Analysis of cross-section and thermonuclear reaction rate of some intermediate p-process nuclear reactions

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Introduction

The astrophysical s and r processes are mostly responsible for the formation of elements beyond iron [1]. Most of the heavy elements are formed mainly via these two neutron-capture processes [2]. But there are 35 proton-rich stable isotopes between the nuclides ^{74}Se and ^{196}Hg, referred to as the p-nuclei, the creation of which requires a different astrophysical process known as the p-process [1]. These p-nuclei, contributing only (0.01-1) % of the elemental abundance (except for the isotopes molybdenum and ruthenium), are thermally produced by proton capture and photo disintegration reactions such as (γ, p), (γ, n), (γ, α) on the s- or r- seed nuclei at temperature ~ 2-3×10^9 Kelvin. From the current understanding, the O-Ne-rich layers of type II supernova explosions are the best possible sites for the production of p-nuclei.

In the recent times, significant efforts have been made to measure the proton-capture cross sections and reaction rates using advanced experimental techniques. But because of the several experimental limitations such as very low cross-section, etc., only a handful of experimental data are presently available in the literature. Therefore, theoretical understanding are crucial for predicting the cross section and thermonuclear reaction rates that can be used for nuclear reaction network calculation. In the present work, we have used nuclear reaction codes TALYS [3] and EMPIRE [4] for the prediction of cross-section and thermonuclear reaction rate of some nuclear reactions that are important for p-process nucleosynthesis. Our objective is to compare the experimental data with theoretical predictions and to understand the appropriate inputs of the reaction codes in the concerned mass and energy region. This could increase our confidence in the near future to predict the cross-section of the nuclear reactions, which are astrophysically significant but experimentally impossible to attain in the lab.

In the present work, we have calculated the cross-sections and thermonuclear reaction rates of proton-capture reactions for the nuclides ^{90,91}Zr, ^{74}Ge, ^{107,109}Ag, etc, using TALYS and EMPIRE nuclear reaction codes by varying different input parameters such as level density model, γ-ray strength functions, and the results have been compared to the available theoretical-results and experimental data. The knowledge of cross sections & thermonuclear reaction rate for (p,γ) reaction of these nuclei is of crucial interest for network calculations predicting the abundances of the p nuclei in the mass region of 70 to 110.

Theoretical Models

Statistical model codes like TALYS and EMPIRE have been used for theoretical analyses of p processes and are based on the Hauser-Feshbach model for the analysis of compound nuclear reactions. In comparison, TALYS and EMPIRE codes differ in the input parameters used, such as the optical model potential, the γ-ray strength function, and nuclear level densities. The details of TALYS and EMPIRE are discussed in Refs. [3, 4]. The nuclear level density and γ-ray strength function are very important as they provide the major source of uncertainties in calculating the nuclear reaction cross-section.

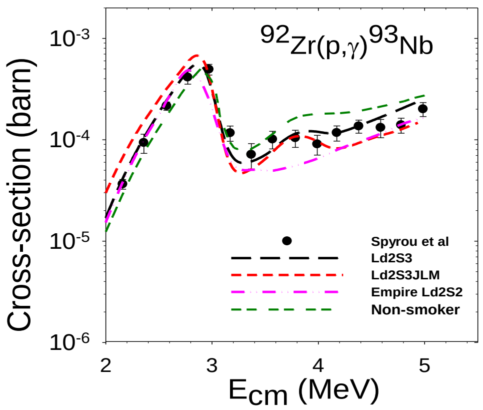

Fig.1 TALYS and EMPIRE predictions of cross-section for the reaction ^{92}Zr(p,γ)^{93}Nb along with the existing experimental data. For TALYS, Ld2 denotes BSFG level density, S3 denotes HFBCS strength function. JLM is the Jeukenne, Lejeune and Mahaux optical model [3]. For EMPIRE, Ld2 is Gilbert-Cameron level density and S2 is MLO2 (Modified Lorentzian) gamma ray strength function [4].

Results and Discussions

We have analyzed different nuclear reactions such as ^{90}Zr(p,γ)^{91}Nb, ^{92}Zr(p,γ)^{93}Nb, ^{74}Ge(p,γ)^{75}As, ^{107}Ag(p,γ)^{108}Cd, etc. TALYS calculation is performed using different level density models such as Constant temperature (CT) model, Back shifted Fermi Gas (BSFG) model, and γ-ray strength function of Kopecky-uhl, Brink-Axel, microscopic Hartree-Fock BCS (HFBCS), etc. For EMPIRE, Gilbert-Cameron level density and MLO2 as gamma ray strength function are used.

The TALYS prediction of cross-section matches very well with experimental dataset for medium mass nuclides such as ^{75}As, ^{91}Nb, ^{93}Nb, etc. But for higher mass nuclides such as ^{107}Ag, TALYS fails to match the data at lower energies, possibly due to the divergence in the level density term. On the other hand, EMPIRE calculation agrees very well with the experimental data at the lower energies but fails to match with the higher energy dataset. EMPIRE performs better in higher mass nuclides. Fig. 1 shows the predictions of TALYS and EMPIRE compared with the experimental data [5] of cross-section in ^{93}Nb.

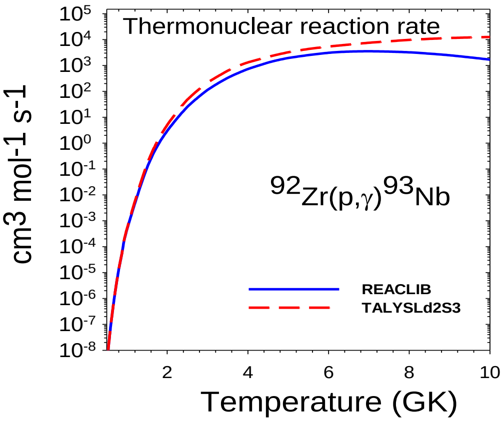

Fig.2 TALYS prediction of reaction rate compared with REACLIB data.

The best-fitted parameters are only shown in the plot. We have also extracted the results of another code Non-Smoker from the literature and shown in the same plot. The performance of TALYS is found best in comparison with the other two codes in this nuclear reaction as shown in Fig. 1.

The thermonuclear reaction rate of the reactions has also been calculated using TALYS and compared with the existing data in REACLIB nuclear database. The difference in reaction rate predicted by different codes, especially in the temperature region of our interest, has been identified. This rate is highly important for the prediction of abundance of p nuclides. Fig. 2 shows TALYS predicted reaction rate compared with REACLIB data.

The analysis is still in progress for different nuclei. The final result will be shown in the symposium.

References

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