Towards a microscopic description of nuclear reactions

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Low-energy nuclear reactions play an important role in many astrophysical scenarios. In many cases experimental data are not available at the energies important for the astrophysical processes. From the theory perspective such reactions have been investigated mainly with cluster models [1]. These models suffer from very simplified effective interactions and rather restricted model spaces for the interaction region. Nowadays *ab-initio* methods are actively pursued. Within the no-core shell model or the Green's Function Monte Carlo Method the same realistic two- and three-body forces can be used for the structure and the reaction calculations. However in both approaches the description of the asymptotic region is a very challenging problem.

With the Fermionic Molecular Dynamics (FMD) model we aim at a consistent description of bound states, resonances and scattering states starting from realistic nucleon-nucleon interactions. The important short-range central and tensor correlations are treated explicitly with the Unitary Correlation Operator Method, providing an effective low-momentum interaction. As no explicit three-body forces are included up to now and due to limitations of the FMD model space an empirical correction term is added to the two-body force.

In the FMD the many-body basis is constructed with Slater determinants of Gaussian wave packets that are projected on angular momentum and total linear momentum to restore the symmetries of the Hamiltonian. For the description of the asymptotic scattering states FMD ground states are joined taking the distance as generator coordinate. To obtain resonance or scattering solutions appropriate boundary conditions have to be included. In the many-body approach of FMD this is not a trivial problem and a new method utilizing a Collective Coordinate approach has been developed.

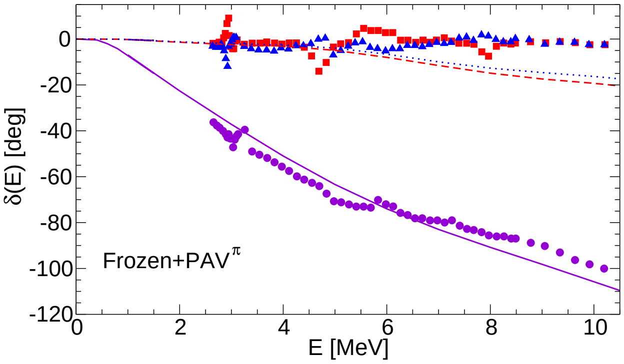

Figure 1: Phase shifts for the positive parity states ($1/2^+$, $3/2^+$ and $5/2^+$ correspond to solid, dashed and dotted lines, respectively) in the ^{3}He-α elastic scattering and comparison with experiment.

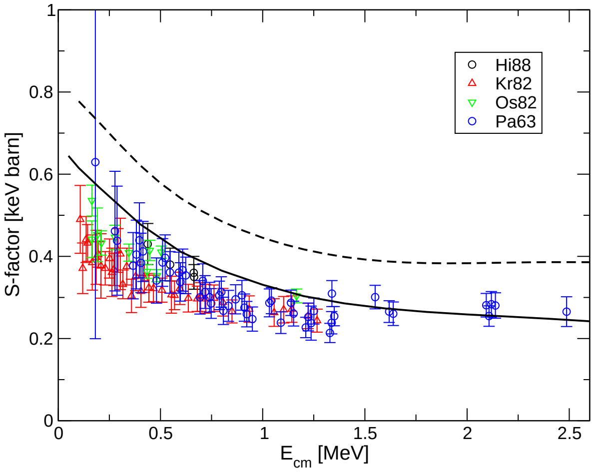

Figure 2: Astrophysical S-factor for $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$. In the interaction region one configuration (dashed line) or two configurations (solid line) have been added to the antisymmetrized channel states $\mathcal{A}\left|^3\mathrm{He}\right\rangle \otimes \left|^4\mathrm{He}\right\rangle$ to improve the $3/2^-$ and $1/2^-$ bound states.

The $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ *reaction*

In this reaction the ^{3}He and ^{4}He nuclei are captured from positive parity scattering states into the $3/2^-$ and $1/2^-$ bound states. In the FMD approach we use multiconfiguration FMD states for the ^{3}He and ^{4}He nuclei. For the ^{7}Be bound states two configurations obtained in a variation after angular momentum projection calculation or alternatively a single configuration obtained in a variation after parity projection procedure is used. A small fine-tuning of the interaction is necessary to reproduce the essential threshold energies. The calculated phase shifts agree very well with experimental data (see Fig. 1). With the many-body scattering solutions and the bound states, both obtained as eigenstates of the same many-body Hamiltonian, the capture cross section is calculated. As can be seen in Fig. 2 the energy dependence of the cross section is correctly reproduced. Also the branching ratio to $3/2^-$ and $1/2^-$ agrees with experimental data. Improvements in the description in the interaction region bring the normalization of the cross section closer to the data. Further improvements are under investigation.

References

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