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# New direct measurement of the $^{10}$B(p,$\alpha$)$^{7}$Be reaction with the activation technique

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**Abstract.** Boron plays an important role in astrophysics and, together with lithium and beryllium, is a probe of stellar structure during the pre-main sequence and main-sequence phases. In this context, the $^{10}$B(p,$\alpha$)$^{7}$Be reaction is of particular interest.

The literature data show discrepancies in the energy range between 100 keV and 2 MeV. This also poses a normalization problem for indirect data obtained with the Trojan Horse Method.

A new measurement of the $^{10}$B(p,$\alpha$)$^{7}$Be reaction cross section was performed at Legnaro National Laboratories (LNL). At LNL, the cross section was determined with the activation technique by measuring the activated samples at a low-background counting facility. The analysis of that experiment is now complete and the results are here presented.

## 1 Introduction

Boron-burning nuclear reactions are of great interest in many different fields ranging from nuclear physics and astrophysics to plasma physics.

The $^{11}$B(p,$\alpha$)$^{8}$Be $\longrightarrow \alpha\alpha$ reaction is one of the main candidates for aneutronic energy production in plasma-induced fusion reactors [1]. Natural boron consists of $^{11}$B (80.1%) and $^{10}$B (19.9%) and the (p,$\alpha$) reaction on $^{10}$B represents a contaminant for aneutronic fusion, since it produces the radioactive nucleus $^{7}$Be. In order to estimate the impact of $^{10}$B contaminations in future fusion reactors, the cross section of the $^{10}$B(p,$\alpha$)$^{7}$Be reaction should be accurately known.

In astrophysics, boron is used together with lithium and beryllium as a tracer of stellar structure and evolution during the pre-main sequence and main sequence phases. In stars, lithium, beryllium and boron are burned at different temperatures ($T > 2.5$ MK for Li, $T > 3.5$ MK for Be and $T > 5$ MK for B). As a consequence, when material is mixed from the surface down to the inner layers of a star,

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each element survives to different depths [2]. Moreover, the relative abundances of the stable boron isotopes $^{10}$B and $^{11}$B in pre-MS stars provides additional information on early stellar evolution: the N($^{11}$B)/N($^{10}$B) ratio for different stellar masses and metallicities shows an increase with time for stellar masses in the range 0.1 - 0.3 solar masses [3]. Therefore, by measuring the amount of each isotope on the surface of a star it is possible to shed light on stellar mixing in the early phases of stellar evolution, provided that the cross sections of all the reactions which may affect the elemental abundances are known.

## 2 State of the art

The $^{10}$B(p,$\alpha$)$^7$Be reaction has been widely studied in the past, with experimental data available in the energy range from 5 to 6000 keV [4] - [13]. At energies below 100 keV, the direct data in ref. [10] show an enhancement of the astrophysical S-factor S(E). This enhancement is produced by the combination of a resonance at $E_{CM} \sim$ 10keV and by the electron screening effect.

In the energy range between 100 and 400 keV, experimental data show great discrepancies, as the data of ref. [9] had to be multiplied by a factor of 1.83 to match the results of ref. [10].

To overcome the difficulties related to the electron screening effect and the suppression of the cross section at ultra-low energies, recent measurements of $^{10}$B(p,$\alpha_0$)$^7$Be with the Trojan Horse Method (THM) [12] have provided the bare-nucleus S(E) down to 5 keV without the needs of extrapolation procedures, providing the only experimental dataset at energies below the 10 keV resonance. However, the mismatch between direct data above 100 keV, where electron screening is negligible, makes it difficult to choose a reliable normalization for the Trojan Horse data.

Together with the present experiment, new results from different groups have been published recently in the 0.630–1.028 MeV energy range [14, 16]. Here we report on the results of a measurement of the $^{10}$B(p,$\alpha$)$^7$Be cross section performed at Legnaro National Laboratories [17].

## 3 Experimental setup

The experiment was performed at the AN2000 accelerator of Legnaro National Laboratories (LNL). A beam energy calibration was performed exploiting the $^{27}$Al(p,$\gamma$)$^{28}$Si narrow resonances at 632 keV and 992 keV [18] and through Rutherford Backscattering Spectroscopy on a SiO$_2$ sample.

The $^{10}$B(p,$\alpha_0$)$^7$Be cross section has been measured through activation technique. A sketch of the setup used for the target irradiation is shown in fig. 1 and an extensive description can be found in [17]. The beam was collimated by slits positioned at a distance of 1 meter from the target, then entered the target chamber through a collimator of 9 mm diameter.

Targets were made by evaporating $^{10}$B powder (isotopic enrichment up to 93%) on thin carbon layers ($\sim$ 20 $\mu$g/cm$^2$). Three different target thicknesses were chosen: 25, 60, and 100 $\mu$g/cm$^2$. Targets with the same thickness were evaporated at the same time in order to ensure their uniformity. Moreover, two samples of each group were not irradiated and used for off-line target analysis.

The reaction kinematics is such that $^7$Be ions are emitted at all angles and their kinetic energy is high enough to escape the target. Therefore, in order to collect all $^7$Be nuclei produced by the reaction, the target was surrounded with a 0.2 mm thick aluminum catcher. The catcher was designed to cover 99.8% of the total solid angle.

Each target was irradiated at a different beam energy and the duration of the irradiation was decided according to the beam energy and expected cross section. Once the irradiation was completed, the $^7$Be activity in the targets and in the catchers was measured at the low-background $\gamma$ counting

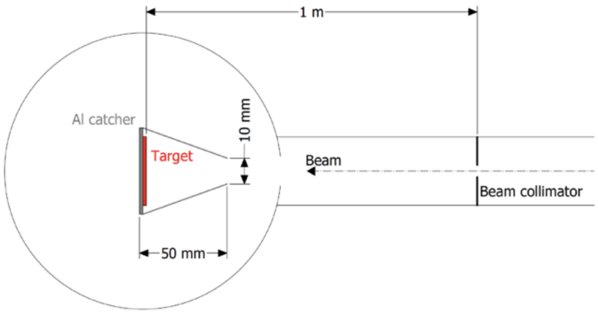

**Figure 1.** Experimental setup used for the irradiation of $^{10}$B samples [17].

facility of LNL [19]. The counting facility consists of two HPGe detectors of 80% relative efficiency facing each other. Both detectors are enclosed in a copper and lead lining serving as a shield against environmental background from naturally occurring radioactive isotopes. Samples were positioned between the two detectors, at a distance of 2.5 cm from each endcap.
$^7$Be decays with (10.44 ± 0.04)% probability to the first excited state of $^7$Li. The de-excitation of $^7$Li to the ground state produces a 478 keV $\gamma$ ray which was used to count the number of $^7$Be decays per unit time.

## 4 Results and conclusions

The $^{10}$B(p,$\alpha_0$)$^7$Be cross section has been measured in the energy range from 249 up to 1182 keV in the center-of-mass system, an energy range poorly explored in previous works.
The number of $^7$Be nuclei produced in each irradiation was deduced from the analysis of the activation spectra. Targets and catchers samples were analysed separately and the results were then summed to obtain the total amount of $^7$Be produced at each irradiation energy.
Targets thickness and elemental composition (including oxygen and nitrogen contaminants) were measured performing Rutherford backscattering spectrometry and nuclear reaction analysis at the AN2000 accelerator.
The astrophysical S-factor from the present experiment is reported in fig. 2, compared to some of the literature S-factors. At the lowest energies investigated, the present data show a discrepancy of about a factor of two with respect to Youn et al. [9], matching the results from Angulo et al. [10]. At energies above 500 keV, our results are in fair agreement with literature data from ref. [4] and [7], as well as with the more recent results from Lombardo et al. [14], while some disagreement exists with the recently published results from Wiescher et al. [16].
A simplified R-matrix analysis of the present-work data was performed (see fig. 2 and ref. [17] for more details). The fit successfully reproduces our experimental data, with the exception of one point at E = 647 keV, which significantly deviates from the calculation and might point to the existence of a new resonance. Further investigations with a smaller energy step may help clarify this point.

The results from the present work have been used in combination with [7] and [14] for the normalization of both low energy [12] and high energy [15] Trojan Horse results, which provide consistent data in the energy range between 5 keV and 1.5 MeV [15].
Some disagreement still exists between the results from different direct experiments and therefore

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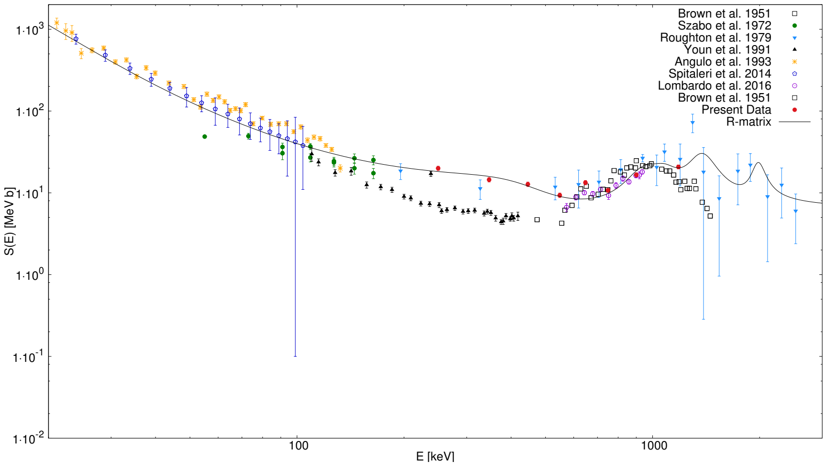

**Figure 2.** Astrophysical S-factor of the $^{10}$B(p,$\alpha_0$)$^7$Be reaction. Present results are compared with literature data.

new direct investigations covering a broader energy range are still needed.

Following the measurement of the $^{10}$B(p,$\alpha_0$)$^7$Be cross section, a new experiment was performed at LNL to measure the cross section of the (p,$\alpha_1$) channel in the energy range between 300 and 2000 keV. The data analysis is still ongoing and results will be presented in a forthcoming publication.

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