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Chiral Effective Field Theory for Nuclear Forces: Achievements and Challenges

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The problem of a proper derivation of nuclear forces is as old as nuclear physics itself, namely, about 80 years. Since the nuclear force is a manifestation of strong interactions, the modern view is that any serious derivation has to start from quantum chromodynamics (QCD). However, the well-known problem with QCD is that it is non-perturbative in the low-energy regime characteristic for nuclear physics. For many years this fact was perceived as the great obstacle for a derivation of nuclear forces from QCD—impossible to overcome except by lattice QCD. The effective field theory (EFT) concept has shown the way out of this dilemma. To ensure that the EFT in not just another phenomenology, it must have a firm link with QCD. The link is established by having the EFT observe all relevant symmetries, particularly, the (broken) chiral symmetry of low-energy QCD. During the past two decades, it has been demonstrated that chiral EFT represents a powerful tool to deal with nuclear forces in a systematic and model-independent way [1]. Two-, three-, and four-nucleon forces have been derived up to next-to-next-to-next-to-leading order (N^3LO) and (partially) applied in nuclear few- and many-body systems—with, in general, a good deal of success. This may suggest that the 80-year old nuclear force problem has finally been cracked. Not so! Some basic issues have been swept under rug for years and now need our full attention, like the proper renormalization of the two-nucleon potential. Moreover, the order-by-order convergence of the many-body force contributions is still obscure at this time.

[1] R. Machleidt and D. R. Entem, *Chiral Effective Field Theory and Nuclear Forces*, Phys. Rep. **503**, 1 (2011); with a comprehensive list of references therein.