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Study of ^{9}Li-alpha cluster states in ^{13}B using the resonant scattering method

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In order to investigate the compound nucleus ^{13}B, the excitation function of the resonant reaction ^{4}He(^{9}Li,α) was measured. This measurement was carried out using the thick target inverse kinematics scattering technique, with a thick ^{4}He gas target and a ^{9}Li beam. The ^{13}B energy region explored was in the excitation energy range 14 - 20 MeV, where ^{9}Li-α configurations of ^{13}B are predicted. The measured excitation function at $\theta_{c.m.}$=180° shows different clear structures in a ^{13}B excitation energy region which was experimentally unknown.

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1. Introduction

Cluster structure is a feature present in many light nuclei. Generally, these cluster structures have the following common characteristics: i) the cluster nucleus is formed by a strong bound nucleus, typically an alpha particle; ii) the inter-cluster interaction is weak enough to preserve the identity of the clusters; iii) the cluster structure is absent in most ground states and that cluster states are to be found at excitation energies near to the separation energy of the clusters. The latter is the so-called *threshold rule* and it is represented by the Ikeda diagram (see Fig. 1), in which when the excitation energy of a nucleus increases, more break-up channels are opened and, therefore, different cluster configuration appear.

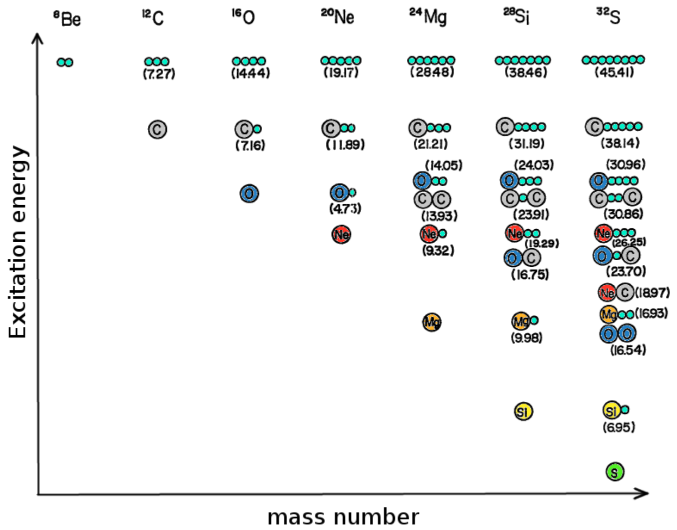

Figure 1: The Ikeda diagram (taken from Ref. [1]) shows the evolution of the cluster degree of freedom with the excitation energy. The cluster degree of freedom shows up close to a cluster decay threshold.

Also non-alpha-conjugate nuclei may present a cluster structure; examples are ^{6}Li and ^{7}Li with α-d and α-t pronounced structure in their ground state. The presence of the cluster configuration in the ground state of these nuclei is related to their very low binding energy, close to the cluster decay threshold.

Light radioactive nuclei may show a different configuration where the stiff cluster is replaced by a soft particle, deformed and easy to break-up. This is the so-called "exotic clustering" that is expected to become more and more favored when nuclei approach the drip-line [2]. From the experimental point of view, there are few observations of exotic clustering, since radioactive beams of low intensity are very often needed for this type of researches. One of the most studied system is the ^{12}Be nucleus for which very different conclusion on the existence of a rotational band associated with the ^{6}He-^{6}He cluster configuration have been drawn [3, 4, 5].

The possible existence of exotic clustering of Li-He type in neutron-rich Boron isotopes have been predicted by both, Antisymmetrized Molecular Dynamics (AMD) [6] and Generator Coordinate Method (GCM) [8] calculations. In the AMD approach, at variance with microscopic cluster models, there are no assumptions made about the presence of cluster configurations. In the AMD framework, basis wave functions of the system are given by Slater determinants where the spatial

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part of each single-particle wave function is a Gaussian wave packet. One of the characteristics of AMD is the flexibility of the wave function which can represent various clustering structures and shell-model-like structures, which is because no inert cores and no clusters are assumed. The ^{13}B nucleus, due to its N=8 neutron shell closure, shows mainly single particle characteristics in its ground state. However, different types of cluster configurations are predicted by AMD in the excited states. Along with a largely deformed configuration (larger than superdeformation), ^{4}He-^{9}Li type structures are foreseen. According to the threshold rule, He-Li configuration are to be searched in the excitation energy region above 11 MeV that is the corresponding decay threshold. A ^{4}He-^{9}Li K^{π}=1/2^{-} band is predicted by AMD, with a band head around 10-13 MeV and excitation energies up to about 20 MeV [7]. A mixing of both, the largely deformed configuration mentioned above and the ^{9}Li-α cluster configuration for the higher spin states constitute the rotational band K^{π}=1/2^{+}.The ^{13}B excitation energy region where these states are predicted is totally unknown experimentally.
With the aim of investigating the existence of ^{9}Li-α structures in ^{13}B, we studied the excitation function for the ^{4}He(^{9}Li,α) elastic scattering process. In this paper the experiment ^{9}Li+^{4}He at E_{lab} = 32 MeV performed at TRIUMF (Canada) will be presented and preliminary results of the ^{13}B excitation function in the region 14 MeV $\leq E_x \leq$ 20 MeV will be shown.

2. Experimental technique and set-up

To study experimentally the ^{9}Li-α cluster states in ^{13}B we have used the thick target inverse kinematics scattering method. This technique consists in sending the beam into a reaction chamber filled with the gas (typically hydrogen or helium) at such a pressure to fully stop the beam. The gas acts at the same time as target and as degrader of the beam energy. The interaction between the projectiles and the target nuclei can occur at different positions of the target along the beam direction, and thus at different energies. Thanks to the different stopping power of the gas for heavy projectiles and light recoils, the recoil particles can reach the detector placed on the opposite end of the chamber with respect to the entrance window. From the measurement of the recoil energy and detection angle one can deduce the emission angle and the impact position along the beam direction and thus the energy of the scattering event. This method permits to measure a wide energy range with a single beam energy and to measure at zero degree, which is the best condition to study resonances in the elastic scattering. Therefore, this technique is particularly suitable when one wants to measure elastic scattering excitation function with radioactive beams since it allows to dramatically reduce the beam time request with respect to the direct kinematics and the thin target technique.

The resonant scattering experiment was carried out at TRIUMF laboratory using a ^{9}Li beam at 32 MeV delivered by the ISAC-II facility. The target consisted of the TUDA chamber filled with a pure ^{4}He gas at such pressures to fully stop the beam (650 and 680 Torr). In order to separate the chamber from the high vacuum line, a kapton window $\sim$ 12 μm thick was used. Alpha particles were detected by three ΔE-E silicon telescopes. Each ΔE was a 50x50 mm^{2}, 50 μm thick four quadrant silicon detector, and each residual energy detector was a 50x50 mm^{2}, 1000 μm thick silicon pad. One of the telescopes (T1) was placed around 0° and a second one (T2) next to it downstream the TUDA chamber. A third telescope (T3) was placed at about half the distance

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from the window of the other two telescopes. Additionally, a micro-channel plate (MCP) detector was positioned before the entrance of the chamber, in vacuum, in order to provide the Time of Flight (ToF) measurement and to count the current of the beam, necessary for the cross-section normalization. In Fig. 2, a sketch of the experimental set-up is presented.

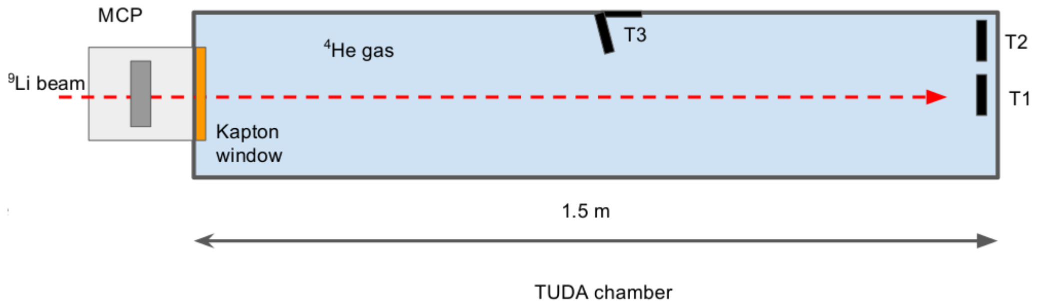

Figure 2: Sketch of the experimental set-up.

3. Results

Elastically scattered α particles were detected and discriminated from other reaction processes using both ΔE-E and ToF techniques.

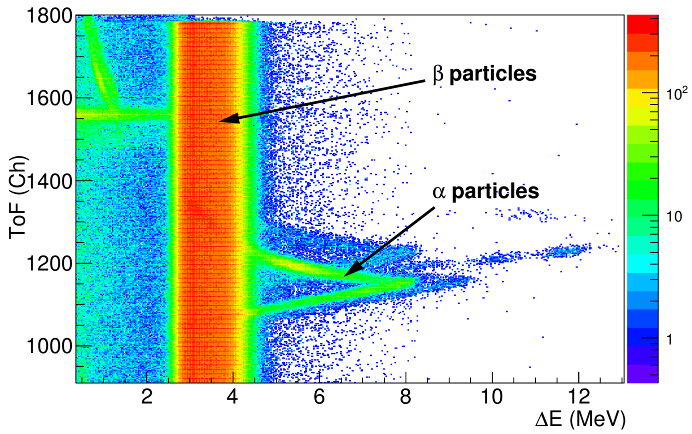

Figure 3: Time of Flight versus ΔE energy 2-D spectrum for a detector placed at 0°. The ToF corresponds to the sum of the Time of Flight of the beam before interacting with the target plus the Time of Flight of the recoiling α particles. Background events, uncorrelated in time, coming from the ^{9}Li radioactive decay can be observed.

In Fig. 3, the time of flight as a function of the ΔE energy for the detector T1, positioned around 0°, is represented. A large β background coming from the radioactive decay of the ^{9}Li beam was detected. Due to the background, the events of interest could be selected with a center of mass energy threshold of $\sim$ 4 MeV. In Fig. 4, the bi-dimensional diagram ΔE versus E residual of the detector T1 is shown. In this figure it is possible to observe the β background due to the large angle scattered β particles that can deposit large energies in the silicon detector.

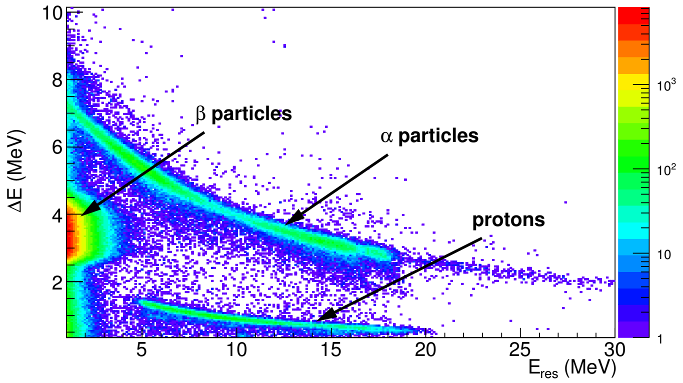

Figure 4: ΔE versus E_{res} 2D-spectrum. Alpha particles, protons and background beta particles are observed.

From the energy deposited in the telescope system and the angles of the recoil α particles, the center of mass energy spectra were obtained. In the case of the elastic scattering process, the energy and angle of the recoil are related to the position in the target at which the scattering process occurs, via kinematics and energy loss calculations of the beam and recoil particles. For events with energy enough to punching through the ΔE detectors, the total energy (E_{tot}=ΔE+E_{res}) was reconstructed. These events were corrected for the energy loss in the dead layers of the detectors and in the gas between the two detectors of the telescope. In figure 5, the excitation energy of ^{13}B is represented, this was obtained from the $E_{c.m.}$ spectrum by adding the two-body Q_{val} and it is shown in figure 5.

At least two large peaks at excitation energies of $\sim$ 16.3 and 19.5 MeV, are observed in figure 5. The observed asymmetry of the peak at 19.5 MeV suggests that it could be originated from the superposition of more states. Preliminary information obtained on the other detectors, placed at different angles, indicates that at least three peaks are contributing to this large structure. The data analysis of the detector T2 and T3 are still in progress. A theoretical analysis of the full experimental data is required in order to determinate if the nature of the observed peaks in the ^{13}B excitation function correspond to the ^{9}Li-α cluster structure as predicted by AMD calculations [7].

4. Conclusions

Preliminary results of the resonant elastic scattering ^{4}He(^{9}Li, α) experiment performed at TRIUMF laboratory have been presented. The excitation function of ^{13}B nucleus measured at $\sim$ 180° in the center of mass framework presents two well defined large structures, which could be due to the superposition of more than two states. This result seems to be in agreement with the AMD calculations performed in Ref. [7], where the ^{9}Li-^{4}He cluster configurations are predicted at excitation energies above the break-up threshold of ^{13}B into ^{9}Li-^{4}He that is 10.8 MeV. The full analysis of the experimental data is being completed in order to provide more information about the excitation function of ^{13}B at the measured angles different from $\theta_{c.m.} \sim$ 180°. Finally, the theoretical analysis will help to understand the exotic cluster states of ^{13}B.

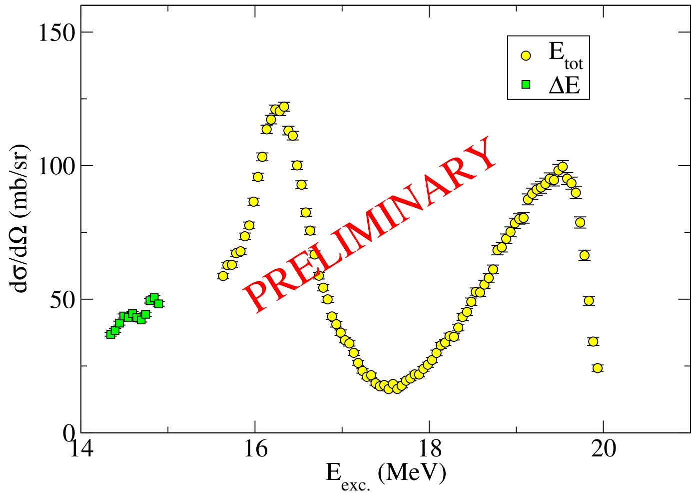

Figure 5: Preliminary ^{13}B excitation energy spectrum at $\theta_{c.m.} \sim 180°$

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