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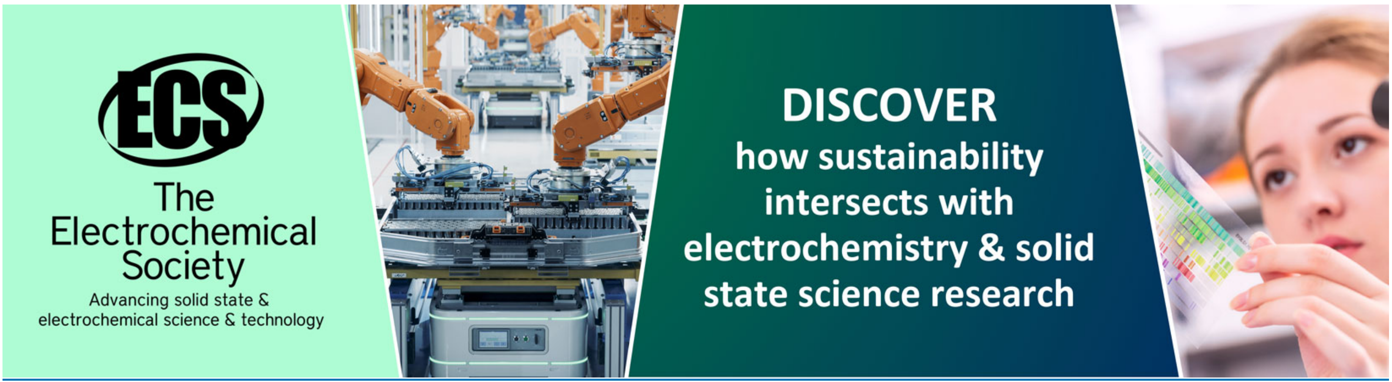

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Astrophysical S factor for the ^{4}He(^{3}He,γ)^{7}Be reaction at medium energies

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Abstract. The astrophysical **S** factor for the ^{4}He(^{3}He,γ)^{7}Be direct capture reaction plays a major role in the context of solar neutrino flux and primordial ^{7}Li abundances that demand accurate information on the reaction. We report here our recent cross section measurements using the activation method in the region of E_{CM}=900-2800 keV, that aim to shed light on the discrepancies in the existing data and lead to a more accurate extrapolation of the S factor.

1. Introduction

The ^{4}He(^{3}He,γ)^{7}Be reaction rate plays an important role in determining the primordial ^{7}Li abundance in the universe from the ^{7}Be disintegration. Furthermore, the high energy solar neutrino flux depends strongly on the ^{8}B abundance due to the ^{7}Be proton capture, and thus on the formation of ^{7}Be, which mainly occurs via the direct capture reaction ^{3}He(^{4}He,γ)^{7}Be. Currently, this reaction is one of the remaining major sources of uncertainty among the nuclear inputs required to calculate the high energy solar neutrino flux [1]. Present work is also timely in view of new results of the detection of solar anti-neurtrinos with the BOREXINO detector at Gran Sasso laboratory [2]. Precise measurements of the cross section σ are therefore necessary. The astrophysical S factor is extracted from σ via: $\sigma(E) = \frac{1}{E} \cdot S(E) \cdot e^{-2\cdot\pi\cdot\eta(E)}$, where E is the energy and η is the Sommerfeld parameter. The $S(E)$ gives the nuclear dependence of the astrophysical reaction rate and theoretical models use the extrapolation of $S(E)$ for the ^{4}He(^{3}He,γ)^{7}Be reaction at zero energy ($S_{34}(0)$) as an input parameter in determining the solar neutrino flux and ^{7}Li abundance. Presently, there are serious discrepancies between the existing measurements of S_{34} using different methods [3-7]. We focus mainly on the striking differences in the centre of mass (C.M.) energy range of 1.6 MeV to 3 MeV, where only data from Ref. [3] from 1963 and Ref. [4] from 2009 exist. Our measurements would help to constrain the experimental shape of $S_{34}(E)$ at medium energy and thus validate the theoretical calculations used for the extrapolation towards zero energy, thereby providing the accurate information needed for calculating solar neutrino and the ^{7}Li primordial abundances.

2. Experiment

In the ^{4}He(^{3}He,γ)^{7}Be capture reaction, prompt γ-rays from the capture state to ground state or to the first excited state (at 429 keV), as well as from the first excited state to the ground state are emitted. Subsequently, the ^{7}Be ions decay by electron capture to ^{7}Li with a half life of 53.35 days. Thus, three different alternatives appear for the determination of the amount of ^{7}Be created: direct detection and counting of the ^{7}Be ions, detection of prompt γ-rays, or detection of delayed 478 keV γ ray activity from the first excited state in ^{7}Li (Activation Method). The latter technique was used for the current work, utilizing the experimental setup from the Weizmann institute [8]. The experiment was carried out at the Nuclear Physics line of the 5 MV Tandem accelerator at the Centro de Microanálisis de Materiales (CMAM), in Madrid. Figure 1 shows a schematic of the setup. The ^{4}He gas target pressure in the chamber is isolated from the beam line high vacuum by using 1 μm thick Ni foil window. A ^{3}He beam with energies between 2.3 MeV and 5.3 MeV of 100 to 200 nA current passed through the Ni foil. The ^{7}Be nuclei, produced via the capture of the beam onto ^{4}He, recoiled through the chamber and were implanted into a Cu catcher placed at the end of the chamber. A silicon detector with a 0.27 mm radius collimator for monitoring the scattered beam was placed inside a chamber arm at 44.9°. A pressure gauge was used to maintain the pressure constant using a regulated gas flow system. The chamber was electrically isolated and a suppressor kept at -180 V upstream of the Ni-foil made possible to use the chamber as a Faraday cup and thus to directly measure the charge accumulated during the irradiations.

Figure 1. Sketch of the setup used in the experiment. See the text and Ref. [8] for more details.

3. Experimental analysis

Measurements, resulting in six Cu catchers with implanted ^{7}Be nuclei produced at different beam energies, were carried out in order to determine the reaction rate over a wide energy range. The amount of ^{7}Be recoiling ions, the number of target ions and the total incoming ion beam was measured precisely. The recoiling ^{7}Be atoms were collected onto the Cu catchers and the subsequent β delayed γ radiation was measured off-line using a low-background HPGe detection station at SOREQ laboratory, in Israel, similar to that of Ref. [8]. The measurement typically was carried out over a few days in order to obtain enough statistics in the 478 keV line in the γ spectrum. Due to the low pressure an ideal gas behaviours is assumed for the gas target and the number of target atoms can be expressed as: $\mathrm{N}°(^4He) = 9.66 \cdot 10^{18} \cdot l \cdot \frac{P}{T_0+T_c}$, where P, l and T_0 are pressure in torr, room temperature in K and length between the Ni foil and the Cu catcher in cm, respectively. T_c is the correction to the temperature due to the beam heating the ^{4}He gas during the measurement. Pressure was kept constant over the different measurements (≈50 Torr). The temperature correction (T_c) was interpolated using the data in reference [8]. In order to determine the number of incident ^{3}He ions two complementary techniques were being used: integration of the charge induced on the chamber and integration (IC) of the elastically scattered particles in the detector (RS).

4. Preliminary results and ongoing work

The results obtained after data analysis are shown in Table 1. The fourth and fifth columns show the S_{34} factors by determining the beam particles by charge integration (IC) and Rutherford scattering (RS), respectively. An agreement between the two methods is observed. Our results show a good agreement with those from ERNA data [4] at the highest energies. Around 2 MeV C.M. energy, the S_{34} factor fall between the results of [1] and [3]. New measurements with the same setup are ongoing at CMAM in order to reduce the statistical error and to check the result around 2 MeV C.M. energy, afterwards extrapolations will be carried out using different theoretical models. For a brief discussion on this data in relation with our TRIUMF work and the recent calculations by T. Neff [9] we refer to Ref. [10].

Table 1. First column gives the C.M. energy $E_{CM} = \frac{4}{7}(E_b - \Delta E_{Ni} - \frac{\Delta E_{He}}{2})$ where E_b is the incoming beam energy, ΔE_{Ni} is the energy loss in the Ni foil, and ΔE_{He} the energy loss in the gas target between the Ni foil and the Cu catcher. As we assume that the reaction takes place in the middle of the gas target, the last term in the equation is divided by two. The fourth and fifth columns show S-factor when the number of incoming particles are obtained from charge integration ($S_{34}(E)^{IC}$) and from Rutherford scattered particles ($S_{34}(E)^{RS}$), respectively. The statical errors associated to the delayed gamma radiation detection are shown. The systematic errors are negligible.

E_{CM} (keV)	P (Torr)	N°^{7}Be (10^6)	$S_{34}(E)^{IC}$ (keV·b)	$S_{34}(E)^{RS}$ (keV·b)
903.6	54.68	1.30	0.40±0.08	0.41±0.08
1487.5	63.77	4.02	0.31±0.02	0.31±0.02
2010.6	50.64	5.02	0.30±0.02	0.31±0.02
2256.0	50.66	4.71	0.37±0.04	0.37±0.04
2499.0	50.83	3.17	0.37±0.03	0.38±0.04
2791.1	56.69	6.01	0.41±0.02	0.41±0.02

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