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The Trojan Horse Method application on the ^{10}B(p,α_0)^{7}Be reaction cross section measurements

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Abstract. The ^{10}B(p,α_0)^{7}Be reaction cross section has been measured in an wide energy range from 2.2 MeV down to 3 keV in a single experiment applying THM. Optimized experimental set-up ensured good energy resolution leading to a good separation of α_0 and α_1 contributions to the cross section coming from the ^{7}Be ground and first excited state, respectively.

1 Introduction

Since excitation function of the ^{10}B(p,α)^{7}Be reaction is dominated by strong s-wave resonance at 10 keV (J^π=3^+, 8.699 MeV ^{11}C level) lying exactly at the energy corresponding to the Gamow peak (EG) [2], the cross section function extrapolation (that is usually carried out from direct experimental data measured at higher energies) should be avoided due to significant uncertainties that can be introduced in this way. Therefore the precise study of the ^{10}B(p,α)^{7}Be reaction cross section at astrophysical energies applying indirect approach such as Trojan Horse Method (THM) ([1] and references therein) is well suited.

The ^{10}B(p,α)^{7}Be reaction plays an important role in prediction of boron abundance in stars because the ^{10}B burning process mostly proceeds via the (p,α) reaction. Since depletion of light elements such as Li, Be and B occurs at different depths, this reaction can be used as probe for internal stellar structure, so, analysis of the resulting atmospheric abundances of these elements can help in understanding and confining the mixing processes [3–5].

Up to now, several experiments were performed applying direct [6–14] and indirect [15, 16] approaches in order to investigate the ^{10}B(p,α)^{7}Be reaction. The biggest problem in the precise cross section analysis comes from the significant differences between the existing experimental data sets [6], probably caused by unknown systematic uncertainties.

2 Applied technique

In order to extract a two-body ^{10}B(p,α_0)^{7}Be reaction cross section free of suppression due to penetration thought the Coulomb barrier and electron screening effects, the THM was applied by selecting the Quasi-Free (QF) contribution to the ^{2}H(^{10}B,α ^{7}Be)n reaction cross section at energies above the Coulomb barrier [17]. Deuteron has been selected as a Trojan Horse (TH) nucleus due to its $p \oplus n$ cluster configuration. After ^{2}H breakup in the collision with the projectile, ^{10}B interacts only with the transferred particle p, while n does not participate in the process and acts as a spectator.

In the Plane Wave Impulse Approximation (PWIA), the three-body reaction cross section can be calculated [18–20] as:

$$\frac{d^3\sigma}{dE_\alpha d\Omega_\alpha d\Omega_{^7\mathrm{Be}}} \propto KF \cdot \phi^2(p_n) \cdot \left(\frac{d\sigma(E_{cm})}{d\Omega}\right)^{HOES} . \tag{1}$$

Here KF represents the kinematical factor containing the final state phase-space factor and it is dependent on the masses, momenta, and angles of the outgoing particles. $\phi^2(p_n)$ represents the squared Fourier transform of the radial wave function describing the p-n inter-cluster motions, usually given for deuterium by the Hulthén function. The factor $(d\sigma(E_{cm})/d\Omega)^{HOES}$ stands for the Half-Off-Energy-Shell (HOES) differential cross section of two-body reaction at the center-of-mass energy E_{cm}=$E_{^2\mathrm{H}-p}$=$E_{^7\mathrm{Be}-\alpha}$-Q_{2b} [21].

3 Experiment

The experimental study of the ^{2}H(^{10}B,α ^{7}Be)n reaction was performed by bombarding a 56 μg/cm^2 self-supported deuterated polyethylene (CD$_2$) target by the 28 MeV ^{10}B ion beam produced with the SMP Tandem Van de Graaff accelerator at the *Laboratori Nazionali del Sud* in Catania, Italy. The beam intensity was around 1 enA. The detection system consisted of four 500 μm thick Position Sensitive Silicon Detectors (PSD) of which two were used to measure the residual energy of the detected particles (E stage) as a part of two ΔE-E telescope systems. As for ΔE stage, two Ionisation Chambers were used with 1.5 μm thick Mylar entrance and exit windows, filled with butane gas (C_4H_{10}) at a pressure of 110 mbar. Two PSDs used as a part of telescope systems were placed at a distance d=400 mm from the target and centred at opposite sides of the beam axis at the laboratory angle of 14.5°. Another two position sensitive detectors were placed at a distance d=200 mm from the target and centred at opposite sides of the beam axis at the laboratory angle of 28°. The trigger for the event acquisition was given by the coincidence of signals of two PSDs.

4 Results

Analysing the ΔE-E plot, it was possible to identify and select only events corresponding to the three-body ^{2}H(^{10}B,α ^{7}Be)n reaction. In following, the Q-value spectrum for selected ^{7}Be nuclei and α-particles detected in coincidence was reconstructed by assuming that mass is equal to 1 for the undetected third particle (neutron). The reconstructed Q-value spectrum is reported in the panel (a) of Fig.1. For the experimentally deduced Q-values corresponding to the α_0 (Q=-1.079 MeV) and the α_1 (Q=-1.54 MeV) channels have been found to be in good agreement with the theoretical values (marked by arrows in this figure). Two peaks are very well separated thus allowing accurate selection of events corresponding only to the ^{2}H(^{10}B,α_0 ^{7}Be)n reaction.

The ^{2}H(^{10}B,α_0 ^{7}Be)n excitation function has been extracted in an energy range from 3 keV to 2.2 MeV. For the experimental energy resolution, evaluated from FWHMs of the ^{11}C levels at energies of 8.654 MeV (E_{cm}=-35 keV) and 8.699 MeV (E_{cm}=10 keV) [22], was found to be $\delta\epsilon$=17±1 keV. This is notable improvement compared to the previous THM experiments on the same reaction, where the experimental resolution was found to be 31±3 keV in [15] and 87±5 keV in [16]. Since the behaviour of the cross section at low energies is strongly dominated by the ^{11}C resonant state at the energy

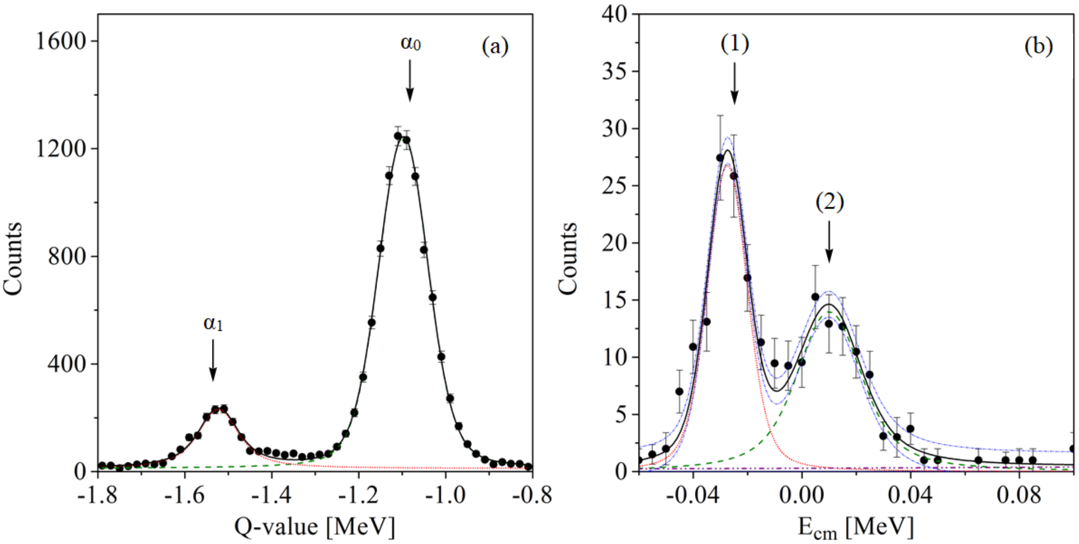

Figure 1. (a) Reconstructed three-body Q-value spectra. The theoretical values $Q^{th}_{\alpha_0}$=-1.079 MeV and $Q^{th}_{\alpha_0}$=-1.54 MeV are marked by arrows. (b) Contributions of the ^{11}C resonances at energies of 8.654 MeV (1) (dotted red line), 8.699 MeV (2) (dashed green line) and 9.200 MeV (dash-dotted line). Cumulative fit is displayed as a full black line, while blue dash-dotted lines give the upper and lower 95% confidence limits to the fit.

of 8.699 MeV, falling just in the Gamow peak energy region, the good separation of this resonance from sub-threshold contribution is crucial for accurate determination of the astrophysical S-factor and so, electron screening potential U_e. The subtraction of the 8.654 MeV level was done as described in [15, 16]. Namely, these two resonances were fitted with sum of three smeared incoherent Breit-Wigner functions, describing the contributions of resonances at energies of 8.654 MeV and 8.699 MeV and the contribution of the tail of the resonance at the energy of 9.200 MeV (see panel (b) of Fig.1).

In order to obtain the bare-nucleus THM S-factor in absolute units, the THM data has been normalised to the direct data from [14] in an energy range from 0.2 MeV up to 1.2 MeV. This procedure yielded an error affecting normalization constant of 2.8%. As for values of the astrophysical S-factor at center-of-mass energy of 10 keV and the electron screening potential (S_b(10 keV)=2950±206 MeV b and U_e=265±46 eV, respectively) was found to be in a good agreement with ones observed in [16] (S_b(10 keV)=2942±395 MeV b and U_e=240±50 eV).

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