Astrophysical (p, γ) reactions for $A = 55 - 60$

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Introduction

The rapid proton capture process or rp-process is one of the major nucleosynthesis processes that are responsible for the heavy element nucleosynthesis. It proceeds beyond iron through the proton rich side of the nucleosynthesis path. There are certain astrophysical sites, for example, X-ray bursters with a large proton flux in the peak temperature of 1 to 3 GK that can account for the elemental abundance of such heavily proton-rich nuclei not available on earth. As the experimental data are very scarce, theory remains the sole guide to predict various nuclear observables important in theoretical evaluation of p-process abundance distribution through a network calculation that involves thousands of reactions.

Methodology

We have calculated the proton capture cross sections for a number of nuclei in the mass region $A = 55 - 60$ using the computer package TALYS1.4 [1]. The reactions are important basically in the low energy range ~ 1 to 3 MeV, known as effective Gamow energy window for the temperature region 2-3 GK. The projectile energy being low, it can probe only the outermost part of the target, hence nuclear skin plays a significant role requiring good density information. We have extracted the nuclear density from the FSUGOLD relativistic mean field (RMF) Lagrangian density which contains coupling between nucleon and meson fields as well as coupling between mesons themselves. Two additional parameters involving meson-meson coupling enable the Lagrangian density to provide a better agreement of nuclear incompressibility to account for EOS of nuclear matter. Nuclear charge density is obtained from the point proton density considering finite size of the nucleus as $\rho(\mathbf{r}) = e \int \rho(\mathbf{r}\prime) g(\mathbf{r} - \mathbf{r}\prime) d\mathbf{r}\prime$, where, $g(r)$ is the Gaussian form factor. From charge density, rms charge radii are obtained and compared with measured values in table I to highlight the predictive power of this particular Lagrangian density.

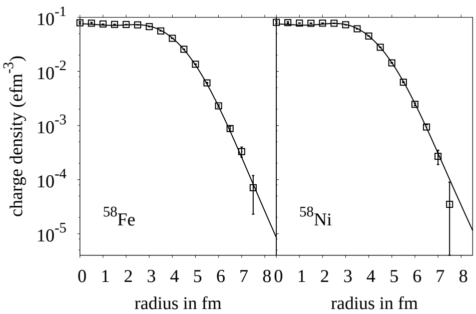

FIG. 1: Theoretical charge density profiles (solid lines) compared with experimental data (using electron scattering) plotted with errors taken from [2]. In most of the cases, especially at lower radii values the errors in the measurement are smaller than the dimensions of the data-points.

Because of rapid variation of cross-section in this low energy range, one usually compares the astrophysical s-factors given by the relation,

$$S(E) = E\sigma(E)e^{2\pi\eta}.$$

Here E is the energy in center of mass frame, σ is the cross section at energy E, and η is the Sommerfeld parameter given by, $\eta = 0.989534 Z_p Z_t \sqrt{\mu/E}$. We have employed a semi-microscopic approach using the density dependent M3Y Reid-Elliot effec-

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TABLE I: Charge radii of various nuclei extracted in the RMF approach compared with measured values. The experimental values are taken from Angeli et al. [3]

Element	Charge radius(fm)	
	Theory	Experiment.
^{56}Fe	3.7361	3.7377
^{58}Fe	3.7634	3.7745
^{58}Ni	3.7917	3.7757
^{60}Ni	3.8193	3.8118

tive nucleon-nucleon interaction within a folding model prescription supplemented by zero range pseudo potential $J_{00}(\epsilon)$ given by, $v(r, \rho, \epsilon) = t^{M3Y}(r, \epsilon)g(\rho, \epsilon)$ where, $t^{M3Y}{=}7999\frac{e^{-4r}}{4r} - 2134\frac{e^{-2.5r}}{2.5r} + J_{00}(\epsilon)\delta(r)$ & $J_{00}(\epsilon) = -276(1 - 0.005\epsilon/A)(MeVfm^3)$. The density dependence is incorporated in the factor $g(\rho, \epsilon){=}C(1 - \beta(\epsilon)\rho^{2/3})$ with C and β having their values assigned to be 2.07 and 1.624 fm^2 [4] respectively. We have taken Goriely's microscopic level densities and Hartree-Fock-Bogolyubov's E1 gamma ray strength functions. For nuclear masses, Goriely-HFB-Skyrme table is chosen. The Hauser-Feshbach calculation is done with full j, l coupling. The width fluctuation correction has also been taken care of. Maximum 30 discrete levels are considered for HF decay and γ ray cascade for target nuclei, residual nuclei and nuclei from binary emission.

Results

We have tried to set a single set of parameters for normalization of the optical potential depths that fits to all nuclei in the concerned mass region as our aim is finally to extend our calculation to proton-rich unstable nuclei. After a large number of trials to ensure a reasonable agreement with available experimental data, the normalization constants arrived at are 2.0 and 1.4 for real and imaginary parts of the potential, respectively. Fig.2 shows the plots of the s-factors in two cases. Our calculation for ^{58}Fe shows a good agreement with [5]. For ^{58}Ni our calculation overpredicts the data of [6, 7] while showing an average matching with [8]. Other nuclei also show similar agreement.

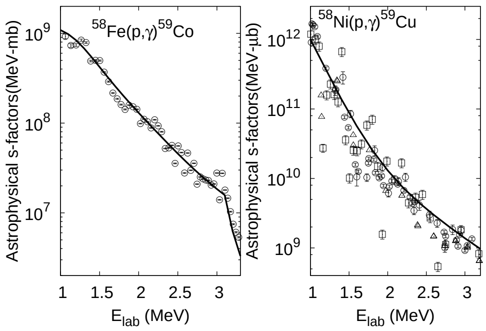

FIG. 2: Theoretical astrophysical s-factors as a function of projectile lab-energy compared with experiment for ^{58}Fe and ^{58}Ni. For ^{58}Fe the data are taken from [5]. For ^{58}Ni experimental data are from [6](circles), [7](triangles) and [8](squares).

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