Theoretical uncertainty in (p, γ) reaction cross section calculations relevant for the nucleosynthesis of p-nuclei

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Introduction

In recent past, number of experimental and theoretical efforts has been devoted to understand the astrophysical p-process mechanism of stellar nucleosynthesis, due to its larger significance in the context of astrophysical network calculations. Almost all the nuclei above iron are synthesized by the neutron capture s and r process. There are only thirty five nuclei between ^{74}Se to ^{196}Hg, which are not synthesized by neutron capture processes, expected to be formed by p-process so called p-nuclei [1]. It has been suggested that the photodisintegrations reactions such as (γ, n), (γ, p) and (γ, α) are responsible for the production of p-nuclei with very high temperature in the stellar environment, yet the exact process of the formation of p-nuclei is to be confirmed.

The detailed modeling of the p-process is highly desired to know the abundance of the p-process. A large reaction network of thousands of reaction rates (which are calculated by the cross sections) involving thousands of nuclei is required to describe the p-process network simulation. There exists a very limited amount of experimental cross section data as it is not possible to perform such a large number of experiments in the laboratory. At present, even with the increasing experimental activities, most of the cross section inputs required for astrophysical network calculations rely mostly upon the theoretical calculations. Most of the reaction cross sections relevant for p-process, are calculated by the theoretical approach using Hauser Feshbach statistical model. The calculation of cross sections further depends on different input parameters i.e. nuclear level density, optical potential, γ-ray strength function and nuclear masses. The reliability/uncertainty of the theoretical cross section calculations depend on the accuracy of these inputs [2]. Nuclear level densities as well as nuclear densities are an integral part of the Hauser-Feshbach theory of statistical nuclear reactions. However, their microscopic calculation is a challenging many-body problem and theoretical models are often based on mean-field and combinatorial methods. A combination of right level density with optical potential model is highly desired for the reliable nuclear reaction analysis. In this work, we have investigated the effect of nuclear level density and nuclear density input for cross section calculations.

Mathematical Formalism

RMF approach is a successful approach among the mean field assumptions and also for solving the nuclear quantum many body problems to calculate nuclear density/wave function. Relativistic mean field (RMF) model which contain the spin-orbit naturally, has been successfully used to understand and explain many features of nuclei such as binding energy of ground states, various excited states, charge radii, etc. Here, NL3* parameter set has been used for solving the standard RMF Lagrangian [3] and further these RMF nuclear densities have been used to calculate the reaction cross section with the help of Talys [4].

Result and Discussion

To see the effect and test the uncertainty in the calculations due to different inputs, used for calculating such cross section, we have considered the example of ^{106}Cd (p, γ) ^{107}In, as it is one of the widely studied reaction. The cross section of ^{106}Cd (p, γ) ^{107}In reaction has been calculated with different microscopic and phenomenological level density models and mean field densities (relativistic as well as non relativistic, ref Table 1). In fig. 1, we have shown the calculated results (within Gamow Window) and compared with the experimentally available data. Experimental result for the cross section has been taken from [5]. The experimental cross section was determined using activation technique with highly enriched Cd targets, irradiated with proton beams from both the Van de Graaff and Cyclotron accelerators. As shown in fig. 1, although all the calculated result show similar trend qualitatively and are in good agreement with the experimental results, however these are quantitatively different and, the calculated results depend slightly on nuclear densities, but are much sensitive to the choice of nuclear level density.

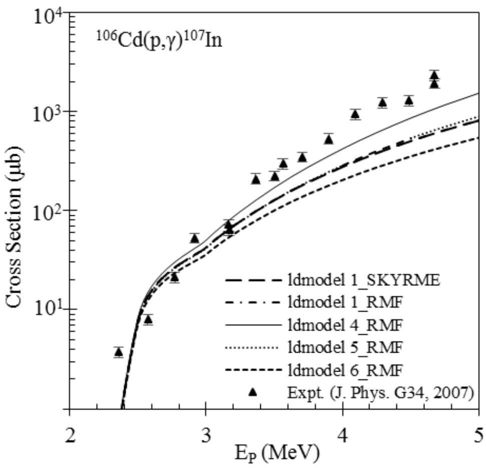

Fig. 1. Comparison of proton capture cross sections with different inputs

Conclusion

In the present work, it has been shown that in case of cross section calculations of stable nuclei, for different astrophysical process, choice of nuclear inputs may alter the calculated reaction rates as high as one to two orders of magnitude and are strongly dependent on nuclear level density. However it would be further interesting to investigate such uncertainty in case of reaction cross section calculations of unstable nuclei, where even the choice of nuclear density may plan an important role, entering the cross section calculation. The reaction network for the nucleosynthesis nuclei require the reaction cross sections data, in bulk, at high temperature so very reliable predictions are needed for such network calculations.

Table 1. The different level density/nuclear density inputs used.

Model	Reference
ldmodel1_SKYRME	HFB-Skyrme based matter densities with Constant temperature + Fermi gas level density model
ldmodel1_RMF	Relativistic mean field densities with Constant temperature + Fermi gas level density model
ldmodel4_RMF	Relativistic mean field densities with Microscopic level densities (Skyrme force) from Goriely’s tables
ldmodel5_RMF	Relativistic mean field densities with Microscopic level densities (Skyrme force) from Hilaire’s combinatorial tables
ldmodel6_RMF	Relativistic mean field densities with Microscopic level densities (temperature dependent HFB, Gogny force) from Hilaire’s combinatorial tables

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