# Resonances, Scattering and Bound States in Fermionic Molecular Dynamics

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Radiative capture reactions like $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ play an important role in astrophysical scenarios. Experimental data are usually only available for higher energies and the extrapolation to the low energies relevant in astrophysical environments may be problematic. Theoretical calculations in the framework of microscopic cluster models [1] suffer from poor effective interactions and restricted cluster wave functions. Furthermore it is difficult to include configurations that are not of cluster nature but that are necessary to get a good description of the $^7\mathrm{Be}$ bound states.

We aim at using the Fermionic Molecular Dynamics (FMD) model to calculate such reactions. The FMD has been used successfully to describe the properties of nuclei in the $p$- and $sd$-shell [2] using an effective interaction that is derived from realistic nucleon-nucleon interactions by explicitly introducing short-range central and tensor correlations in the Unitary Correlation Operator Method (UCOM) [3]. The FMD wave functions use Gaussian wavepackets that are localized in phase space – cluster configurations can therefore be included naturally in the FMD model space. At small distances the clusters will loose their identity and we use FMD configurations that are obtained by minimizing the energy with respect to the parameters of all the individual nucleons. For larger distances the cluster configurations will become important and asymptotically the system can by described as a system of two point-like clusters. Outside the rang of the nuclear interaction the wave function has then to be matched to a Whittaker function (bound states) or a Coulomb wave function (resonances or scattering states).

This matching is not a trivial procedure as the Slater determinants used in the FMD description couple the relative motion of the clusters with the internal degrees of freedom of the clusters and the center of mass motion. If the same Gaussian width (the same oscillator parameter) is used for all wave functions the center-of-mass motion factorizes and an analytical deconvolution for the relative motion can be done. For the FMD this is not possible and a Collective-Coordinate Representation has been developed [4]. The center-of-mass problem is solved by explicit projection on total linear momentum. The deconvolution of the relative motion is done with the help of *localized states*. These are the eigenstates of the $r^2$ operator and asymptotically they can be matched to systems of point-like clusters whose distances are related to the eigenvalues.

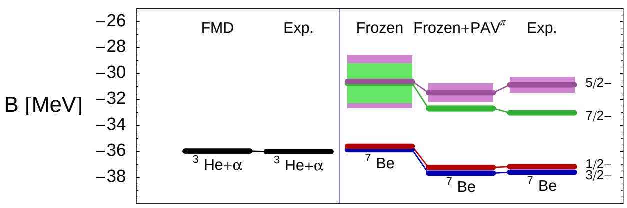


Figure 1: Calculated and experimental threshold energies (left). Bound State energies, resonance energies and widths obtained using only cluster configurations (Frozen) and an additional FMD (PAV$^\pi$) state (right).

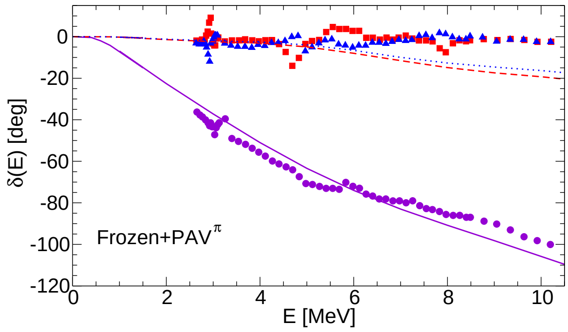


Figure 2: Phase shifts for the positive parity states ($1/2^+$, $3/2^+$ and $5/2^+$ correspond to solid, dashed and dotted lines, respectively) in the $^3\mathrm{He}$-$\alpha$ elastic scattering and comparison with experiment.

In Fig. 1 we show the results for the negative parity bound states and resonances. To reproduce the threshold energy quite sophisticated wave functions for the clusters have to be used. Linear combinations of Slater determinants and the use of two Gaussians of different width for each single-particle state are necessary for a good description especially of $^3\mathrm{He}$.

We depict the phase shifts for positive parity states in Fig. 2. A good agreement of this fully microscopic model with experiment is observed. With the inclusion of the dipole transition operator we will be able to calculate the reaction rates.

## References

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