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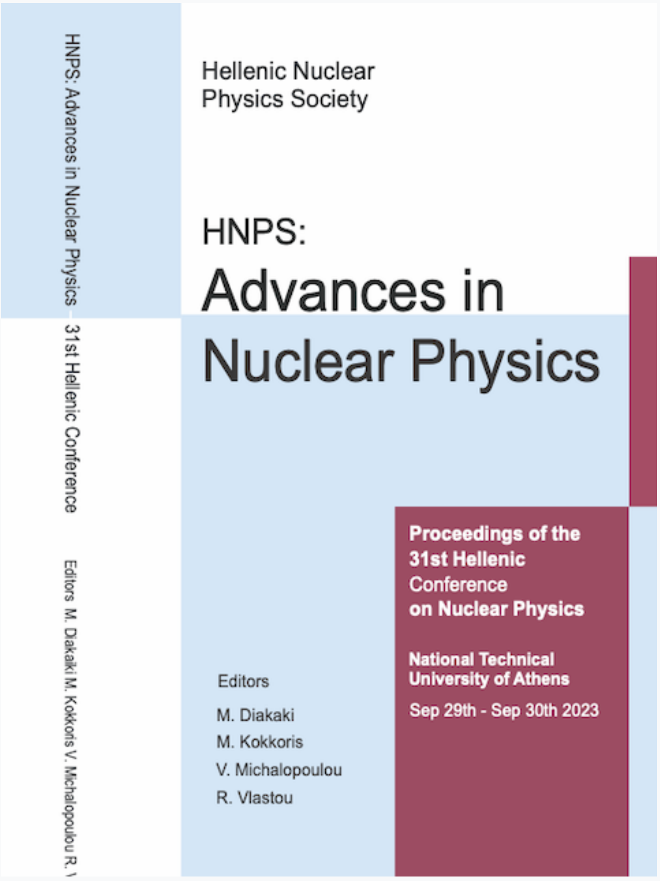

TALYS calculations for α capture reactions on Cu isotopes

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TALYS calculations for α capture reactions on Cu isotopes

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Abstract Within the present work, previously measured experimental cross-sections of the ^{63}Cu(α,γ)^{67}Ga reaction at astrophysical energies are compared with a variety of different theoretical calculations. Utilizing the nuclear reaction code TALYS (v1.96), the research incorporates all available models for the α-particle Optical Model Potential (α-OMP), Nuclear Level Densities (NLD), and γ-ray Strength Functions (γ-SF), as well as, all the combinations of the aforementioned parameters, resulting in a large number of theoretical calculations. The primary goal is to optimize the parametrization of the HF calculations to best describe the experimental data. The same methodology is applied to the ^{65}Cu(α,γ)^{69}Ga reaction to comprehensively examine the impact of different models on cross-section calculations in this mass region. While this work is ongoing, preliminary results are presented within this contribution.

Keywords Talys, Hauser-Feshbach, p-process, (α,γ) cross-section

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INTRODUCTION

The abundances of the so-called p-nuclei observed in our solar system provide a direct signature of its creation mechanism. In addition, these abundances are a real challenge for all nucleosynthesis models, known as p-process models, aiming at reproducing them. Up to date, large discrepancies still exist between the observed solar system p-nuclei abundances and those calculated by p-process models. In order to understand the origin of these discrepancies, it is mandatory, on top of any uncertainties in the p-process models, to also investigate possible uncertainties in the nuclear physics quantities entering the abundances calculations, which rely almost entirely on the predictions of the Hauser-Feshbach theory. These quantities refer mainly to the Optical Model Potential (OMP) between the nucleons (proton or neutron) and the nucleus, the OMP between the α-particle and the nucleus, the Nuclear Level Density (NLD) and the γ-ray strength function (γSF). These investigations require comparing the HF calculations, performed with different OMP, NLD and γSF models, with experimental data, notably cross sections of capture reactions at energies relevant to p-process, i.e, between 1 and 5 MeV for proton captures and 5 to ≈10 MeV for α-particle induced capture reactions [1].

Following our recent cross section measurements of the ^{63}Cu(α,γ)^{67}Ga reaction at the University of Bochum [2], we report here on detailed theoretical calculations performed using the widely-used TALYS nuclear reaction code (version 1.96) [3]. In this study, we also included the cross section data of the ^{65}Cu(α,γ)^{69}Ga reaction measured previously [4].

TALYS CALCULATIONS

Fig. 1 depicts the cross-sections of all open reaction channels at the energies covered by the aforementioned cross-section measurements. As shown in these figures, the cross section of the (α,p) channel is larger or comparable to that of the (α,γ) channel. Therefore the (α,p) channel cannot be neglected in the TALYS calculations and the choice of the proton-OMP for these calculations is of special interest.

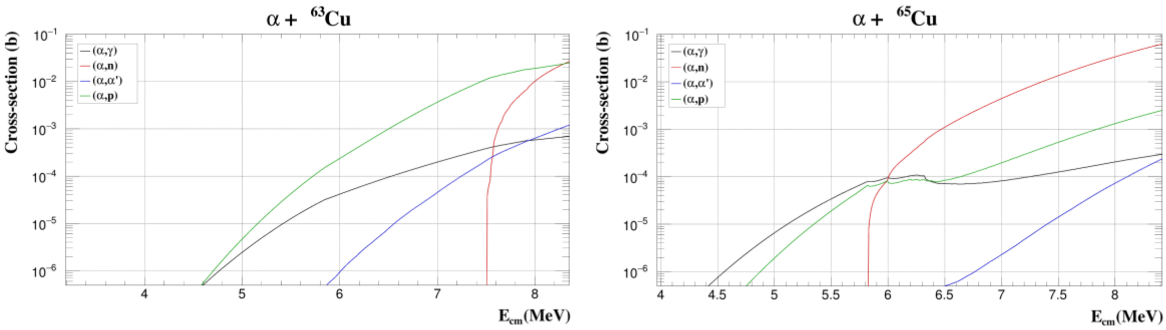

Figure 1. *Cross-sections of a-induced reactions on ^{63}Cu and ^{65}Cu*

Table 1. *All available models of TALYS v1.96 used within this work [3]*

Parameter	Phenomenological	Semi-microscopic
p-OMP	KD: Global model of Koning and Delaroche	JLM: Semi-microscopic OMP of Bauge, Delaroche, and Girod at low energies
α-OMP	WKD: Talys-specific α-particle–nucleus OMP McFS: α-particle–nucleus OMP of McFadden and Satchler AV/I: α-particle–nucleus OMP of Avrigeanu et al. Nlt: α-particle–nucleus OMP of Nolte et al. AV/II: α-particle–nucleus OMP of Avrigeanu et al.	α-OMPI: Demetriou et al. α-OMPII: Demetriou et al. α-OMPIII: Demetriou et al.
NLD	CTFG: Constant temperature Fermi gas BSFG: Back-shifted Fermi gas GSM: Generalized superfluid model	HFBCS: Hartree-Fock-BCS HFB: Hartree-Fock-Bogolyubov HFB/T: Temperature-dependent Hartree-Fock-Bogolyubov
γ-SF E1	KU: Generalized Lorentzian of Kopecky and Uhl BA: Generalized Lorentzian of Brink and Axel SMLO: Simplified Modified Lorentzian	HFBCS/QRPA: Hartree-Fock-BCS–quasiparticle random-phase approximation HFB/QRPA: Hartree-Fock-Bogolyubov–quasiparticle random-phase approximation HG: Hybrid model of Goriely HFB/T: Temperature-dependent Hartree-Fock-Bogolyubov RMF/T: Temperature-dependent RMF D1M/HFB/QRPA: Gogny D1M Hartree-Fock- Bogolyubov–quasiparticle random-phase approximation
γ-SF M1	1 2	3 4 8

The options of TALYS v1.96 for the proton OMP (p-OMP), the α-particle OMP (α-OMP), the Nuclear Level Densities (NLD) and the γ-ray Strength Functions (γ-SF E1 and γ-SF M1) are listed in Table 1.

All available models, along with their various combinations, were employed, leading to a significant number of theoretical calculations. These calculations were categorized into two groups: fully phenomenological and fully semi-microscopic and were analyzed accordingly.

RESULTS AND DISCUSSION

In each scenario, a standard combination was used, with phenomenological models represented by the green line (AV + KD + CTFG + SMLO + γ-SF M1 3) and semi-microscopic models (α-OMPIII + JLM + HFB + D1M/HFB/QRPA + γ-SF M1 8) by the red line in the following Figures. Using these standard combinations as a reference, the range of minimum and maximum cross-section values were calculated, by changing one parameter while keeping the other three constant. These ranges are visually depicted as shaded areas in the corresponding Figures.

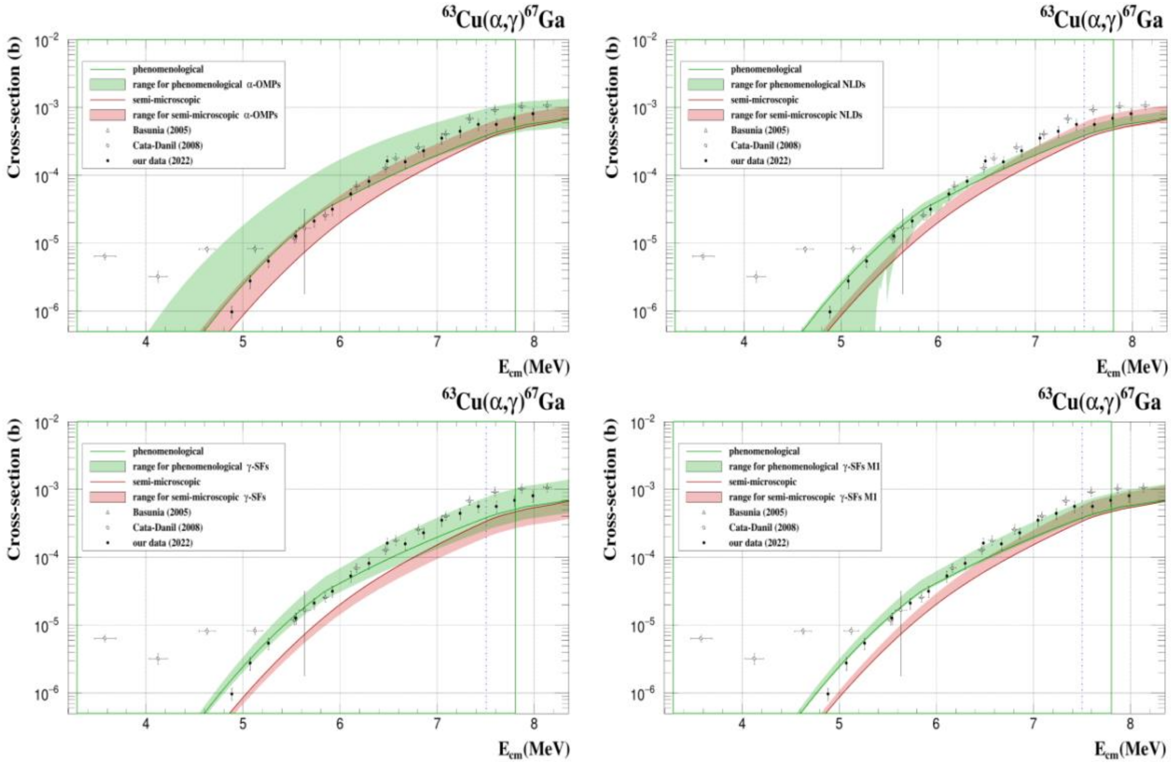

Figure 2. *Cross-sections of the phenomenological and semi-microscopic combination for the ^{63}Cu(α,γ)^{67}Ga reaction along with the ranges for the four parameters under investigation [2]*

The primary source of uncertainty is notably attributed to the α-OMP. The phenomenological combination seems to exhibit a better fit to the data for both isotopes. However, it is worth noting that in the case of ^{63}Cu, the difference between the semi-microscopic and the phenomenological combination is relatively smaller.

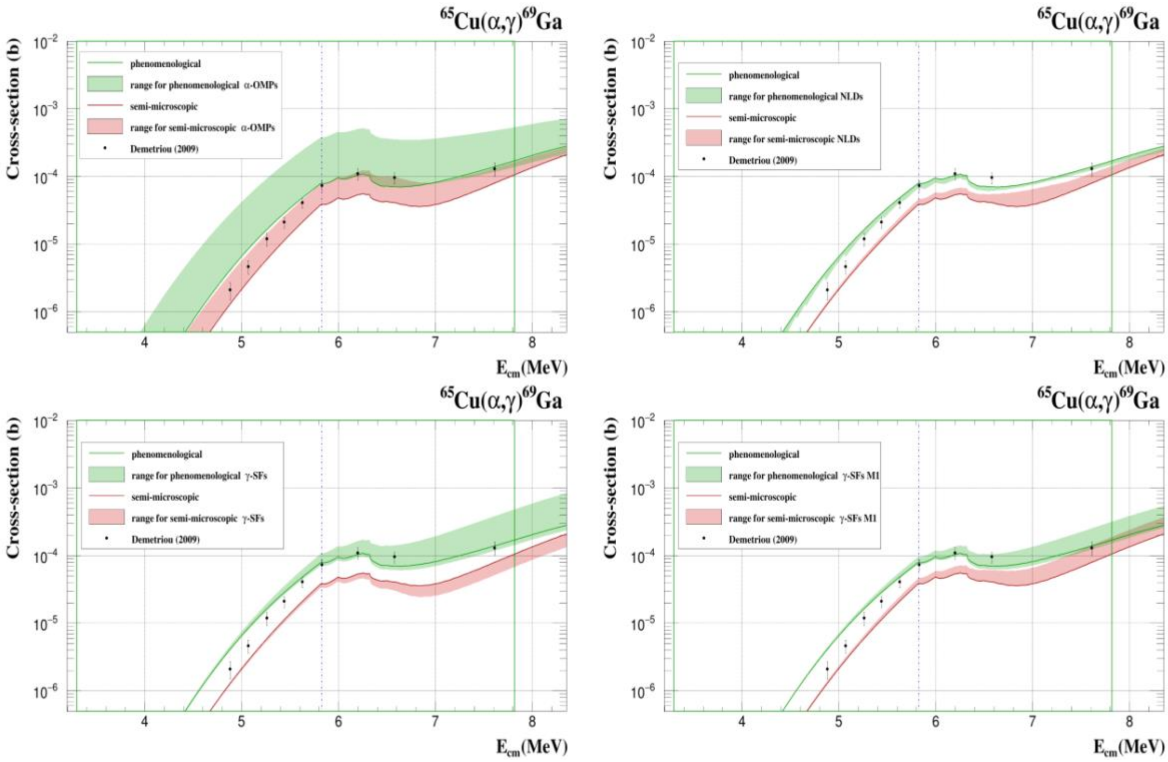

Figure 3. *Cross-sections of the phenomenological and semi-microscopic combination for the $^{65}Cu(\alpha,\gamma)^{69}Ga$ reaction along with the ranges for the four parameters under investigation [4]*

CONCLUSIONS

As the Figures indicate, the α-OMP-III is underestimating the cross-section in both isotopes. A more in-depth investigation into the impact of the aforementioned parameters on the results is currently ongoing, along with an attempt to constrain and refine the semi-microscopic α-OMP for an optimal fit of the data.

Acknowledgments

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