From Nuclei to Cold Atoms and Back

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Systems with large two-body scattering lengths are of particular interest because they exhibit universal behavior. While such systems have become popular in atomic physics only in the last decade, they have been investigated in nuclear physics since its beginning. Hence, it is not surprising that techniques developed for solving the nuclear few-body problem are immediately applicable to such systems in atomic physics.

The no-core shell model (NCSM) is a powerful many-body technique that has been successfully employed to determine the properties of few-body systems with no adjustable parameters. In this approach, a numerical solution to the many-body non-relativistic Schrödinger equation is obtained by exact diagonalization in a restricted space. Correlations left out by the space restriction are traditionally taken into account by deriving, via a unitary transformation, an effective interaction from two- and three-body forces adjusted to experimental two- and three-nucleon data.

In order to mitigate some shortcomings in the traditional NCSM and, at the same time, provide a transparent connection with the underlying strong interactions at the quark level, we have proposed a novel approach [1] in which the interaction in the restricted NCSM model space is constructed following the general principles of effective field theories (EFTs). The basic idea underlying EFTs is that the restriction of a theory to a model space generates all interactions allowed by the theory's symmetries. Since particle momenta are limited within the restricted space, one can treat short-distance interactions in a derivative expansion, similar to the multipole expansion in classical electrodynamics. The coefficients of this expansion carry information about the details of the short-range dynamics. We have successfully applied this hybrid NCSM and EFT method in the four- and six-body systems, obtaining reasonable agreement with experiment.

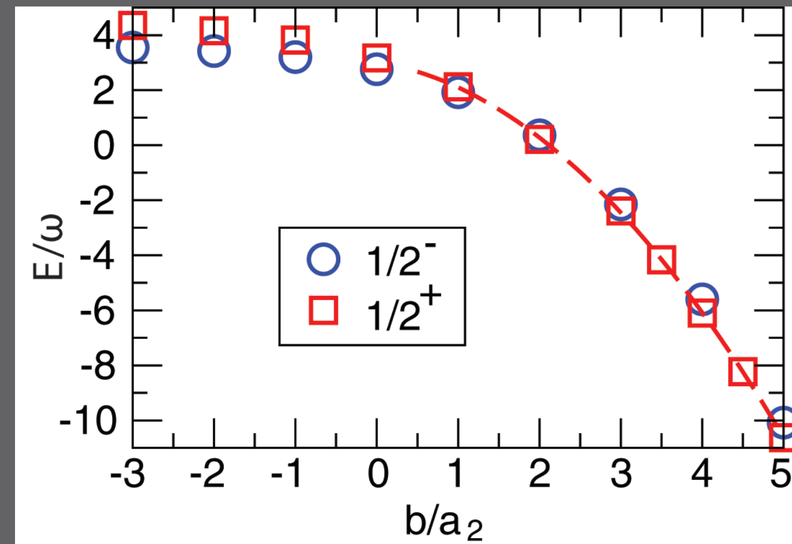

Fig. 1. Lowest energy levels for $j^\pi = ½^-$ (circles) and $j^\pi = ½^+$ (squares) states of the three-fermion system in a harmonic trap as function of the ratio b/a_2. Around $b/a_2 \sim 1.5$, we observe an inversion of the parity of the system's ground state. The dashed line is a fit of the positive-parity points by a quadratic form.

The same general principles to construct effective interactions in restricted model spaces can be applied to other systems. Thus, we have applied similar methods for the description of systems of three and four spin 1/2 fermions in harmonic traps [2]. This allows us to investigate the properties of few-atoms from the weakly interacting to the strongly interacting limits. Note that, although for low-momenta the effective Hamiltonian for cold atoms and nuclear systems are formally similar, the coefficients involved carry different information. In the three-fermion system, we found that the ground state changes parity when the interaction increases beyond the unitary limit. In Fig.1, we show the lowest positive and negative 1/2 states of the three-fermion system, as a function of the ratio between the trap length b-, and the two-body scattering length a_2. In the $b/a_2 \to \infty$ limit, the positive-parity state likely represents the untrapped S-wave particle-dimer scattering state that one expects to dominate sufficiently close to threshold.

We further consider the application of the same principles to the construction of the effective interaction in finite NCSM spaces for the description of the nuclear many-body problem. Thus, the formal similarity between the physically trapped fermions and interacting nucleons trapped by a center-of-mass harmonic term allows us to use similar means to obtain the effective interaction more efficiently for few-nucleon calculations.

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[1] I. Stetcu, B.R. Barrett, and U. van Kolck, *Phys. Lett. B,* **653,** 358 (2007).
[2] I. Stetcu, et al., *Phys. Rev. A* (in press), arXiv:0705.4335 (2007).

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