

FMD Multiconfiguration Calculations for ^8Be

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The nucleus ^8Be is unbound at an energy slightly above that of two ^4He nuclei. As one finds in the cross section of $^4\text{He} - ^4\text{He}$ scattering very sharp resonances that form a rotational band it is generally believed that ^8Be is a nuclear molecule rather than a p -shell nucleus with 4 nucleons in the $p_{3/2}$ shell. In order to test the correlated interaction that we derived from the realistic Bonn-A Potential [1,2] we treated this nucleus in a multiconfiguration calculation using Fermionic Molecular Dynamics (FMD) [3] many-body states.

The effective Hamiltonian H^{eff} consists of the correlated Bonn-A potential $\hat{H} = C^\dagger H C$ minus the center of mass kinetic energy plus a small momentum dependent correction V_{corr} that is supposed to correct for missing three-body parts in the correlated Hamiltonian as well as genuine three-body forces. Its parameters have been adjusted to reproduce the ground state energies and radii of ^4He , ^{16}O and ^{40}Ca .

First the energy $\langle Q | H^{eff} | Q \rangle$ is minimized with respect to all FMD parameters of the single-particle states that make up the Slater determinant

$$|Q\rangle = \mathcal{A} \{ |q_1\rangle \otimes \dots \otimes |q_8\rangle \} . \quad (1)$$

The one-body density distribution of the resulting eight-particle state $|Q\rangle$ is depicted in Fig. 1 (shape in upper right corner). As expected the intrinsic state of ^8Be consists of two loosely connected ^4He nuclei. The intrinsic energy $\langle Q | H^{eff} | Q \rangle$ is -45.6 MeV (see also Fig. 2).

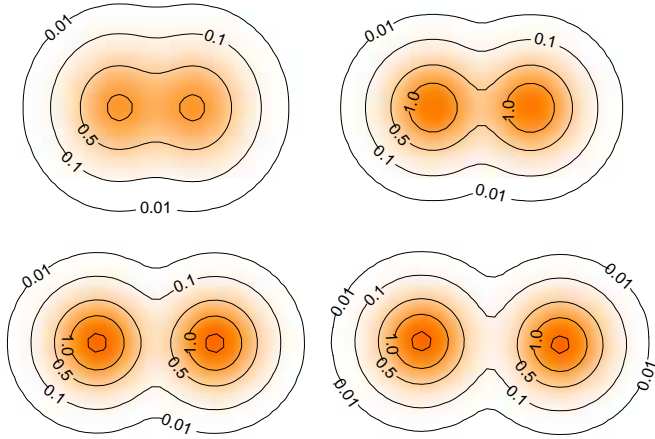


Figure 1: One-body density of collective vibrational excitations at four different elongations. (Cut at $z = 0$, unit $\rho_0 = 0.17\text{fm}^{-3}$). Upper right shape depicts intrinsic state. Other three shapes are obtained by minimizing energy under constraints on rms-radius.

Like an atomic dimer ^8Be is able to rotate and vibrate. The first collective motion results in a rotational spectrum with level spacings reflecting the moment of inertia. In order to test this property we take the intrinsic state $|Q\rangle$

and create 128 many-body-states $|Q^{(i)}\rangle$ by rotations into randomly chosen directions in three-dimensional space. This nonorthogonal set spans a subspace of the Hilbert space in which we diagonalize the Hamiltonian:

$$\sum_j \langle Q^{(i)} | H^{eff} | Q^{(j)} \rangle c_j^\alpha = E^\alpha \sum_j \langle Q^{(i)} | Q^{(j)} \rangle c_j^\alpha . \quad (2)$$

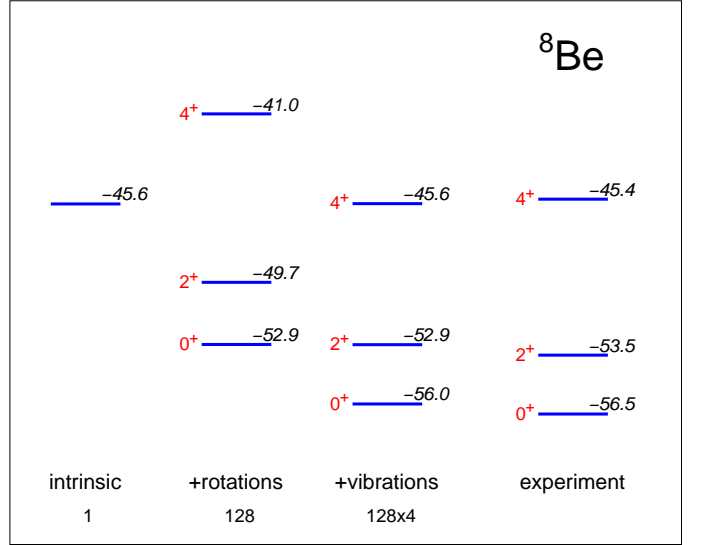


Figure 2: Level scheme of ^8Be : intrinsic energy $\langle Q | H^{eff} | Q \rangle$; eigenvalues of H^{eff} in space of 128 rotated intrinsic states; in space spanned by the four representatives of vibrations depicted in Fig. 1, each rotated 128 times; experiment (units in MeV)

The resulting lowest eigenvalues E^α belonging to states with spin 0^+ , 2^+ and 4^+ are indicated in the second column of Fig. 2. If the system were a rigid rotor the ratio of the transition energies $4^+ \rightarrow 2^+$ to $2^+ \rightarrow 0^+$ should be 3 instead of the obtained 2.7. One expects it to be even smaller because the moment of inertia increases with higher angular momentum, the system getting stretched under the influence of the centrifugal forces.

When we include vibrational collective degrees of freedom by means of one squeezed and two stretched configurations, as depicted in Fig. 1, all of them rotated in 128 directions, we obtain as eigenvalues of the correlated Hamiltonian the spectrum in the third column with a ratio of 2.3, that compares nicely with the measured energies.

This result indicates that, both macroscopic properties, the moment of inertia and the strength of the force between the two ^4He nuclei are described well by the central and tensor correlated Bonn potential.

- [1] T. Neff, H. Feldmeier, *NP A713(2003)311*
- [2] H. Feldmeier et al., *NP A632(1998)61*
- [3] H. Feldmeier, J. Schnack, *Rev.Mod.Phys. 72(2000)655*