Meson dynamics and the resulting “3-Nucleon-Force” diagrams: Results from a simplified test case

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One of the important aspects in modern three-nucleon dynamics is the explicit inclusion of mesonic degrees of freedom that can not be described by conventional two-nucleon potentials. These additional effects are described by three-nucleon forces ($3NF$), which effectively describe the addition of possible irreducible mesonic contributions. The implementation of these terms is not trivial and care has to be taken not to include double-contributions. Nevertheless, the standard $3NF$ approaches turned out to be able to account for the underbinding of the three-nucleon bound state. However, so far they could not fully explain the puzzle of the vector analyzing powers in nucleon-deuteron scattering at low energies.
Recently, starting from the rigorous four-body theory of Grassberger-Sandhas [1] and Yakubovski [2], a new method to describe the coupled $NNN - \pi NNN$ system has been developed [3]. In a subsequent paper, an approximation scheme for this new method was derived by the authors [4], based on a procedure to freeze-out the pion channel.
After the pionic channel was frozen with the Feshbach procedure, it also was shown that the residual pion-dynamics produced correction terms corresponding to three-nucleon force diagrams. This approach has the distinctive feature that these irreducible diagrams naturally appear in the Faddeev equation, and the corresponding 3NF is therefore generated consistently with the 3N dynamical equation used for the actual calculations. To our knowledge, this level of consistency has been obtained for the first time. In this way, we recover also a new topological type of correction term that should not be ignored.
In this work, we illustrate the results obtained in a simplified one-dimensional model which describes in first approximation the dynamics of the three-nucleon system [5]. We calculate the explicit effects of these 3NF terms on the binding energy. In this simplified calculation we show that the considered 3NF diagrams account for an underbinding of the three-nucleon bound state. However, the new type of $3NF$ also has an approximately 30% effect on the three-nucleon binding energy. Therefore, one might expect that the new type of correction terms could have an effect also in more realistic calculations.
This suggestion has been recently confirmed by Canton and Schadow in a more realistic study [6,7] on the nd vector analyzing powers, where it was shown that a new term of tensor structure can be generated by these $3NF$ diagrams, and could indeed hold the key to solve the A_y-puzzle. In conclusion, a new way of handling the pion dynamics in $3N$ calculations has been developed. Calculations suggest that a newly developed type of $3NF$ should also be included in realistic three-nucleon calculations.

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