Measurement of the photon strength function in ^{115}In at the γELBE facility

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Abstract
The photon strength function (PSF) in ^{115}In is an important parameter for the estimate of the neutron capture cross section on ^{114}In in the field of astrophysics and nuclear engineering. Until now, the so-called PSF method for ^{115}In was applied only above the neutron-separation energy (Sn), and the evaluated ^{114}In (n,γ) cross section has uncertainties caused by the lack of the PSF below Sn. We studied the dipole strength distribution of ^{115}In with a photon-scattering experiment using bremsstrahlung produced by an electron beam of an energy of 10.3 MeV at the linear accelerator ELBE at HZDR.

1 Introduction

The nuclei heavier than iron are mainly produced via s-, r- or p- processes. The origin of p-nuclei is assumed from photodisintegration in the O/Ne layers of core-collapse of massive stars, of type I or II supernovae explosions, or/and s-, r- processes [1]. However, the production abundance of one of the p-nuclei, ^{115}Sn, still cannot be explained [2-3]. Recently, an s-process contribution is tried to explain the neutron capture reaction and β-decay at ^{113}Cd^{m} as competing reactions, i.e. ^{112}Cd (n, γ) ^{113}Cd^{m} (β-) ^{113}In (n, γ) ^{114}In (β-) ^{114}Sn (n, γ) ^{115}Sn [4] (see figure 1). γ-rays were measured following neutron captures on ^{112}Cd at the MLF in J-PARC and it was found that the s-process contribution from ^{113}Cd^{m} is not big enough to explain the production problem of ^{115}Sn. So, origin of ^{115}Sn is still open question.

In this study, we will shift the viewpoint to ^{115}In, which is produced via the main s-process. In the p- or/and r- process environment (T > 2 - 3 x10^{9} K), ^{115}In has 3 possible reactions such as

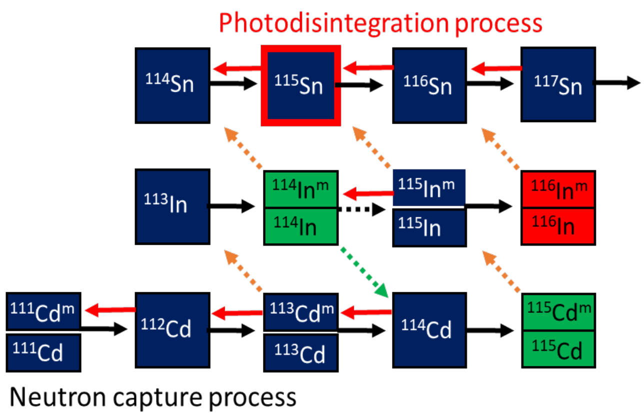

Figure 1. Nuclear reaction path to produce ^{115}Sn

photodisintegration, neutron capture and β-decay. While the effective β-decay rate for ^{115}In is the order of 10^{-5} s^{-1} at the temperature higher than 3 x10^9 K [5], the stellar reaction rate of photodisintegration of ^{115}In calculated using the TALYS code [6] is around 10^7 to 10^8 s^{-1} and the neutron-capture rate for ^{115}In is around 10^8 -10^7 s^{-1} at a temperature of 3.5 - 4.0 x 10^9 K, respectively.

In addition, the neutron capture rate of ^{114}In is around 10^8 s^{-1}. It means that the production process of ^{115}In (γ, n) ⇆ (n, γ) ^{114}In (β-) ^{114}Sn (γ, n) ⇆ (n, γ) ^{115}Sn may contribute to produce ^{115}Sn. This story is also mentioned shortly in Ref. [3]. However, both the photodisintegration rate for ^{115}In and the neutron capture rate for ^{114}In have not well been known experimentally, so they could not be discussed quantitatively.

From the view point of nuclear physics, photo-neutron cross sections have been measured above Sn [7-10]. However, precise measurements have not been performed (see figure 2). The PSF below Sn was measured using the Nuclear Resonance Fluorescence (NRF) in the energy range between 2-5 MeV at Darmstadt [11]. A photoactivation yield measurement on ^{115}In performed at the ELSA facility reported the possibility of an extra enhancement of the PSF in ^{115}In below Sn [12]. On the other hand, neutron capture cross sections for ^{114}In have not been measured because of the unstable isotope. A possible way to estimate cross sections for ^{114}In (n,γ) is to use the inverse-reaction method, which means the measurement of the PSF in ^{115}In below Sn. So, we propose to measure the PSF in ^{115}In below Sn using the NRF method at the γELBE facility.

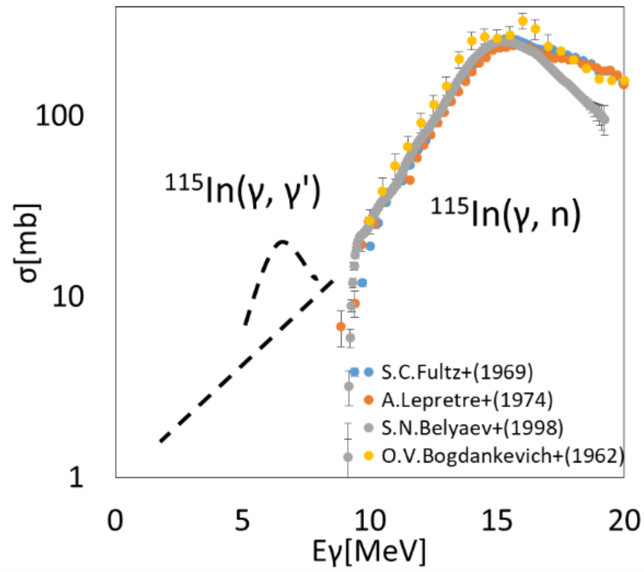

Figure 2. Current status of photoabsorption cross sections of ^{115}In.

2 Experimental methods and results

The photon-scattering cross section $\sigma_{\gamma f}(E_R)$ can be measured via the γ–ray transition from a given excited level E_R and deexcitation to a level E_f in the target. In case of non-overlapping resonances, photon scattering is described to process via a compound nucleus reaction with uncorrelated channels f characterized by the partial width Γ_f, so the photon-scattering cross section $\sigma_{\gamma f}(E_R)$ can be described as:

$$\sigma_{\gamma f}(E_R)=\sigma_\gamma(E_R)\frac{\Gamma_f}{\Gamma} \qquad (1)$$

Here, all partial widths contribute to the total level width $\Gamma=\Sigma\Gamma_f$.

$$I_S = \int_0^{\infty} \sigma_{\gamma\gamma}(E)dE = \frac{2J_R+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_R}\right)^2 \Gamma_0 \frac{\Gamma_f}{\Gamma} \qquad (2)$$

I_S is the integral over the scattering cross section for the level R and Γ_f is the partial width for a transition from R to a level f. The measured intensity of γ-rays emitted to the ground state at $E_\gamma=E_R$ at an angle θ can be expressed as,

$$I_\gamma(E_\gamma,\theta)=I_s(E_R)\Phi(E_R)\varepsilon(E_\gamma)N_{at}W(\theta)\frac{\Delta\Omega}{4\pi} \qquad (3)$$

Here, N_{at} is number of the target nuclei per area unit, $\varepsilon(E_\gamma)$ is the absolute full-energy peak efficiency at E_γ , $\Phi(E_R)$ is the absolute photon flux at E_R, $W(\theta)$ is the angular correlation of this transition, and ΔΩ is solid angle of the detector.

If the electron energy is high enough above a particular level, the experiments with bremsstrahlung lead to the possibility of the population of a level by a feeding transition from a higher-lying level. Such feeding increases the intensity of the transition to the ground state from the considered resonance R. The intensity of the transition to the ground state becomes a superposition of the rate of elastic scattering and the intensity of the transitions feeding level R. The cross-section integral I_{s+f} can be expressed as:

$$I_{s+f} = \int_0^{\infty} \sigma_{\gamma\gamma}(E)dE + \sum_{i>R} \sigma_{\gamma i}\frac{\Gamma_0}{\Gamma}dE$$
$$= \frac{2J_R+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_R}\right)^2 \frac{\Gamma_0^2}{\Gamma} + \sum_{i>R}\frac{\Phi(E_i)}{\Phi(E_R)}\frac{2J_i+1}{2J_0+1}\left(\frac{\pi\hbar c}{E_i}\right)^2 \Gamma_0^i\frac{\Gamma_R^i}{\Gamma^i}\frac{\Gamma_0}{\Gamma} \qquad (4)$$

Here, the summation over i>R means that the energy E_i of a level which feeds the considered resonance R is higher than the energy E_R of this resonance. Γ_i, Γ_{i0}, and Γ^i_R are the total widths of the level E_i, the partial width of the transition to the ground state and the partial width of the transition to the level R, respectively. Details of the experimental method are given in Refs. [13-20].

The photon-scattering cross section measurement on ^{115}In was performed at the superconducting electron accelerator ELBE of the Research Center Dresden - Rossendorf. Bremsstrahlung was produced by hitting 7 μm niobium radiator with an electron beam of 10.3 MeV electron kinetic energy and an average current of 490 μA. The produced bremsstrahlung was collimated by an Al collimator with a length of 2.6 m and an opening angle of 5 mrad. A cylindrical Al absorber of 10 cm length was placed between the radiator and the collimator to reduce the low-energy part of the bremsstrahlung spectrum. The scattered photons were measured with four 100% HPGe detectors surrounded by BGO escape-suppression shields. Two Ge detectors were placed at 90 degrees relative to the photon-beam direction. The other two HPGe detectors placed at 127 degrees were used to deduce angular distributions of the γ rays. To reduce the intensity of the low-energy part of background photons, absorbers of 3 mm Pb plus 3 mm Cu were placed in front of the detectors at 127 degrees and 8 mm Pb plus 3 mm Cu were used for the detectors at 90 degrees. The target consisted of 2376.4 mg of natural indium, formed into a disk of 2cm in diameter. The natural abundance of ^{115}In is 95.7%. The indium target was combined with a disk of 300.0 mg boron, enriched to 99.5 % in ^{11}B which was used to determine the photon flux. Spectra of scattered photons were measured for 118 hours.

The photoabsorption cross section data of ^{115}In obtained from the (γ,γ') experiment are shown in figure 3, together with cross sections deduced from (γ,n) experiments [8] and with the TLO model in

RIPL [21]. The ^{115}In (γ,γ') cross sections smoothly connect to the photoneutron data, and show extra enhanced resonances around 6 MeV and 9 MeV.

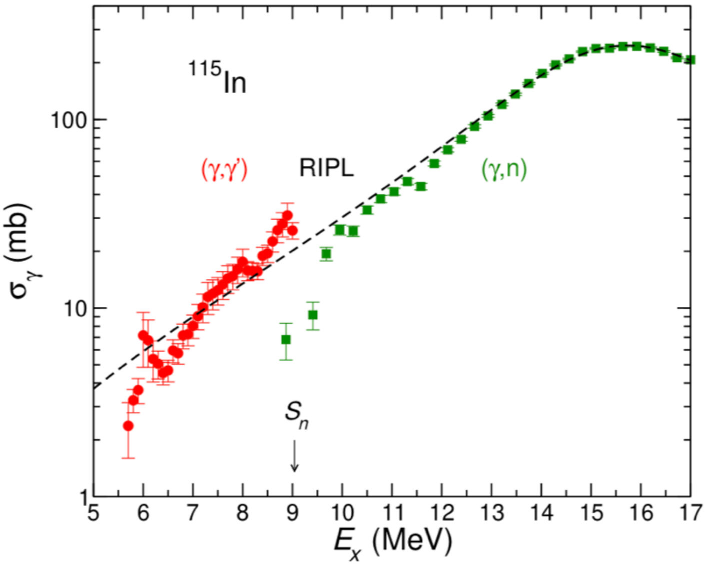

Figure 3. (Color online) Photoabsorption cross sections deduced from the present measurement (red circles) in comparison with (γ, n) data from Ref. [8] (green squares), and TLO [21] (black dashed curve).

3 Summary

The dipole-strength distribution in ^{115}In up to the neutron-separation energy has been studied in an NRF experiment at the ELBE accelerator using a kinetic electron energy of 10.3 MeV.
The ^{115}In (γ,γ') cross section smoothly connects with the experimental photoneutron data. Extra enhancement of the PSF in ^{115}In is also observed. A detailed analysis within nuclear models will be performed.

Acknowledgments

We thank the crew of the ELBE accelerator for the cooperation during the experiment. This work was supported by Helmholtz -Zentrum Dresden-Rossendorf and Hokkaido University.

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