Review of Proton and Alpha Capture reaction cross-section of the p-Nucleus ^{106}Cd

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Introduction

In stellar environment, the dominant nucleosynthesis process for the elements with A≤ 60 is charged particle fusion reactions, above which neutron capture processes namely s- and r-process are the primary production mechanisms. There are about 35 proton rich nuclides between Se (Z=34) and Hg (Z=80) which are bypassed by either of these processes and are called the p-nuclei [1,2]. These are produced by γ-process or p-process consisting of proton radiative capture (p,γ) and photon induced particle (n,p,α) removal reactions in the hot environment. The most probable site for these processes is the pre-supernova or supernova phases [1,2].

The p-process evolves through a huge network of more than 20000 nuclear reactions involving almost 2000 isotopes between iron and bismuth. To provide reliable nuclear data for the astrophysical network calculations, the experiments have to be performed preferably at or close to the Gamow energy which being much below Coulomb barrier becomes extremely difficult. Hence, the inputs for network calculations are often obtained from whatever little experimental information is available. In recent years the theoretical cross-section values is being extensively used [3] from TENDL tabulation [4].

Present Work

^{106}Cd is one of the two p-nuclei in the chain of Cd isotopes, the other one being ^{108}Cd. It has a quite small solar abundance of 1.25%. The proton capture on ^{106}Cd leads to the final state nucleus ^{107}In which primarily decays to ^{107}Cd via β^+ and electron capture with a finite half life of 32.4 minutes. Similarly the alpha capture reaction leads to the nucleus ^{110}Sn which decays to ^{110}In with a half life of 4.154 hours via electron capture. The precise knowledge of these reaction rates is essential to the reliable prediction of the ^{106}Cd abundance in p-process modeling. The values of Coulomb Barrier (CB), Gamow Energy (E_G) and Q-values of these reactions are given in Table1.

Table1: E_{CB}, E_G and Q-values

System	E_{CB}	E_G	Q-value
^{106}Cd(p,γ)^{107}In	7.23	3.30	3.72
^{106}Cd(α,γ)^{110}Sn	14.43	8.35	1.13

The experimental [5-7] and theoretical [TENDL]

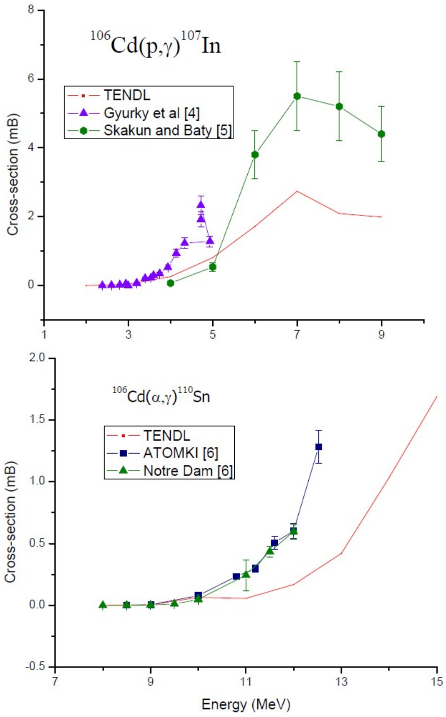

Fig. 1: Experimental and theoretical excitation energy plot

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excitation energy plots for the ^{106}Cd(p,γ)^{107}In and ^{106}Cd(α,γ)^{110}Sn reactions are given in figure 1. The figure shows that the cross-section values for both the proton and alpha capture reactions appear to be well reproduced by the TENDL values in the Gamow energy region, but is substantially underestimated at the higher energies.

Proposed Experiment

We plan to experimentally re-investigate these reactions using activation technique [8]. The existing accelerator facilities in India provide the alpha and proton beams with energy higher than Gamow energy. So we shall start with the lowest available energies and use stacked target [9] to stepwise degrade the energy to our desired values. The reaction cross sections will be derived from the yield of the detected γ-rays.

As evident from Fig.1 the desired cross-section values are extremely small and the isotopic proportion of ^{106}Cd being only 1.25% it is necessary to use enriched target to obtain reliable cross-section values. Initially we shall be using Natural Cd target as at present the enriched ^{106}Cd isotope is not readily available.

When Natural Cadmium target is bombarded with either proton or alpha beam they react with the different stable isotopes present in the target ($^{106,108,110\text{-}114,116}$Cd). A number of nuclei are produced having significant cross-sections. The most abundant final products are found to be various isotopes of Ag, Cd and In for the p+$^{\mathrm{Nat}}$Cd reaction [10], and Cd, In and Sn for the α+$^{\mathrm{Nat}}$Cd reaction [11]. We have estimated the cross-section of the ^{106}Cd(p,γ)^{107}In and ^{106}Cd(α,γ)^{110}Sn with respect to the total yield arising from all other comparatively stronger channels. It is found that both the proton and alpha capture cross-sections on ^{106}Cd are significantly small compared to the sum. A preliminary study shows that for the p+$^{\mathrm{Nat}}$Cd reaction some of the important channels may be ^{108}Cd(p,n)^{108}In (39.6m), ^{111}Cd(p,γ)^{108}In (39.6m and 58m) and ^{112}Cd(p,n)^{112}In or ^{111}Cd(p,γ)^{112}In (20.56m and 14.97m).

SRIM calculations are being performed to determine the suitable thickness of the different components of the stack. A preliminary calculation shows that the energy loss of 8 MeV proton beam is ~ 0.6 MeV in 25μm Cd target. A 35 MeV alpha beam suffers an energy loss of ~2.2 MeV in the same target.

Summary:

The present review work on the proton and alpha capture on the ^{106}Cd nucleus suggests that there is a scope of further experimental investigation of the cross-section values at both the Gamow energy region as well as the higher energy values for the proton and alpha capture reactions on different p-nuclei in this mass region. Further study is in progress and a more detailed report will be presented in the symposium.

Acknowledgements

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References

[1] E. M. Burbidge et al, Rev. Mod. Phys. 29 (1957) 547

[2] M. Arnould & S. Goriely, Phys. Rep. 384 (2003) 1

[3] Bo Mei et al, Phys. Rev C 92 (2015)035803

[4] A.J. Koning et al, NDS 155 (2019) 1

[5] Gy.Gyürky et al, J. Phys. G: Nucl. Part. Phys. **34** (2007) 817

[6] E.A.Skakun, V.G.Baty; Program and Thesis, Proc.41st Ann.Conf.Nucl.Spectrosc.Struct.At. Nuclei, Minsk, p.273 (1991)

[7] Gy.Gyürky et al, Phys. Rev. C74 (2006) 025805

[8] F. Tarkanyi et al, Nucl. Inst. Meth. Phys. Res. B 245 (2006) 379

[9] F. Ditrói et al, Applied Radiation and Isotopes 118 (2016) 266

[10] Erik Odeblad, Acta Radiologica, (1956) 396

[11] D. Banerjee et al, Phys. Rev. C 91 (2015) 024617 and references therein.