

Effective NN-Interaction Including Radial and Tensor Correlations

T. Neff and H. Feldmeier

GSI Darmstadt

Our aim is to use realistic NN-potentials in nuclear structure calculations where the many-body Hilbert space is spanned by Slater determinants. Although those form in principle a complete basis they are very badly suited to describe the correlations induced by the repulsive core and the strong tensor part in the NN-potential \tilde{V} . A large scale shell model calculation with the bare interaction for ${}^3\text{He}$ needs already 50 $\hbar\Omega$ excitations, a Hilbert space of dimension 10^5 , to achieve convergence.

Therefore we propose to first perform a unitary transformation of the Hamiltonian [1-3]

$$\hat{\tilde{H}} = \tilde{C}^\dagger (T + V) \tilde{C} = \tilde{T} + \hat{\tilde{H}}^{[2]} + \hat{\tilde{H}}^{[3]} + \dots \quad (1)$$

that incorporates the common effects of the repulsive and tensor correlations in the sense of a pre-diagonalization. Thus instead of Slater determinants $|Q\rangle$ we actually use $\tilde{C}|Q\rangle$ as basis states. \tilde{T} denotes the kinetic energy, $\hat{\tilde{H}}^{[2]}$ the two-body, $\hat{\tilde{H}}^{[3]}$ the three-body part of the correlated Hamiltonian.

The unitary correlator $\tilde{C} = \tilde{C}_\Omega \tilde{C}_r$ consists of the unitary radial correlator

$$\tilde{C}_r = \exp \left\{ -i \sum_{i < j} \frac{1}{2} \left(s(r_{ij}) \tilde{p}_{rij} + h.a. \right) \right\} \quad (2)$$

and the unitary tensor correlator

$$\tilde{C}_\Omega = \exp \left\{ -i \sum_{i < j} \frac{3}{2} \vartheta(r_{ij}) \left((\vec{\sigma}_i \vec{\tau}_{ij}) (\vec{\sigma}_j \vec{p}_{\Omega ij}) + h.a. \right) \right\}. \quad (3)$$

In the many-body state $\tilde{C}_\Omega \tilde{C}_r |Q\rangle$ the radial correlator \tilde{C}_r shifts all particle pairs (i, j) radially away from each other whenever they are too close, i.e. inside the range of the repulsive core. The strength function $s(r_{ij})$ controls the amount of the radial shift and is optimized to the \tilde{V} under consideration. \tilde{p}_{rij} is the radial component of the relative momentum.

The tensor correlations are induced by \tilde{C}_Ω where the tensor operator in the exponent creates shifts perpendicular to the relative coordinate depending on the spin directions $\vec{\sigma}_i$ and $\vec{\sigma}_j$ of the particles. The operator $\vec{p}_{\Omega ij} = \vec{p}_{ij} - \vec{p}_{rij}$, called orbital relative momentum, is perpendicular to \vec{r}_{ij} and should not be confused with the relative orbital momentum. The r_{ij} -dependent strength of the tensor correlations is controlled by $\vartheta(r_{ij})$ and allows for example to map a purely $l=0$ deuteron wave function onto the exact one which includes an $l=2$ component and thus all tensor correlations.

Fig. 1 shows that in contrast to the bare Bonn-A interaction \tilde{V} the correlated interaction $\hat{\tilde{H}}^{[2]} = \hat{\tilde{H}} - \tilde{T}$ (super-script [2] indicates that only the two-body part of $\hat{\tilde{H}}$ contributes) has much smaller off-diagonal matrix elements,

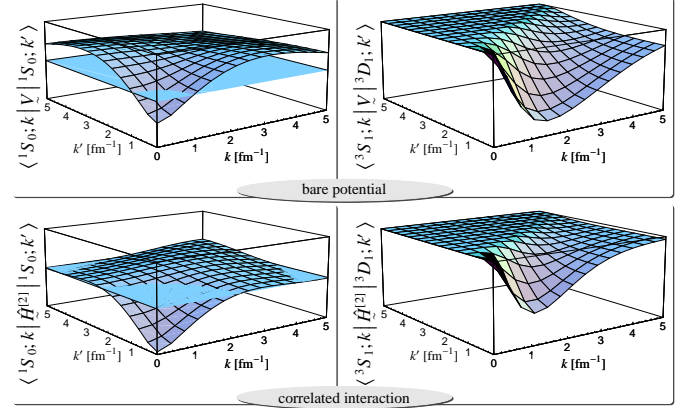


Figure 1: Matrix elements in momentum representation for the uncorrelated and correlated Bonn-A potential. In the 1S_0 channel only C_r is active, while in the 3S_1 channel also the tensor correlator acts. (plane denotes zero, vertical axis ranges from -2 to 2 fm^{-1})

for both, $S=0$ and $S=1$ states. Thus the correlated interaction is pre-diagonalized by the unitary transformation and does not scatter to high momenta any longer.

In Fig. 2 the effect of the correlations on the kinetic and potential energies of three closed shell nuclei is depicted. The correlators cause somewhat higher kinetic energies because the radial and tensor correlations imply more curvature in the wave functions but on the other hand they shape the many-body state such that the NN-interaction can gain the optimal binding and the sum of large positive kinetic plus large negative potential energy adds up to -8 A MeV total binding. Without tensor correlations the tensor force does not contribute to doubly-magic closed shells and all nuclei would be unbound.

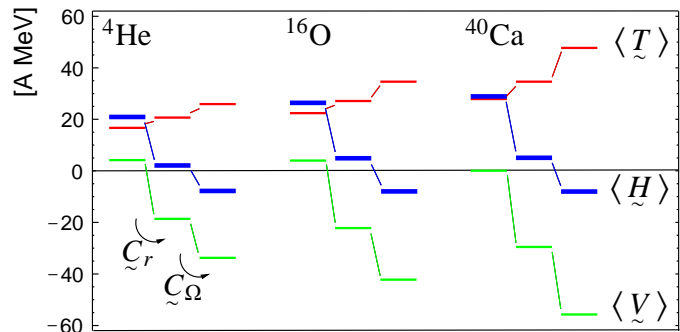


Figure 2: Kinetic, potential and total energies per particle of ${}^4\text{He}$, ${}^{16}\text{O}$ and ${}^{40}\text{Ca}$, without, with radial, and with radial and tensor correlations (Bonn-A).

[1] T. Neff, H. Feldmeier, NP **A713**(2003)311

[2] H. Feldmeier et al., NP **A632**(1998)61

[3] T. Neff, *Short-Ranged Central and Tensor Correlations in Nuclear Many-Body Systems*, PhD thesis, 2001