PROCEEDINGS OF SCIENCE

PoS(NIC X)224

Study of the $^{10}B(p,\alpha)^{7}Be$ reaction through the Trojan Horse Method

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Del Santo, M. G.[1]
E-mail: `msanto@dfn.if.usp.br`

Lamia L.[1], Romano S.[1], Munhoz M.G.[2], Carlin, N.[2], Cherubini S.[1], de Moura M. M.[2], Kroha V.[3], La Cognata M.[1], Liguori Neto R.[2], Pizzone R.G.[1], Puglia S.M.R.[1], Rapisarda G.G.[1], Sergi M.L.[1], Somorjai E.[4], Kiss G.G.[4], Souza F. A.[2], Spitaleri C.[1], Suaide A. A. P.[2], Szanto E. M.[2], Szanto de Toledo A.[2], Tudisco S.[1], Tumino A.[1], Kubono S.[5], Wakabayashi Y.[5], Yamaguchi H.[5]

[1]*Laboratori Nazionali del Sud – INFN and University of Catania, Catania, Italy*
[2]*Universidade de São Paulo – DFN, São Paulo, Brazil*
[3]*Institute for Nuclear Physics, Prague-Rez, Czech Rep.*
[4]*Atomki – Debrecen – Hungary*
[5]*CNS – The University of Tokyo – Tokyo – Japan*

The $^{10}B(p,\alpha)^{7}Be$ reaction plays an important role in the boron burning process acting inside stars. The astrophysical *S(E)-factor* for the $^{10}B(p,\alpha_0)^{7}Be$ reaction was extracted by means of the Trojan Horse Method applied to the $^{2}H(^{10}B,\alpha^{7}Be)n$ three body reaction at low neutron momentum. The experiment was performed at the Laboratori Nazionali del Sud in Catania, Italy. Preliminary results indicates that the *S(E)-factor* obtained at the Gamow energy (10 keV), is around 2 times smaller than the one extracted from extrapolation of direct measurements at very low energies (< 20 keV).

10th Symposium on Nuclei in the Cosmos
Mackinac Island, Michigan, USA
27 July – 1 August, 2008

1. Introduction

In the stellar interior, LiBeB are destroyed mainly by (p,α) reactions at different depths corresponding to increasing temperatures. Mixing mechanisms transport material from the surface down to the region where nuclear process occur. In particular, the $^{10}B(p,\alpha)^{7}Be$ reaction is the main responsible for ^{10}B destruction and occurs at depths where the temperature is higher than 5×10^{6} K. In such environments, this p-capture process occurs at a Gamow energy of ~10 keV where a resonance is expected to strongly influence the behavior of the astrophysical *S(E)-factor*. The simultaneous determination of the surface abundances of such elements in stars

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together with precision cross section measurements for such processes at the relevant Gamow region, can be used as a “probe” for the internal structure and consequently for the mixing mechanisms acting inside the stars [1], such as rotationally induced turbulent mixing, convection, microscopic diffusion, mass loss and others.

The behavior of the cross setion *σ(E)* at very low energy is usually extrapolated from higher energies using the astrophysical *S(E)-factor*. Although the *S(E)-factor* allows the extrapolation with simple energy dependence it can introduce large uncertainties due the presence of unexpected resonances and due the electron screening effect [2]. To overcome these difficulties, a number of indirect methods have been introduced and successfully applied in recent years. In particular, the Trojan Horse Method (THM) is used to obtain the bare nucleus *S(E)-factor* of charged particle induced reactions without extrapolation. This paper reports the study of the ^{10}B(p,α)^{7}Be reaction through the THM applied to the ^{2}H(^{10}B,α^{7}Be)n three body reaction. The ^{10}B(p,α)^{7}Be takes place at the astrophysically relevant energy through a $J^{\pi} = 5/2^{+}$ state in the intermediate ^{11}C at $E_x = 8.701$ MeV ($\Gamma \sim 20$ keV).

2. Theory

In the THM, the main idea is to use a suitable three body reaction $A+a \rightarrow C+c+s$, to extract the cross section of an astrophysical two body reaction $A+x \rightarrow C+c$. The trojan horse nucleus a should have a strong $x+s$ cluster structure with a well know momentum distribution. From the three body to the two body process, we are interested in the process that is characterized as a transfer reaction to the continuum, where the trojan horse nucleus a breaks-up into a nucleus x that is transfered and where the nucleus s acts as a spectator to the subreaction. This mechanism is present and clearly distinguishable from other ones in a region of the three body phase space where the transfered momentum to the spectator s is small, i.e., for QF scattering conditions. In the theoretical description of such mechanism using the impulse approximation (IA) [3] in the framework of the Plane Wave Impulse Approximation (PWIA), the three-body cross section can be factorized into three terms [4] by the relation:

$$\frac{d^3\sigma}{dE_c\, d\Omega_c\, d\Omega_C} \propto (KF)\left|\Phi(\vec{p}_n)\right|^2 \frac{v_{Cc}}{v_{Ax}} P_l^{-1} \left(\frac{d\sigma_l}{d\Omega}\right)_{cm} \qquad (1)$$

where the term KF is a kinematical factor, $\Phi(\vec{p}_n)$ is the Fourier transform of the radial wave function for the $x-s$ intercluster relative motion. The term $(d\sigma / d\Omega)_{cm}$ is the differential two body cross section at E_{cm} given in post-collision prescription by $E_{cm} = E_{ax} = E_{Cc} - Q_{2\text{body}}$ (2). The variable E_{Cc} is the relative energy between the two detected outgoing particles and $Q_{2\text{body}}$ is the Q-value of the virtual two body reaction. The binding energy of the cluster compensates for the energy of the incoming nucleus that can be chosen high enough to overcome the Coulomb barrier in the entrance channel of the three body reaction. The break up of the “trojan horse nucleus” occurs in the nuclear field allowing one to extract the cross section for the astrophysical two body reaction without any contribution coming from both Coulomb barrier and electron screening effects. A comparison between the indirect "bare" and the direct "shielded" data represents an independent experimental approach to extract the experimental value for the electron screening potential U_e for the system studied [5].

3. Experimental Setup

The ^{2}H(^{10}B,α^{7}Be)n experiment was performed at the Laboratori Nazionali del Sud, Catania, Italy. The SMP Tandem Van de Graaf accelerator provided a 24.4 MeV ^{10}B beam with intensities up to 1nA. Self-supported deuterated polyethylene targets (CD$_2$) of about 200 μg/cm^2 thickness were placed at 90^{o} with respect to the beam direction.

The detection setup consists of a telescope system (A) made up of an ionization chamber (IC) and a silicon position sensitive detector (PSDA) to discriminate Be nuclei and of two silicon position sensitive detectors PSDB and PSDC placed on the oposite side with respect to the beam direction. The placement of the detectors was chosen in order to cover the angular range where a strong contribution of the QF is expected. It means to cover the angles where the undetected spectator has a momentum value ranging from 0 to 30 MeV/c. Two kind of events were triggered by using a time-to-amplitude converter (TAC): PSDA-PSDB and PSDA-PSDC coincidences.

4. Data Analysis

4.1. Three-body reaction identification

After calibration, the E_{Be} x E_{α} kinematical locus of the events was reconstructed assuming mass number 1 for the undetected third particle and compared with simulation (Fig.1). The relative energies between the outgoing particles were also reconstructed. The two horizontal loci around 0.9 and 1.15 MeV (Fig.2) correspond to the 8.42 and to the very close 8.65 and 8.70 MeV excited levels of the ^{11}C, while there is no evidence for ^{5}He and ^{8}Be excited states.

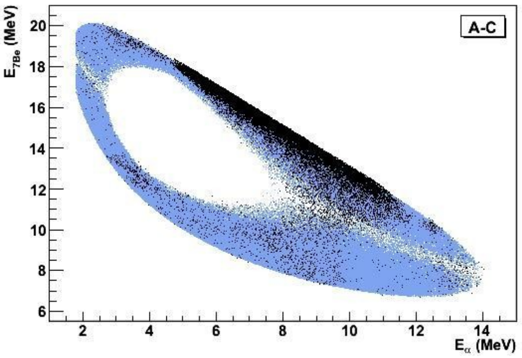

Fig.1: Experimental kinematical locus for the ^{2}H(^{10}B,α^{7}Be)n reaction (black points) in comparison with a simulation (gray points).

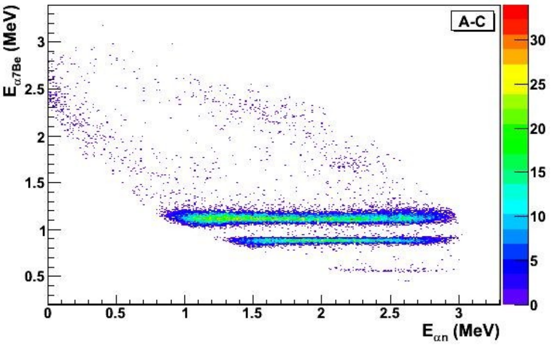

Fig.2: Relative energy $E_{\alpha 7Be}$ x $E_{\alpha n}$. The two horizontal loci correspond to the 8.42 and 8.65-8.70 MeV excited levels of the intermediate state ^{11}C.

4.2 QF-selection

The next step is to evaluate the presence and the contribution of the QF mechanism. The coincidences appear to be quite high in the $0 < |p_n| < 30$ MeV/c and decreases while moving to $20 < |p_n| < 40$ MeV/c and to $40 < |p_n| < 60$ MeV/c. In the QF hypothesis, the neutron should maintain in the exit channel the same momentum distribution it had inside the deuteron. Selecting a small window 1.13 MeV $< E_{\alpha 7Be} <$ 1.15 MeV where the two body cross section can be assumed almost constant, the three body coincidence yield corrected for the *KF* will be proportional to the momentum distribution (Fig.3). The good agreement between the experimental data and the theoretical Hulthén function for the p-n motion inside the deuteron represents a further experimental evidence that the neutron acts as a spectator. Once the conclusion that the QF mechanism is present we can extract the astrophysical *S(E)-factor*.

4.3 Astrophysical *S(E)-factor*

The 8.70 MeV level of ^{11}C, centered at about 10 keV in the ^{10}B-p relative energy axis, represents the most important feature for the study of the astrophysical reaction ^{10}B(p,α)^{7}Be, while the level 8.65 MeV is a subthreshold one and a subtraction was peformed. The center of mass energy was calculated by equation (2), for Q_{2body} = 1.145 MeV. After the selection of the QF mechanism ($|p_n|$<30 MeV/c), we use the PWIA approach (1) to extract the cross section of the two body reaction dividing the three body cross section by the term $KF\left|\Phi(\vec{p}_n)\right|^2$ calculated using Monte Carlo simulation. As the THM two-body cross section has only the nuclear contribution, it should be multiplied by the penetrability factor $P_{l=0}$ in order to compare and normalize with the direct data and then extract the *S(E)-factor* (fig.4).

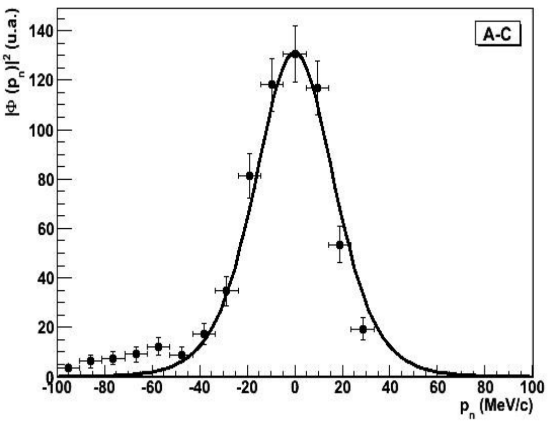

Fig.3: Experimental momentum distribution (black points) compared with the theoretical Hulthèn function (full line).

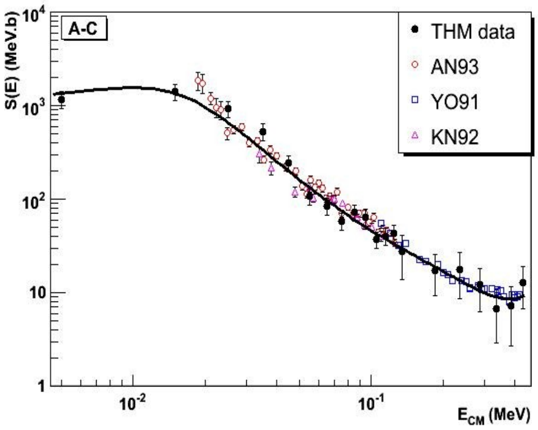

Fig.4: *S(E)-factor* for the ^{10}B(p,α)^{7}Be reaction. Indirect THM data (black points) compared with the direct data [7].

A fit in the THM data was performed using a Briet-Wigner and a 2nd order polynomial (full line on Fig. 4). The *S(E)-factor* at the 10 keV resonance is $S_R = 1547 \pm 230\, MeV \cdot b$. This value is around 2 times less if compared with the extrapolation curve of the direct data $S_R = 2870 \pm 500\, MeV \cdot b$ [6].

5. Conclusions

In this present article we have reported an improvement in the determination of the astrophysical *S(E)-factor* for the $^{10}B(p,\alpha)^{7}Be$ reaction at very low energies, regarding both previous indirect (THM) [7] and direct measurements [6]. The data obtained covers all the Gamow window for a temperature of 5×10^{6} K and the associated error in the *S(E)-factor* was estimated at about 20 % from normalization procedure in addition with the statistical error. The current result confirms the behavior of the *S(E)-factor* at high energies (E_{cm} > 40 keV) but the $S_R = S(10\, keV) = 1547 \pm 230\, MeV \cdot b$ is around 2 times less if compared with the extrapolation curve of the direct data $S_R = S(10\, keV) = 2870 \pm 500\, MeV \cdot b$ [6]. A possible explanation for this discrepancy observed in the S_R values might be ascribed to uncertainties deriving from the extrapolation procedure on direct data or to the penetrability corrections in the very low energy region, which produces an excessive decrease of the lowest energy indirect points. This disagreement is not completely understood and further study is needed. This result confirms the power of the THM to reach the low energy region usually reached only through direct data extrapolation. Moreover, the *S(E)-factor* obtained via the THM is free of electron screening effects and in a further analysis studies about the laboratory electron screening potential will be performed.

References

[1] A. Stephens *et al., APJ* ***491****, 339-358 (1997).*

[2] G. Fiorentini *et al.*, Z. Phys. **A350**, 289 (1995).

[3] Chew G. F. & Vicky G. C., Phys. Rev. **85**, 636 (1952).

[4] Jain M. et al., Z. Phys. **A345**, 231-242 (1993).

[5] C. Spitaleri et al., Nucl. Phys., **A719**, 99c (2003).

[6] C. Angulo et al., Z. Phys. **A345**, 231-242 (1993).

[7] Lamia, L. et al., Nucl. Phys. **A787**, 309-314 (2007).