Measurement of Radiative Capture Cross Sections Relevant In Astrophysical Scenarios

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Introduction

Almost half of the nuclei heavier than iron are synthesized by the rapid (r-) neutron capture process. However, the astronomical site for this nucleosynthesis process has not been determined with certainty. The abundance pattern of r-process elements has been suggested to be independent of the metallicity of its progenitor stars [1]. This makes core-collapse supernovae one of the most likely astronomical sites for r-process nucleosynthesis. Additionally, neutron star merger observed by LIGO in 2017 [2] detected huge amounts of rare earth elements which could therefore also be a site for r-process nucleosynthesis.

The network study of [1] was centered on a neutrino-driven wind model for the supernova explosions with a very short dynamical expansion timescale of a few milliseconds. To validate their r-process model and to provide direct experimental information about neutron capture cross sections, we have determined the reaction rates for the reactions $^{28}\mathrm{Na}(n,\gamma)^{29}\mathrm{Na}$ and $^{29}\mathrm{Na}(n,\gamma)^{30}\mathrm{Na}$, which have been considered as seed nuclei in the low-mass region of their reaction network. The following section contains the experimental analysis. For the

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experimental setup see [3] and the references therein.

Experimental Analysis

Since the nuclei ^{28}Na and ^{29}Na are unstable, the method of Coulomb Dissociation (CD) have been utilized to study the time reversed reactions $^{29}\mathrm{Na}(\gamma,n)^{28}\mathrm{Na}$ and $^{30}\mathrm{Na}(\gamma,n)^{29}\mathrm{Na}$ in inverse kinematics. Our analysis follows the procedure given in [4, 5] wherein we have obtained the time reversed (γ,n) photoabsorption cross sections for different values of excitation energy E^* and then the corresponding (n,γ) capture cross sections have been found for different neutron energies E_n.

The nuclei ^{29}Na and ^{30}Na were made incident on ^{208}Pb target. The projectiles were excited to their unbound states by absorbing virtual photons from the Coulomb field generated due to their accelerated motion towards the target. The virtual photon numbers were used to find the photoabsorption cross sections from which the neutron capture cross sections were obtained via the detailed balance theorem [5].

$$\sigma_{E1}^{capture} = \frac{2(2j_{^{29,30}Na}+1)}{(2J_{^{28,29}Na}+1)(2J_n+1)}\frac{k_\gamma^2}{k^2}\sigma_{E1}^{photo}$$

where $k_\gamma = \frac{E^*}{\hbar c}$ and $k^2 = \frac{2\mu E_{rel}}{\hbar^2}$ with μ and E_{rel} being the reduced mass of and relative energy between ^{28,29}Na and neutron. From the neutron capture cross sections, the thermonuclear reaction rates were determined for both the nuclei. The variation of reaction rates for neutron captures on ^{28,29}Na as a function of r-process temperature T_9 have been shown in Fig. 1 and Fig. 2, where $T_9 = T$ in K/10^9. The measured reaction rates have been compared with the Hauser-Feshbach statistical model NON-SMOKER [6] calculation. It is observed that the measured capture reaction rates (solid line) are significantly less than the Hauser-Feshbach estimates (filled circles) for r-process temperatures $0.62 \leq T_9 \leq 2$ [1] for both the nuclei.

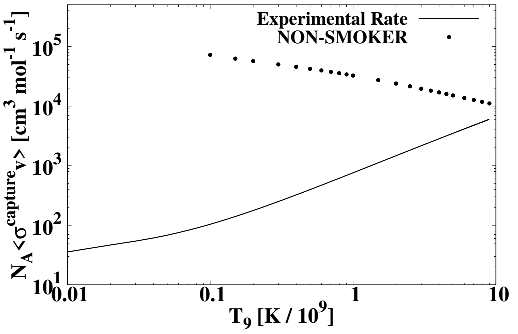

FIG. 1: Reaction rate for neutron capture on ^{28}Na in variation with r-process temperature T_9 (solid line) compared with Hauser-Feshbach model (filled circles).

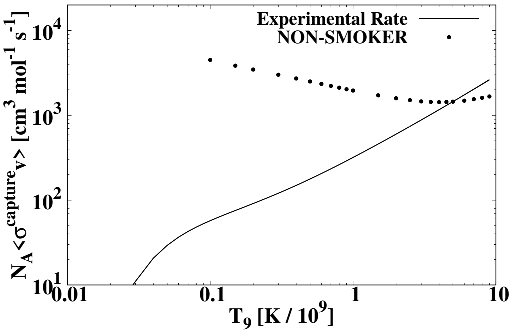

FIG. 2: Reaction rate for neutron capture on ^{29}Na in variation with r-process temperature T_9 (solid line) compared with Hauser-Feshbach model (filled circles).

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