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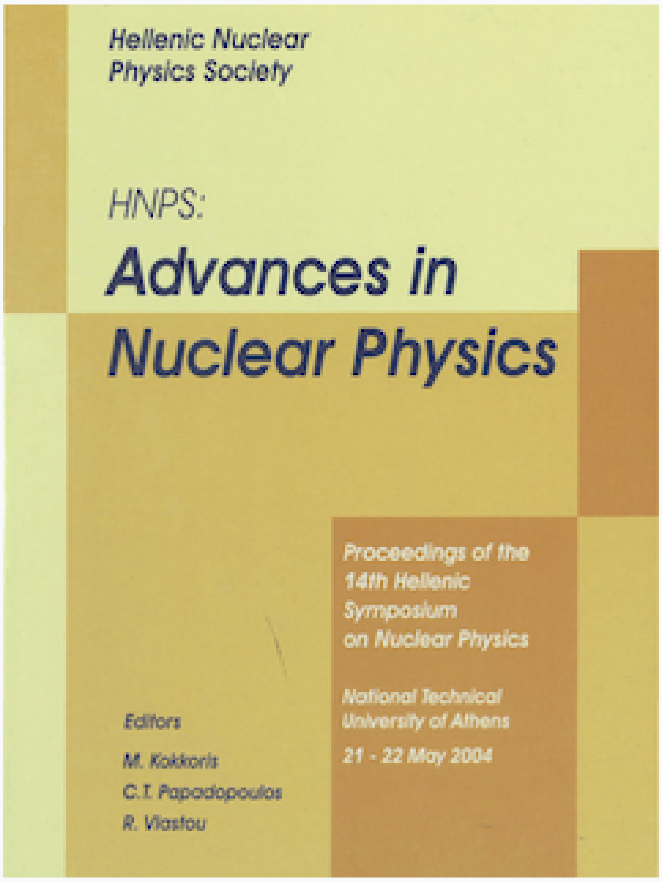

(p,γ) Reaction Cross Sections Relevant to the p process: First Results for the Se Isotopes

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(p,γ) Reaction Cross Sections Relevant to the p process: First Results for the Se Isotopes

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Abstract

Proton-capture reaction cross sections of Se isotopes were determined in the 1 – 6 MeV energy range by means of γ-angular distribution measurements as well as via the activation technique. In this report we compare our first cross-section results with statistical model calculations performed using various microscopic and phenomenological approaches of Optical Model Potentials and Nuclear Level Densities.

1 Motivation

During the last five years an intense experimental effort has been devoted to cross section measurements of proton and alpha-particle capture reactions in the medium-heavy mass range at astrophysically relevant energies. These studies aim at establishing an extended cross-section database necessary for astrophysical abundance calculations of the so-called p nuclei. This class of nuclei consists of 35 stable nuclei that are heavier than iron and cannot be synthesized by the two neutron capture processes referred to as s and r processes [1]. Instead, their synthesis, which is assumed to occur in the Oxygen/Neon rich

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layers of type II supernovae during their explosion, requires a special mechanism known as p process [2] consisting of mainly photodisintegrations but also (p,γ) and (α,γ) reactions. To date, all the models of p-process nucleosynthesis are able to reproduce most of the p-nuclei abundances within a factor of 3, but they fail in the case of the light p nuclei. Due to the huge number of reactions involved in abundance calculations the latter have to rely almost completely on the predictions of the Hauser-Feshbach (HF) theory. It is therefore of key importance, on top of any astrophysical model improvements, to investigate the uncertainties in the evaluation of nuclear properties, such as nuclear level densities (NLD), nucleon-nucleus optical model potentials (OMP), and γ-ray strengths entering the HF calculations.

In view of these problems, we have performed several in-beam cross sections measurements of proton- as well as α-capture reactions in the Se-Sb region at energies well below the Coulomb barrier with an aim to contribute to a database of cross sections relevant to the modelling of the p process and to the derivation of global input parameters for HF calculations. This paper reports on the first results obtained for the Se isotopes.

2 Experimental procedures

In the present work γ-singles spectra were taken in measurements of γ-angular distributions as well as in activations. In the former case, the cross sections of the ^{78}Se(p,γ)^{79}Br and ^{80}Se(p,γ)^{81}Br reactions were measured in the energy range 1.5 – 3 MeV. A typical γ-singles spectrum measured at 3 MeV for the ^{78}Se(p,γ)^{79}Br reaction is shown in Fig. 2. The angular distributions were measured at the 4 MV DYNAMITRON accelerator at the University of Stuttgart by means of an array of 4 HPGe detectors that is described in detail in [3]. Each detector had a relative efficiency of 100% and was shielded with BGO crystals for Compton suppression. The targets used in the angular distribution measurements were both metallic and highly enriched. They have been produced by evaporation of 97.8% enriched ^{78}Se and 97.8% enriched ^{80}Se on 0.2 mm thick Tantalum foils. The thickness of the ^{78}Se target was 85 μg/cm^2 and that of ^{80}Se was 106 μg/cm^2. The thickness of both targets was determined by means of the XRF technique before the measurements with an accuracy of 5%. They were additionally checked for target deterioration by XRF after the runs and no signifficant material loss has been observed.

The activation spectra of the Se isotopes were taken at the 5 MV Van de Graaff TANDEM accelerator facility of "Demokritos", Athens. Hereby, natural targets of $\approx$200 μg/cm^2 thickness were used and γ activities induced by proton beams in the 1-6 MeV region were measured off-line by means of one HPGe detector of 50% relative efficiency. The reactions investigated in the latter measurements were ^{74}Se(p,γ)^{75}Br, ^{76}Se(p,γ)^{77}Br, ^{77}Se(p,n)^{77}Br, and ^{82}Se(p,n)^{82}Br. A typical off-line γ spectrum is shown in Fig. 2

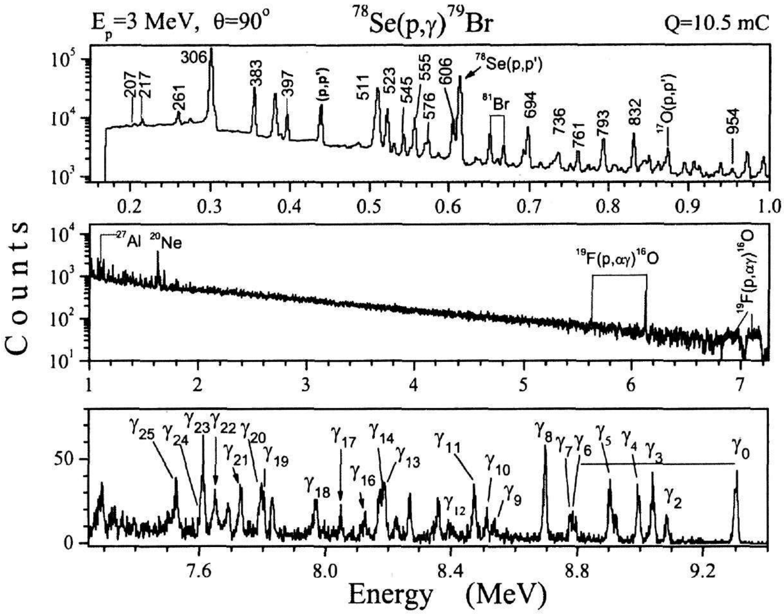

Fig. 1. Typical γ spectrum measured at E_p=3 MeV with the detector placed at 90°. The strong secondary γ transitions de-populating excited states of the produced ^{79}Br nucleus are labeled with numbers. The strong primary γ transitions, i.e. these de-populating the entry state and feeding the ground, 2nd, 3rd, 4th and so on excited state, are indicated as γ_0, γ_2, γ_3, γ_4, etc. No γ_1 transition has been observed since it is rather unfavorable due to spin and parity arguments.

3 Results and Discussion

In the in-beam method, the total cross section σ_T is derived from the reaction yield Y_0, i.e. the absolute number of γ rays emitted by the reaction in 4π per beam-particle. Y_0 can be determined from the angular distributions of all γ transitions feeding the ground state of the produced nucleus. The total cross section is then given by

$$\sigma_T = (A/N_A\xi)\ Y_0 \tag{1}$$

where A is the atomic weight of the target in amu, N_A is the Avogadro number, and ξ is the target thickness in μg/cm^2.

In the present angular distribution measurements γ-singles spectra were taken at 8 angles with respect to the beam as described in [3]. The number of the

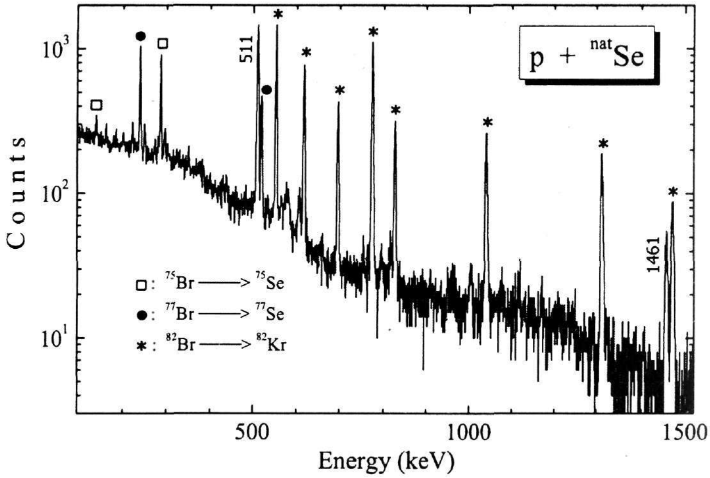

Fig. 2. Activation spectrum measured at E_p=5 MeV for the p+^{nat}Se reaction.

incoming proton-beam particles was obtained from the charge accumulated at each angle. This was determined by using a current integrator. This procedure was repeated at all beam energies measured. This way, the intensities of all the relevant γ transitions were determined at all angles and all beam energies. These intensities were first normalized to the corresponding charge and then they were corrected for the absolute efficiency of the detector used. Hence, at each beam energy we obtained for each γ transition an angular distribution, i.e. the quantity $Y(\theta)$=(photons/charge-unit/4π). The angular distribution was then fitted by a sum of Legendre polynomials $P_k(\theta)$ given by

$$W(\theta) = A_0(1 + \sum_k \alpha_k P_k(\theta)) \tag{2}$$

and the corresponding coefficients A_0 and α_k were determined. Note that the maximum value of index k ($k \geq 2$) depends on the multipolarity of the γ transition in consideration. This way we obtained at each beam energy N different A_0 coefficients in $photons/mC$, one for every γ transition feeding the ground state of the produced compound nucleus. The total yield Y_0 was then taken from

$$Y_0 = \sum_i^N A_0^i \tag{3}$$

and was inserted in Eq. 1 to give the total cross section σ_T.

The analysis of activation measurements is also a straightforward task. In the present work we followed the analysis procedures described in [4] and [5] so that no further details are given hereafter. The in-beam cross sections obtained for the ^{78}Se(p,γ)^{79}Br reaction together with those derived by the activation technique for the ^{74}Se(p,γ)^{75} reaction are plotted in Fig. 3.

The cross sections obtained in the present work have been compared with the predictions of the Hauser-Feshbach (HF) theory. The latter have been obtained from the statistical model code MOST [7]. In these calculations, we have used the nuclear masses of [8] and the ground state properties predicted by the microscopic Hartree-Fock-Bogoliubov model [9]. The E1 strength functions are obtained from Hartree-Fock-QRPA calculations [10] and the M1 from the parametrization of [11]. Different nucleon-nucleus OMPs and NLD models have been used in four different combinations, referred to in the following as MOST-1, 2, 3, and 4. In MOST-1, 2, and 3, the microscopic NLD of [12] has been combined with the microscopic OMPs of [13] and [14], and the phenomenological one of [15], respectively. MOST-4 correspond to the combination

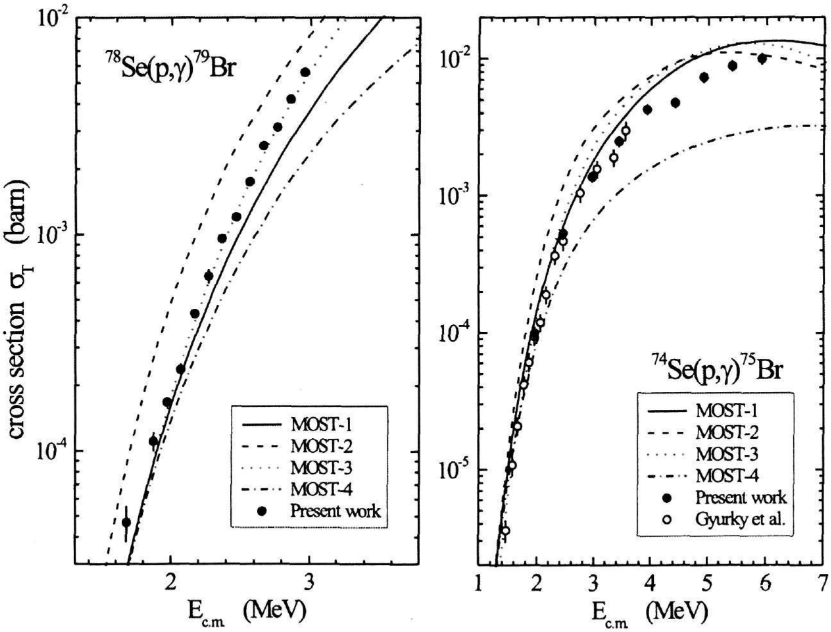

Fig. 3. Cross sections determined in the present work (solid circles) from γ-angular distribution measurements of the ^{78}Se(p,γ)^{79}Br reaction (left panel) and from activation measurements of the ^{74}Se(p,γ)^{75}Br (right panel) compared with various statistical model calculations (curves) obtained by using different combinations of Optical Model Potentials and Nuclear Level Densities as explained in the text. The open circles shown in the right panel indicate the data reported in [6].

of the microscopic OMP of [13] with the phenomenological NLDs of [16]. According to Fig. 3, the predictions of MOST-1 and MOST-3 are quite close to the data. Combining the results of the present work with those of other cross section measurements performed by the Nuclear Astrophysics Group of "Demokritos", we can conclude that the uncertainties affecting the nuclear input (OMP, NLD) give rise to at most 40% uncertainties in the reaction rates. HF predictions are more sensitive to OMPs rather than to NLDs. At this stage, however, no global predictions are possible since the OMPs and NLDs need further improvement.

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