Microscopic description of the ^{12}C continuum

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The structure of ^{12}C above the three-α threshold poses a challenge for nuclear theory. The ground state band can be well described in the no-core shell model using a harmonic oscillator single-particle basis. However, many of the states in the continuum have a well developed cluster structure, and these states are completely missing in the no-core shell model. Microscopic cluster models have been able to reproduce many properties of these continuum states. On the other hand, the cluster model is an idealization. Experimentally Gamow-Teller as well as $M1$ and $E1$ transitions into continuum states can be observed. Within a cluster model such transitions are forbidden, indicating that for a full picture both shell and cluster structure have to be included in a theoretical description.

Fermionic molecular dynamics (FMD) is a microscopic many-body approach that uses Slater determinants built from Gaussian wave-packets as intrinsic basis states [1]. It contains both harmonic oscillator shell model states and Brink-type cluster configurations as limiting cases and is therefore well suited to study the structure of ^{12}C. Previous FMD calculations [2] treated states in the continuum in a bound-state approximation. This might be justified for the very narrow Hoyle state but is certainly very unreliable for the broad resonances observed higher up in energy.

To address these questions we extended our approach with a proper treatment of the continuum. We first performed a study within the microscopic α-cluster model with full antisymmetrization and a phenomenological two-body interaction [3]. In the internal region the Hilbert space is here built from three-α configurations on a triangular grid. In the external region ^{8}Be-^{4}He configurations are added. Recently we also added the continuum to the full FMD calculation. Here basis states in the internal region have been obtained using variation after projection on angular momentum and parity. For each spin we first vary the parameters of the many-body state to obtain the lowest possible energy. A second basis state is then obtained by minimizing the energy of the second state with respect to its parameters keeping the first state fixed. We further increase the model space by using the radius of the intrinsic states as generator coordinates. The ^{8}Be clusters are obtained by diagonalization in a basis of FMD states and of α-α configurations, treating them as pseudostates. We include two 0+, two 2+ and a 4+ state for ^{8}Be. The microscopic R-matrix method is used to match the microscopic wave functions in the internal region to the asymptotic behavior described by point-like ^{8}Be- and α-clusters. For bound states the asymptotics is given by Whittaker functions, for resonances we match to purely outgoing Coulomb wavefunctions. The energies then become complex, with the real part giving the resonance position and the imaginary part the resonance width. We can also obtain scattering states with real energies by matching to linear combinations of incoming and outgoing Coulomb wave functions which provides the full scattering matrix.

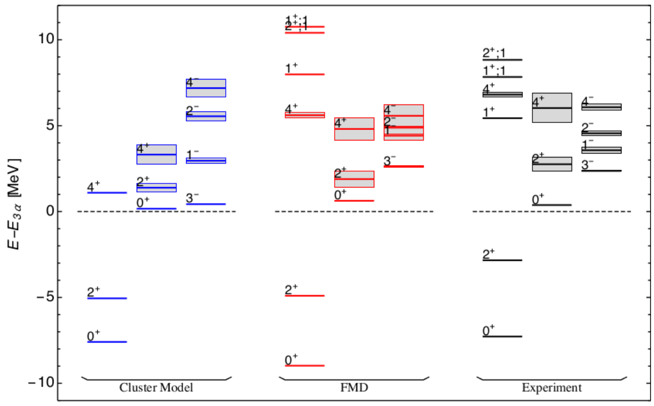

Figure 1: ^{12}C energy spectra obtained within a microscopic cluster model, fermionic molecular dynamics (FMD) compared with experiment. Energies are given with respect to the 3-α threshold. Resonance widths are indicated by gray bars.

In Fig. 1 we show the spectra containing bound states and resonances obtained with the microscopic cluster model and with FMD. The cluster model can not describe spin-flip states like the 1^+ states or the 2^+ (T=1) state. The FMD calculations show in general a good agreement with experimental observations. For example we obtain the 4^+ from the ground state band, the 4^+ state of the Hoyle state band and the 4^- at roughly the same energy, in good agreement with experiment. Future studies will focus on transitions into the continuum. Apart from the monopole strength investigated in [2], recent experiments studied transitions into the second 2^+ state and the 1^- state. Also Gamow-Teller transitions from ^{12}B and ^{12}N and electromagnetic transitions from the 2^+ (T=1) state into the ^{12}C continuum have been measured carefully.

References

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