Phenomenological Three-Body Interactions in the UCOM Framework [*]

A. Zapp, H. Hergert, P. Papakonstantinou, and R. Roth
Institut für Kernphysik, Technische Universität Darmstadt, Germany

In the Unitary Correlation Operator Method (UCOM) the short-range central and tensor correlations induced by the nuclear interaction are treated explicitly by a unitary transformation. This method is employed to transform the Argonne V18 potential into a phase-shift equivalent correlated interaction $\mathrm{V}_{\mathrm{UCOM}}$ which is used for the following calculations [1].

Previous investigations of ground states and collective excitations based on the two-body interaction $\mathrm{V}_{\mathrm{UCOM}}$ revealed systematic deviations of different observables for heavier nuclei. Figure 1 shows the binding energies per nucleon (upper part) and charge radii (lower part) of closed-shell nuclei obtained in a Hartree-Fock (HF) calculation using $\mathrm{V}_{\mathrm{UCOM}}$ (disks). The range of the tensor correlator was fixed in few-body calculations ($I_\vartheta = 0.09\ \mathrm{fm}^3$) [1]. The HF approximation underestimates the binding energies, since long-range correlations cannot be described. Their inclusion within many-body perturbation theory leads to a good agreement of the binding energies with experiment [2]. Furthermore, the charge radii are clearly too small for heavier nuclei and the inclusion of long-range correlations via perturbation theory does not lead to a substantial improvement. Besides ground-state properties, collective excitations were investigated within the Random Phase Approximation (RPA) [3] using $\mathrm{V}_{\mathrm{UCOM}}$. An example is shown in Figure 2, where the response function of the isoscalar quadrupole resonance of ^{90}Zr is displayed. The solid line represents the results with the two-body interaction $\mathrm{V}_{\mathrm{UCOM}}$. The strength is concentrated at energies which are too high compared to experiment.

Here we study the impact of a simple three-body interaction on the radii and strength distributions. As a first ansatz, the correlated two-body interaction is supplemented by a three-body contact interaction with a strength parameter C_3. The three-body matrix elements are calculated in the harmonic-oscillator basis and included in our HF and RPA codes [4]. Using a long-range tensor correlator ($I_\vartheta = 0.20\ \mathrm{fm}^3$) in conjunction with a repulsive three-body interaction ($C_3 = 2500\ \mathrm{MeVfm}^6$) in HF leads to the binding energies and radii depicted by the square symbols in Fig. 1. Obviously the charge radii are now in good agreement with experiment. Again, the binding energies are underestimated on the HF level – it is expected that many-body perturbation theory would lead to an agreement with experiment. The collective response obtained in an RPA calculation including the three-body interaction (dashed line in Fig. 2) is shifted towards lower energies improving the agreement with experiment – further improvement can be achieved by increasing the single-particle space.

In summary, the inclusion of a simple repulsive three-body interaction seems to cure the discrepancies observed with the two-body interaction $\mathrm{V}_{\mathrm{UCOM}}$ for heavier nuclei. As a next step we will use a finite-range three-body force, which then allows systematic calculations beyond Hartree-Fock, in order to provide a quantitative description of ground states and collective excitations.

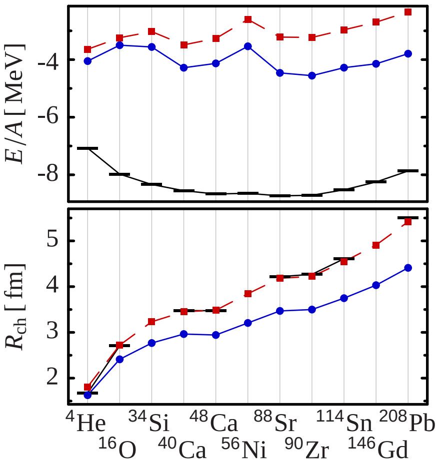

Figure 1: Binding energies and charge radii of selected closed-shell nuclei resulting from HF calculations with a two-body interaction (disks) and a two- plus three-body interaction (square symbols). The bars indicate the experimental values.

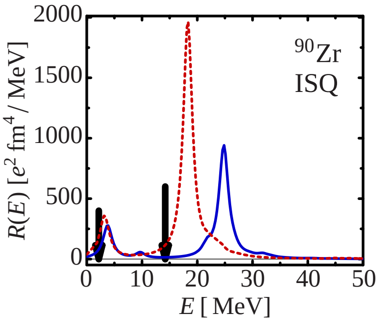

Figure 2: Isoscalar quadrupole resonance of ^{90}Zr resulting from RPA calculations with a two-body interaction (solid line) and a two- plus three-body interaction (dashed line). The arrows indicate the experimental centroids.

References

[1] R. Roth et al., *Phys. Rev.* **C 72**, 034002 (2005).
[2] R. Roth et al., *Phys. Rev.* **C 73**, 044312 (2006).
[3] N. Paar et al., *Phys. Rev.* **C 74**, 014318 (2006).
[4] A. Zapp, diploma thesis, TU Darmstadt, 2006.

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