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New measurement of the ^{10}B(p,α_0)^{7}Be reaction cross section at low energies and the structure of ^{11}C

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Abstract

We report preliminary results of a new measurement of the ^{10}B(p,α_0)^{7}Be cross section in the 0.6 - 1.0 MeV bombarding energy domain. In this region very few data have been reported in the literature. Excitation functions at both forward and backward angles have been obtained. Angular distributions testify the contribution due to several excited states in the ^{11}C compound nucleus. The experimental S-factor is about 30% lower than the one reported in the literature and based on activation methods.

1 Introduction

The ^{10}B(p,α)^{7}Be reaction is important in various fields of Nuclear Physics. In fact, (1) it allows to study the spectroscopy of the non self-conjugated

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^{11}C compound nucleus, with particular regard to the appearance of α-cluster states (see, e.g. [1–3]); (2) it is important to accurately describe the destruction of the ^{10}B isotope in stars [5–7]; (3) it is involved in radio-protection issues in Nuclear Fusion technology [4].

For example, from the Nuclear Structure point of view, it is important to have available angular distributions and excitation functions of several reaction channels leading to the population (or coming from the decay) of ^{11}C excited states. In this case, a R-matrix analysis of experimental data allows to determine the partial width and the branching ratios of the various channels. In particular, the analysis of states near and above the α emission threshold is an useful tool to unveil the possible existence of molecular rotational bands [2, 3] in ^{11}C, that can constitute a fingerprint of α-clustering in non self-conjugated nuclei.

^{10}B(p,α) reaction is important also for Applied Physics purposes, and in particular in Nuclear Fusion technology [4]. In fact, the ^{11}B(p,α)$\alpha\alpha$ reaction has been proposed as a possible candidate for laser-induced fusion reactions without neutron production (*aneutronic fusion*) [8, 9]. In this way, it would be possible to overcome radio-protection hazards due to the large neutron flux emitted by the usual $d + d$ or $d + t$ fusion reactions. Unfortunately, the natural boron is composed both of ^{11}B (80.1% natural abundance) and ^{10}B (19.9% natural abundance). Reactions induced by protons on ^{10}B contaminants can lead to the emission of α particles and of long-lived ^{7}Be radioactive nuclei ($\tau \simeq 52.7$ days) that can implant on the reactor vessel, leading to radiation safety issues. For this reason, it is necessary to isotopically enrich the ^{11}B target, but a correct estimate of the enrichment level needed to avoid radioactive hazard necessarily relies on an accurate knowledge of the ^{10}B(p,α)^{7}Be cross section at low energies (< 0.3 MeV) [10].

Unfortunately, direct data reported in the literature at low bombarding energies, especially in the $E \approx 1 - 2$ MeV region, are few [11–13], being often characterized by large error bars. Recent measurements performed with the Trojan Horse method allowed to explore the S-factor down to zero energy [5]. These data are usually obtained in arbitrary units, and therefore they need to be normalized to higher energy direct data. Considering all these reasons, we decided to perform a new experiment aimed at measuring the ^{10}B(p,α)^{7}Be reaction in the E_p=1.028-0.630 MeV bombarding energy domain. Some experimental details and preliminary results of this analysis are reported in the following sections.

2 Experimental methods

Proton beams at bombarding energies E_p=0.630-1.028 MeV were delivered by the TTT3 tandem accelerator of the Laboratorio dell'Acceleratore (LdA) at Federico II University of Naples [14]. The energy step here used was about 40 keV. To reduce pile-up effects, in this experiment the beam intensity did not overcome 1 nA. The beam energy calibration was determined by analysing the γ yield of the ^{19}F(p,$\alpha\gamma$)^{16}O reaction around the 0.872 MeV resonance and by investigating several elastic scattering resonances induced by proton and α-particles on several light targets. The maximum beam energy spread was of the order of 0.2%, and the diameter of the beam on target was smaller than 2 mm. The beam intensity was measured by means of a Faraday-cup. The vacuum in the scattering chamber was of the order of 10^{-6} mbar.

A boron foil (38 μg/cm^2 thick) was used as reaction target. Because of its extreme fragility, a small amount of polyvinyl formal ($C_3H_6O_2$, some μg/cm^2 thick) has been used to strengthen it. The target surface was orthogonal to the beam direction. Because of the manufacturing process, the target was affected by the presence of several contaminants. They have been characterized with elastic backscattering analysis, with proton beams of about 1 MeV. The main observed contaminants were Li, C, O, Al, Cl, Cu, Ba. Because of kinematic reasons, peaks due to the heavier of these contaminants are expected to overlap with the α_0 signal at backward angles, leading to strong difficulties in the extraction of α_0 yields from the energy spectrum of ejectiles.

For this reason, to measure the α_0 yields at backward angles ($\theta_{lab} = 120° - 160°$) we used a method based on the simultaneous measurements of two ejectile spectra at the same angle (in opposite directions with respect to the beam axis), the first one taken with an unshielded silicon detector, the second one taken by a silicon detector covered by a thin Al foil (3μm thick) that is able to stop (or highly slow down) the α_0 particles, allowing the elastically scattered protons to punch through. Then, the α_0 yields have been derived by subtraction, taking into account the energy loss and straggling of protons in the aluminium foil. Details on this experimental technique will be described in a forthcoming paper.

The experimental setup consisted of an array of 10 silicon detectors. Four detectors were placed at forward angles (θ_{lab} =30°, 40°, 50°, 60°), while the remaining six detectors were placed at $\theta_{lab} = \pm 120°, 140°, 160°$. In this way, we obtained angular distributions at 7 angles, covering the range from θ_{lab}=30° to 160°. α_0 yields have been transformed into absolute cross

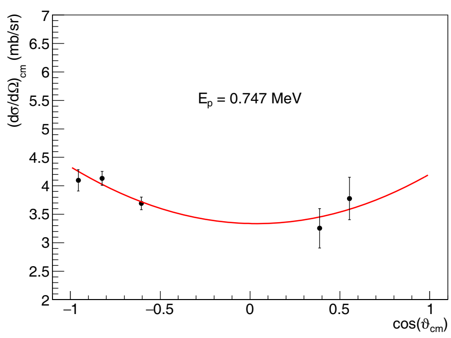

Figure 1: (color online) Angular distribution of the ^{10}B(p,α_0)^{7}Be reaction at E_p=0.747 MeV. The red line indicates Legendre polynomial fit of data (truncated to the 2^{nd} order).

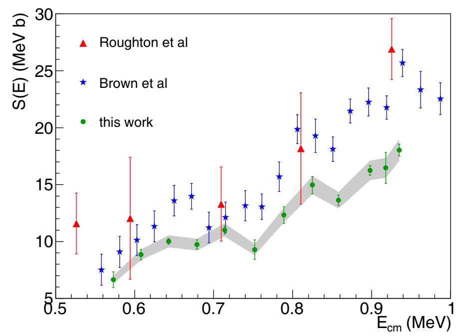

Figure 2: (color online) Preliminary S-factor of the ^{10}B(p,α_0)^{7}Be reaction (green dots). The grey band represents non statistical errors. Blue stars: data by Brown et al [18]; red triangles: data by Roughton et al [11] as reported by [12, 13].

sections by internal normalization to the ^{10}B(p,p$_0$) elastic scattering signal, taking into account the ^{10}B(p,p$_0$) elastic scattering differential cross sections reported in Refs. [15, 16].

3 Preliminary experimental results

An example of preliminary angular distribution obtained at E_p=0.747 MeV is reported in Figure 1. The red line represents its fit by using Legendre Polynomials up to the 2^{nd} degree, corresponding to ℓ_{max}=1 in the p+^{10}B channel. This angular distribution might be slightly anisotropic, testifying the possible contribution given by $\ell \neq 0$ partial waves. The preliminary analysis of experimental data shows a continuous evolution of angular distribution shapes as a function of energy. In particular, in the E_p = 0.630-0.785 MeV energy range, angular distributions show quite small anisotropies, similar to the one reported in Figure 1, while at higher energies (E_p = 0.827-1.028 MeV) the angular distributions are more anisotropic. R-matrix calculations of angular distributions are currently in progress; they will help us to improve the spectroscopy of ^{11}C states in an excitation energy region E_x ≈9-11 MeV,) where several ambiguities in the J$^\pi$ assignments exist [17].

A preliminary estimate of the angle integrated reaction cross section has been obtained from the present angular distributions; consequently, our preliminary ^{10}B(p,α_0)^{7}Be S-factor is shown in Figure 2, as green dots. Vertical bars represent statistical errors, while the grey band indicates non statistical ones, derived from the internal normalization procedure. We compared our experimental data with results taken from the NACRE and NACRE2 compilations [12, 13], and derived from a differential cross section reported by Brown et al [18] at θ_{lab}=137.8° (blue stars) and from an activation experiment reported by Roughton et al [11] (red triangles; these measurements refer to the $\alpha_0 + \alpha_1$ channels; the α_1 channel is expected to have cross section well lower than 10% of the α_0 channel at energies E_p <1 MeV [19]). Our data are ≈30% lower than the estimates based on Roughton et al data, even if they agree within the error bars. Similar conclusions can be drawn by considering the Brown et al data.

The next step in the data analysis will be the related to the definitive estimate of the S-factor from the present experimental data. This analysis is currently in progress.

4 Conclusions

In these proceedings we report some preliminary results concerning a new measurement of the ^{10}B(p,α)^{7}Be reaction at low energies (E_p=0.630-1.028 MeV). The experiment has been performed by using the TTT3 tandem accelerator in Naples. Angular distributions have been obtained at several angles, both in the forward and backward hemisphere; their shape changes as a function of energy, indicating the contribution of several excited states of ^{11}C to the excitation function. A preliminary estimate of the S-factor has been compared with results reported in the literature in the same energy region.

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