Describing core excitation in the scattering of halo nuclei using a Transformed Harmonic Oscillator (THO) basis

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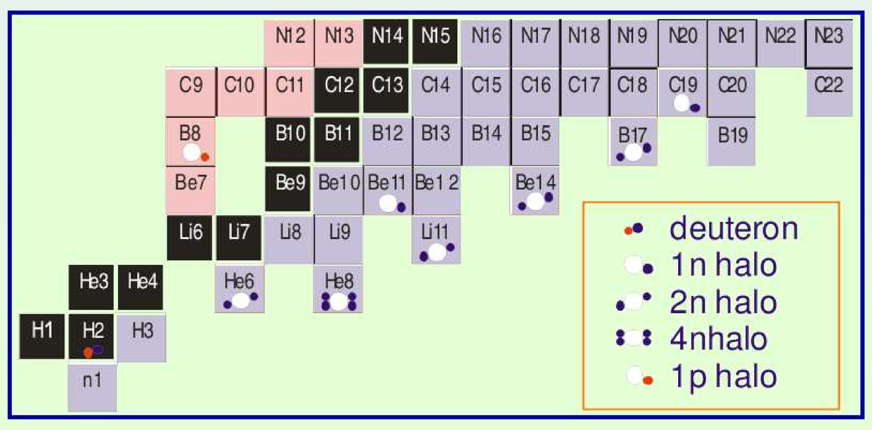
ABSTRACT

The continuum of a two-body system with core excitations is studied using a recently developed basis of square-integrable states. The basis has been applied to describe the projectile continuum in the ^{11}Be scattering by a ^{208}Pb target at 69 MeV/nucleon. The excitation of the ^{10}Be core is found to be important to improve the agreement with the available experimental data for this reaction.

1 Introduction

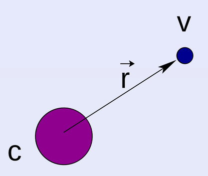
During the last few years, the study of reactions involving loosely bound exotic nuclei has been one of the most active fields in Nuclear Physics. These reactions are known to be strongly influenced by the coupling to the unbound states. Beryllium and Carbon isotopes belong to a heavy deformed region. This fact affects to their continuum structure and, therefore, to reactions with these nuclei.



2 Discrete representation of the Continuum

2.1 2-body projectile in a Pseudo-States (PS) basis

In a pure single particle model, the projectile Hamiltonian is:



$$\mathcal{H}_{s.p.} = T_v(r) + V_{cv}(r) \quad (1)$$

The wave functions describing the internal motion of the projectile are obtained as the eigenstates of the projectile Hamiltonian in a truncated basis of square-integrable functions.
By diagonalizing the Hamiltonian we obtain a set of eigenfunctions:

$$|\varphi^{(N)}_{n,\ell}\rangle = \sum^N C^n_i |\phi_{i,\ell}(r)\rangle.$$

The energy of these states would be:

$$\varepsilon_i = \begin{cases} \varepsilon_i < 0 & \Rightarrow \quad \text{Bound States} \\ \varepsilon_i > 0 & \Rightarrow \quad \text{States representing the Continium} \end{cases}$$

one eigenstate for each bound state and the rest, up to N, conform a discrete representation of the continuum.

2.2 The THO basis

In principle any complete basis would be able to reproduce the continuum. However, a suitable selection of the set of functions will reduce this number simplifying scattering calculations. In this case we investigate a PS method based on the application of a Local Scale Transformation (LST) to the Harmonic Oscillator (HO) basis, giving rise to the so-called Transformed Harmonic Oscillator (THO) basis. Specifically, for the LST we adopted the parametric form of Ref. [1]:

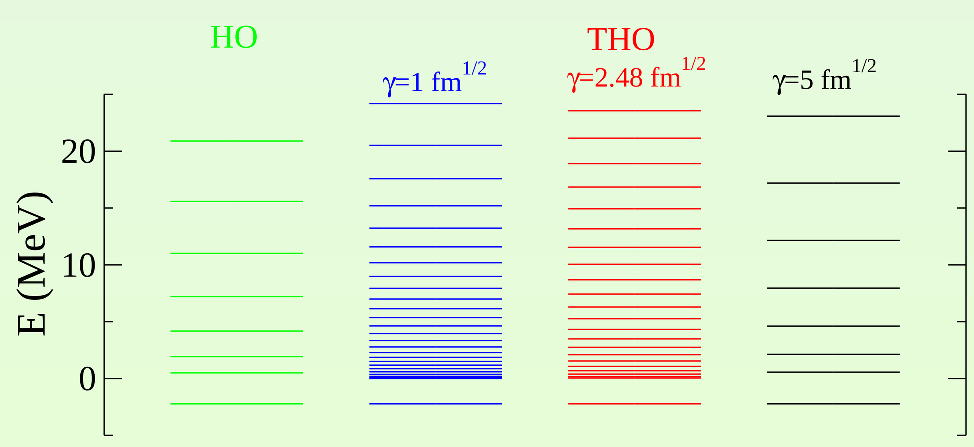
$$s(r) = \frac{1}{\sqrt{2}b}\left[\frac{1}{\left(\frac{1}{r}\right)^m + \left(\frac{1}{\gamma\sqrt{r}}\right)^m}\right]^{\frac{1}{m}}. \quad (2)$$

This transformation change the asymptotic behaviour from Gaussian to exponential decay:

$$\text{HO basis} \quad \Longrightarrow \quad \phi[s] \longmapsto e^{-\frac{s^2}{b^2}}$$

$$\text{THO basis} \quad \Longrightarrow \quad \phi[s(r)] \longmapsto e^{-\frac{\gamma^2}{2b^2}r}$$

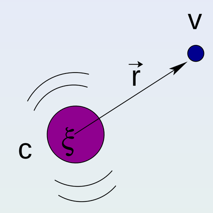
⇒ γ/b determines the density of PS [2, 3]



⇒ An appropriate choice of γ tailors the basis to the dynamical conditions of the reaction

3 Including Core Excitations

In order to include core excitations, we should consider a new Hamiltonian like:



$$\mathcal{H} = T_v(r) + h_{core}(\vec{\xi}) + V_{cv}(\vec{r},\vec{\xi}), \quad (3)$$

with general solution:

$$\Psi^{JM}(\vec{r},\vec{\xi}) = \sum_\alpha R_\alpha(r)\left[\mathcal{Y}_{\ell sjm}(\hat{r}) \otimes \phi_I(\vec{\xi})\right]_{JM} \quad (4)$$

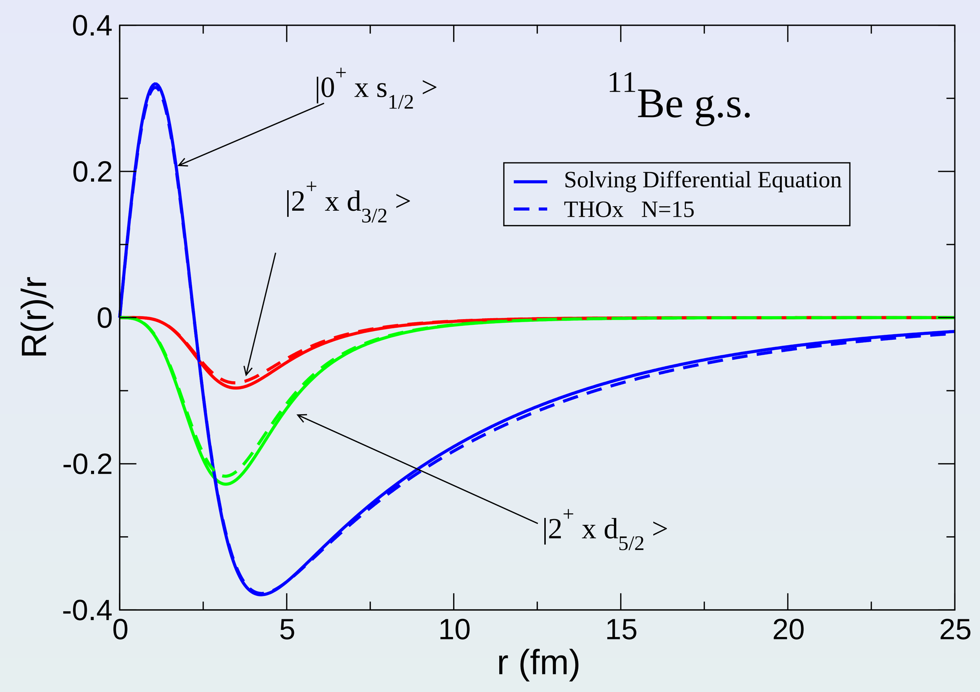
⇒ Mixture of different valence configurations & core states

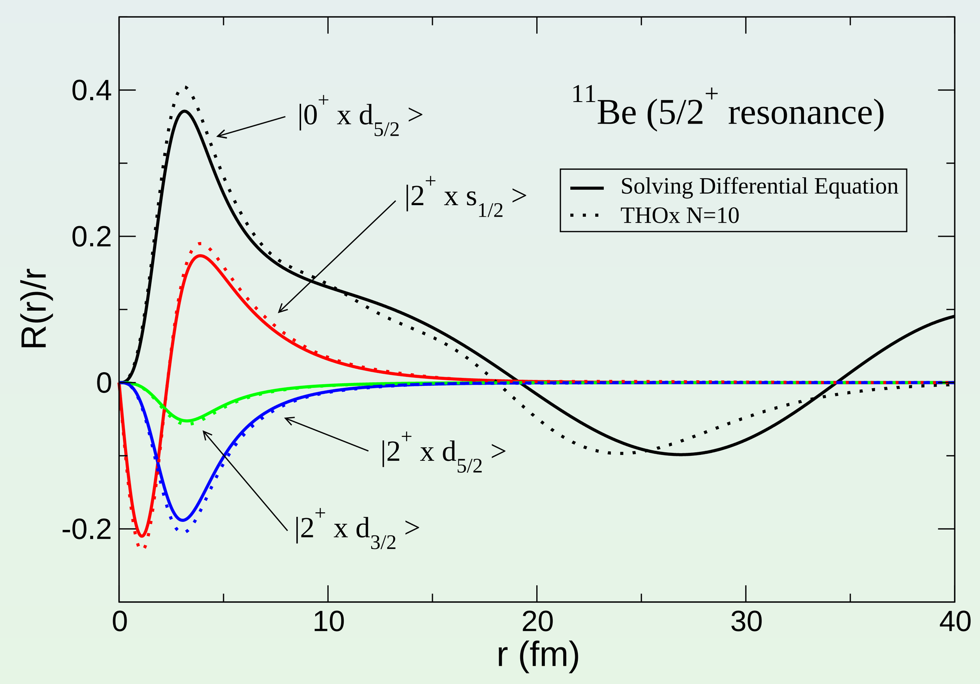
⇒ Core excitations driven by $V_{cv}(\vec{r},\vec{\xi})$

The interaction between core and valence is obtained within a particle-rotor model (deformed core) although the formalism is similar for vibrating cores or any microscopic description of the core excitations.

4 Application to ^{11}Be Structure

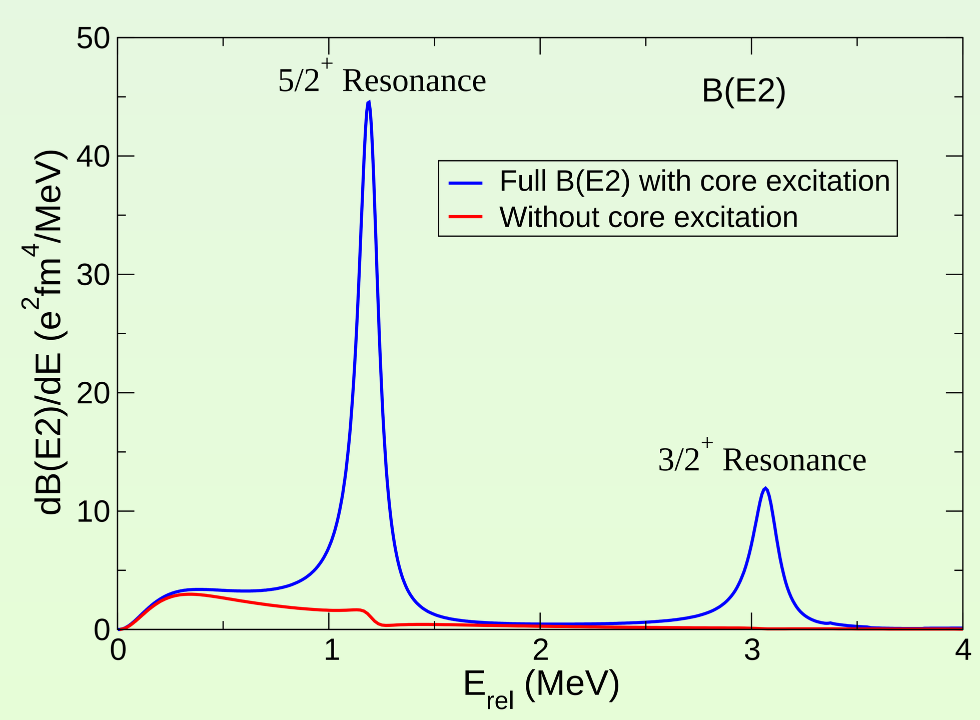
Here it is described the halo nuclei ^{11}Be as ^{10}Be+n including excitations within the ground and first excited states of the core (^{10}Be 0^+ and 2^+ states). We use the interaction V_{vc} from [4] to reproduce ^{11}Be continuum structure. This potential considers a quadrupole deformation parameter $\beta_2 = 0.67$ for ^{10}Be. By looking at ^{11}Be bound state and $5/2^+$ resonance in this model we find:





⇒ Bound States and Resonances appear naturally with a reduced THO basis

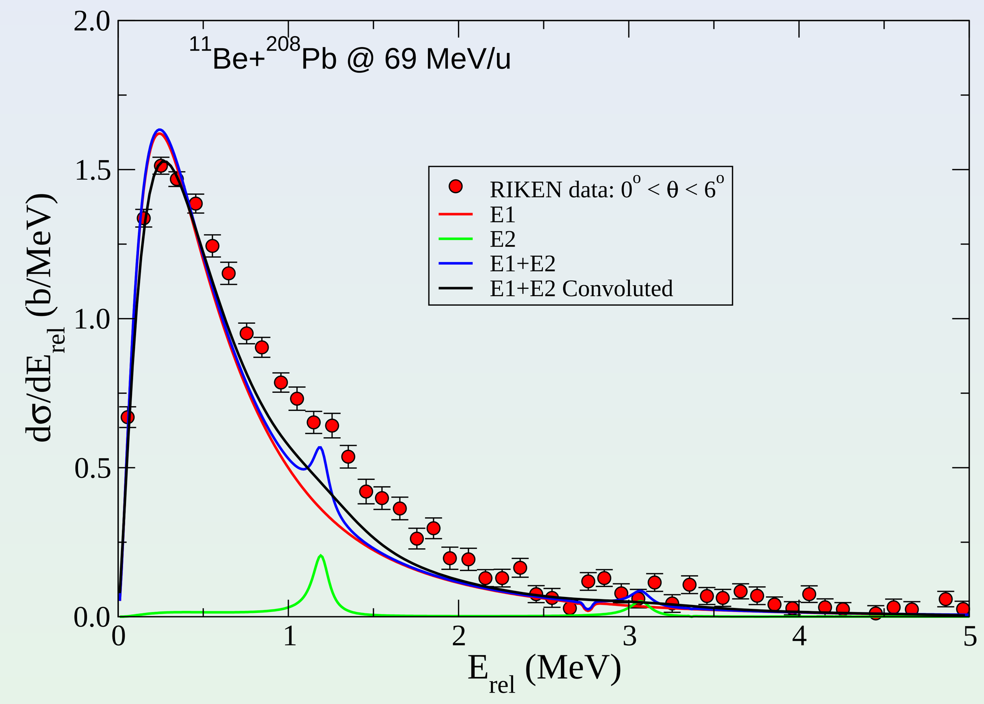
Looking at the quadrupole electric transition probability B(E2):

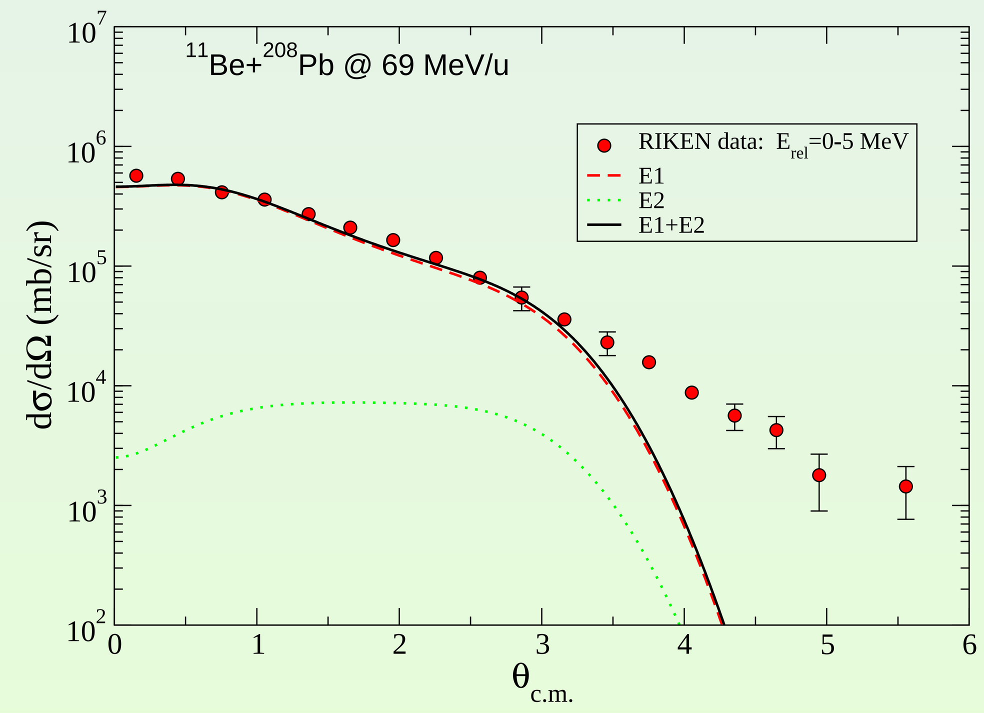


⇒ B(E2) dominated by collective excitation of the ^{10}Be core

5 Application to ^{11}Be+^{208}Pb reaction

We have applied the THO method for the discretization of the continuum of ^{11}Be to describe the ^{11}Be scattering by a ^{208}Pb target at 69 MeV/nucleon within the Equivalent Photon Method [5]. Only direct dipole and quadrupole Coulomb break-up is considered in this model. We compare with the experimental data from RIKEN [6]. In the pictures below we can see the energy and angular distribution of the break-up:





⇒ Excitation of the core is important to understand the data in the region of the $5/2^+$ resonance

6 Summary and conclusions

We have shown how the PS method with THO functions provides a suitable discrete description of the continuum of a two-body system including possible excitations of the core.

1. The THO method provides a natural treatment of resonances.
2. The importance of the core excited states in the Halo nuclei ^{11}Be calls for the application of this method to other deformed core systems like ^{19}C.
3. Generalization of more complex reaction mechanisms such as CDCC to include this halo nuclei structure is in progress

In conclusion, the THO method is an accurate option to describe the structure of loosely bound nuclei with deformed core [7]. The reduction of the number of functions needed to reproduce the structure of the projectile will be crucial in more complex reaction mechanisms.

References

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