PROCEEDINGS OF SCIENCE

Measurement of the ^{25}Mg(α,n)^{28}Si reaction cross section at LNL

A. Caciolli*[1,2], T. Marchi[1,2], R. Depalo[1,3], S. Appannababu[2], N. Blasi[4], C. Broggini[3], M. Cinausero[2], G. Collazuol[1,3], M. Degerlier[5], D. Fabris[3], F. Gramegna[2], M. Leone[1], P. Mastinu[2], R. Menegazzo[3], G. Montagnoli[1,3], C. Rossi Alvarez[2], V. Rigato[2] and O. Wieland[4]

[1] *Physics and Astronomy Department, Padua University, Padua, Italy*
[2] *INFN National Laboratories of Legnaro, Legnaro (Padua), Italy*
[3] *INFN Section of Padua, Padua, Italy*
[4] *INFN Section of Milan, Milan, Italy*
[5] *Nevsehir Haci Bektas University, Science and Art Faculty, Physics Department, Nevsehir, Turkey*
E-mail: caciolli@pd.infn.it

The detection of the 1809 keV emission line associated with the decay of ^{26}Al ($T_{1/2} \sim 7.2 \cdot 10^5$ years) in the interstellar medium provides a direct evidence that nucleosynthesis is ongoing in our galaxy. ^{26}Al is thought to be mainly produced in massive stars, but in order to have a quantitative understanding of the ^{26}Al distribution, the cross section of all the nuclear reactions involved in its production should be accurately known. ^{25}Mg(α,n)^{28}Si is one of the reactions with the strongest impact on the synthesis of ^{26}Al during explosive neon and carbon burning. Its cross section has been measured by many authors, but below 3 MeV, the literature data are still characterized by large uncertainties due to beam-induced background. The reaction rate reported by NACRE is based on unpublished data and, at higher energies, on Hauser-Feshbach calculations, disregarding other experimental cross section datasets. In order to improve the experimental knowledge of the ^{25}Mg(α,n)^{28}Si cross section, a new direct measurement has been performed at Legnaro National Laboratories. A pulsed alpha beam with energies E = 3-5 MeV was provided by the CN accelerator. The neutrons were detected with 10 liquid scintillators BC501 from the RIPEN array, positioned at different angles. γ-n discrimination is achieved applying the Pulse Shape Analysis technique. Furthermore, measuring the neutron energy with the Time Of Flight method it is possible to disentangle the contribution to the cross section of different ^{28}Si excited states, and to identify the background neutrons produced by (α,n) reactions with light contaminants in the setup. The angular distributions measured with this experimental system will be presented.

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*Speaker.

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1. Introduction

The standard model of stellar evolution predicts that the synthesis of isotopes occur in massive stars during both quiescent nuclear burning and nova and supernova explosions [1]. One of the few observational evidences of the presence of such isotopes in the Milky Way was provided by the detection of 1809 keV γ-ray associated with the decay of ^{26}Al ($T_{1/2} \sim 7.2 \cdot 10^5$ years) [2]. All-sky surveys in the γ energy range [3] discovered a clumpy ^{26}Al distribution confined to the galactic plane. These observations are consistent with a stellar origin of ^{26}Al, but the inferences on the amount of ^{26}Al that can be synthesized in massive stars are strongly affected by the uncertainties on the cross sections of the nuclear reactions involved in the nucleosynthesis network. A recent investigation by Iliadis et al. (2011) [4] pointed out that the nuclear reaction with the strongest impact on the uncertainty of ^{26}Al yield in explosive Ne/C burning is the ^{25}Mg(α,n)^{28}Si, which destroys ^{25}Mg seeds.

The ^{25}Mg(α,n)^{28}Si cross section has been already measured in the energy range from E_{α}^{Lab} = 1 to 6 MeV ([5] - [9]). All measurements are characterised by large uncertainties due to the contribution of background reactions on light nuclei, present as contaminants in the setup (mainly ^{13}C(α,n)^{16}O, ^{18}O(α,n)^{21}Ne, and ^{19}F(α,n)^{22}Na). The reaction rate reported by NACRE [10] at energies below 2.2 MeV is based on the cross sections reported in the unpublished thesis of Wieland [7]. Recently, a new measurement at energies between 1 and 2.5 MeV, performed at the Nuclear Structure Laboratory of the University of Notre Dame by Falahat et al. [8], provided a cross section which is at least one order of magnitude smaller than the values measured by Wieland [7]. In both these measurements the neutrons were thermalized and detected with a 4π detector and could only determine the total cross section. The most recent measurement [8] pointed out the extreme importance of an improved target technology, able to pin down the background contributions to the very limit of inclusive measurements and showing the necessity of a future investigations using for example the γ-n coincidence technique.

2. Experimental setup

The experiment was performed at the 0° beam-line of the CN Van de Graaff accelerator at Legnaro National Laboratories (INFN-LNL). A pulsed ^{4}He$^+$ beam was used (I$\approx$ 200 pnA, 3 MHz repetition rate, bunch width <2 ns). The measurements were performed at 5 different energies from 3 MeV to 5 MeV.

Neutrons were detected by using 10 BC501 liquid scintillators of the RIPEN array [11]. Each detector has an active cell of 12.5 cm diameter and 12.5 cm length. A 5 mm Lead shielding surrounded each cell to reduce the background induced by low-energy γ rays. The center of each cell was placed at 206.3$\pm$0.5 cm distance from the target position covering an angular range from 17.5° to 106° with respect to the beam direction (see fig. 1). Each detector covers 3 msr solid angle. The time of flight technique was used to determine the neutron energy on an event by event basis, while pulse shape analysis provided n/γ discrimination information.

Two inductive pickup devices placed 9.40 m apart provided the reference signal needed for the time of flight measurement. Moreover, the time of flight between the two pickups allowed to measure the beam energy. The distance between the two pickups was precisely determined through

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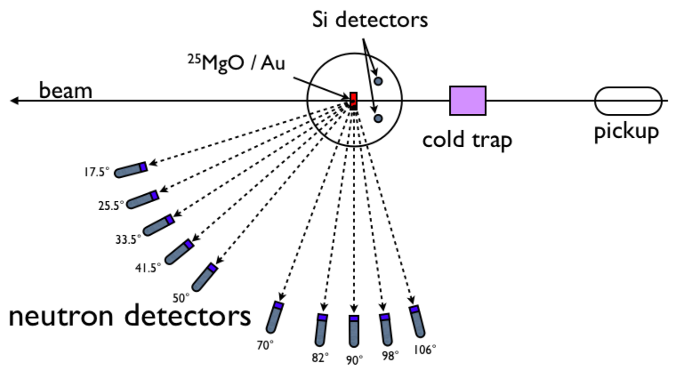

Figure 1: Sketch of the experimental setup.

the $^{16}O(\alpha,\alpha)^{16}O$ resonance at 3.045 MeV which is known to have a FWHM lower than 10 keV. With this method a 0.7% uncertainty on the energy was obtained for the 3 MeV alpha beam.

Two collimated Silicon detectors (1 mm diameter) were placed inside the chamber at a distance of 7 cm from the target and at $\pm 150^\circ$ with respect to the beam direction. They are used both to count the backward scattered α ions for cross section normalisation and to monitor the target integrity and the possible presence of contaminants.

The target holder was made of copper and cooled with water at a temperature of 14°C in order to limit the target deterioration. The beam focusing was checked regularly using a copper frame with a 7 mm diameter hole (1 mm less than the target diameter) minimising the beam current on the copper frame.

From previous experiments [6, 7, 8], carbon and fluorine contaminants are supposed to be the main sources of background. The Time Of Flight (TOF) technique was used to perform neutron spectroscopy. Using this methods is possible to separate the neutrons produced by the (α,n) reactions on contaminants from the neutrons emitted by the $^{25}Mg(\alpha,n)^{28}Si$ reaction. The beam induced background signal was negligible during the experiment.

The background problem was also faced installing two turbomolecular pumps and a cold trap as close as possible to the scattering chamber. This allowed to keep the vacuum in the scattering chamber always below $8\cdot 10^{-7}$ mbar. The cold trap was necessary to reduce the carbon build-up on the target surface. It was made of a copper tube (2 cm diameter 20 cm length) placed at 1 m from the target and cooled with liquid nitrogen.

MgO targets (enriched in ^{25}Mg up to 95.75%) were used during the experiment. They were made of 70 μg/cm^2 MgO evaporated on a gold thin layer (1mg/cm^2).

3. Results

Pulse Shape Analysis was used to distinguish the γ rays from the neutrons, reducing the γ-background in the spectra. It allows to reach a statistical uncertainty far below 15% at all energies.

In Figure 2 - 6 some of the results for the differential cross section obtained during the experiment. We fit the data by using Legendre polynomials from P_0 to P_2 (blue dashed line in the

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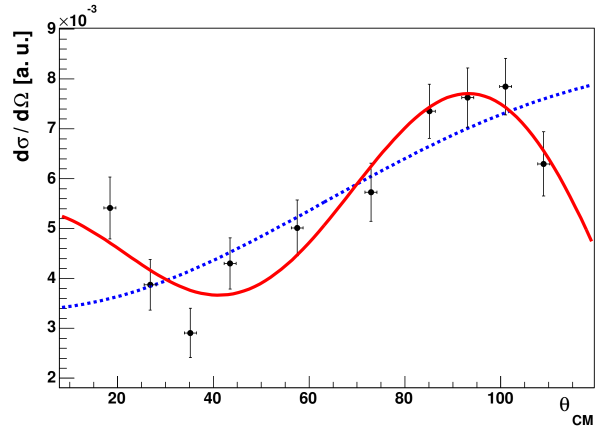

Figure 2: The angular distribution of n_0 at the α-beam energy of 3.045 MeV are reported in black. The fit using from P_0 to P_2 Legendre polynomials is in blue dashed line, while the fit made including the Legendre polynomials until P4 is reported in red line.

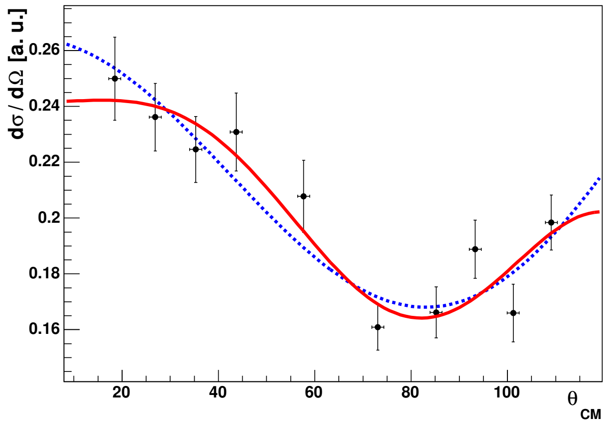

Figure 3: The angular distribution of n_1 at the α-beam energy of 3.95 MeV are reported in black. The fit using from P_0 to P_2 Legendre polynomials is in blue dashed line, while the fit made including the Legendre polynomials until P_4 is reported in red line.

figures) and from P_0 to P_4 (red line). The first fitting procedure was also used by Van der Zwan and Geiger[5].

As shown in some of the plots the fitting procedure used in the previous work is not reliable at all energies and for all branchings as discussed in [15].

The relative differential cross sections are always normalised to the differential cross section at 18.5° relative to the population of the ^{28}Si first excited state (n_1) at E_α = 4.95 MeV (see fig. 6).

The values of all measured angular distributions are reported in a previous work [15].

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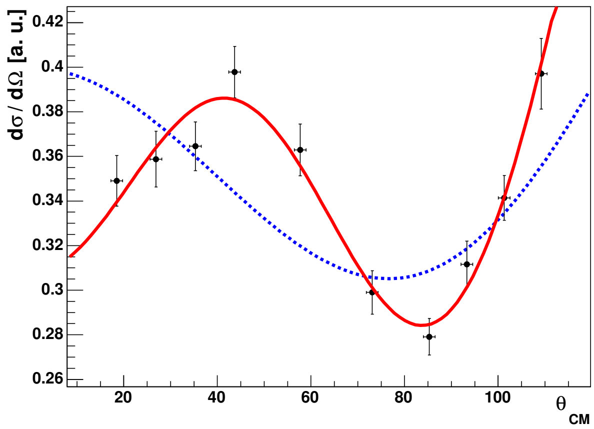

Figure 4: The angular distribution of n_1 at the α-beam energy of 4.3 MeV are reported in black. The fit using from P_0 to P_2 Legendre polynomials is in green dashed line, while the fit made including the Legendre polynomials until P_4 is reported in red line.

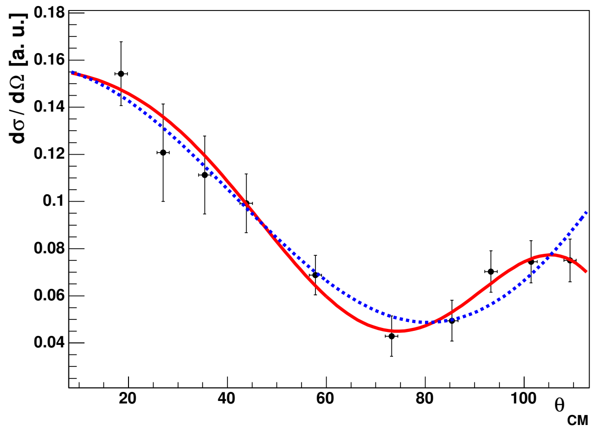

Figure 5: The angular distribution of n_0 at the α-beam energy of 4.95 MeV are reported in black. The fit using from P_0 to P_2 Legendre polynomials is in blue dashed line, while the fit made including the Legendre polynomials until P_4 is reported in red line.

INFN-LNL mechanical workshop.

References

[1] R. Ramaty & R.E. Lingenfelter, ApJ 213: L5-L7 (1977).

[2] W.A. Mahoney *et al.*, ApJ, 286:578-585 (1984).

[3] S. Plüschke *et al.*, Proceedings of the 4th INTEGRAL workshop, ESA SP-459,55.

[4] C. Iliadis *et al.*, ApJSS 193:16 (2011).

[5] L. Van der Zwan & K.W. Geiger Nucl. Sci. Eng. 79, 197-201 (1981).

[6] M.R. Anderson *et al.*, NPA 405, 170-178 (1983).

[7] O. Wieland, thesis, IFS-University of Stuttgart (1995).

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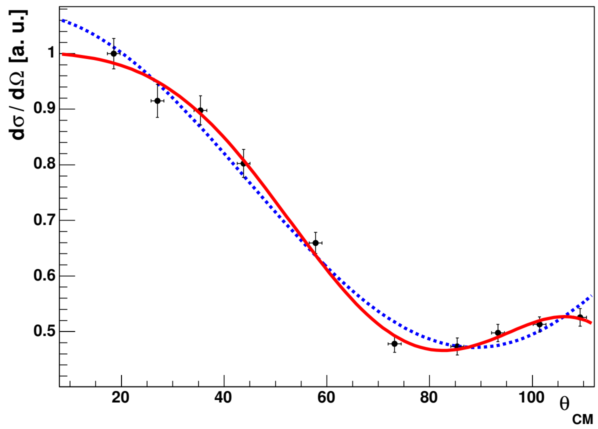

Figure 6: The angular distribution of n_1 at the α-beam energy of 4.95 MeV are reported in black. The fit using from P_0 to P_2 Legendre polynomials is in blue dashed line, while the fit made including the Legendre polynomials until P_4 is reported in red line.

[8] S. Falahat, PhD thesis, Johannes Gutenberg University-Mainz (2010).

[9] S. Küchler, thesis, IFS-University of Stuttgart (1990).

[10] C. Angulo *et al.*, NPA 656, 3-187 (1999).

[11] N. Colonna *et al.*, Nucl. Instr. Meth. A381, 472 (1996).

[12] J. K. Bair & F. X. Hass, Phys. Rev. C 7, 1356 (1973).

[13] M. Balakrishnan, S. Kailas & M. K. Mehta, Pramana, 10, 329 (1978).

[14] S. Harissopulos *et al.*, Phys. Rev. C, 72, 062801(R) (2005).

[15] A. Caciolli *et al.*, Eur. Phys. J. A (2014) 50: 147

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