RPA and ERPA with Correlated Realistic NN Interactions

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The Unitary Correlation Operator Method (UCOM) provides a powerful scheme for carrying out ab initio nuclear structure calculations [1, 2, 3, 4]. In particular, it makes it possible to combine numerically affordable many-body Hilbert spaces with modern realistic NN interactions. Short-range correlations are explicitly taken into account. First results ranging from no-core shell model to Hartree-Fock (HF) and perturbation-theory calculations using correlated NN interactions have been reported previously.

In this work we employ correlated interactions in RPA studies of nuclear response. Only natural-parity excitations of spherical, closed-shell nuclei have been considered so far. First, HF calculations of the nuclear ground state are performed. The RPA is self-consistently formulated in the HF single-particle basis (HF+RPA model). We have also used an extended RPA version [5] (ERPA), which is built on top of the true RPA ground state and involves an iterative solution of the RPA equations. The influence of ground-state correlations on excitation properties can then be assessed. Corrected single-particle energies and occupation numbers can also be obtained.

We use the correlated interactions discussed in Ref. [4], based on the Argonne V18 potential. The results presented here were obtained in a harmonic-oscillator basis of 13 shells with the optimal value of the tensor correlation volume, $I_\vartheta^{(S=1,T=0)} = 0.09\ \mathrm{fm}^3$.

Our RPA results on the isoscalar (IS) giant monopole resonance (ISGMR), for various medium and heavy nuclei, are in good agreement with the experimental data. An example is shown in Fig. 1, where we see also that the ground state correlations taken into account in ERPA have a relatively small effect. In general, lower I_ϑ values result in lower ISGMR energies [6]. The isovector (IV) dipole strength (not shown) is distributed at energies which are too high compared with experiment; ERPA is not able to correct for this result. Inclusion of $2p2h$ configurations within second-order RPA is expected to bring the IVD strength to lower energies. Our results could be further improved by considering a phenomenological three-body correction to the correlated interaction.

Ground-state occupation numbers $n_i = \langle a_i^\dagger a_i \rangle$ (in standard notation) have been calculated within ERPA. In principle, UCOM-correlated operators should be used. The small depletion of the Fermi sea that we obtain using uncorrelated operators reflects the effect of the residual long-range correlations. Results for ^{40}Ca are presented in Fig. 2.

The UCOM scheme can be used in conjunction with other realistic (local or non-local) NN interactions, as well as with various many-body methods (Second RPA, QRPA, Shell Model, etc) for calculations across the nuclear chart. A next step in our exploration will be the use of second-order RPA as well as QRPA for open-shell systems.

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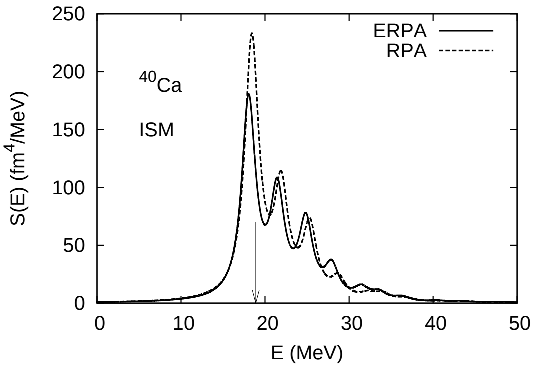

Figure 1: Isoscalar monopole resonance of ^{40}Ca, in HF+RPA (dashed lines) and ERPA (solid lines). An arrow indicates the experimental centroid.

References

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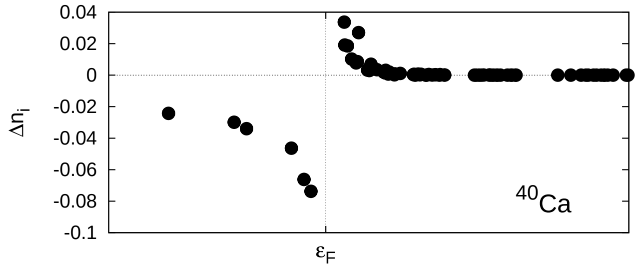

Figure 2: Change of the occupation probabilities of the HF single-particle states due to long-range correlations. Shown are ERPA results for proton orbitals in ^{40}Ca (ε_F is the Fermi energy).