Ground-State Structure based on Realistic NN-Potentials

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A long standing goal of theoretical nuclear physics is the description of nuclear structure starting from a realistic nucleon-nucleon potential. All realistic NN-interactions show however two characteristics that inhibit a treatment of the many-body problem in a mean-field model. Firstly, the local part of the interaction shows a strong short-range repulsion (the so called *core*) and, secondly, there is a strong tensor part. Both properties give rise to special correlations in the many-body state, which cannot be described by Slater determinants or a superposition of shell model states from a few major shells.

In the framework of the Unitary Correlation Operator Method (UCOM) [1] we describe both types of correlations explicitly by unitary transformations of shell model type many-body states. Thus we obtain states that contain the relevant correlations induced by the interaction between the nucleons.

To describe the short-range correlations caused by the repulsive core of the interaction the unitary correlation operator generates a radial distance-dependent shift in the relative coordinate of each pair of particles. By that the particles are shifted out of the repulsive region of the interaction. Alternatively the correlation operator can be used to transform the Hamilton operator with the bare interaction.

For the correlations induced by the tensor part of the interaction a similar procedure is applied. The new aspect is that tensor interactions correlate coordinate and spin space in a complex way. The unitary transformation, which describes these correlations, acts on the angular part of the relative coordinates in dependence on the spin orientation of the two particles.

As a preliminary step towards a full ab initio calculation on the basis of the central and tensor correlated Bonn-A potential [2] we use a parameterized correction to account for tensor correlations. The core-induced central correlations are fully included by a spin- and isospin-dependent correlation operator [1]. In order to account for tensor correlations we add to the Bonn-A potential a correction in the $S = 1, T = 0$ channel. According to the structure expected for the tensor correlated interaction the correction consists of an additional attractive central potential and a repulsive momentum-dependent part. Three parameters (strength of local correction, and strength and range of momentum part) are adjusted to reproduce the experimental binding energies and charge radii of ^{4}He, ^{16}O, and ^{40}Ca.

Based on this correlated Bonn-A potential the many-body problem is treated in the framework of Fermionic Molecular Dynamics (FMD) [3]. The uncorrelated many-body state is described by a Slater determinant of gaussian one-body states, which contain the mean position, mean momentum, complex width and spin orientation as variational parameters. The ground-state wave function is determined by energy minimization with the correlated interaction.

The Figure shows the ground state one-body density distributions of ^{16}O, ^{20}Ne, and ^{24}Mg obtained with this method. For ^{16}O we find a spherical shell-model like distribution with a characteristic depletion of the central density. ^{20}Ne shows a prolate axially symmetric density distribution with α-like structures at the ends and a toroidal distribution in the central plane. Finally ^{24}Mg exhibits a complicated triaxial deformation with some remnants of α-clustering.

These calculations demonstrate the flexibility of the FMD basis as well as the possibility to perform nuclear structure calculations based on realistic NN-interactions in a nearly ab initio way. Our next step will be the inclusion of tensor correlations in a stringent way by calculating the appropriate unitary correlation operator explicitly.

[1] H. Feldmeier, T. Neff, R. Roth, J. Schnack; Nucl Phys. A632 (1998) 61.

[2] R. Machleidt; Adv. Nucl. Phys. 19 (1989) 189.

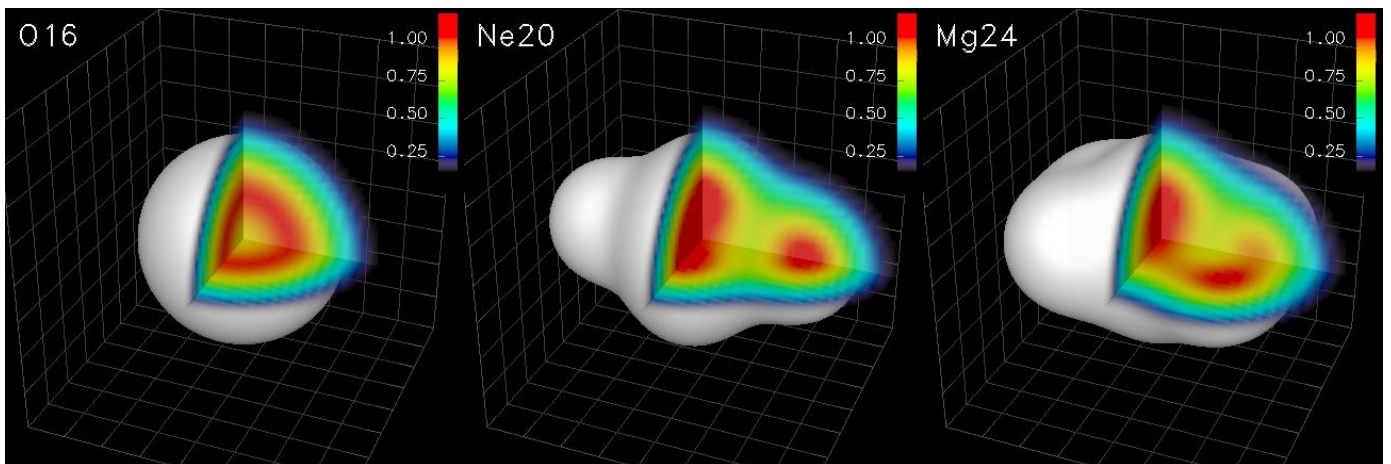[3] H. Feldmeier, J. Schnack; Rev. Mod. Phys. 72 (2000) 655.

Figure 1: One-body density distributions (3-dimensional) of ^{16}O, ^{20}Ne, and ^{24}Mg. The white body shows the iso-density surface corresponding to half nuclear matter density ($\rho_0 = 0.17$fm^{-3}). The embedded planar cuts show the interior density distribution with color coding according to the color bar (in units of ρ_0). The mesh size of the background grid is 1fm $\times$ 1fm. Visit the FMD-Gallery at http://www.gsi.de/~fmd/.