Nuclear Structure within the Fermionic Molecular Dynamics Approach

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The Fermionic Molecular Dynamics (FMD) model has been used successfully for the description of light nuclei in the p- and sd-shell. One important feature is the versatility of the Gaussian single-particle basis that allows to include shell effects as well as clustering and halos.

Hoyle-State

Recently we used the FMD model to study the conjecture that the first excited 0^+ state in ^{12}C (Hoyle state) forms a dilute self-bound gas of α-clusters [1]. The Hoyle state plays a prominent role as a prototype for α-cluster states. Even the most recent no-core shell model calculations fail to describe these states due to insufficient model space sizes. While cluster models have been used for the description of the Hoyle state for a long time [2], they rely on very simple effective interactions and fail to provide a consistent picture with the low lying states.

In our calculation we use the FMD model with an effective nucleon-nucleon force derived from the realistic Argonne V18 interaction by means of the Unitary Correlation Operator Method. A phenomenological two-body correction term is added to account for missing three-body forces. We diagonalize the Hamiltonian in a basis of 42 FMD configurations obtained by Variation after Projection on angular momentum 0^+ with constraints on radii and intrinsic quadrupole deformation and 165 explicit α-cluster configurations. These α-cluster configurations cover the model space of the microscopic α-cluster model. For the ground state we find an overlap of 0.52 with the α-cluster space. This illustrates the importance of shell model like configurations where the α's are broken by the spin-orbit force. The Hoyle state has a much more pronounced α-structure with an overlap of 0.85. To test our wave functions we calculate the densities and form factors for the FMD and also for a microscopic α-cluster model and compare with electron-scattering data in Fig. 1. The FMD results confirm the interpretation of the Hoyle-state as a dilute gas of α-clusters as proposed by the pure α-cluster models.

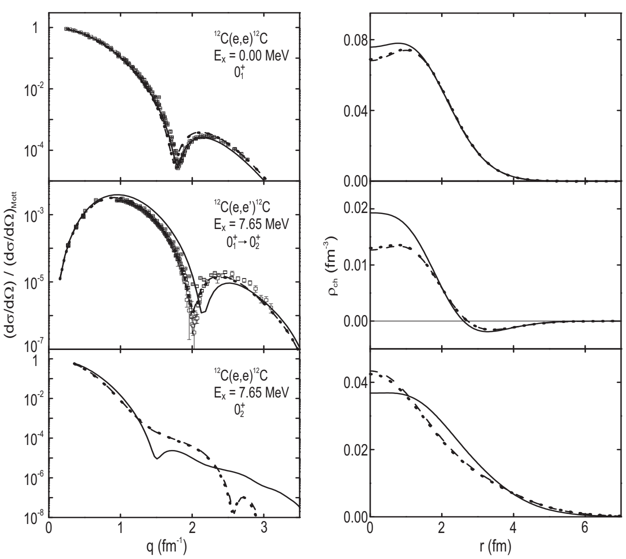

Figure 1: Measured and calculated (FMD solid lines, α-cluster dashed lines) electron scattering cross sections in ^{12}C for the ground state, the transition from the ground into the Hoyle and for the Hoyle state (left). Corresponding charge densities (right).

Isospin degree of freedom

As one of the new developments in FMD the isospin orientations of the nucleons are treated as variational parameters. This allows for intrinsic correlations among spatial, spin, and isospin degrees of freedom, which are mainly induced by the exchange of the pseudoscalar isovector pion. While the short-range part of the tensor correlations is treated explicitly with the Unitary Correlation Operator Method the long-range tensor correlations are incorporated by an intrinsic many-body state which breaks parity and charge number. In the calculation the variation of the single-particle degrees of freedom is done after restoring the symmetries by projecting on parity, total spin and charge number. The non-vanishing spin- and isospin vector-densities of the intrinsic state (see Fig. 2) illustrate the presence of the virtual pion field.

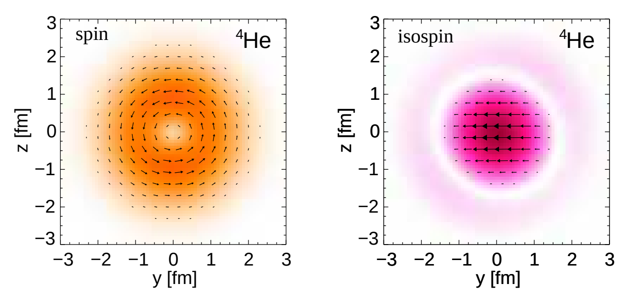

Figure 2: Spin- and isospin-density in ^{4}He. Arrows denote projections on the yz-plane while colour coding is according to absolute values.

References

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