

Alpha capture reaction cross section measurements on Sb isotopes by activation method

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Abstract. Alpha induced reactions on natural and enriched antimony targets were investigated via the activation technique in the energy range from 9.74 MeV to 15.48 MeV, close to the upper end of the Gamow window at a temperature of 3 GK relevant to the γ -process. The experiments were carried out at the Institute for Nuclear Research, the Hungarian Academy of Sciences (MTA Atomki). $^{121}\text{Sb}(\alpha, \gamma)^{125}\text{I}$, $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ and $^{123}\text{Sb}(\alpha, n)^{126}\text{I}$ reactions were measured using a HPGe detector. In this work, the $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ cross section results and the comparison with the theoretical predictions (obtained with standard settings of the statistical model codes NON-SMOKER and TALYS) were presented.

1. Introduction

The main products of the last hydrostatic burning stages of massive stars are nuclei in the Fe region. For an efficient production of elements beyond Fe, reactions with neutral particles, i.e. neutrons, are required. Two main neutron capture processes, the s- and r-processes, are involved in the synthesis of nuclei heavier than the Fe group. The s-process (slow neutron capture process) is the mechanism for the formation of about half of the nuclides heavier than Fe up to Bi via neutron capture reactions and following β^- -decays. The r-process (rapid neutron capture process) is thought to be responsible for the synthesis of the other half of nuclei heavier than Fe and all nuclei heavier than Bi. Since the s- and r-process build up isotopes at the bottom and on the neutron-rich side of the valley of stability, about 35 proton-rich isotopes cannot be produced in these processes.

The main production mechanism of these so-called p nuclei that are 10 to 100 times less abundant than the s and r nuclei is called the γ -process [1]. The γ -process proceeds by γ -induced reactions starting from pre-existing s- and r-process seed nuclei and requires sufficiently high temperatures (2 - 3 GK) achieved e.g. in pre-explosive or explosive O/Ne burning of massive stars, depending on the their mass [2, 3]. Another



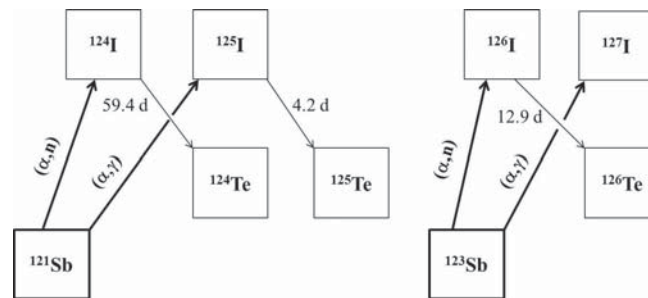


Figure 1. Alpha capture reactions on Sb. The half-lives of the decays of the reaction products are also indicated.

alternative for the astrophysical site is a subclass of type Ia supernovae where the γ -process may occur [4].

This work focuses on the extension of the experimental database for the astrophysical γ -process [5] which has problems in reproducing the p-isotope abundances e.g. in the $A < 124$ mass range [6], and on testing the reliability of statistical model calculations particularly in the astrophysically relevant energies.

In the following, we present the investigated reactions in Sec. 2, further details of experimental procedure in Sec. 3, and some preliminary results with a comparison to statistical model calculations in Sec. 4.

2. Investigated Reactions

The element antimony has two stable isotopes: ^{121}Sb and ^{123}Sb with the natural abundances of 57.21 % and 42.79 %, respectively. Since the ^{124}I , ^{125}I and ^{126}I isotopes are radioactive, the following reaction channels on the two stable Sb isotopes can be studied with activation method: $^{121}\text{Sb}(\alpha, \gamma)^{125}\text{I}$, $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ and $^{123}\text{Sb}(\alpha, n)^{126}\text{I}$. These reactions are shown schematically in Fig 1. The cross section of $^{121}\text{Sb}(\alpha, \gamma)^{125}\text{I}$ reaction has not been measured so far. Previous investigations of cross section data for $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ and $^{123}\text{Sb}(\alpha, n)^{126}\text{I}$ reactions have been in the literature [11, 12, 13, 14].

The $^{121}\text{Sb}(\alpha, \gamma)^{125}\text{I}$ cross section was measured by the detection of the 35.49 keV γ -ray which follows the ^{125}I decay. At the lowest studied energies, where the yield of this γ -line was not sufficient, the cross section was determined based on the detection of the characteristic X-ray radiation following the electron capture. This is possible since the half-life of ^{125}I is 59.4 days which is much longer than that of the other two produced isotopes (4.2 days for ^{125}I and 12.9 days for ^{126}I).

The cross section of the $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ and $^{123}\text{Sb}(\alpha, n)^{126}\text{I}$ reactions were determined based on the detection of the relatively high intensity γ -radiations following the ε decays of the reaction products. The $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ reaction cross sections presented here were measured by measuring the yield of 602.73 keV, 722.78 keV and 1690.96 keV γ -lines.

3. Experimental Method

The targets were produced by evaporating natural Sb and enriched ^{121}Sb (99.59%) in metallic form onto high purity thin aluminum foils with 12 mm in diameter. For the evaporation resistive heating of a tantalum boat was used. The enriched targets were prepared with thicknesses varying between $159\text{ }\mu\text{g}/\text{cm}^2$ and $265\text{ }\mu\text{g}/\text{cm}^2$. The number of target atoms was determined by weighing and Rutherford Backscattering Spectroscopy. During the irradiations the target stability was monitored by detecting the backscattered α -particles from the target. For this purpose an ion implanted silicon detector was built in the chamber at 165° with respect to the beam direction.

The irradiations were carried out at the cyclotron accelerator of the Institute for Nuclear Research, Hungarian Academy of Sciences (MTA Atomki). The length of the irradiations were about 24 hours for each target and the beam current was restricted to $1\text{ }\mu\text{A}$ in order to avoid target deterioration. The current was recorded in every minute by using a multi channel scaler to monitor the changes of the beam intensity. After each irradiation, the target was taken from the irradiation chamber to measure the induced activities. In order to measure the $^{121}\text{Sb}(\alpha,\gamma)^{125}\text{I}$ cross section, a LEPS (Low Energy Photon Spectrometer) detector, which has a thin germanium crystal with large surface and a thin Be entrance window, was used. For (α,n) reactions, γ -rays were detected by a 100 % relative efficiency HPGe detector in an ultra low background (ULB) configuration with a commercial 4π lead shield. The γ -spectra were stored regularly (for each hour) to follow the decay of the reaction products. The absolute full energy peak efficiencies of LEPS and ULB detectors have been measured with several calibrated gamma sources.

4. Experimental Results

Cross section of the $^{121}\text{Sb}(\alpha,\gamma)^{125}\text{I}$, $^{121}\text{Sb}(\alpha,n)^{124}\text{I}$, and $^{123}\text{Sb}(\alpha,n)^{126}\text{I}$ reactions have been measured via γ -ray counting at effective center of mass energies between 9.74 to 15.48 MeV, close to the upper end of the Gamow window (between 6.15 and 8.68 MeV at a temperature of 3 GK). Figure 2 shows the preliminary results of $^{121}\text{Sb}(\alpha,n)^{124}\text{I}$ reaction cross sections. The alpha beam energy points of 10.14, 10.46, 12.58, 13.10 and 15.06 MeV were measured with energy degrader foils which eventuate the larger uncertainties. For the cross section of $^{121}\text{Sb}(\alpha,n)^{124}\text{I}$ reaction some previous measurements are available [11, 12, 13, 14] (see Figure 2). Statistical model calculations obtained with standard settings of the statistical model codes NON-SMOKER [9] and TALYS [10] gives better agreement with the new results. Further measurements, precise the determination of Al thicknesses and the final analysis of data are in progress.

5. Acknowledgments

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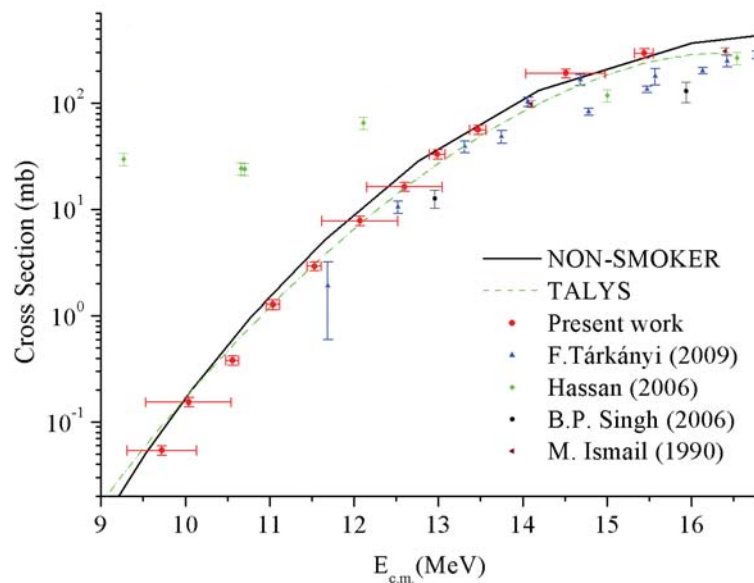


Figure 2. Preliminary experimental cross sections for $^{121}\text{Sb}(\alpha, n)^{124}\text{I}$ in comparison with standard NON-SMOKER (solid line), TALYS (dashed line) predictions and with the results of previous experiments.

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