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RECENT RESULTS ON THE ^{10}B$(p,\alpha)^7$Be REACTION STUDIED VIA THM AT LOW ENERGIES*

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The Trojan Horse Method has been applied to the ^{2}H$(^{10}$B$,\alpha^7$Be$)n$ three-body reaction in order to study ^{10}B$(p,\,\alpha)^7$Be two-body interaction. Improvement in the experimental set-up allowed to obtain a better experimental resolution and to get for the first time separation between the α_0 and α_1 channels. Moreover, with respect to the previous THM experiment, an improvement of the energy resolution for the ^{10}B$(p,\,\alpha_0)^7$Be excitation function has been achieved. For the first time, experimental data allowed the THM study of the ^{10}B$(p,\,\alpha_1)^7$Be channel. Preliminary results will be discussed.

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1. Introduction

Interest in the study of the ^{10}B$(p,\,\alpha)^7$Be reaction arises from astrophysical motivation as well as from applied physics. Regarding the first research field, the ^{10}B$+p$ interaction is the main process for the ^{10}B destruction inside the stars. Moreover, the light elements — lithium, beryllium and boron (LiBeB) burn inside stars at different temperatures corresponding to different stellar depths. As a consequence, the study of the residual abundances of LiBeB in stellar atmospheres turns out to be a possible probe for a better understanding of stellar structure and plasma mixing phenomena occurring inside stars [1]. Furthermore, it has been pointed out that for pre-MS stars, information on the internal structure and evolution can be inferred not only from the boron isotopes, ^{11}B and ^{10}B, absolute abundances but also from

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their relative abundance $N(^{11}\mathrm{B})/N(^{10}\mathrm{B})$. The slight difference in burning temperature leads to a earlier burning of the ^{10}B, so the $N(^{11}\mathrm{B})/N(^{10}\mathrm{B})$ ratio should increase with time [2].

Inside stars, nuclear reactions take place within the Gamow energy region, depending on the stellar environment temperature [3]. For the $^{10}\mathrm{B}+p$ case, the Gamow energy is centered at 10 keV $\pm$ 5 keV ($T \sim 10^6$). At this energy, the $^{10}\mathrm{B}(p,\,\alpha)^7\mathrm{B}$ reaction cross section is characterized by the presence of a resonance due to the 8.699 MeV ^{11}C excited level.

In this framework, nuclear cross sections must be carefully evaluated at these low energies in order to constrain stellar theoretical models.

In the applied physics field, the boron+proton interaction is of great interest for the aneutronic fusion. The $^{11}\mathrm{B}(p,\,2\alpha)^4\mathrm{He}$ reaction, where ^{11}B represents the 80.1% of the natural boron, is taken into account for this type of fusion system since it provides in the exit channel only stable particles with no neutron emission, releasing a sufficient amount of energy. Despite of that, the 19.9% of ^{10}B in natural boron fuel leads, through the reaction $^{10}\mathrm{B}(p,\,\alpha)^7\mathrm{Be}$, to the production of a long-lived radioactive isotope, that is the ^{7}Be ($T_{1/2} = 53.22 \pm 0.06$ d) [4, 5]. Therefore, the study of the $^{10}\mathrm{B}(p,\,\alpha)^7\mathrm{Be}$ cross section in the 200–1000 keV energy range is of interest for fusion systems [6], since it is important to evaluate the produced amount of the ^{7}Be radioactive ions, representing a possible source of radio-safety problems for such kind of facilities. Moreover, in the framework of the new generation of laser-driven hot plasma facilities, the amount of ^{7}Be produced by boron–proton interaction can provide a different way for the monitoring of the plasma temperature [6].

The $^{10}\mathrm{B}(p,\,\alpha)^7\mathrm{Be}$ reaction has been investigated in several direct measurements covering a wide energy range from tens of keV to 10 MeV (see Ref. [6] and references therein). Both α_0 and α_1 channels with the ^{7}Be emitted in the ground state and in the first excited state, respectively, have been studied (the α_1 channel becomes more important as the energy increases). Nevertheless, data sets present in the literature show significant differences and uncertainties, and no direct experiment succeeded in the cross-section measurement at the Gamow energy [7]. The indirect study of the $^{10}\mathrm{B}(p,\,\alpha_0)^7\mathrm{Be}$ by means of the Trojan Horse Method (THM) has provided the first measurement of the cross section within the Gamow window [8]. Relative astrophysical applications are described in Ref. [9]. Then, a second THM measurement obtained the cross section in a wide energy range, from 5 keV to 1.5 MeV, in a single experiment [10]. Notwithstanding that, the experimental resolution obtained in that THM measurements was not enough to allow the separation between α_0 and α_1 channels and to provide a good separation of the ^{11}C levels that characterize the $^{10}\mathrm{B}+p$ excitation function.

Here, we report on the preliminary results of a new THM study of the ^{10}B(p, α)^{7}Be where, thanks to an optimized experimental setup, we have obtained for the first time separation between the α_0 and α_1, an improved energy resolution for the α_0 channel excitation function and the first THM measurement of the ^{10}B(p, α_1)^{7}Be reaction.

2. The Trojan Horse Method

The THM [11–15] is a well-established indirect method for the measurement of the nuclear reaction cross section at low energies of astrophysical interest. The method is widely discussed in several papers and reviews ([13–15] and references therein). Here, we just give a summary. The THM allows the extraction of the cross section of a two-body process of astrophysical interest, $a + x \to c + C$, performing the experimental measurement and selecting the quasi-free breakup reaction mechanism of an appropriate three-body reaction $a + A \to c + C + s$, where A, the so-called Trojan Horse (TH) nucleus, has a high probability for the $x \oplus s$ cluster configuration. Unlike direct measurements performed at low energies relevant for astrophysics, the extracted THM two-body cross section is free from the Coulomb barrier suppression and electron screening effects [14]. THM is usually applied using theoretical approach of the Plane Wave Impulse Approximation.

In the present case, the ^{10}B(p, α)^{7}Be two-body cross section has been investigated applying the THM to the ^{2}H(^{10}B, α^7Be)n three-body process, where ^{2}H is the TH nucleus due to its $p \oplus n$ cluster configuration. The beam energy for the three-body process is selected to be higher than the ^{10}B–^{2}H Coulomb barrier, so that ^{2}H break-up into proton and neutron is induced inside the ^{10}B nuclear field. Then the proton interacts with ^{10}B inducing the two-body process of interest, that is ^{10}B(p, α)^{7}Be. The neutron does not interfere with the ^{10}B–p interaction, acting as a *spectator* to the process. In order to compare the THM cross section with data from direct measurements, we introduce the Coulomb field effects multiplying our data for the penetrability of the Coulomb barrier. In spite of using a high-energy beam, it is possible to induce the two-body process at low astrophysical energies thanks to the TH nucleus binding energy in compensating for the beam energy value [14].

3. The experiment

The experiment was performed at the Laboratori Nazionali del Sud, INFN Catania. The SMP Tandem Van de Graaff accelerator provided a ^{10}B beam at 28 MeV with an average intensity of 1 nA. A collimation system gave a spot size on the target of about 1 mm. The beam hit a 56 μg/cm^2 thick CD_2 target. Target thickness was carefully evaluated in order to improve the experimental resolution. Detection system consisted of two telescopes for ^{7}Be identification, made up of an ionization chamber (IC) filled with isobutane gas, as ΔE stage, and a position sensitive silicon detector (PSD) as E stage. Other two PSDs were employed for alpha particles detection. Telescopes and PSDs were placed symmetrically with respect to the beam axis, covering the angular range of 11.0°–18.0° and 21.0°–35.0° respectively. PSDs provided energy and position of the outgoing particles. The trigger to the ACQ system was generated by the coincidence signals between any two of the four PSDs. Energy calibration was carried out using a ^{228}Th alpha source, alphas produced by ^{12}C(^{6}Li, α)^{14}N and ^{6}Li from elastic scattering on ^{12}C and gold target. Angular calibration was done by putting a mask with equally spaced slits in front of each PSD during calibration runs.

4. Data analysis and preliminary results

After the calibration procedure, THM data analysis consists of several steps. The first is the selection of the $^2\mathrm{H}(^{10}\mathrm{B}, \alpha^7\mathrm{Be})n$ reaction channel. In Fig. 1, an experimental ΔE–E matrix is shown. Events populating the ^{7}Be locus have been selected by a graphical cut (grey/red line in Fig. 1).

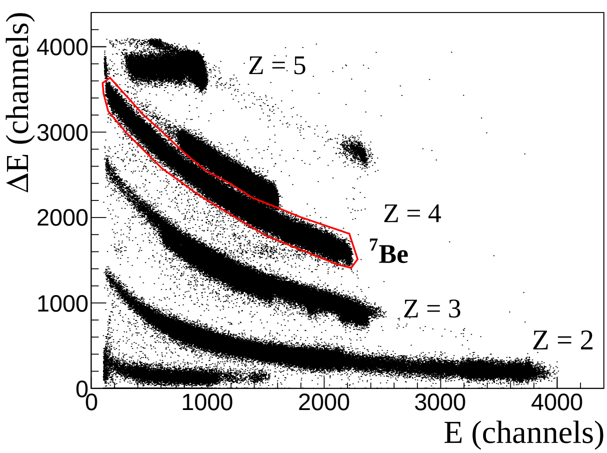

Fig. 1. Typical ΔE–E matrix. Grey/red contour indicates the selected ^{7}Be events.

From the selected data, the experimental Q-value of the three-body process is reconstructed. The result is reported in Fig. 2.

The spectrum shows two well-separated peaks centered at -1.10 MeV and -1.52 MeV, in a very good agreement with the theoretical Q-value, -1.079 MeV and -1.508 MeV, for the $^2\mathrm{H}(^{10}\mathrm{B}, \alpha^7\mathrm{Be})n$ three-body process with ^{7}Be at ground state and first excited state, respectively. These results make us confident of the correct selection of the reaction channel, as well as of the calibration procedure. Moreover, Fig. 2 shows that, for the first time in the THM study of the ^{10}B(p, α)^{7}Be reaction, the separation between α_0 and α_1 channels has been achieved, thanks to the improved experimental resolution. The following analysis has been performed separately for α_0 and α_1 channels, selecting the relative data from the Q-value spectrum.

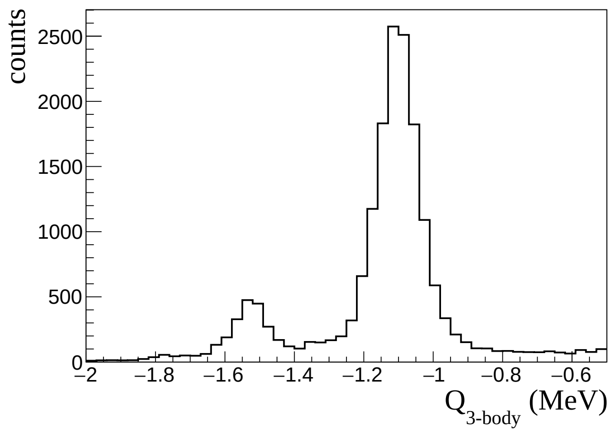

Fig. 2. Experimental Q-value spectrum for the three-body ^{2}H(^{10}B, α^7Be)n reaction.

In order to verify the presence of the quasi-free reaction mechanism in the selected data, the experimental momentum distribution of the neutron spectator has been extracted and compared with the theoretical distribution of deuteron ([8] and references therein), turning out to be in agreement with the theoretical prediction in both, α_0 and α_1 case, confirming the presence of quasi-free mechanism in the selected data.

The next step in data analysis concerned the extraction of the THM ^{10}B(p, $\alpha_{0,1}$)^{7}Be two-body cross sections.

Regarding the α_0 channel, the cross section has been extracted in a wider energy range, from 3 keV to 2.2 MeV. Preliminary results indicated an improvement in the energy resolution of a factor 2 and 6 with respect to the previous experiments [8] and [10], respectively. This will lead to a better separation of the ^{11}C excited levels, in particular at astrophysical energies between the 8.699 MeV level and the subthreshold one at 8.654 MeV. Consequently, an improvement in the determination of the astrophysical $S(E)$ factor as well as of the electron screening potential is expected.

Concerning the α_1 data, even if the experiment was not optimized for the study of this reaction channel, preliminary results are very interesting since the extracted excitation function has shown the population of several ^{11}C excited levels. The obtained results have to be considered as a successful feasibility test and encourage the realization of a dedicated experiment. Final results for both reaction channels will be available soon.

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