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$^{12}\text{C}+^{12}\text{C}$ reactions at astrophysical energies: Tests of targets behaviour under beam bombardment

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Abstract.

$^{12}\text{C}(^{12}\text{C}, \alpha)^{20}\text{Ne}$ and $^{12}\text{C}(^{12}\text{C}, p)^{23}\text{Na}$ are the most important reactions during the carbon burning phase in stars. Direct measurements at the relevant astrophysical energy ($E=1.5\pm 0.3\text{MeV}$) are very challenging because of the extremely small cross sections involved and of the high beam-induced background originating from impurities in the targets. In addition, persistent resonant structures at low energies are not well understood and make the extrapolation of the cross section from high energy data very uncertain. As a preliminary step towards the measurements of the $^{12}\text{C}(^{12}\text{C}, \alpha)^{20}\text{Ne}$ and $^{12}\text{C}(^{12}\text{C}, p)^{23}\text{Na}$ reactions we intend to investigate the behaviour of targets under beam bombardment, specifically the quantitative measurement of hydrogen and deuterium content of highly pure stable carbon targets in relation to target temperature. Experiments are taking place at the CIRCE accelerator in Caserta, Italy and preliminary results are presented here.

Keywords: Direct reactions, low and intermediate energy heavy-ion reactions, nucleosynthesis in late stellar evolution, ^{12}C

PACS: 24.50.+g, 25.70.-z, 26.20.Np, 27.20.+n

GENERAL OVERVIEW

The rate of $^{12}\text{C}+^{12}\text{C}$ reactions is one of the key quantities needed to understand the evolution of massive stars (more than $8 M_{\odot}$) [1] and the nucleosynthesis of heavy elements [2]. These reactions take place at a typical temperature of 5×10^8 K that corresponds to an energy of $E_0 = 1.5 \pm 0.3$ MeV [3] and typical densities of $(2-5)\times 10^9$ g cm^{-3} [4, 5]. At these energies, the carbon burning proceeds through the reactions of $(^{12}\text{C}, \alpha)$ and $(^{12}\text{C}, p)$ on ^{12}C , known as the α and p channels.

These key reactions have been studied extensively for the past four decades. A summary of the current status of $^{12}\text{C}+^{12}\text{C}$ reactions measurements is shown in figure 1 (extracted from [6]). At low energies, the S-factor extrapolations coming from different theoretical models differ by orders of magnitude, the different data sets [7, 8, 9, 10] show discrepancies between them and there are extremely large error bars at energies lower than 2.6 MeV associated with a strong background induced by reactions with impurities in the target, mainly hydrogen. Since current extrapolations of the S-factor differ and discrepancies between data sets are not understood, the $^{12}\text{C}+^{12}\text{C}$ reactions need to be measured using an optimized set up in order to address the beam induced background problem.

Some groups [9, 10, 11] have tried to reduce the hydrogen contamination of the targets by heating them up in different ways, either using resistance heating to raise the temperature to 1800° C of carbon foils ($9 - 88 \mu\text{g}/\text{cm}^2$) placed on a tantalum backing [11] or beam heating thick (1 mm) graphite targets at 600° C (for 6-8 hours) [9] and 700° C [10]. In all cases, clearer spectra at low energies were found, which resulted from a reduction in hydrogen content of the targets. Nevertheless, this reduction was never quantified because of time or equipment limitations. Thus, the aim of this work is to quantify the time variation of hydrogen content in a target as a function of target temperature using a systematic approach.

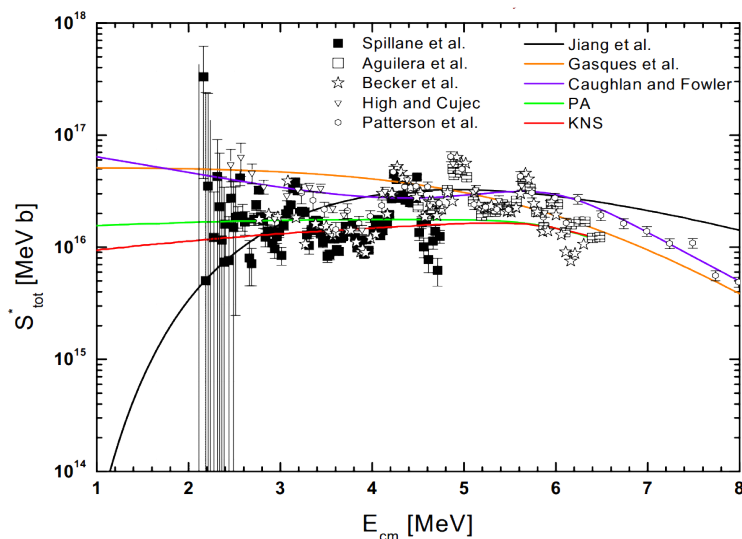


FIGURE 1. Astrophysical S^* -factor for the $^{12}\text{C} + ^{12}\text{C}$ reactions as a function of centre of mass energy. Open and filled symbols represent experimental data points (errors are statistical only); curves represent theoretical extrapolations based on different theoretical models.

EXPERIMENTAL SETUP AND PRELIMINARY RESULTS

The purpose of these tests is to quantitatively determine the ^1H and ^2H content of our targets as a function of temperature during ion beam bombardment. In order to quantify the hydrogen content of the targets, we employ Nuclear Reaction Analysis (NRA) using C, N and O beams coming from the 3 MV pelletron tandem accelerator at CIRCE (Centre for Isotopic Research on the Cultural and Environmental heritage) laboratory in Caserta, Italy. To monitor the target temperature continuously, we use a thermocamera FLIR SC325 (already calibrated by the company [12]) which has an accuracy of $\pm 2\%$ at reading. Since the thermocamera cannot be installed under vacuum, a viewport with a Ge window is used. This window is transparent to the wavelengths the thermocamera is sensitive to ($7.5\mu\text{m} - 13\mu\text{m}$). The thermocamera measurements are attenuated by the Ge window but this attenuation is well known (calibration certificate No. SED04024 by FLIR) and taken into account during the analysis.

The experimental set up is schematically shown in figure 2. Briefly, it consists in a small chamber housing a water cooled target holder, a detector holder, a detector and a cold finger with an Al foil in front of the detector. The target holder can accommodate two different targets and two collimators of 3 and 6 mm to focus the beam and it is water cooled in order to be able to control the temperature of the target and minimize its degradation. The detector holder places a $(\Delta E - E_{\text{rest}})$ telescope Si detector ($25\mu\text{m}$ and $300\mu\text{m}$ respectively) at 135° with respect to the beam axis; a $\Delta E - E_{\text{rest}}$ detector was chosen in order to allow for particle identification. The cold finger holds a $2\mu\text{m}$ Al foil placed in front of the detector to protect it from elastically scattered particles; the cold finger is kept at a potential of -300V to suppress secondary electrons.

Initial tests were made with a $^{12}\text{C}^{+3}$ ion beam of $E = 4 \text{ MeV}$ and an intensity of 7 particle μA . The beam hit an infinitely thick target (1mm) of natural graphite for about 50 minutes. From the images acquired with the thermocamera it was possible to derive the size of the beam and found it was less than 2.5 mm. We also observed that the beam constantly heated the target at the beam spot, reaching a temperature of about 500° C in 50 minutes (figure 3a).

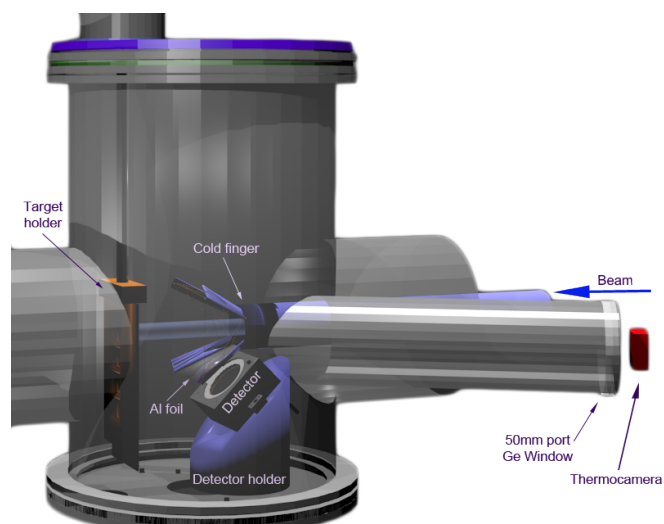


FIGURE 2. Sketch of the experimental set up. Shown are the detector, the target holder, the cold finger, and the Al foil that protects the detector from elastically scattered particles. The thermocamera is placed outside the chamber in front of a Ge window.

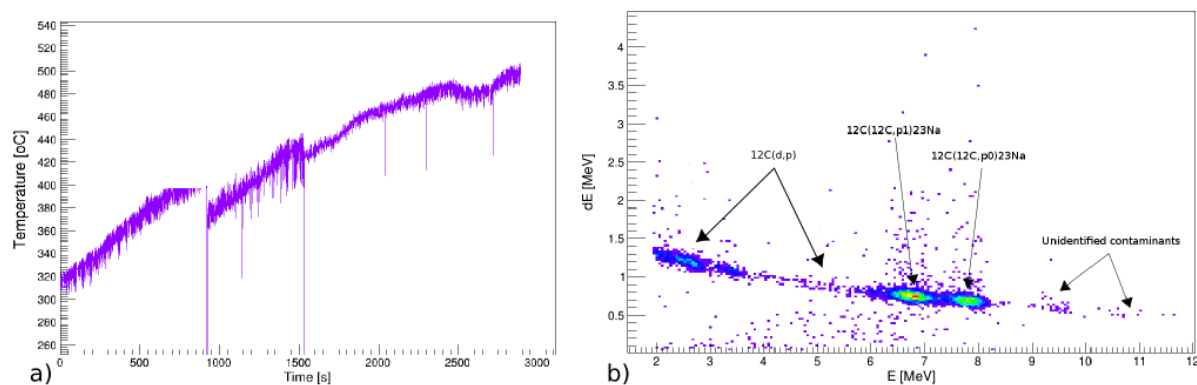


FIGURE 3. a) Evolution of target temperature (at the beam spot position) as a function of time. Discontinuities in the trend correspond to changes in the temperature range settings of the thermocamera. b) $\Delta E - E$ matrix from the telescope detector. The axis correspond to the ΔE detector energy and the total energy ($\Delta E + E_{\text{rest}}$). The most intense groups between 6 and 8 MeV correspond to the $^{12}\text{C}(^{12}\text{C}, p)^{23}\text{Na}$ reaction; protons with lower energies come from deuterium contamination in the target and high energetic protons possibly correspond to ^{13}C contaminants in the target.

As a preliminary result, a $\Delta E - E$ matrix is shown in figure 3b. The axis correspond to the ΔE detector energy and the total energy ($\Delta E + E_{\text{rest}}$). The most prominent groups in the locus shown correspond to the proton groups from the $^{12}\text{C}(^{12}\text{C}, p)^{23}\text{Na}$ reaction, with p_0 corresponding to reactions with ^{23}Na left in its ground state and p_1 to reactions with ^{23}Na left in its first excited state. The total energies of p_0 and p_1 proton groups are in agreement with the calculated values of $E = 7.3$ MeV and $E = 6.31$ MeV, respectively. Background events, at energies lower than 6 MeV, from $^{12}\text{C}(d, p)$ reactions due to contaminants in the target were also observed, as expected given that we did not use highly pure targets for this test. High energy background can also be seen in the matrix and it presumably corresponds to reactions with ^{13}C contaminants in the target, although this is still under study.

The hydrogen content of the target will be continuously monitored during the tests of the target behaviour under beam bombardment. Measurements will be repeated with different beam intensities, thus allowing us to determine the time evolution of the target's H content as a function of target temperature. An estimate of the absolute H concentration in the target will be obtained using targets with known hydrogen concentration.

CONCLUSIONS

We have shown that the designed setup is able to provide a temperature map of the beam impact area on the C target and, concurrently, a measurement of the target's H content. This approach could be extended to other light isotopes, possible sources of beam induced background. Comparative tests of different target materials will be performed to determine the best conditions for the measurements of the $^{12}\text{C} + ^{12}\text{C}$ fusion reactions.

REFERENCES

1. L. Gasques, a. Afanasjev, E. Aguilera, M. Beard, L. Chamon, P. Ring, M. Wiescher, and D. Yakovlev. *Physical Review C*, 72:025806, August 2005.
2. C Rolfs and S Rodney. *Cauldrons in the Cosmos*. The University of Chicago Press, Chicago and London.
3. F. Strieder and C. Rolfs. *Progress in Particle and Nuclear Physics*, 59:562–578, October 2007.
4. S.E. Woosley, S. Wunsch, and M. Kuhlen. *Astrophysical Journal*, 607:921, 2004.
5. I. Baraffe, A. Heger, and S.E. Woosley. *Astrophysical Journal*, 615:378, 2004.
6. F Strieder. *Journal of Physics G: Nuclear and Particle Physics*, 35:014009, January 2008.
7. J.R. Patterson, H. Winkler, and C.S. Zaidins. *Astrophysics journal*, 157:367, 1969.
8. MG Mazarakis and WE Stephens. *Physical Review C*, 7:4, 1973.
9. L. Barrón-Palos, E.F. Aguilera, J. Aspiazú, a. Huerta, E. Martínez-Quiroz, R. Monroy, E. Moreno, G. Murillo, M.E. Ortiz, R. Policroniades, a. Varela, and E. Chávez. *Nuclear Physics A*, 779:318–332, November 2006.
10. T. Spillane, F. Raiola, C. Rolfs, D. Schürmann, F. Strieder, S. Zeng, H.-W. Becker, C. Bordeanu, L. Gialanella, M. Romano, and J. Schweitzer. *Physical Review Letters*, 98:122501, March 2007.
11. K U Kettner. *Zeitschrift für Physik A, Atoms and Nuclei*, 75:65–75, 1980.
12. <http://www.flir.com/>.