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Recent results on the ^{11}B(p,α)^{8}Be reaction studied through the THM: S(E)-factor and electron screening measurements

L. Lamia*, **C. Spitaleri, S. Cherubini, V. Crucillà, M. Gulino, M. La Cognata, R.G. Pizzone, S.M.R. Puglia, G.G. Rapisarda, S. Romano, M.L. Sergi, A. Tumino**†
Università degli Studi di Catania, Dipartimento di Fisica e Astronomia, Catania, Italy
Laboratori Nazionali del Sud-INFN, Catania, Italy
E-mail: llamia@lns.infn.it

V. Burjan, Z. Hons, V. Kroha, J. Mrazek
Institute for Nuclear Physics, Prague-Rez,Czech Republic

N. Carlin, M. Gameiro Munhoz, M. Gimenez Del Santo, F.A. Souza, A. Szanto de Toledo
Departamento de Física Nuclear, Universidade de São Paulo, São Paulo, Brasil

S. Kubono, Y. Wakabayashi, H. Yamaguchi
CNS-University of Tokyo-Japan

G.G. Kiss, E. Somorjai
Atomki, Debrecen, Hungary

C. Li, Qungang Wen, Shu-Hua Zhou
China Institute of Energy, Beijing, China

A. Mukhamedzhanoz, G. Tabacaru
Cyclotron Institute, Texas A&M University, College Station, TX 77843,Usa

C. Rolfs
Ruhr-Universität, Bochum, Germany

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The $^{11}B(p,\alpha)^8Be$ reaction has been studied from ∼600 keV down to ∼10 keV, the lower energy corresponding to the Gamow window for stellar quiescent burning occurring at temperatures of $\approx 5\times10^6$ kelvin. Its investigation has been performed by applying the Trojan Horse Method to the quasi-free reaction $^2H(^{11}B, \alpha^8Be)n$ induced at a boron beam energy of 27 MeV. The zero-energy S(E)-factor and the electron screening potential were measured and compared with the available direct data.

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*Speaker.
†Present address: Università degli Studi di Enna “Kore", Enna, Italy

1. The experiment

The indirect measurements of the ^{11}B(p,α)^{8}Be reaction was performed at the Laboratori Nazionali del Sud of Catania [1]. The Trojan Horse Method (THM, see for example [2, 3]) has been applied to the quasi-free (QF) reaction ^{2}H(^{11}B,α^{8}Be)n, where the ^{2}H is "TH-nucleus". Deuteron represents one of the most suitable TH-nuclei, together with ^{6}Li or ^{3}He, thanks to its obvious $p \oplus n$ cluster structure and to a well known radial wave function described in terms of a Hulthén function ([4] and references therein). The aim of the experiment was to improve the results of the previous experimental study of the ^{11}B(p,α_0)^{8}Be [2], α_0 implying the study of the channel corresponding to alpha-particles leaving beryllium in its ground state, and then to extract the low energy S(E)-factor in the astrophysically relevant energy range. The detection setup was then thought and designed for detecting both outgoing particles, α and ^{8}Be, with the "event" ^{8}Be reconstructed following the experimental procedure described in [1]. The SMP Tandem Van de Graaf accelerator provided a 27 MeV ^{11}B beam with a spot size on target of about 1.5 mm with an energy spread of about 10^{-4}, and intensities ranging between 2 enA and 4 enA. A self-supported 170μg/cm^{2}-thick deuterated polyethylene target (CD$_2$) was placed at 90°ř with respect to the beam direction. The high energy beam was chosen in order to overcome the Coulomb barrier in the entrance channel of the ^{2}H(^{11}B,α^{8}Be)n reaction. The detection setup was conceivede to cover the region where a strong contribution of the QF mechanism is expected and to cover momentum values of the *undetected* neutron between 0 and $\sim$200 MeV/c. This assures that the bulk of the quasi-free contributions for the breakup process of interest falls inside the investigated regions, because the momentum distribution for the $p-n$ system has a maximum at p$_s$ = 0 MeV/c.

To accomplish the selection of the 2$\rightarrow$3 channel, the Q-value of the ^{2}H(^{11}B,$\alpha_0{}^{8}$Be)n reaction was reconstructed by means of momentum and energy conservation equiations. The experimental spectrum of the Q$_{3body}$ for the ^{2}H(^{11}B,$\alpha_0{}^{8}$Be)n is shown in the left panel of Fig.1, centered at about 6.35 MeV, in agreement with the theoretical value of 6.36 MeV. Only the events falling inside this peak were considered for the next steps of data analysis. After the channel selection, the events from the QF-mechanism had to be disentangled from those due to other reaction mechanisms. An unambiguous signature of the QF-mechanism is provided by the shape analysis of the momentum distribution of the undetected third particle in the exit channel. In the QF hypothesis, the neutron in the exit channel should maintain its momentum distribution as inside deuteron before the interaction with the impinging particle. By selecting a small energy region where the two-body cross section is assumed to be constant, the three-body coincidence yield divided by KF is proportional to the momentum distribution $|\Phi(\vec{p}_n)|^2$.

A typical experimental result is shown in the right panel of Fig.1, where the coincidence yield for the events in the energy window E$_{cm}$=0.15$\pm$0.05MeV divided by the phase-space factor is shown (black points). The experimental points were then compared with the theoretical Hulhén wave function in momentum space (red dotted line), while the black line is the fit of the experimental data, leading to a FWHM of 65$\pm$10 MeV/c. The agreement, within the experimental uncertainties, strongly confirms the presence of the QF-machanism thus allowing us to select only those events corresponding to the Shapiro-window [5], i.e. |p$_n$|<30 MeV/c.

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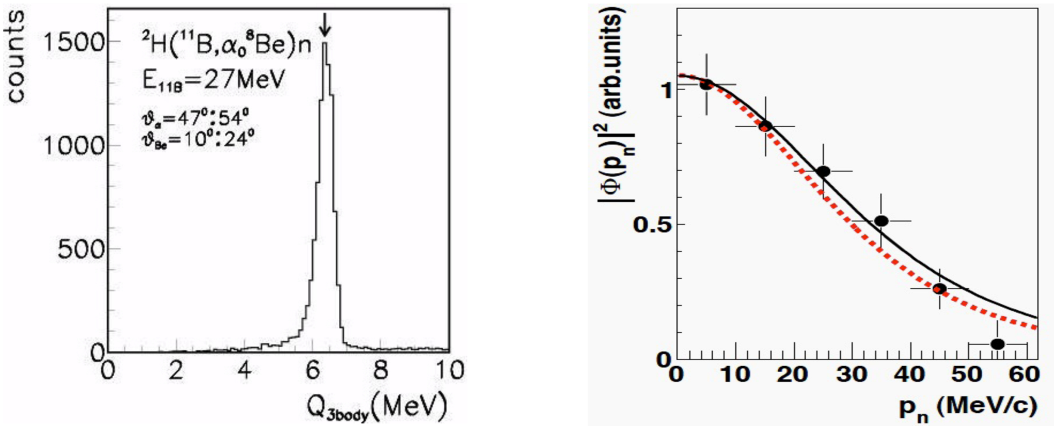

Figure 1: Left panel: the experimental Q-value spectrum for the ^{2}H(^{11}B,α_0^{8}Be)n reaction, centered at about 6.4 MeV. Right panel: the experimental momentum distribution (black points) compared with the theoretical Hulhén wave function in momentum space (red dotted line). The black line is the fit of the experimental data, leading to the value of 65±10 MeV/c.

2. Results

The experimental study discussed in [1] has been focused on to the new measurement of the ^{11}B(p,α_0)^{8}Be reaction via a more advanced and detailed analysis. In fact, a careful evaluation of the background processes competing with the QF one was also performed, since the same particles α_0, ^{8}Be and n in the exit channel can derive from QF reaction and from SM as well. A selection of the experimental data was then performed to eliminate the background contribution from the decay of ^{5}He$_{g.s.}$ and ^{9}Be states, affecting the energy region chosen for the normalization procedure. To this aim, the experimental spectra were compared with the simulated ones to evaluate the Sequential Mechanisms contribution to the experimental data and the THM data inside the kinematic region where SM contributions dominate were discarded. Moreover, the behavior of the experimental momentum distribution has been carefully evaluated, by considering the distortions altering the shape of the neutron momentum distribution. For such a reason, the experimental momentum distribution was compared with both the theoretical one, deduced from the Hulthén wave function, and the DWBA distribution, evaluated by means of the FRESCO code [6], as already done in others TH works [7, 8]. From the comparison, we can state that a good agreement between DWBA and PWIA is present, within the experimental uncertainties, for neutron momentum values lower than 40MeV/c. The analysis of [1] has pointed out that in the low neutron momentum value range the uncertainty due to the used form of momentum distribution is negligible.
The TH data were then normalized to the direct ones of [9] by following the procedure described in [1]. The result shown in the left panel of Figure2 represents the TH S-factor (black points) compared with the fit of [9] (with a ∼40 keV of energy resolution, see [1] for details). The extracted value of S(0)^{THM}=2.07±0.41 MeV b is in good agreement with the extrapolated one [9]. To give an evaluation of the electron screening potential for the ^{11}B(p,α_0)^{8}Be, we used data from [10] "re-scaled" to those of [9]. Such procedure was needed due to the lack of direct data in [9] below

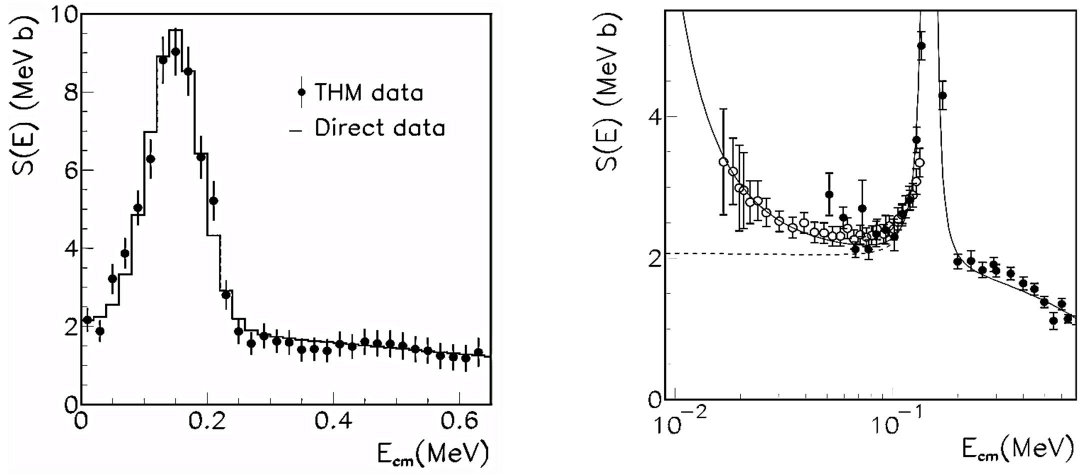

Figure 2: Left panel: the experimental ^{11}B(p,α_0)^{8}Be S(E)-factor measured by means of the THM (black points) compared with the smeared (∼40 keV) fit of the direct data of [9]. Right panel: the direct measurements of [9] (black points) and [10] superimposed onto the bare nucleus TH S-factor (dotted line). The full line represent the result of the fit, obtained leaving the electron screening potential U_e as the only free parameter.

40 keV. The value of U_e^{THM}=472±160 eV (full line in the right panel of Figure2) is in agreement within the experimental errors with the value of U_e=430±80 eV measured in [10] using the total α_0 and α_1 contribution to the ^{11}B(p,α)^{8}Be cross section. However, the value obtained here is higher than the value of U_e=340 eV predicted by the adiabatic limit, confirming the discrepancy between theoretical predictions and experimental U_e values. In conclusion, the present indirect study of the ^{11}B(p,α_0)^{8}Be reaction via THM represents the first measurement of the astrophysical S(E)-factor in correspondence of the Gamow peak for quiescent stellar burning. However, future efforts must be addressed to measure the ^{11}B(p,α_1)^{8}Be channel via the TH application, to allow for the determination of its bare-nucleus S(E)-factor and a further determination of the electron screening potential for the ^{11}B-p case.

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