central Gaussian potentials arising from Pomeron and tensor trajectories. The Bonn group included a number of one-boson exchange terms plus two meson exchanges (2π , $\pi\rho$ and $\pi\omega$), correlated TPE in the form of the exchange of an effective scalar meson, effective three pion exchange, and intermediate Δ isobars, all in the context of "old fashioned" perturbation theory. Each of these models contains many parameters and each provides impressive agreement with the deuteron data and with NN scattering data up to 350 MeV laboratory kinetic energy.

Despite this considerable effort the connection between the NN interaction and the underlying theory of the strong interaction, assumed to be

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