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Astrophysical S factor and reaction rate of $^{92,94}Mo(p,\gamma)$ relevant to the p-process

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Abstract. Low energy proton capture cross sections on heavy isotopes are necessary for a better understanding of the astrophysical p-process. There are around 35 proton-rich stable isotopes between ^{74}Se and ^{196}Hg which are bypassed by the s- and r- processes. These are commonly referred as p-nuclei whose origin is still not completely understood. In the present study, proton capture reactions are studied on Mo isotopes at astrophysically relevant energies using nuclear modular code TALYS. Astrophysical S factor and reaction rates are also calculated inside a core-collapse supernova. The obtained results are compared with the literature data taken from EXFOR data library. In addition, the effect of different combinations of the nuclear input parameters entering the stellar reaction rate have been investigated.

1 Introduction

The proton capture process, often known as the "p-process", is the origin of several naturally occurring neutron-deficient isotopes of elements ranging from selenium to mercury. These nuclides are known as p-nuclei, and it is still unclear where they came from. The p isotope abundances seen in the solar system can not be replicated by the current p process [1] models. This can be partially explained by the ambiguous astrophysical conditions under which the process may take place. On the other hand, the failure might potentially be caused by deficiencies in the models of nuclear physics.

$^{92,94}Mo$ are such most abundant p-nuclei whose proton-capture reaction rate has been studied in the astrophysically relevant energy range. The reaction cross section is simulated using TALYS [2] nuclear modular code and compared with previous literature data available in EXFOR [3]. Astrophysical S factor is also calculated which shows greatly reduced energy dependence. Reaction rate for both the isotopes have been simulated and compared.

2 Calculations and Results

Theoretical calculations has been performed by the nuclear modular code TALYS-1.95 utilizing the Hauser-Feshabck (HF) statistical model. The code calculates cross section in the

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energy range of 1 keV to 200 MeV taking into account all types of direct, pre-equilibrium, and compound mechanisms. The Hauser-Feshbach model is used to incorporate the compound reaction mechanism [4]. The pre equilibrium contribution is accounted by using the Kalbach exciton model [5]. The optical model parameters are calculated using Koning and Delaroche's suggested global potential [6]. Stellar reaction rate at different temperature has been calculated by using the TALYS code. This calculations is performed within the framework of statistical model because in stellar interior, nuclides do not only exist in ground state but also in different thermally excited states and a thermodynamic equilibrium holds locally to a very good approximation.

In general, the cross section strongly varies with the energy and declines rapidly to a very low value, making extrapolation to lower energies impractical. Therefore instead of the cross section, much less energy dependent quantity called astrophysical S factor is used for the extrapolation of reaction cross section which removes the fast coulomb dependence and is mainly sensitive to the nuclear effects [7]. The astrophysical S factor is defined by

$$S(E) = \frac{E}{e^{-2\pi\eta}}\,\sigma(E) \tag{1}$$

where η is sommerfeld parameter.

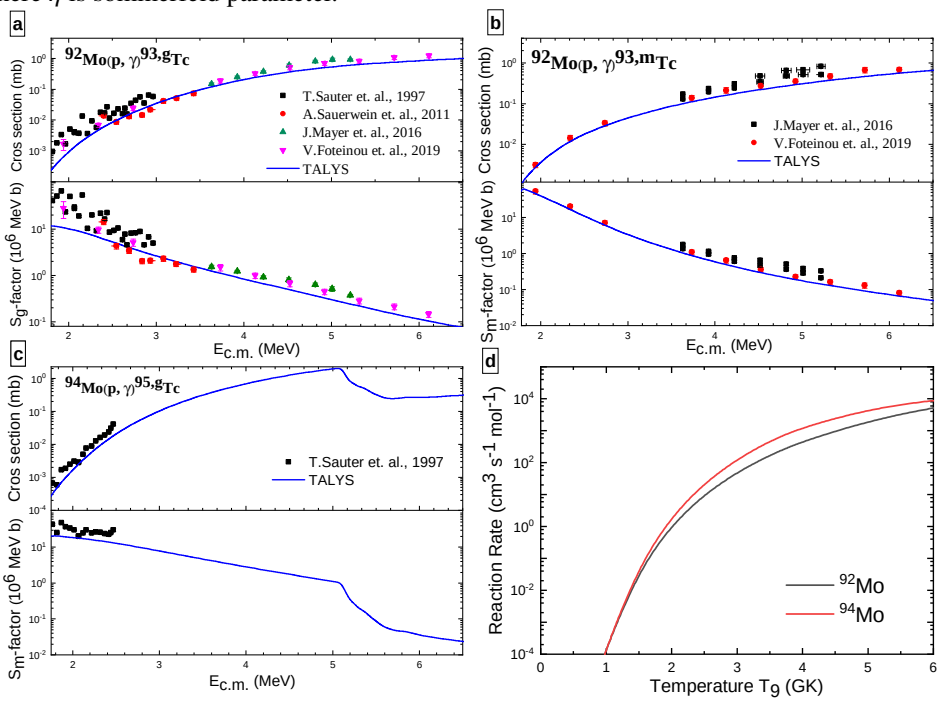

Figure 1. (Color Online) (a) Cross section and S factor for $^{92}Mo(p,\gamma)^{93,g}Tc$, (b) Cross section and S factor for $^{92}Mo(p,\gamma)^{93,m}Tc$, (c) Cross section and S factor for $^{94}Mo(p,\gamma)^{95,g}Tc$ and (d) Comparison of reaction rate for ^{92}Mo and ^{94}Mo.

The range of energies where the nuclear reactions occur in stars is given by the Gamow peak which is the overlap region of low energy tail of reaction cross section and the Maxwell Boltzmann distribution of the interaction particles. Gamow peak for $p+^{92}Mo$ at T = 2 GK is shown in the figure 2 - (a). The reaction rate was simulated for ^{92}Mo and ^{94}Mo using TALYS code. The comparison of reaction rate for ^{92}Mo and ^{94}Mo is shown in the figure 1 - (d).

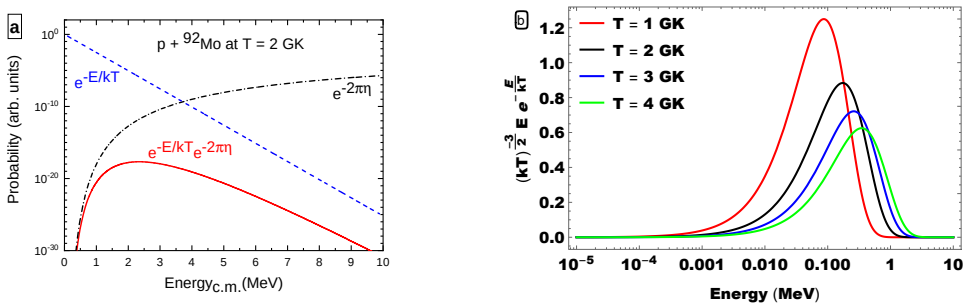

Figure 2. (Color Online) (a) Gamow window for p + ^{92}Mo at T = 2 GK and (b) Reaction rate equation parameters behaviour at different temperature.

Reaction rate equation has been studied and verified by using all the important parameters that is included in the equation. One such graph showing the variation of parameters at different temperature is shown in figure 2 - (b).

3 Summary and Conclusions

The cross section for the reactions $^{92}Mo(p,\gamma)^{93,g}Tc$, $^{92}Mo(p,\gamma)^{93,m}Tc$ and $^{94}Mo(p,\gamma)^{95,g}Tc$ has been simulated using TALYS and compared with the experimental results from the EXFOR data library, as shown in figure 1 - (a), (b) and (c) respectively. S factor with greatly reduced energy dependence is also shown with one to one correspondence to the cross section. Our theoretical predictions agree well with the experimental data. Moreover, there is no experimental cross section available for the $^{94}Mo(p,\gamma)^{95,g}Tc$ reaction in the EXFOR above 2.5 MeV as shown in figure 1 - (c), which reveals the scope of an experimental investigation. The reaction products are radioactive and the activation method [8] can be used to determine the cross section. Theoretical prediction or systematic approach [9] and indirect methods as well can be useful where reaction cross section is not directly possible to measure.

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