Chapter 47

Photoneutron Reaction Cross Section Measurements on ^{94}Mo and ^{90}Zr Relevant to the p -Process Nucleosynthesis

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Abstract The photodisintegration cross sections for the $^{94}\text{Mo}(\gamma, n)$ and $^{90}\text{Zr}(\gamma, n)$ reactions have been experimentally investigated with quasi-monochromatic photon beams at the High Intensity γ -ray Source (HI γ S) facility of Triangle Universities Nuclear Laboratory (TUNL). Energy dependence of the photoneutron reaction cross sections was measured with high precision close to the respective neutron emission thresholds and up to 13.5 meV. These measurements contribute to a broader investigation of nuclear reactions relevant to the understanding of the p -process nucleosynthesis. The results are compared with the predictions of Hauser-Feshbach statistical model calculations using different models for the γ -ray strength function. The resulting $^{94}\text{Mo}(\gamma, n)$ and $^{90}\text{Zr}(\gamma, n)$ photoneutron stellar reaction rates as a function of temperature in the typical range of interest for the p -process nucleosynthesis show how sensitive the photoneutron reaction rate can be to the experimental data in the vicinity of the neutron threshold.

47.1 Introduction

Despite the endemic problem of reproducing the solar abundances of $^{92,94}\text{Mo}$ and $^{96,98}\text{Ru}$ most abundant p -nuclei [1], as well as the part of the $A < 124$ region, recent studies performed by Travaglio et al. [2] in supernova Type Ia calculations using both deflagration and delayed detonation models demonstrated that both light and heavy p -nuclei, including the much debated isotopes ^{92}Mo and $^{96,98}\text{Ru}$, are produced

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with similar enhancement factors relative to solar abundances, provided an *s*-process enrichment of the progenitor is assumed. The model, however, predicts production of ^{94}Mo with a much lower abundance in comparison to all the other light *p*-nuclei. Another remarkable finding of [2] points out that the γ -process can make important contributions to the production of the neutron magic ^{90}Zr , previously known as genuine *s*-process nuclide.

In light of the intriguing findings of [2], we were motivated to investigate the photoneutron reactions on ^{94}Mo and ^{90}Zr . The measurements were focused on studying the energy dependence of the photoneutron reaction cross sections near the respective neutron emission thresholds and up to 13.5 MeV.

The experimental results are compared to the predictions of Hauser-Feshbach (HF) statistical model calculations using different models for the γ -ray strength function (γSF). They allow the γSF to be constrained by the present experimental data and are used to estimate the corresponding stellar photoneutron reaction rates which directly influence the *p*-process nucleosynthesis.

47.2 Experimental Setup

The measurements reported in this paper were performed using TUNL's High Intensity γ -ray Source (HI γ S) facility. A schematic not-to-scale drawing of the experimental setup as it was assembled for the present experiment is shown in Fig. 47.1.

The quasi-monoenergetic γ -ray beam had an energy width in the range of 4–5% (FWHM). The γ -ray beam flux was continuously monitored and yielded values in the range of 10^7 – 10^8 γ/s on target. The very high γ -ray flux available at HI γ S makes this

Fig. 47.1 Schematic drawing of the experimental setup in the HI γ S upstream target room (not to scale). See [3] for details of the detectors sketched in the figure

facility ideal for investigation of photoneutron reaction cross sections with p -nuclei as targets. In-depth experimental description is provided in [3].

47.3 Results

The photoneutron reaction cross sections of the present work are compared with theoretical calculations obtained with the TALYS nuclear reaction code and two different models of the γ SF, namely the Generalized Lorentzian (GLO) model and the axially-symmetric-deformed Hartree-Fock-Bogoliubov (HFB) plus QRPA model based on the DIM Gogny interaction, as illustrated in Fig. 47.2. Reference [3] provides details about these statistical models calculations.

In Fig. 47.3 are shown the resulting $^{90}\text{Zr}(\gamma,n)^{89}\text{Zr}$ and $^{94}\text{Mo}(\gamma,n)^{93}\text{Mo}$ stellar photoneutron rates as a function of the temperature in a typical range of interest for the p -process nucleosynthesis [1].

Fig. 47.2 Comparison between the present (γ,n) photoneutron reaction cross sections as a function of the γ -ray beam energy and previous data. Also included are the predictions obtained with the DIM + QRPA $E1$ and $M1$ strengths (solid line) and with the GLO model (dotted line)

Fig. 47.3 $^{90}\text{Zr}(\gamma,n)^{89}\text{Zr}$ and $^{94}\text{Mo}(\gamma,n)^{93}\text{Mo}$ stellar reaction rates, as a function of the temperature, obtained with the DIM + QRPA (solid lines) or the GLO (dotted lines) γ SF shown in Fig. 47.2

References

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