

Study of the neutron induced reaction $^{17}\text{O}(n, \alpha)^{14}\text{C}$ at astrophysical energies via the Trojan Horse Method

A. A. Oliva^{1,2,3,*}, L. Lamia^{1,2}, G. L. Guardo^{2,4}, C. Spitaleri^{1,2}, S. Cherubini^{1,2}, A. Cvetinovic², G. D'Agata^{2,5}, N. de Sereville⁶, A. Di Pietro², P. Figuera², M. Gulino^{2,7}, F. Hammache⁶, S. Hayakawa⁸, I. Indelicato², M. La Cognata², M. La Commara^{9,10}, D. Lattuada⁴, M. Lattuada^{1,2}, G. Manicò^{1,2}, M. Mazzocco^{11,12}, S. Messina^{1,2}, S. Palmerini^{13,14}, R.G. Pizzone², M.L. Pumo^{1,2}, G.G. Rapisarda², S. Romano^{1,2}, M.L. Sergi², N. Soic¹⁵, R. Spartà^{1,2}, and A. Tumino^{2,7}

¹Dipartimento di Fisica e Astronomia "E. Majorana", Univ. di Catania, Italy.

²INFN-LNS, Laboratori Nazionali del Sud, Catania, Italy.

³Centro Siciliano Fisica Nucleare e Struttura della Materia, Catania, Italy.

⁴Horia Hulubei Natl R&D Inst Phys & Nucl Engn, ELI-NP, Magurele, Romania.

⁵Nuclear Physics Institute of the Czech Academy of Science, Rez, Czech Republic.

⁶Institut de Physique Nucléaire, CNRS/IN2P3, Univ. de Paris Sud, Univ. de Paris-Saclay, Orsay, France.

⁷Facoltà di Ingegneria e Architettura, Univ. "Kore", Enna, Italy.

⁸Center for Nuclear Study, Univ. of Tokyo, Japan.

⁹INFN-Sezione di Napoli, Italy.

¹⁰Dipartimento di Scienze Fisiche, Univ. di Napoli, Italy.

¹¹Dipartimento di Fisica e Astronomia, Univ. di Padova, Italy.

¹²INFN-Sezione di Padova, Italy.

¹³INFN-Sezione di Perugia, Italy.

¹⁴Dipartimento di Fisica e Geologia, Univ. di Perugia, Italy.

¹⁵Rudjer Boskovic Inst, Zagabria, Croatia.

Abstract. Neutron induced reactions are fundamental for the nucleosynthesis of elements in the universe. Indeed, to correctly study the reactions involved in the well-known s-process in stars, which produce about half of the elements beyond the iron peak, it is mandatory to know the neutron abundance available in those stars.

The $^{17}\text{O}(n, \alpha)^{14}\text{C}$ reaction is one of the so-called "neutron poisons" for the process and it could play an important role in the balance of the neutron abundance. The reaction is therefore investigated in the energy range of astrophysical interest between 0 and 350 keV in the center of mass by applying the Trojan Horse Method to the three body reaction $^2\text{H}(^{17}\text{O}, \alpha^{14}\text{C})\text{H}$.

1 Introduction

Neutron induced reactions play a fundamental role in the nucleosynthesis of the elements in the universe since its primordial stage, after the Big Bang. However, the study of such reactions is, still today, problematic. Either creating or detecting a neutron beam is a challenging task which requires experimental and technological efforts.

*e-mail: a.oliva@studium.unict.it

A more viable alternative is using the Trojan Horse Method (THM)[1] that does not require either the production or the detection of neutrons. By using the method, the half-off-the-energy-shell cross section of a certain two body reaction is obtained studying an appropriate three body reaction with proper kinematical constraints.

2 The $^{17}\text{O}(n, \alpha)^{14}\text{C}$ reaction

The well-known s-process for nucleosynthesis in stars produces about half of the elements beyond the iron peak, mostly in massive stars ($M > 8M_{\odot}$) and in AGB stars ($1.3M_{\odot} \leq M \leq 8M_{\odot}$)[2, 3]. To correctly study the reactions involved in the s-process, it is mandatory to know the neutron abundance available. For the weak component of the s-process the main neutron source are the $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$ and $^{13}\text{C}(\alpha, n)^{16}\text{O}$, however in the same stellar environment other reactions, the so called "neutron poisons" can occur [3]. In particular, once formed by the radiative capture reaction $^{16}\text{O}(n, \gamma)^{17}\text{O}$, the ^{17}O can undergo various competing branches, among which there are the $^{17}\text{O}(\alpha, n)^{20}\text{Ne}$, which recycles a neutron, or the $^{17}\text{O}(n, \alpha)^{14}\text{C}$ reaction which is one of those neutron poisons. Knowing the exact branching ratio of those two reactions is therefore essential for the correct evaluation of the neutron abundance. Various experiments in the past have already studied this reaction using direct methods [4–7], however the results show discordance in the evaluation of the cross section at astrophysical energies as can be seen in Figure 1. For that reason the Trojan Horse Method has been applied to study the $^{17}\text{O}(n, \alpha)^{14}\text{C}$ reaction [8, 9]. However the results obtained with the THM still have scope for improvements: the aim of this experiment is therefore trying to obtain an indisputable result.

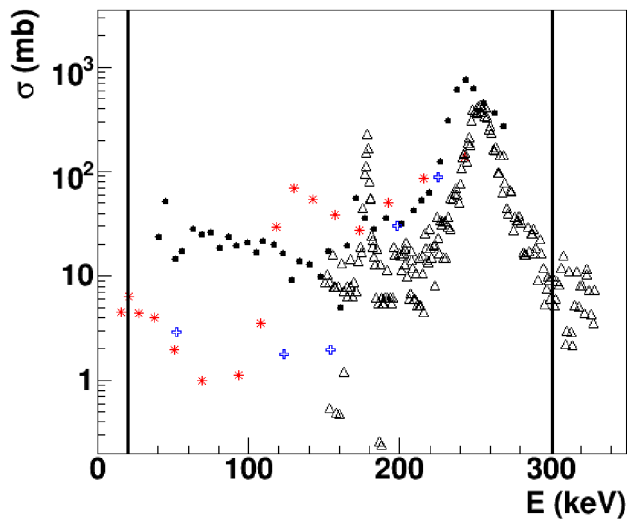


Figure 1. Experimental cross section for the direct measurement of the two body $^{17}\text{O}(n, \alpha)^{14}\text{C}$ reaction as available in the literature. Black points are from the data of Sanders et al. [4], red asterisks are from Koehler&Graff [5], blue crosses are from Shatz et al. [6], while black triangles are from Wagemans et al. [7]. The vertical black lines approximately indicate the Gamow region.

3 The Experiment

The neutron capture reaction $^{17}\text{O}(n, \alpha)^{14}\text{C}$ has been investigated at astrophysical energies, between 0 and 350 keV in the center of mass frame, applying the THM to the three body reaction $^2\text{H}(^{17}\text{O}, \alpha)^{14}\text{C}\text{H}$. The experiment was carried out at Laboratori Nazionali del Sud (LNS-INFN) in Catania using a ^{17}O beam accelerated by the VdG tandem at 43.5 MeV on a CD_2 target. Choosing the deuteron as a Trojan Horse nucleus is convenient since it is in a clustered p - n state and the radial wave function for the inter-cluster s-wave motion is known to be the Hulthén wave function.

The experimental setup consisted of two groups of detectors placed at the "quasi-free" (QF) angles [1]: in each group there was a position sensitive detector (PSD) for the detection of the α particles and a $\Delta E - E$ telescope made up by an ionization chamber (ΔE stage) and another PSD (E stage), for the detection and the subsequent selection of the carbons, since only the events with carbons in the telescope have to be chosen for the offline analysis. It is possible to easily identify in the $\Delta E - E$ plot the events coming from the elastic scattering of the oxygen beam, which correspond to the typical bulge that can be seen in Figure 2.

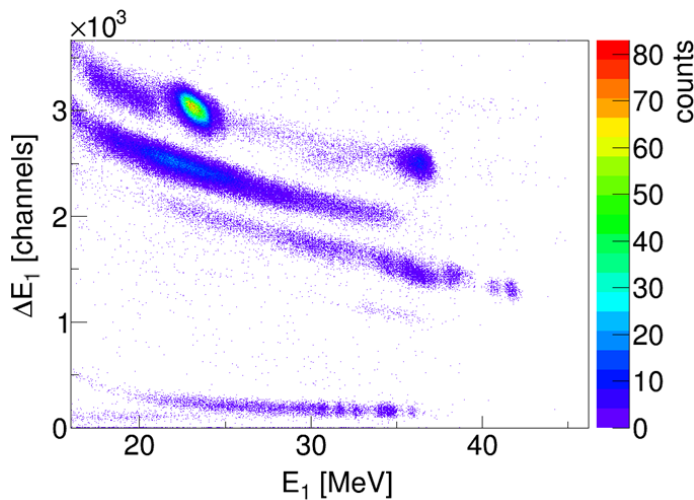


Figure 2. $\Delta E - E$ plot as seen in the telescope $\Delta E_1 - E_1$.

The reaction channel $^2\text{H}(^{17}\text{O}, \alpha)^{14}\text{C}\text{H}$ is then selected, among the others possible with the same $\alpha + ^{14}\text{C}$ output, by reconstructing the energy of the proton (not detected in the experiment) and subsequently evaluating the three body Q-value (-0.5 ± 0.2 MeV), which is in agreement with the theoretical one ($Q = -0.407$ MeV) as can be seen in Figure 3.

One necessary condition for the THM is the selection of the events coming from a QF break-up reaction mechanism [1] where the proton, known as the "spectator" in this formalism, preserve, after the reaction, the same momentum distribution that had inside the deuteron before the break-up. Thus, selecting only the events with $|P_s| < 40\text{MeV}/c$ it is possible to fulfill the QF kinematical conditions and, subsequently, extract from the three body QF breakup reaction $^2\text{H}(^{17}\text{O}, \alpha)^{14}\text{C}\text{H}$ the cross section for the two body reaction $^{17}\text{O}(n, \alpha)^{14}\text{C}$.

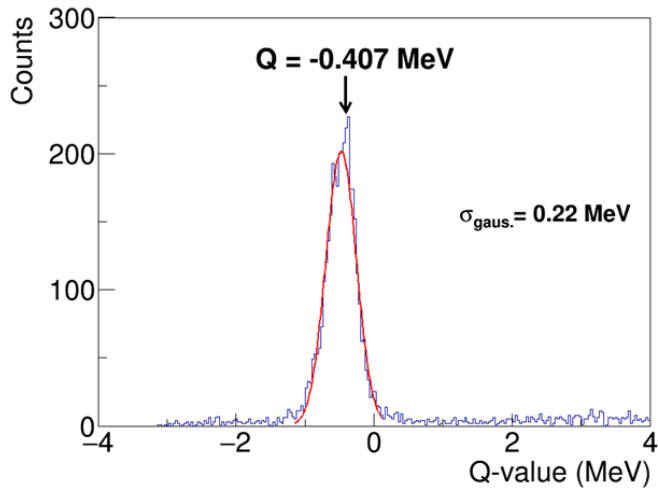


Figure 3. Experimental Q-value spectrum for the ${}^2\text{H}({}^{17}\text{O}, \alpha){}^{14}\text{C}$ reaction, the arrow marks the theoretical value, while the red line is a gaussian fit of the histogram with $\sigma_{\text{gaus.}} = 0.22\text{MeV}$.

4 Conclusions

While the data analysis is still ongoing, the preliminary results show the correct population of the reaction channel of interest, so the complete analysis could finally give a definite answer to the open questions regarding the cross section of the ${}^{17}\text{O}(n, \alpha){}^{14}\text{C}$ reaction.

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