Hartree-Fock-Bogoliubov Calculations with Correlated Realistic Interactions

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Abstract

We investigate the use of correlated realistic interactions derived within the framework of the Unitary Correlation Operator Method (UCOM) in fully self-consistent Hartree-Fock-Bogoliubov calculations.

1 Introduction

Recently, we have successfully employed the Unitary Correlation Operator Method (UCOM) ([1] and Refs. therein) in nuclear structure studies using a wide range of many-body methods. It provides an efficient way to explicitly describe the strong central and tensor correlations which govern the nucleon-nucleon system at short ranges. By performing a similarity transformation of a given realistic NN-interaction with the unitary central and tensor correlation operators, C_r and C_Ω, we obtain a correlated realistic interaction $\mathrm{V}_{\mathrm{UCOM}}$ which retains phase-shift equivalence with its parent interaction while offering greatly improved convergence properties. The strength and range of the transformation are regulated by the central and tensor correlation functions $s(r)$ and $\vartheta(r)$, which are determined by an energy minimization in the two-nucleon system. For the free deuteron, this may lead to a very long-ranged $\vartheta(r)$, which is unnatural for many-nucleon systems where tensor correlations will be screened. Hence, we introduce a constraint $I_\vartheta^{(1,0)}$ on the volume integral (and thereby the range) of $\vartheta(r)$ in the $(S,T) = (1,0)$ channel. By varying this constraint, we were able, e.g., to map out the Tjon line [1].

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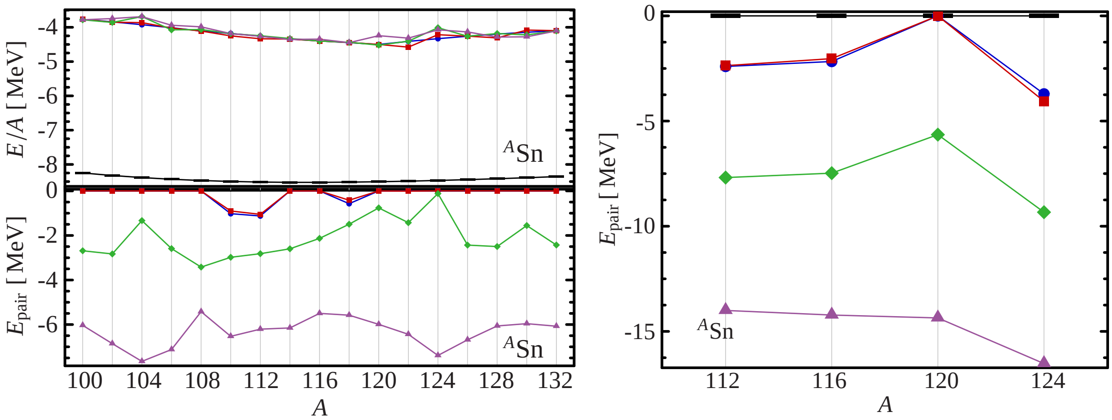

Figure 1: *Left:* Binding energy per nucleon and pairing energy for V_{UCOM} with $I_{\vartheta}^{(1,0)} = 0.09\,\mathrm{fm}^3$. *Right:* Pairing energy for V_{UCOM} with $I_{\vartheta}^{(1,0)} = 0.2\,\mathrm{fm}^3$ and a $3N$ contact force with strength $V_{3N} = 2.5\,\mathrm{GeV}$. In both figures, the shown curves are experiment (——), HFB (●), PAV (■), PLN (♦), PM1 (▲).

2 Hartree-Fock-Bogoliubov Calculations

Hartree-Fock-Bogoliubov (HFB) theory [2] is the tool of choice for mean-field calculations including pairing effects. Starting from the nuclear many-body Hamiltonian, we use V_{UCOM} in *the particle-hole as well as the particle-particle channel*. As in the Hartree-Fock (HF) calculations discussed in [3], we address the issue of the center-of-mass motion by using the *intrinsic kinetic energy* $T_{int} = T - T_{cm}$ in the Hamiltonian rather than subtracting $\langle\, T \,\rangle_{cm}$ after the variation. Since T_{int} is (formally) a two-body operator involving a summation over all relative kinetic energies of the nucleon pairs, it has to be included in the pairing field, along with the Coulomb force, to achieve a *fully self-consistent treatment of direct, exchange, and pairing terms*.

Proton and neutron numbers are restored simultaneously by using the *Lipkin-Nogami* and *M-periodic* approximations [4, 5] to the full variation after projection (VAP) problem, which make use of truncated expansions of the number-projected energy. In addition, an exact particle-number projection (PNP) is performed after variation, as outlined in [6]. Curves in Fig. 1 are marked PLN and PM1, accordingly.

The left side of Fig. 1 shows results for the Sn isotope chain, calculated using a V_{UCOM} with $I_{\vartheta}^{(1,0)} = 0.09\,\mathrm{fm}^3$. Spherical and reflection symmetry were explicitly assumed. The binding energies agree with the HF result, and pairing is almost non-present. The reason for this is the low level density of the HF single-particle spectra, which impedes the pairing between different (l, j)-shells. As discussed in [7], the level density becomes comparable to those of single-particle spectra extracted from experiment if a $3N$ contact force is used in addition to a V_{UCOM} with a longer-ranged tensor correlator. We have tested this combination's effect on the pairing approximately by contracting the $3N$ matrix elements with a density matrix obtained from a HF run for a given nucleus and adding the resulting density-dependent NN matrix elements to those of V_{UCOM}. This yields a more satisfying picture, as shown in the right panel of Fig. 1. As the sophistication of the approximate PNP increases (PAV→PLN→PM1), we reach pairing energies up to 16 MeV, which are of comparable size, e.g, as the $E_{pair} \simeq 21 - 22$ MeV obtained from a VAP calculation with the Gogny D1 interaction [5]. Keeping in mind that the Gogny force has been adjusted to experimental data and therefore implicitly contains beyond mean-field effects, the trend noticed in the pairing energy as well as the remaining difference between the two approaches seem reasonable.

3 Conclusions

First results from fully self-consistent HFB calculations with a correlated realistic interaction V_{UCOM} look promising and are in reasonable agreement with calculations based on established methods. Exact variation after PNP as well as a non-approximate treatment of the $3N$ force are presently investigated. The reduction of symmetry constraints, which is likely to necessitate parity and/or angular momentum projection, will be a subject of future research. To improve the treatment of long-range correlations in our calculations we plan to develop a quasi-particle RPA code.

Acknowledgment

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