The Inverse Kinematics Thick Target scattering method as a tool to study cluster states in exotic nuclei.

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Abstract. The inverse kinematics thick target scattering method (TTIK) was used to measure the $^8$Li resonant elastic scattering on a $^4$He target in order to investigate $^8$Li-$\alpha$ cluster configurations in excited states of $^{12}$B. A $^8$Li beam at $E_{\text{beam}} = 30.6$ MeV, provided by the radioactive beam facility EXCYT of LNS in Catania, while passing through a thick Helium target decreases continuously its energy. Thus, elastic scattering can be induced starting from the initial beam energy down to zero. Time of flight measurement between beam particles passing through a MCP detector and $\alpha$-particles impinging on the $\Delta E$ stage of a Si telescope detector allows the discrimination of elastic scattering from nuclear reaction events, thus representing an improvement of the TTIK method. In this paper the used experimental technique and preliminary results will be described.

1. Introduction

It is well known that cluster structures occur in many light nuclei in their excited states and in some cases also in their ground states. Due to their very large binding energy, $\alpha$-particles have been considered to be the ideal cluster. Excited states of light $N=Z$ nuclei can indeed be described as having $\alpha$-cluster configurations [1]. Recently more exotic description of cluster configurations have been introduced in order to describe the structure of n-rich nuclei. For example, theoretical studies of cluster structures on neutron-rich Boron isotopes were performed by Kanada En’jo [2] using the Antysimmetrized Molecular Dynamics. These calculations show how cluster structure become more evident and more exotic when the neutron number of the isotopes increases. For instance, the $^{19}$B ground state can be described by a $^{11}$Li-$^8$He configuration, while the less neutron rich $^{13}$B, due to the N=8 shell closure, exhibits a single particle behavior. The existence of a cluster structure above the $\alpha$-particle emission threshold is predicted for the excited states of $^{12}$B. Calculations using the Generator Coordinate Method
(GCM) have been performed by [3]. In this study the presence of a positive parity band with a large reduced width for α-decay, located just above the α-decay threshold, supports the picture of α-\(^6\)Li cluster configurations for excited states in \(^{12}\)B.

With the aim of investigating such peculiar cluster configurations in \(^{12}\)B we performed the measurement of \(^8\)Li+\(^4\)He resonant elastic scattering.

2. Experimental technique

The \(^8\)Li beam was produced by the radioactive beam facility EXCYT at INFN-Laboratori Nazionali del Sud in Catania [5]. EXCYT uses the ISOL technique to produce the beam and it uses a K-800 superconducting cyclotron as a driver and of a 14 MV tandem as post-accelerator for the radioactive beams. The energy of the \(^8\)Li beam delivered by the accelerator was \(E_{\text{lab}}=30.6\) MeV. Before entering the scattering chamber the beam passes through the aluminized Mylar foil (0.8 \(\mu\)m thick) of a Micro Channel Plate (MCP) detector. This detector provides a reference signal (stop signal) for the time of flight measurement (TOF) and, at the same time, it allows for counting the beam particles. The average beam intensity was \(\sim5\cdot10^4\) pps. Downstream the MCP detector it is placed a kapton foil (13 \(\mu\)m thick) that separates the in-vacuum beam line from the scattering chamber CT2000. This latter was filled with \(^4\)He enriched gas at a pressure \(P\sim700\) mbar. An array of four \(\Delta E-E\) Silicon detector telescopes is placed at forward angles at a distance of \(\approx180\) cm from the kapton foil. The \(\Delta E\) stage is made by four quadrant Silicon Pad detectors, 50-60 \(\mu\)m thick whereas, the E stage consists of Double Sided Silicon Strip Detectors, 16+16 strips, 500-1000 \(\mu\)m thick. The \(\Delta E\) detector provides also the start signal for the TOF measurement. In figure 1 a sketch of the used experimental set-up is shown.

When passing through the \(^4\)He gas the beam reduces its energy, hence the elastic scattering is induced in a continuous range of energies starting from the initial beam energy (30.6 MeV) down to zero; this is called TTIK method [4]. With this technique the \(^4\)He gas target has a threefold role. It acts at the same time as target, as degrader and as beam stopper. The \(^8\)Li beam is in fact stopped in the gas before reaching the detectors, while the recoiling \(^4\)He particles, owing to their lower stopping power, reach the detectors which are placed at forward angles (backward angles in CM system). An experimental limitation of using the TTIK method is

![Figure 1. Sketch of the experimental set-up used for the experiment. Si-detector telescope B was used to measure the stopping power.](image-url)
Figure 2. TOF versus $\Delta E$ plot for the detector at $0^\circ$. The scatter plot represents the experimental data. The full line represents the calculations for elastic scattering $\alpha$ particles events, the dashed lines represent the calculations for the inelastic scattering of the first three states of $^8\text{Li}$ $E_x=0.9808, 2.255, 3.21$ MeV.

represented by $\alpha$-particles coming from other possible reaction mechanisms. Only by analyzing the particle energy deposition spectra it not possible to identify the reaction mechanisms for the $\alpha$-particle production. For this reason we decided to improve the TTIK method published in [4] by introducing the TOF measurement. The measured energy of a detected $\alpha$-particle depends on the reaction process in which it was produced, as well as on the position in the gas target, where the reaction has occurred. Therefore, the TOF measurement allows us to discriminate elastic from reaction events. When using the TTIK method, the excitation energy of the compound nucleus is reconstructed from the energy of the detected $\alpha$-particle by computing the energy loss in the $^4\text{He}$ gas of both the beam and the recoiling $\alpha$. Therefore, stopping power knowledge is of paramount importance in this type of measurements. Stopping power measurements of $^4\text{He}$ gas for Li-ions have also been performed. This was done using a $^7\text{Li}$ beam. The incorrect knowledge of the stopping power affects, not only on the position of a peak in the extracted excitation function but also on the extracted cross-section, as it has been discussed in [6].

3. Results
In the following, results obtained for the detector placed at $\theta_{\text{lab}}=0^\circ$ will be discussed. As mentioned above, TOF and $\Delta$E-E measurement were performed. The TOF measurement, beside allowing the identification of elastic scattering from other reaction processes it allowed also to identify in charge. It was possible, in fact, for particles stopping on the $\Delta$E detector, to discriminate H from He. Particles punching-through the $\Delta$E detector were identified via the telescope technique.

In figure 2, the TOF is shown as a function of the energy deposited in the $\Delta$E detector. Since inverse time logic was used, large TOF ($\sim 220$ ns) corresponds to events which occur at the highest energies (entrance of the chamber), whereas smaller TOF ($\approx 175$ ns) corresponds to events which originated closer to the $\Delta$E detectors. The $\alpha$-particle punch-through energy is around 8 MeV. The lines drawn upon the experimental data show calculated values of the TOF as a function of the detected energy both for elastic and inelastic scattering, corresponding to the first three excited levels of $^8\text{Li}$. The calculations include the kinematics, energy losses of
Li and α-particles in 4He gas and energy losses of α-particles in the entrance dead layer of the detector. On this plot it is evident the separation of elastic contribution from inelastic or break-up events. In figure 2 it can also be observed that α-particles are well separated from hydrogen isotopes at energies above ≈2 MeV. The elastic events, which stop in the ΔE detector, were selected by graphical cuts on the TOF-ΔE plot; the ones that punch-through were selected by graphical cut on the ΔE-E plot. For these events the excitation energy spectrum of the 12B compound nucleus was reconstructed.

In figure 2 one can also see events, at E ≤ 5 MeV, which are uncorrelated in time. These events are coming from the α decay of 8Be* produced in the 8Li radioactive decay (8Li (β−)8Be* → 2α) and they are uncorrelated in time since the T1/2(8Li)=840 ms. These events are source of background for the elastic events and they have been subtracted by shifting the graphical cut of the elastic events on a different time region of the TOF-ΔE plot.

In order to reconstruct the 12B excitation function from the detected α-particle energies a precise knowledge of the stopping power of 4He for 8Li and 4He is required. For this reason, as mentioned above, during the same experiment a measurement of the stopping power was also performed. The results were found in agreement with SRIM calculations.

The elastic scattering excitation function extracted for the telescope placed at 0° degree is shown in figure 3. Three different peaks are clearly observed at 13.6, 14.4 and 15.8 MeV. Evidences of the peaks at Ex(12B)= 13.6 and 15.8 MeV have already been reported in the literature [7], whereas this is the first evidence for a state in 12B at 14.4 MeV.

4. Conclusions

In this contribution the measurement of the 8Li-α elastic scattering excitation function performed by using the TTIK method is reported. In this measurement the technique reported in [4] was improved by introducing the time of flight measurement. The TOF allows for the discrimination of elastic scattering events from the ones produced by other reaction processes. The elastic scattering excitation function in the range 13.5 MeV ≤ Ex ≤ 19.5 MeV was measured. Three different peaks are observed at 12B excitation energies of 13.6, 14.4 and 15.8 MeV. These results are in agreement with previous measurements reported in [7] for Ex=13.6 and 15.8 MeV whereas no information is present in the literature for the peak at 14.4 MeV.

Before extracting resonance parameters with R-matrix calculations, evaluation of the experimental resolution, for which one needs to take into account beam size, angular and energy straggling for beam particles and recoiling α-particles, is required.
5. References

[1] K. Ikeda et al. Progr. Theo. Phys. Suppl. Extra Number (1968) 464.
[2] Y. Kanada En’yo et al., Prog. Theor. Phys. 93 (1995) 115.
[3] P. Descouvemont, Nucl. Phys. A 596 (1996) 285.
[4] V.Z. Goldberg et al., Phys. Rev. C 69 (2004) 024602.
[5] G. Ciavola et al., Nucl. Phys. A 701 (2002) 54c.
[6] M. Zadro et al., NIM B 259 (2007) 836.
[7] N. Soic et al., Europhys. Lett. 63 (2003) 524.