Microscopic Study of $(\mathbf{p}, \gamma)$ Reactions in Mass Region $\mathbf{A = 110 - 125}$

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Introduction

Creation of heavy nuclei above iron occur mainly through three processes - slow and rapid neutron capture and proton capture (p). Though some studies have shown that p-process amounts to only 0.1% of the total abundance of nuclei heavier than iron, still there are nearly 35 elements on the neutron deficient side of valley of stability expected to be produced by the p-process. The p-process depend on (p, γ) and (γ, n) reactions, as well as on the seed nuclei. Various astrophysical sites produce these proton rich nuclei in spite of the high Coulomb barrier for the first reaction. One of them is X-Ray Burst with peak temperature 1-3 GK.

To calculate the actual abundance of different nuclei and evolution of the process, a network calculation is needed involving reaction rates for a large number of nuclei. Thus we need to know the interaction potential. As the p-process proceeds along proton rich side of the stability valley, it involves many nuclei which are unstable and inaccessible as targets on earth to do experiments. So theory remains the sole guide to gather information about the reactions. Presently, we are concerned about the nuclei in the mass region $A = 110 - 125$. It is imperative to test the theoretical calculations, where experimental data are available, to verify its applicability before extending it to unknown regions. Thus reactions for stable targets in the mass region have been studied in the present work.

Rauscher et al[1] have calculated the reaction rates for various proton, neutron and alpha induced reactions and their reverse reactions in Hausher-Feshbach formalism for targets with wide ranges of atomic numbers, masses and temperature in global approach. We use a more microscopic approach where the optical model potential has been obtained folding the nuclear density with a NN interaction. Nuclear densities are not available for unstable targets and theoretical densities are used to obtain the microscopic optical potential. Similar studies in the mass region $A = 60 - 100$[2, 3] have already been been carried out and our aim is to extend this process to the $A = 110 - 125$ region.

Methodology

Relativistic mean field (RMF), already seen to be very useful in explaining various nuclear properties[4, 5], has been used to obtain nuclear density to construct the nucleon-nucleus interaction potential. The FSU Gold Lagrangian density[6] and the density dependent M3Y (DDM3Y) NN interaction[7–9] has been used. The interaction is given by,

$$v(r, \rho, \epsilon) = t^{M3Y}(r, \epsilon) g(\rho, \epsilon) \quad (1)$$

where,

$$t^{M3Y} = 7999 \frac{e^{-4r}}{4r} - 2134 \frac{e^{-2.5r}}{2.5r} + J_{00}(\epsilon)\delta(r) \quad (2)$$

$J_{00}(\epsilon)$ is a pseudo-potential

$$J_{00}(\epsilon) = -276(1 - 0.005\epsilon/A)(MeV fm^3) \quad (3)$$

and

$$g(\rho, \epsilon) = C(1 - \beta(\epsilon)\rho^{2/3}) \quad (4)$$

Here, the constants C and β are assigned values 2.07 and 1.624 fm^2, respectively. A spin

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orbit potential has been added according to the Sheerbaum prescription [10]

$$U^{so}_{n(p)}(r) = (\lambda_{vso}+i\lambda_{wso})\frac{1}{r}\frac{d}{dr}(\frac{2}{3}\rho_{p(n)}+\frac{1}{3}\rho_n(p)) \quad (5)$$

where, λ_{vso} and λ_{wso} are complex potential depths functions of energy in MeV. With the help of computer code TALYS[11], where we incorporated the DDM3Y interaction, we carry out a Hausher-Feshbach calculation. It is important to note that we are using microscopic calculation to have a general parameters set, not for individual nuclei but for a wide mass range for (p, γ) reaction. We use HF microscopic level density and HFB E1 gamma strength. All these options are available in the TALYS code. Due to rapid variation of cross-sections with energy, we compare the experimental and calculated astrophysical S-factors

$$S(E) = E\sigma(E)e^{2\pi\eta} \quad (6)$$

with

$$\eta = 0.989534 Z_p Z_t \sqrt{\mu/E} \quad (7)$$

Here, η is the Somerfield parameter, E is the centre of mass energy, σ is the cross-section, Z_p, Z_t are the charges of projectile and target while μ is the reduced mass.

Results

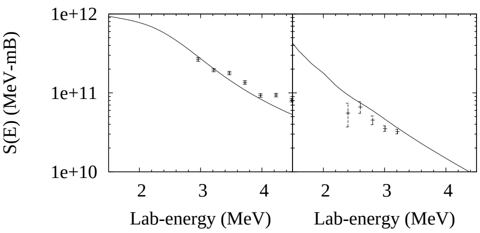

FIG. 1: Comparison between theoretical calculation and experimental S-factors for ^{112}Sn (left panel) and ^{123}Sb (right panel).

Within the narrow range of energy, 1.8 - 4.5 MeV, corresponding to the Gamow window important for astrophysical sites in this mass region, we investigate the (p, γ) reactions. Comparison of S-factors in some cases are shown in Fig. 1. We obtain the optical potential by multiplying the folded potential with normalization constants 0.9 for both the real and the imaginary parts. Experimental data have been taken from Refs. [12, 13] for ^{123}Sb and ^{112}Sn, respectively. The solid lines denote the theoretical results.

Acknowledgement

The authors acknowledge the financial support provided by DRS programme, UGC, DST and the University of Calcutta.

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