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Neutron Capture Cross Section for ^{10}Be

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Abstract. The determination of the involved reaction cross sections is essential for the understanding of how the big bang nucleosynthesis and nuclear reactions in stars contribute to the observed abundances. One of those, which has not been measured so far, is the ^{10}Be(n,γ) cross section.

A ^{10}BeO sample, provided by PSI Villigen, was irradiated in a cyclic activation at the TRIGA reactor in Mainz. The characteristic γ-rays following the decay of ^{11}Be were measured using LaBr$_3$ scintillation detectors. The thermal neutron cross section and the resonance integral were experimentally determined for the first time.

Keywords: Nucleosynthesis, Activation, Neutrons

1. Introduction

The pattern of the solar abundances of nuclides features a conspicuous minimum in the region of the light elements Li, Be, and B. The main origin of these scarce elements are thought to be spallations of C, N and O in the interstellar and circumstellar matter by galactic cosmic rays. It is referred to as interstellar nucleosynthesis. The understanding of the ^{10}Be(n,γ) cross section is crucial for the modelling of the reaction rates of the light nuclei, which directly affect the abundances. Thus far the recommended capture cross sections are based on theoretical direct capture calculations and inverse reactions [1, 2, 3], as shown in figure 1, or the asymptotic normalization coefficient (ANC) of the wavefunction [4]. The latter being used in a recent publication by S. Dubovichenko and A. Dzhazairov-Kakhramanov [5]. In 1965, an attempt on the experimental determination of the cross section had been performed by the atomic energy division of the US Atomic Energy Comission [6], but only lead to an upper limit of $\sigma_{therm} = 1$ mb, due to low statistics. Thus, experimental data of the ^{10}Be(n,γ) reaction is needed. Direct measurements can serve as an important test of the Coulomb breakup experiments.

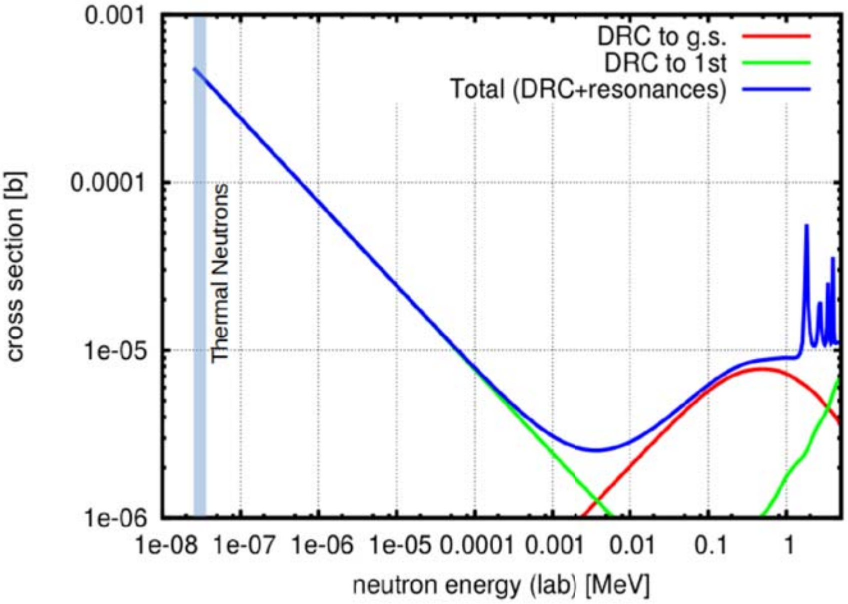

Figure 1: The calculated neutron direct capture cross section of ^{10}Be based on the neutron halo configuration of ^{11}Be.

2. ^{10}Be Activation

The experiment was carried out at the Johannes Gutenberg-University (JGU) in Mainz, Germany. The TRIGA reactor provided pulsed thermal neutrons (25 meV) with a flux of up to 10^{15} cm^{-2} per pulse. The short half life of ^{11}Be (13.8 s) and the extremely small cross section could be addressed with cyclic activations [7]. A pneumatic tube system for sample transfer from the detector lab to the reactor core enabled relatively short waiting times of around 10 s between the activation and the start of the γ-counting. The sample was a capsule with 8.93 mg BeO with 1.1 mg ^{10}Be. It was produced at the PSI muon production facility via proton spallation and extracted using pyrolysis and chemical purification. The amount of ^{10}Be was determined via mass spectroscopy and confirmed by total activity measurements [8]. The ^{11}Be activity was measured by detecting the 2125 keV γ-radiation of the excited to ground state decay using 2" LaBr$_3$ scintillation detectors. Two different flux monitors, ^{197}Au and ^{45}Sc, were used to separate the thermal and the epithermal components of the neutron spectrum of the reactor.

3. Analysis

The number of nuclei produced was calculated from the counts in the γ line by

$$N_{produced} = \frac{Counts}{I_\gamma \cdot \epsilon \cdot f_{wait} \cdot f_{meas}} \,,$$

where I_γ is the corresponding intensity, ϵ is the detector efficiency, f_{wait} is the correction factor for decay losses between the activation and the measurement, f_{meas} is the correction factor for the decays during the measurement. A correction for the decays during the activation was not necessary as the duration of a pulse amounted to 30 ms.

In order to measure the thermal cross section and the resonance integral separately, the cadmium difference method was applied. A layer of 1 mm cadmium was wrapped around the sample during some of the activations to determine the contribution by the non-thermal high energy tail of the neutron spectrum, using the energy dependent neutron transmission of cadmium, as shown in figure 2. This way, the integrated thermal neutron capture cross section as well as the resonance integral can be obtained by plotting R_{Be}/ϕ_{therm} against ϕ_{epi}/ϕ_{therm} and using

$$\frac{R_{Be}}{\phi_{therm}} = \sigma_{therm,int} + I_{res} \cdot \frac{\phi_{epi}}{\phi_{therm}} \,,$$

where R_{Be} is the ratio of ^{11}Be to ^{10}Be, ϕ_{therm} is the thermal neutron flux, ϕ_{epi} is the epithermal neutron flux, $\sigma_{therm,int}$ is the thermal cross section and I_{res} is the resonance integral, as shown in figure 3. A least square fit of a linear function gives the thermal cross section as the intercept with the y-axis and the resonance integral as the slope. The x-axis scattering of the cadmium data points was influenced by the fact that the sample had to be taken out of the cadmium shielding for the gamma detection and put back into it for the next activation. Variations of the effective cadmium thickness can not be ruled out.

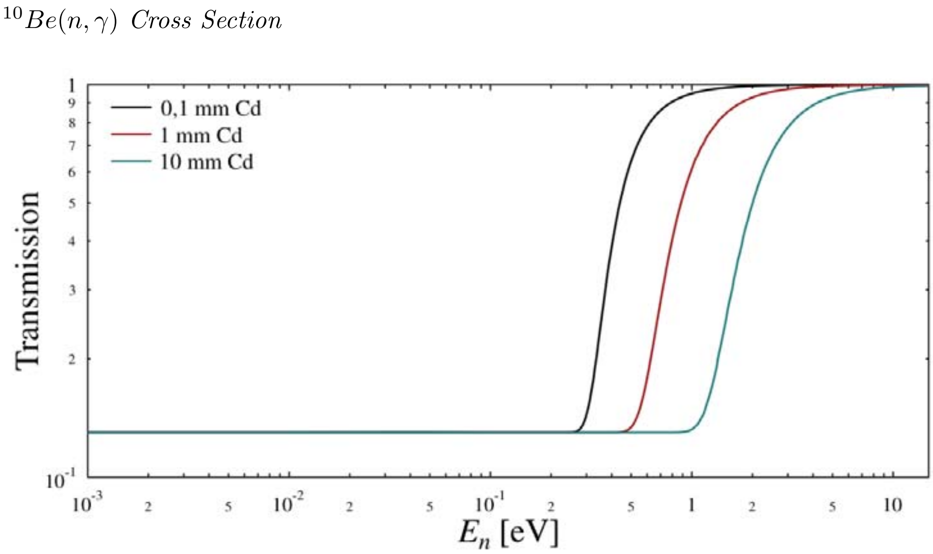

Figure 2: The neutron transmission in relation to the thickness of cadmium. The used 1 mm cadmium shielding translates to a 5 eV cutoff energy.

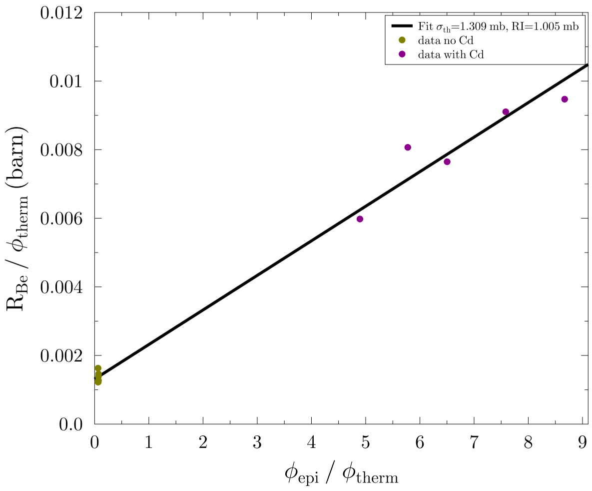

Figure 3: The activation ratio over the integrated thermal flux plotted against the epithermal to thermal flux ratio. The resulting linear fit provides both cross sections as its variables. The activations without cadmium shielding can be seen in green, those with cadmium shielding in purple.

4. Preliminary results

The analysis results in a preliminary integrated thermal neutron capture cross section of

$$\sigma_{therm} = 1.309 \text{ mb}$$

$^{10}Be(n,\gamma)$ *Cross Section*

and a resonance integral of

$$I_{res} = 1.005\,\text{mb}$$

The data evaluation is currentliy ongoing. Uncerntainties of less than 10% are expected. Figures 4 and 5 show the new experimental results in comparison to a compilation of cross section values from different databases and publications based on theoretical models.

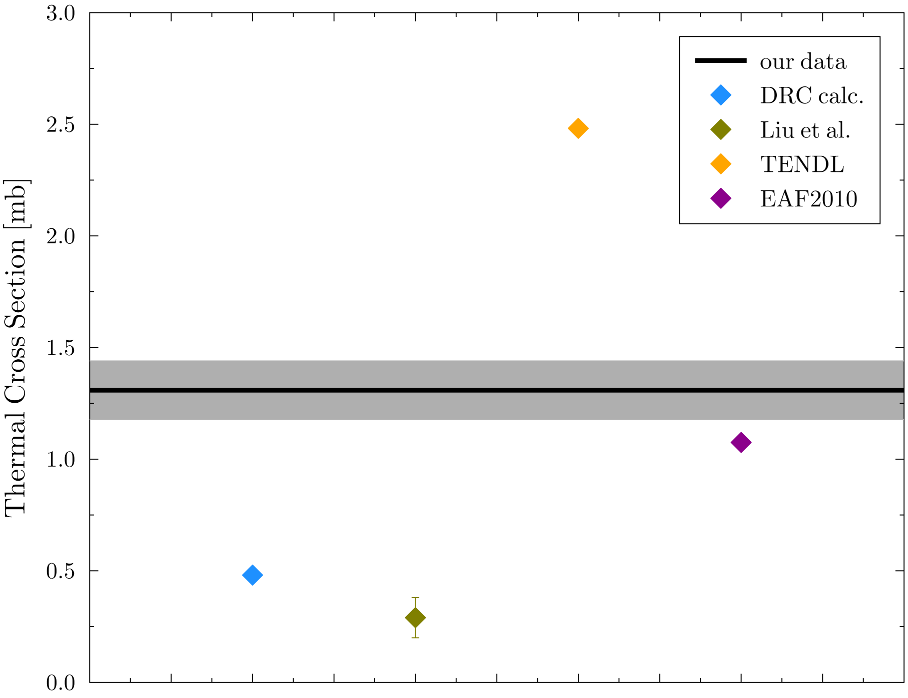

Figure 4: Comparison of the preminimary results for the thermal ^{10}Be(n,γ) cross section with theoretical estimates [4, 9, 10]. An uncertainty band of 10% is indicated, which is the envisaged total uncertainty of the final analysis.

Acknowledgments

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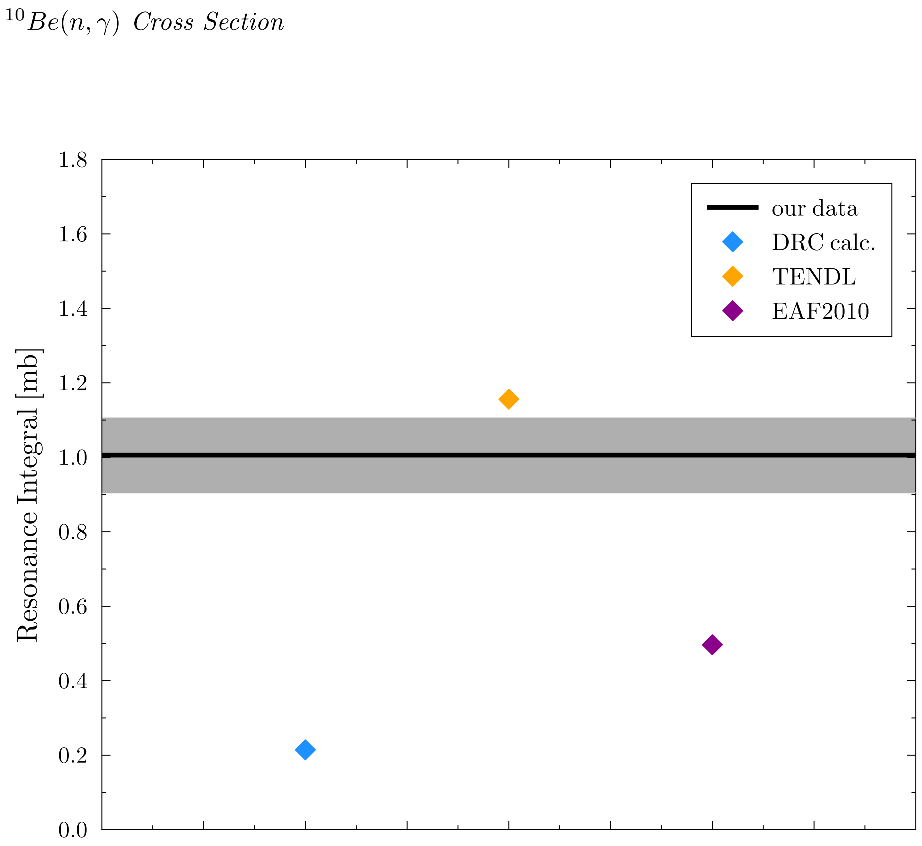

Figure 5: Comparison of the preminimary results for the ^{10}Be(n,γ) resonance integral with theoretical estimates [9, 10]. An uncertainty band of 10% is indicated, which is the envisaged total uncertainty of the final analysis.

5. Bibliography

[1] Mengoni A, Otsuka T, Nakamura T and Ishihara M 1997 *Nuclear Physics A* **621** 323–326
[2] Palit R *et al* 2003 *Phys. Rev. C* **68**(3) 034318
[3] Fukuda N *et al* 2004 *Physical Review C* **70** 054606
[4] Liu Z H and Zhou H Y 2005 *Chinese Physics* **14** 1544–1548
[5] Dubovichenko S B and Dzhazairov-Kakhramanov A V 2016 *Journal of Physics G* **43** 095201
[6] deBoisblanc D R, Francis W C and Fluharty R G 1966 *Nuclear Technology Branches Quarterly Report Jul 1 - Sep 30, 1965* IDO–17147
[7] Beer H, Rupp G, Walter G, Voss F and Käppeler F 1994 *Nuclear Instruments and Methods in Physics Research Section A* **337** 492–503
[8] Heinitz S, Kiselev D, Kivel N and Schumann D 2017 *Applied Radiation and Isotopes* **130** 260–263
[9] Sublet J C, Packer L, Kopecky J, Forrest R, Koning A and Rochman D 2010 *EASY Documentation Series, CCFE-R (10)*
[10] Koning A, Rochman D, Sublet J C, Dzysiuk N, Fleming M and van der Marck S 2019 *Nuclear Data Sheets* **155** 1 – 55