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Study of the ^{10}B(p,α)^{7}Be reaction via the Trojan Horse Method

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Abstract. Boron abundances in stellar atmosphere, as well as beryllium and lithium ones, can be relevant for understanding several astrophysical processes, such as primordial nucleosynthesis and spallation reactions in ISM. For this reason nuclear processes producing or depleting boron isotopes need to be studied at astrophysical energies. The ^{10}B(p,α)^{7}Be reaction is the main responsible for the ^{10}B destruction in stellar interior. In such environments this p-capture process occurs at Gamow energy of $\approx$ 10 keV and it takes places mainly through a resonant state of the compound ^{11}C nucleus. The ^{10}B(p,α)^{7}Be reaction as been investigated by means of the Trojan Horse Method (THM) applied to ^{2}H(^{10}B,α ^{7}Be)n three-body process and the results are discussed.

Key words. Light elements: abundances – Light elements: depletion – Nuclear astrophysics: Trojan Horse Method– Nuclear astrophysics: S(E)-factor

1. Introduction

The elements, lithium beryllium and boron, play an important role in astrophysics and in the last years big efforts have been devoted to the study of their abundances. Their importance is strongly related to cosmology as well as to stellar structure and evolution. In fact, hints on the primordial nucleosynthesis can be achieved from Li, Be and B primordial abundances. Moreover these knowledge can be a precious tool for testing and understanding the inner stellar structure, especially for what regards the mixing processes in stellar envelops (Boesgaard et al. (2004)). These

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elements are mainly destroyed in the stellar interior by (p,α) reactions at temperatures from $2.5{\cdot}10^6$ K for Li, $3.5{\cdot}10^6$ K for Be and $5{\cdot}10^6$ K for B. The simultaneous determination of the surface abundances can give additional information about the mixing mechanisms acting inside, which transport the surface stellar material down to the region where the nuclear processes occur (Stephens et al. (1997)). The (p,α) reactions induced at a Gamow energy E_G of few keV's are the main way to destroy the light elements when they are transported inside, so a precise cross-section measurement for such processes is needed. Due to the difficulties encountered in charged-particle cross-section measurements at sub-Coulomb energies (e.g. coulomb barrier and electron screening effect), in the last years a number of indirect methods, e.g: the Coulomb dissociation (CD) (Baur et al. (1994)), the Asymptotic Normalization Coefficient (ANC) (Mukhamedzhanov et al. (1995)), the THM (Baur et al. (1986), Spitaleri et al. (2001), Strieder et al. (2001), Cherubini et al. (1996)) were developed. Among these methods the THM appears to be particularly suited to investigate low-energy charged-particle two-body reactions by selecting the quasi-free (QF) contribution to an appropriate three-body reaction. This method allows to extract the information down to the astrophysical energies, overcoming the problem connected with Coulomb barrier and electron screening effects. The present paper reports on an indirect investigation of the $^{10}B(p,\alpha)^7Be$ reaction, responsible for boron destruction in stellar environment. This reaction has been extensively studied in direct way (Angulo et al. (1993)), (Youn et al. (1991)) and the bare S-factor has been extrapolated to the Gamow region from higher energies. The two-body $^{10}B(p,\alpha)^7Be$ reaction was studied through the THM applied to the $^2H(^{10}B,\alpha^7Be)n$ three-body process, and its astrophysical S(E) factor was extracted down to the Gamow energy. The study of this reaction is important for the presence of a resonance at about $E_{cm}(^{10}B\text{-}p)=10$ keV (within the Gamow region) corresponding to the $J^\pi=5/2^+$ ^{11}C level at 8.701 MeV of excitation energy.

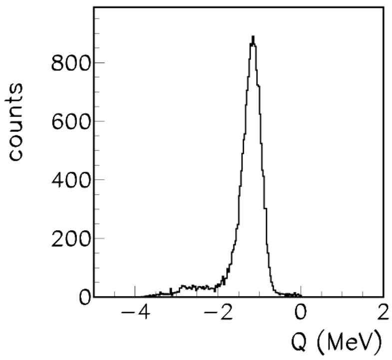

Fig. 1. Q-value for the selected $^2H(^{10}B,\alpha\ ^7Be)n$ reaction. The peak at ≈-1MeV is in good agreement with the theoretical value ≈-1.08MeV.

2. The experiment

The experiment was performed at the Laboratori Nazionali del Sud in Catania. The Tandem Van de Graaf accelerator provided at 24.4 MeV ^{10}B beam with a spot size on target of about 2 mm and intensities up to 1.5 nA. A deuterated polyethylene target (CD_2) ≈190 $\mu g/cm^2$ thick was placed at 90° with respect to the beam direction. The experimental setup consisted of two 1000 μm position sensitive detectors (PSD_B, PSD_C) and one 'telescope' system ΔE-E with an ionization chamber as ΔE detector and a position sensitive detector PSD (PSD_A) as E detector. The telescope provided the charge discrimination of the detected particle. The displacement of the experimental setup was chosen in order to cover the whole QF-angular range, known from a Monte Carlo simulation. Standard electronics was used to filter and shape the signals. The trigger for the acquisition was made by selecting the coincidences between the PSD_A and anyone of the other two PSD's. The detectors were calibrated in position and energy by using the data from the $^{12}C(^6Li,\alpha)^{14}N$, $^{12}C(^6Li,{}^6Li)^{12}C$ and $^{197}Au(^6Li,{}^6Li)\,^{197}Au$ reactions and from an α-source.

3. Data analysis

After detector calibration, the first step in the analysis is the selection of the $^2H(^{10}B,\alpha^7Be)n$

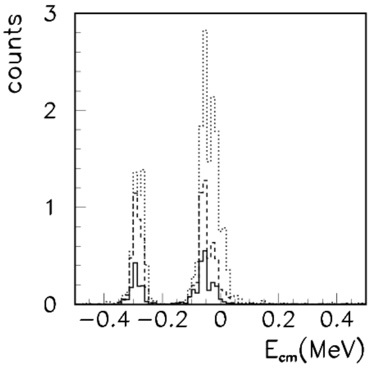

Fig. 2. The coincidence yield for different ranges of the neutron momentum. The maximum of the peak decreasis while moving from $0 \leq p_n \leq 20$ MeV/c (solid line) to $20 \leq p_n \leq 40$ MeV/c (dashed line) and to $40 \leq p_n \leq 60$ Mev/c (dotted line).

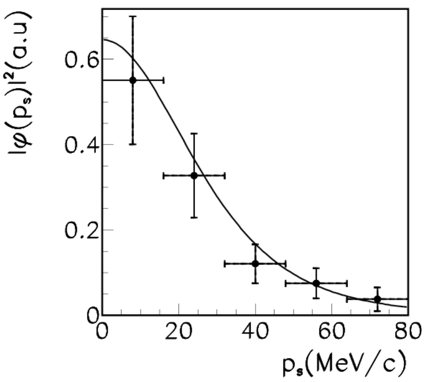

Fig. 3. Experimental momentum distribution (black point) compared with the theoretical one given in terms of a Hulth$\acute{e}$n function (full line).

three-body process by reconstructing the E_{Be}.vs.E_{α} kinematic locus and the experimental Q-value spectrum (fig. 1). The peak around Q≈- 1 MeV, is in good agreement with the theoretical value Q≈-1.08 MeV, what makes us confident on the quality of the performed calibration. Only the events under the Q≈-1 MeV peak were selected for the subsequent analysis. The next step of the analysis is the study of the data as a function of the neutron momentum in order to identify, if present, the QF contribution. A way to test the presence of the QF mechanism is to investigate the correlation between the coincidence yield and the neutron momentum p_n. Thus the experimental data divided by the phase-space factor were reported as a function of the center of mass energy E_{cm} for different neutron momentum values (Fig.2). The coincidence yield appears to be quite high in the region $0 \leq p_n \leq 20$ MeV/c and decreases while moving to $20 \leq p_n \leq 40$ MeV/c and to $60 \leq p_n \leq 70$ MeV/c. These results represent an evidence of the dominance of the quasi-free mechanism. A further check is performed by studying the experimental momentum distribution of the neutron. One of the fundamental hypothesis for the QF mechanism is that the moment distribution of the neutron in the exit channel should correspond to the one inside the deuteron before the interaction with the impinging particle (Spitaleri et al. (2001)). The moment distribution was reconstructed in Plane Wave Impulse Approximation (PWIA) following the procedure reported in (Spitaleri et al. (2001)). These results have been superimposed to the theoretical momentum distribution given by a Hulth$\acute{e}$n wave function and are shown in Fig 3. The good agreement between the two sets of data represents a further experimental evidence that the neutron acted as a 'spectator' during the break-up occurred in the $^{2}H(^{10}B,\alpha^{7}Be)n$ reaction. At this point in the data analysis, we conclude that the QF mechanism gives the main contribution in the selected kinematical experimental regions, allowing us to apply the Trojan Horse Method in order to extract the $^{10}B(p,\alpha)^{7}Be$ astrophysical S(E)-factor.

4. Results and conclusions

Very important in this analysis is the study of ^{7}Be-α relative energy, allowing us to obtain information on the presence of excited states of ^{11}C, in particular of the E_x=8.701 MeV ^{11}C resonant level ($J=5/2^{+}$) corresponding at about $E_{cm}(^{10}B\text{-}p)$=10 keV within the Gamow window for this reaction. A validity test for the method consists in the comparison between

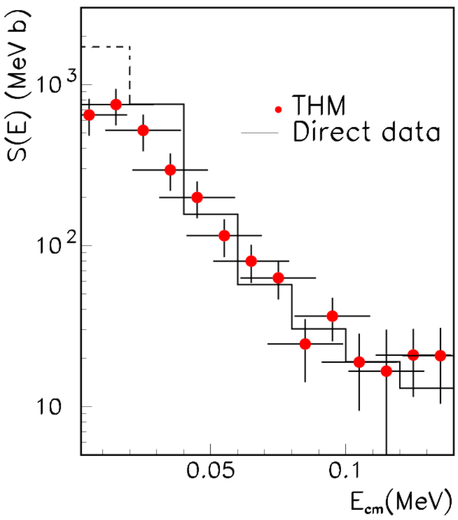

Fig. 4. Astrophysical S(E) factor for the ^{10}B(p,α)^{7}Be extracted via the THM (points) compared with direct data (histogram)(Angulo et al. (1993),Youn et al. (1991)). The dotted line represents the extrapolation of direct data down to zero energy.

the behaviours of direct and indirect excitation functions. Therefore the indirect two body cross section has been extracted and the bare-nucleus S(E)-factor calculated using the equation:

$$S(E) = E\sigma(E)exp(2\pi\eta) \quad (1)$$

In Fig.4 are reported direct data (histogram) which are present in the energy region above $E_{cm}\approx$30 keV together with the THM results (points). In order to compare the two sets of data, the direct astrophysical factor was smeared out to the energy resolution of THM data (about 24 keV). The two sets of data quite well match in the whole energy interval. The extrapolation of direct data down to Gamow energy is also indicated in the figure (dashed line), allowing the comparison with the THM results. In the lower interval, the comparison is between the experimental THM data and the extrapolation of direct points. In conclusion, the THM was able to experimentally reproduce the 10 keV resonance, within the Gamow peak for the ^{10}B(p,α)^{7}Be reaction. The extracted S(E)-factor is lower than the extrapolated one. This discrepancy, still under study, can have important implications in the astrophysical scenario.

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