Effective Three-Body Interactions in the UCOM Framework *

A. Günther, R. Roth, H. Hergert, and S. Reinhardt
Institut für Kernphysik, Technische Universität Darmstadt, Germany

We investigate the influence of phenomenological three-body forces supplementing unitarily transformed two-body potentials. For interactions constructed within 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. The character of the correlations is encapsulated in the operator structure of the correlation operators while the radial dependencies are described by correlation functions [1]. The Similarity Renormalization Group (SRG) also aims at the construction of a soft phase-shift equivalent interaction via a unitary transformation. But contrary to UCOM, the SRG leads to a pre-diagonalization of a matrix representation of the Hamiltonian by using a renormalization group flow evolution. The SRG can be used to extract correlation functions for the UCOM transformation [2]. For the following calculations, UCOM with SRG-generated correlation functions is employed to transform the Argonne V18 potential into a phase-shift equivalent correlated interaction $\mathrm{V}_{\mathrm{UCOM}}$.

Investigations based on a pure two-body interaction show systematic deviations of different observables for heavier nuclei, e.g. charge radii are systematically too small. Therefore a phenomenological three-body interaction is introduced. Currently, we use a contact interaction with variable strength $C_{3\mathrm{N}}$ and an additional energy cut-off. The cut-off parameter is implemented in the calculation of matrix elements in harmonic-oscillator basis: $(2n_1 + l_1) + (2n_2 + l_2) + (2n_3 + l_3) \leq e_{3\max} = 10$. This simple three-body interaction is included in different many-body methods, for example in Hartree-Fock (HF) and many-body perturbation theory (MBPT).

* Supported by DFG through SFB 634 and the Helmholtz International Center for FAIR.

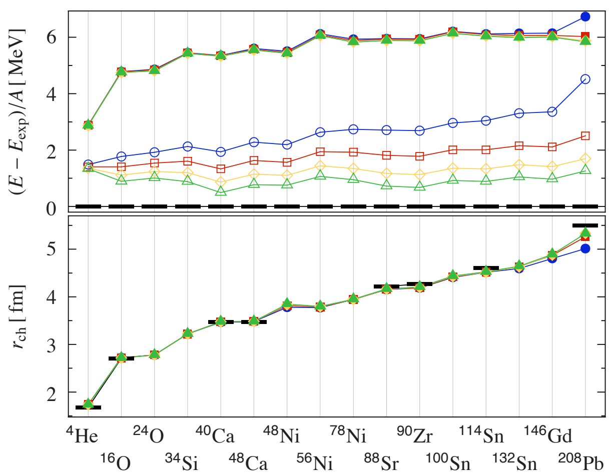

Figure 1: Differences between calculated and experimental binding energies and charge radii of selected closed-shell nuclei resulting from HF calculations (filled symbols) and MBPT (open symbols) for different basis sizes (see text). The bars indicate the experimental values.

One has two free parameters – the strength of the three-body interaction and the SRG flow parameter – which can be used to adjust the observables to experimental values. The strength of the three-body interaction is fixed to $C_{3\mathrm{N}} = 1200\ \mathrm{MeV\,fm}^6$ in order to reproduce the experimental charge radii while the SRG flow parameter is set to $\bar{\alpha} = 0.06\ \mathrm{fm}^4$. With this parameter set one can simultaneously reproduce the binding energies and the charge radii very well.

Figure 1 shows results from HF calculations (full symbols) and many-body perturbation theory (open symbols) for selected closed-shell nuclei from ^{4}He to ^{208}Pb. Differences between the calculated and experimental binding energies are depicted in the upper part and charge radii in the lower part. The different curves represent different model-space sizes, starting with $e_{\max} = 8$ (circles), $e_{\max} = 10$ (squares) up to $e_{\max} = 12$, $l_{\max} = 10$ (diamonds) and $e_{\max} = 14$, $l_{\max} = 10$ (triangles) with $e = 2n + l$. The perturbation theory corrections are calculated only for the two-body part of the interaction since the contributions for the three-body interaction are expected to be small. The charge radii and the HF energies are converged whereas the perturbed energies are not fully converged, but the missing 0.5 MeV can roughly be covered by an extrapolation to infinite basis size. The charge radii as well as the binding energies show a systematic agreement with experimental data which was not achieved with pure two-body interactions.

In summary, the repulsive three-body contact interaction in connection with the SRG-generated correlation functions yields nice agreement with experimental data for binding energies and charge radii. So far, the investigations were restricted to calculations on the level of HF and perturbation theory. Currently, we work on the construction of an effective two-body interaction out of the three-body force which can be included in several different many-body methods. In the near future, calculations in the framework of the No-Core Shell Model are envisioned.

References

[1] R. Roth et al., *Phys. Rev.* **C 72**, 034002 (2005).

[2] R. Roth et al., *Phys. Rev.* **C 77**, 064003 (2008).