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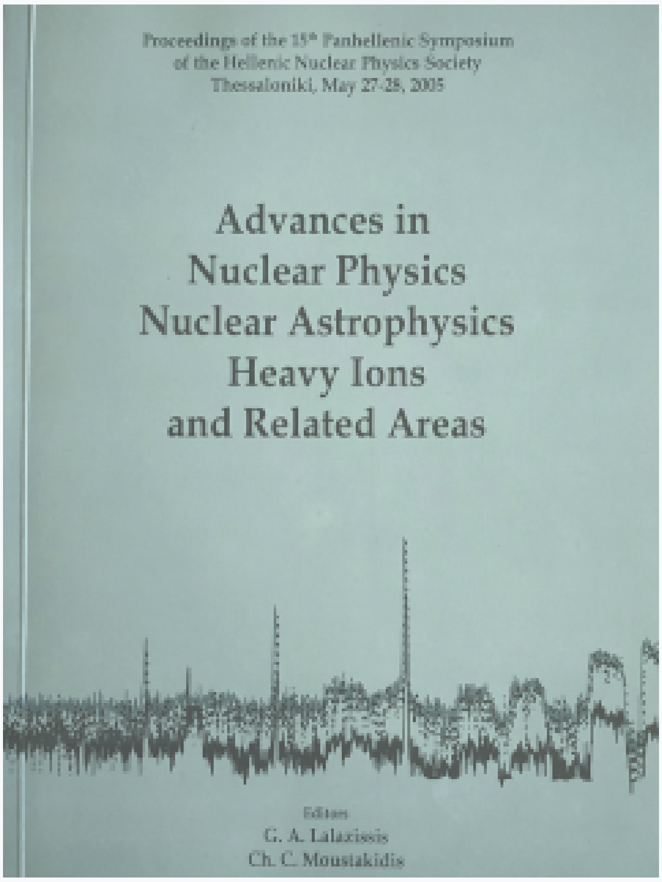

Proton capture reactions on 116Sn and 118Sn relevant to the p process

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Proton capture reactions on ^{116}Sn and ^{118}Sn relevant to the p process.

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Abstract

The proton capture reaction cross sections on ^{116}Sn and ^{118}Sn have been determined at astrophysically relevant energies by means of activation, γ-ray angular distribution and angle-integrated γ-flux measurements. The results of the present work together with those obtained in previous measurements are compared to the predictions of the Hauser-Feshbach theory.

1 Introduction

In order to perform abundance calculations for the so-called p nuclei that are produced in certain stellar sites via the p process [1], one has to take into account the cross sections of more than 20.000 nuclear reactions that form a huge reaction network involving almost 2.000 nuclei. Obviously, the cross sections of all these reactions cannot be determined experimentally. As a consequence, the p-nuclei abundance calculations have to rely almost entirely on the predictions of the Hauser–Feshbach (HF) theory. Given these facts, the aim of the present work is to contribute to a cross-section database of proton capture reactions at energies relevant to the p process. This database will enable us to test the reliability of the HF theory at low energies as well as to derive global input parameters for HF calculations.

2 Experiments

In the present work, we employed three different experimental procedures to determine the cross sections of the ^{116}Sn(p,γ)^{117}Sb and ^{118}Sn(p,γ)^{119}Sb reactions. These are described in detail in the following three subsections.

2.1 Activation measurements

The activation technique was used to determine the cross section of the reaction ^{116}Sn(p,γ)^{117}Sb. The relevant irradiations have been performed at the 5 MV TANDEM accelerator of NCSR "Demokritos" at energies between 2.3 and 4.5 MeV. The irradtion time at each energy measured was $\approx$ 6 hours. Hereby, the beam current on target was $\simeq 1\ \mu A$. This way, an activity of 77% of the core activity was achieved. After the irradiation, the off-line activity was measured by means of one HPGe detector of 55% relative efficiency. The target–detector assembly was shielded with 5 cm thick lead blocks, for the reduction of natural background. The time interval between two sucessive irradiations was long enough ($\approx$ 3 days) compared to the half-life of the produced ^{117}Sb nucleus ($T_{1/2}$=2.8 h). This way it was possible to use –at every energy measured– the same target, which was 95.7% enriched in ^{116}Sn. The target was produced by evaporation of SnO_2 on a 2 mm thick Tantalum foil. Its thickness was 31 μg/cm^2 and was determined by means of the XRF technique. A typical spectrum of this decay, taken after 6 hrs of irradiation with a 3.5 MeV proton beam, is presented in Fig. 1. As shown in this figure, the most intense γ ray from the decay of ^{117}Sb is the 159 keV γ ray, with an intensity of 86% which is clearly present in the spectrum. No other γ rays associated with the decay of ^{117}Sb are present in this spectrum since their intensity is very week ($\leq$ 0.3%). In addition to the 159 keV γ ray, the spectrum includes

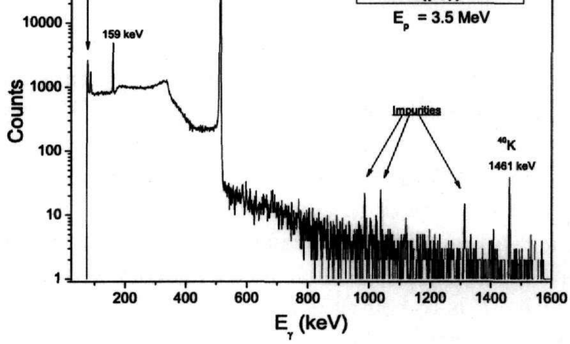

Fig. 1. *Activation spectrum of the ^{116}Sn(p,γ)^{117}Sb reaction taken at 3.5 MeV. The 159 keV γ ray is the most intense γ transition following the decay of ^{117}Sb.*

also peaks due to natural background, target impurities as well as X-rays arising from the lead shielding. The present activation measurements have been analyzed as described in [2].

2.2 Angular distribution measurements

Gamma-ray angular distribution measurements were carried out at the 4 MV DYNAMITRON accelerator of the University of Stuttgart in order to determine the cross sections of both, the ^{116}Sn(p,γ)^{117}Sb and ^{118}Sn(p,γ)^{119}Sb reactions. During these measurements, the energey of the proton beam varied from 2.2 to 3.5 MeV and the beam current on target was ranging from 8 to 16 μA. The target used to study the first reaction was produced by evaporating SnO_2 on a 2mm thick Tantalum foil. The same technique was also applied to produce the target of the second reaction by evaporating metallic ^{118}Sn. The thickness of the ^{116}Sn isotope in the first target was 122 μg/cm^2, whereas that of the ^{118}Sn target was 202 μg/cm^2. The enrichment in the corresponding isotopes was 95.7 and 97.1%, respectively. During all runs, the Ta backings were cooled directly with water.

The setup used in these measurements is described in detail in [3]. Gamma-singles spectra were taken at 8 angles with respect to the beam direction. Spectra were taken also by impinging the proton beam on a blank backing in order to investigate possible contributions from "dirt" reactions occuring in the backing material. Typical spectra of both reactions taken at 3 MeV, together with the corresponding backing spectrum are shown in Fig. 2. Hereby, the γ transitions that have to be taken into account to derive the cross section, i.e. those feeding the ground state of the produced nuclei are labeled with their energies. The data analysis of these measurements has performed according to the procedure described in [3].

2.3 Angle-integrated measurements

Angle integrated γ-fluxes were measured at the 4 MV Dynamitron-Tandem accelerator of the University of Bochum at energies between 2.5 and 5.2 MeV using a 12"x12" NaI(Tl) single crystal with a bore hole along its axis [4]. The absolute efficiency of this 4π summing detector was determined over a wide energy range by measuring resonances of very well known strengths and γ branchings. The energy resolution of the NaI detector at 10 MeV was 2%. The thickness of the ^{116}Sn and ^{118}Sn targets, which were placed at the center of the summing crystal, were 34 and 202 μg/cm^2 respectively. The targets were mounted on a target holder that was cooled with air. The beam current on target was ranging from 10 to 150 nA.

Typical γ spectra taken with the 4π NaI detector at 4 MeV are shown in Fig. 3 for both reactions studied. The corresponding sum peaks are clearly present in the spectra. These result either from the the γ rays depopulating the entry

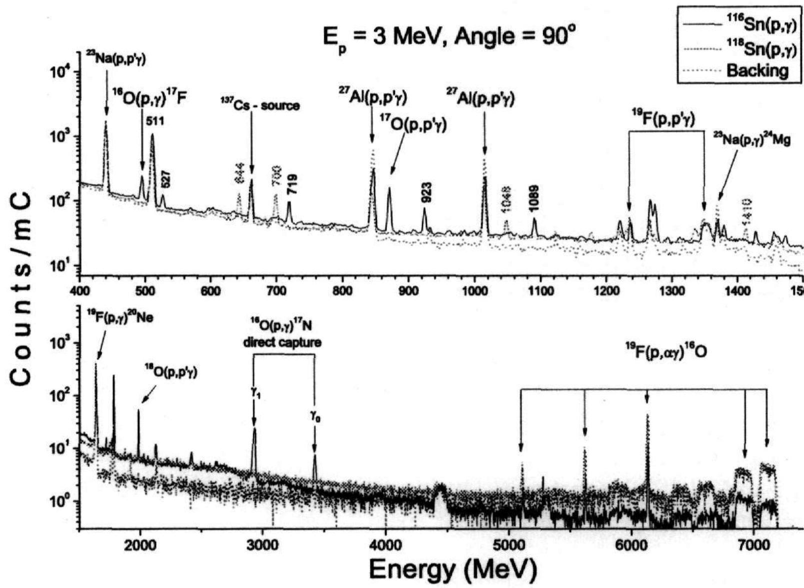

Fig. 2. *Typical γ spectra of the $^{116}Sn(p,\gamma)^{117}Sb$ and $^{118}Sn(p,\gamma)^{119}Sb$ reactions measured at E_p=3 MeV with the HPGe detector placed at θ=0°. The corresponding "backing" spectrum is also shown. The indicated reactions are these occuring at the backing material.*

state and feeding the ground state either directly or via γ cascades. Due to the almost 4π solid angle covered by the detector angular distribution effects of the emmited γ transitions are eliminated. Hence, the cross section σ_T of the reaction of interest can simply be obtained by

$$\sigma_T = \frac{A}{N_A}\frac{1}{\xi}\frac{Y}{\varepsilon N_b} \tag{1}$$

where, A is the atomic weight of the target nucleus, N_A is the Avogadro's constant, ξ is the target thickness (in units of g/cm^2), Y is the measured γ-ray yield, ε is the detector efficiency at the corresponding γ-ray energy and N_b is the total number of incident particles. The analysis of these measurements is still in progress.

3 Results and Discussion

The cross sections determined in the present work are plotted in Fig. 4 together with the corresponding HF predictions (curves). The data obtained from our angular distributions are indicated by solid circles, whereas those derived in our activation measurements with solid squares. In addition, the open circles

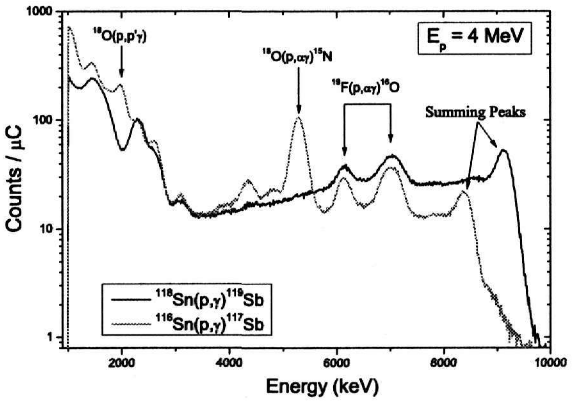

Fig. 3. *γ ray spectra for the $^{116}Sn(p,\gamma)^{117}Sb$ and $^{118}Sn(p,\gamma)^{119}Sb$ reactions taken with the 4π detector at E_p=4 MeV.*

shown in Fig. 4 correspond to the cross sections measured by Özkan *et al.* [5].

The curves shown in Fig. 4 are the HF calculations obtained by using different combinations of nucleon-Nucleus OMPs and NLDs. Hence, the dotted curves correspond to calculations obtained by combining the microscopic OMP of Jeukenne *et al.*(JLM) [6] with the microscopic NLDs of Demetriou and Goriely (DG) [7], whereas the dashed curves result from the combination of the same OMP with the phenomenological NLDs of Thielemann *et al.* (TAT) [8]. Moreover, the solid curves indicate the calculations derived from the combination of the phenomenological OMP of Koning and Delaroche (KD) [9] with the microscopic NLDs of Demetriou and Goriely (DG) [7]. Finally, the dashed-dotted curve shown only for the ^{116}Sn(p,γ)^{117}Sb reaction corresponds to the combination of the latter OMP with the phenomenoligal NLDs of Thielemann *et al.* (TAT) [8]. All theoretical calculations presented in Fig. 4 were performed by using the code MOST [10].

Based on Fig. 4 one can conclude that the HF calculations obtained using the OMP of Koning and Delaroche (KD) [9] with the microscopic NLDs of Demetriou and Goriely (DG) [7] are in very grood agreement with the data. However, the deviations of the remaining theoretical curves from the data are roughly not very signifficant. To conclude, the results of the present work, together with those obtained by our group for other (p,γ) reactions (see e.g. in [11] or in [12]) suggest that in the relevant energy region the HF calculations are more sensitive to the OMPs rather than to NLDs. However, both OMPs and NLDs need further improvement and no global predictions are possible at this stage.

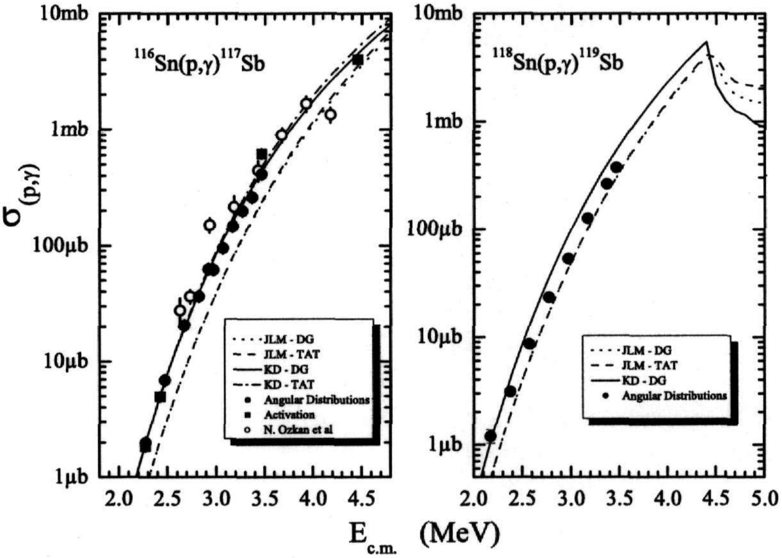

Fig. 4. *Cross sections determined in the present work (solid circles and squares) and corresponding HF predictions (curves). Details are given in the text.*

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