Contribution ID: **295** Type: **not specified**

Achievements and challenges in understanding nucleon-deuteron reactions

Comparison of theoretical predictions based on a nucleon-nucleon potential with data for elastic nucleon-deuteron (Nd) scattering and nucleon
induced deuteron breakup reveals the importance of a three-nucleon
force (3NF). Inclusion of semi-phenomenological 3NF models, such as Tucson-Melbourne or Urbana IX, into calculations in many cases improves the data description. However, some serious discrepancies remain even when a 3NF is included.
At low energies the prominent examples of discrepancies between theory and data were found for the vector analyzing power in elastic Nd scattering and
for the neutron-deuteron (nd) breakup cross sections in neutron-neutron (nn) quasi-free-scattering (QFS) andsymmetric-space-star (SST) geometries. Since both these configurations depend predominantly on the S-wave nucleon-nucleon (NN) force components, these cross section discrepancies have serious consequences for the nn 1S0 force component.
At energies above about 100 MeV current 3NF's only partially improve the description of data for cross section and spin observables in elastic Nd scattering and breakup. The complex angular and energy behavior of analyzing powers, spin correlation and spin transfer coefficients fails to be explained by standard nucleon-nucleon interactions alone or combined with current models of 3NF's.
One of the reasons for the above disagreements could be a lack of consistency between 2N and 3N phenomenological potentials used or/and omission of important terms in the applied 3NF.
The Chiral Effective Field Theory approach provides consistent two- and three-nucleon forces. The 3NF occurs for the first time at next-to-next-to
leading order (N2LO) of chiral expansion. The N3LO and N4LO NN forces when used in 3N calculations provide description of NN data of the same quality as standard, realistic NN potentials.
Application of improved, semilocal coordinate-space regularized chiral NN nteractions up to N4LO order of chiral expansion combined with N2LO 3NF's supports conclusions obtained with standard forces. It can be expected that an application of consistent chiral NN and 3NF's up to N3LO will play an important role in understanding of elastic scattering and breakup reactions at higher energies.

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