Alpha structure of $^{12}$B studied by elastic scattering of $^8$Li EXCYT beam on $^4$He thick target

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Abstract. The $^8$Li elastic scattering on $^4$He in inverse kinematics has been studied in order to search for $^8$Li-α cluster configurations in excited states of $^{12}$B. The experimental technique, the inverse kinematic thick target method (TTIK), involved a $^8$Li beam provided by the EXCYT facility at an initial energy of $E_b=30.6$ MeV which is continuously degraded down to zero in the passage through a helium extended thick target. After the interaction, the recoil alpha particles were detected by using four $\Delta E-E$ silicon detector telescopes. The explored $^8$Li-α centre-of-mass energy ranges from $E_{CM}=2.7$ MeV up to $E_{CM}=9.6$ MeV. A micro-channel plate, placed before the gas chamber, is used to measure the time interval between the entrance of the $^8$Li into the chamber and the arrival of the recoil alpha particle on the detectors. This “time interval” measurement improves the TTIK technique allowing the discrimination of elastic from inelastic events. In this paper, the experimental technique will be described and the preliminary results for the elastic cross section will be shown.

1. Introduction
The availability of radioactive ion beams is allowing for the study of nuclei in the region far from the stability valley. In particular, the search for cluster structure in neutron rich nuclei is now possible. Kanada En’yo et al. [1] report a study on the spatial density distribution for Boron isotopes in their ground states. A microscopic calculation for the ground states of Boron isotopes, based on Antisymmetrized Molecular Dynamics (AMD) model, shows the change in nuclear shape and properties when the neutron number increases. In particular $^{11}$B ground state is described by a
deformed cluster state $^{\alpha-7}$Li whilst $^{13}$B (N=8) has a more spherical shape. When N increases in $^{15}$B, $^{17}$B and $^{19}$B a cluster structure with a prolate shape is again present. A specific theoretical study of $^{12}$B and its excited states has been performed by Descouvemont [2]. This study, based on the Generator Coordinate Method (GCM), predicts the presence of cluster states above the alpha decay threshold in $^{12}$B ($E_x \sim 10$ MeV).

Experimental signatures of $^{8}$Li-$\alpha$ cluster configuration in the excited states of $^{12}$B can be the large reduced width for alpha decay (see ref. [2]).

2. Resonant elastic scattering in inverse kinematics

The resonant elastic scattering method [4-5] has been used in order to investigate the $\alpha-^{4}$Li structure of $^{12}$B from $E_x \sim 12.7$ MeV up to $E_x \sim 19.6$ MeV.

The resonant elastic scattering method in inverse kinematics (study of the reaction $a(A,a)A$) makes use of the sensitivity of the detected recoil yield to the presence of a resonant state in the intermediate system ($a+A$). By using the beam energy loss in the target it is possible to induce the elastic scattering in a given continuous range of $E_{CM}$ energies (see Fig. 1). The inverse kinematics ($A$ (projectile) heavier than $a$ (target)), gives forward focused recoiled particles ($\alpha$ particles in the present case). In this context a crucial role is played by the smaller $dE/dx$ of the recoils with respect of that of the beam particles.

![Figure 1. Pictorial view of elastic scattering induced at $E_{beam}$ and at a degraded beam energy $E_{beam-\Delta E_{b1}}$. Different reaction points inside the gas target will correspond to different $E_{cm}$ energies.](image)

In particular the beam particles are stopped inside the target while the recoils can reach the detectors placed around $\theta_{lab}=0^\circ$ which correspond at backward angles in centre-of-mass system. At these angles the elastic cross section is more sensitive to the interference effects due to the presence of both nuclear and Coulomb contribution.
An R-matrix analysis [4] of the elastic cross section can provide precise information on the energy position of the levels and their reduced particle widths. An experimental limitation of the thick target method is represented by the contribution of other possible reaction mechanisms to the final elastic scattering spectrum. For example, if the centre-of-mass energy is high enough to open the inelastic channel (see Fig. 2, right side), we can have the superposition of elastic events generated at a given beam energy \( E_{\text{beam}} - \Delta E_1 \) onto inelastic events generated at higher beam energy \( E_{\text{beam}} - \Delta E_2 \), where \( \Delta E_2 > \Delta E_1 \).

Figure 2. Pictorial view of elastic scattering \((Q=0)\) induced at \( E_{\text{beam}} - \Delta E_1 \) and inelastic scattering \((Q\neq 0)\) induced at \( E_{\text{beam}} - \Delta E_2 \). Due to a compensation of the energy loss of beam particles and recoils, they give the same alpha final energy \( E = E_{\alpha} - \Delta E_\alpha = E_{\alpha}' - \Delta E_{\alpha}' \).

This means that recoil particles reaching the detectors at the same energy \( E = E_{\alpha} - \Delta E_\alpha = E_{\alpha}' - \Delta E_{\alpha}' \) can be generated by different events (see Fig. 2, left side). In order to bypass this problem it would be necessary to disentangle the different events by knowing the position inside the target where these events have taken place. A way to perform this analysis will be described in the following paragraph.

3. Experimental set-up

The \(^7\text{Li}\) beam was produced by using the EXCYT facility at INFN-LNS, Catania (see [5,6]). The EXCYT production-acceleration system uses the ISOL technique. It is based on a K-800 superconducting cyclotron, as a driver for stable heavy ion beams (up to 80 MeV/amu, 1 \( \mu \)A), and on a 15 MV tandem for post-accelerating the radioactive ion beams produced in a target-ion source (TIS) assembly. The production of the radioactive ions was performed by injecting a \(^{13}\text{C}^{4+}\) primary beam of 45 MeV/amu on a graphite target up to a beam power of 150 W. For \(^7\text{Li}\), the higher extraction efficiency from the TIS is obtained by positive ionisation achieved by a tungsten positive surface ioniser. After passing through a charge exchange cell (CEC) to obtain negative ions, the beam is injected into the tandem. The tandem accelerates the \(^7\text{Li}^{3+}\) beam at a final energy of 30.6 MeV.

The \(^7\text{Li}\) beam impinges on the aluminized Mylar foil (0.8 \( \mu \)m thick) of a Micro Channel Plate (MCP) detector. The foil is placed at 45° with respect to the beam direction (see Fig. 3, upper part). The MCP signal provides a reference for time of flight measurements and at the same time allows counting of the beam intensity, \((\sim 5 \times 10^5 \text{pps})\). The \(^7\text{Li}\) then enters the CT2000 scattering chamber which is filled with \(^4\text{He} \) enriched gas. The gas chamber is isolated from the beam line (which is at a pressure of \(10^{-6}\) mbar) by using a kapton foil (13\( \mu \)m thick). Pressure \((\sim 700 \text{mbar})\) and temperature \((\sim 300 \text{K})\) inside the chamber are continuously monitored. A system of four Silicon \(\Delta E-E\) telescope detectors is placed at forward angles and at distance of 80 cm with respect to the centre of the chamber. The \(\Delta E\) detectors...
are four quadrant Silicon Pad detectors (50-60 µm thick) whilst the residual energy is measured by Double Sided Silicon Strip detectors, 16x16 strips, (500-1000 µm thick) (see Fig. 3). The detectors energy calibration was performed by using the known alpha energy peaks from a $^{241}$Am-$^{244}$Cu-$^{239}$Pu source and the elastic diffusion of a $^7$Li beam on a gold target. Stopping power measurements of $^7,^8$Li in $^4$He have also been preliminarily performed. As it has been underlined by Zadro et al. [7], this is essential to correctly recover the beam energy which induces a given scattering event.

During the measurement, the micro-channel plate, placed before the gas chamber, is used to measure the “time interval”, $\Delta t$, between the passage of the $^8$Li through the foil of the micro-channel and the arrival of the recoil alpha particles in the detectors. This “time interval” measurement improves the TTIK technique for infinite target allowing the discrimination of elastic from inelastic events.

During the measurement, the acquisition trigger is generated by events from $\Delta E$ detectors. $\Delta t$ is measured by using the signal produced by the $\Delta E$’s as a start. The stop is given by a delayed signal coming from the MCP (inverse logic). The time resolution is $\sim 1$ ns.

![Figure 3. Experimental set-up. In the bottom the $\Delta E_3$-$E_3$, designed from Micron Semiconductors, used at 0°.](image)

4. Preliminary Results

In the following we will focus the attention on the preliminary results obtained from the most forward detector $\Delta E$-$E$, placed at $\theta_{lab}$=0° with respect to the beam direction (see Fig.3, bottom part).

For this telescope, the $\Delta E$ nominal thickness is 47 µm. In Fig. 4, the $\Delta E$-$E$ plot is shown. We can distinguish alpha particles from hydrogen isotopes. We can notice the presence of a large yield of tritons, coming most probably from $^7$Li break-up.
Figure 4. $\Delta E$-$E$ spectrum.

In Fig. 5, the time interval $\Delta t$ is shown as a function of the energy loss in the $\Delta E$ detector. Since inverse time logic has been used, large time intervals (~220ns) correspond to events which occur at the beginning of the chamber, while smaller intervals (~175ns) corresponds to events which take place closer to the $\Delta E$ detectors. The $\alpha$-particle punch-through energy is around 8MeV.

Figure 5. $\Delta t$ v.s. $\Delta E$ spectrum. In $\Delta t$ axis, the “zero” has been arbitrarily chosen.

As one can observe, the elastic events are clearly distinguished from the inelastic events. The time interval $\Delta t$ has been calculated as a function of the detected energy both for the elastic and inelastic events ($^6$Li first three excited levels). The calculation includes the kinematics and energy loss of $^6$Li and $\alpha$ in $^4$He gas. It can be seen that the calculated locus of the elastic events is in agreement with the data. As regards the inelastic events, we can notice that the $2^+$ level is scarcely populated.

In the plot one can also observe a large quantity of tritons as well as alpha background events (for $\Delta E$<5MeV). The first are due, as previously mentioned, to $^6$Li break-up, while the last, which are uncorrelated in time, are due to the $^6$Li decay ($^6$Li($\beta^-$) $^6$Be$^*$ → 2$\alpha$). The elastic events which stop in the $\Delta E$ detector, have been selected by a graphical contour has been done on the $\Delta E$-$E$ plot. For these events the centre-of-mass energy has been reconstructed and the preliminary cross section has been plotted in Fig.6.
Figure 6. Elastic differential cross section for alpha particles stopped in the $\Delta E_3$ detector. As example, the curves corresponding to two of the four different $\Delta E_3$ quadrants are plotted.

In Fig. 6, the $^8\text{Li}+^4\text{He}$ elastic scattering cross section obtained for $E_{cm}=2.7-4.8\text{MeV}$ (events stopped in $\Delta E$ detector) is plotted, as example, just for two quadrants of the $\Delta E_3-E_3$ telescope. The two data sets are in agreement within the experimental error bars. The cross-section shows evidences of large peaks.

5. Conclusions
The $^8\text{Li}-\alpha$ elastic scattering cross section has been studied by using the TTIK method. The improvement of the technique, concerning the tagging of the events by using time interval measurements, leads to the discrimination of elastic scattering from other reaction mechanisms. The preliminary results of the elastic cross section for $E_{cm}=2.7-4.8\text{ MeV}$ have been shown. A more precise reconstruction of $E_{cm}$, including the beam size, angular and energy straggling for beam particles and alpha recoils, is in progress. Moreover, before extracting information from the data, the background subtraction for $\Delta E<5\text{ MeV}$ is also needed.

6. References
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