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Photodisintegration of ^{80}Se as a probe of neutron capture for the s-process branch-point nucleus ^{79}Se

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Photoneutron cross sections were measured for ^{80}Se near the neutron separation energy with the laser Compton scattering γ rays. The stellar neutron capture rate for ^{79}Se was evaluated by using the photodisintegration data as constraints on the E1 γ strength function within the framework of the Hauser-Feshbach statistical model. The result is compared with the model calculation of Bao and Käppeler.

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1. Introduction

Abundances of the s-only nuclei, ^{80}Kr and ^{82}Kr, are sensitive to the s-process branching at ^{79}Se. Major fractions of these nuclei originate from the weak s-process which takes place in the core-helium burning of massive stars with a neutron source of the ^{22}Ne(α,n) reaction [1]. The stellar condition for the nucleosynthesis of the weak s-process component can be locally examined provided that a competition between β^- decay and neutron capture at ^{79}Se is highly sensitive to the stellar temperature and neutron density. The half life of ^{79}Se in the ground state is less than 65,000 years [3] and may be greater than the assumed value, 1,700 years [2]. In contrast to the long half life of the ground state, the first excited state of ^{79}Se at 96 keV, which is thermally populated in the stellar condition, undergoes β^- decay to ^{79}Br with the half life 7000 minutes[2]. As a result, the stellar β-decay rate is highly sensitive to temperature [2, 4]. On the other hand, the stellar neutron capture rate for ^{79}Se depends on both the neutron density n_n of the relevant steller site and neutron capture cross sections $\sigma_{n\gamma}$. Up until now, $\sigma_{n\gamma}$ has remained experimentally unknown though a direct measurement is planned at the CERN n-TOF facility in the future [5].

We have measured photoneutron cross sections ($\sigma_{\gamma n}$) for ^{80}Se to evaluate $\sigma_{n\gamma}$ for ^{79}Se within the framework of the Hauser-Feshbach model. In the model calculation, the experimental $\sigma_{\gamma n}$ is used as constraints on the low-energy E1 γ strength function for ^{80}Se. Uncertainties associated with the nuclear level density are taken into account. It is to be noted that the present $\sigma_{\gamma n}$ constitutes the basic nuclear data for nuclear transmutation of a long-lived fission product ^{79}Se.

2. Experiment

Beams of quasi-monochromatic γ rays were produced in the energy range of 9.98 - 11.80 MeV from laser Compton scattering (LCS) in the electron storage ring TERAS at AIST. The LCS γ-ray beams were used to irradiate a sample of 1003.3g ^{80}Se enriched to 99.95% that is encapsulated in an aluminum container. A Nd:YVO$_4$ Q-switch laser was operated at 20 kHz in the second harmonics (λ = 532 nm). The γ-ray beams had the same macroscopic time structure of 80 ms beam-on and 20 ms beam-off as that of the laser. The ^{80}Se sample was mounted at the center of a 4π-type neutron detector consisting of 20 ^{3}He counters embedded in a polyethylene moderator in a triple-ring configuration. Background neutrons were detected during the 20 ms beam-off. The neutron detection efficiency is more than 56% in the neutron energy range below 1 MeV. The so-called ring ratio technique [6] was used to determine the average neutron energies. The LCS γ beam was measured with a 120% high-purity germanium detector (HPGe). The energy distribution of the LCS beam was determined by a least-squares analysis of the response function of the HPGe detector. The LCS beam was monitored with a large volume (8" in diameter $\times$ 12" in length) NaI(Tl) detector. Pile-up spectra were used to determine the number of the incident LCS γ rays. Photoneutron cross sections were determined at the average γ-ray energies with the Taylor expansion method [7]. The systematic uncertainty for the cross section is 4.4% whose breakdown is 3.2% for the neutron detection efficiency and 3% for the number of incident γ rays.

3. Photoneutron cross sections for ^{80}Se

Results of the present photoneutron cross section measurement for ^{80}Se are shown in Fig. 1.

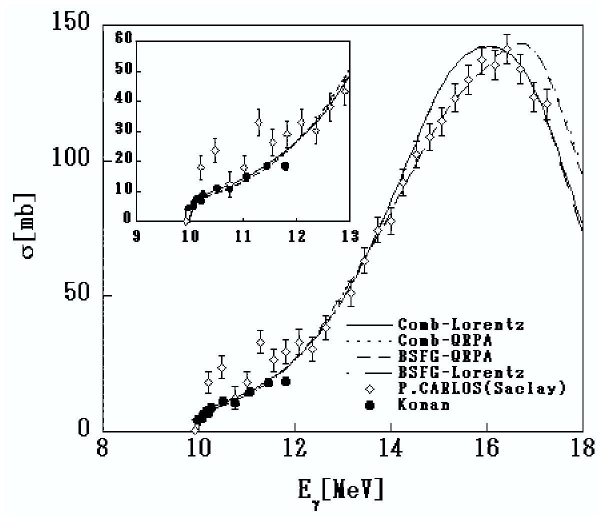

Figure 1: The present result of photoneutron cross sections for ^{80}Se near the neutron threshold. For comparison, the data of Carlos *et al.* [10] taken with the positron annihilation γ rays are shown.

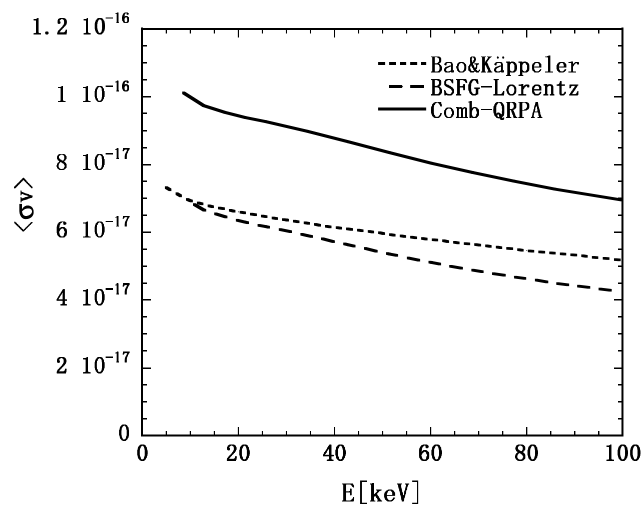

Figure 2: Stellar neutron capture rates for ^{79}Se evaluated within the framework of the Hauser-Feshbach model by using the present photoneutron cross section for ^{80}Se as constraints on the E1 γ strength function.

One can see that the present $\sigma_{\gamma n}$ are significantly smaller than those of the previous measurements near the neutron threshold. Hauser-Feshbach model calculations were carried out based on different ingredients of model parameters: Lorentzian [8] and QRPA [9] models for the E1 γ strength function and back-shifted Fermi gas (BSFG) and combinatorial models[11, 12] for the nuclear level density. Two calculations with the Lorentz - BSFG and the combinatorial - QRPA model parameters satisfactorily reproduce the present cross sections near the neutron threshold.

4. Stellar neutron capture rates for ^{79}Se

Neutron capture cross sections were evaluated for ^{79}Se by using the same ingredients of the model parameters that were found for the present cross section for $^{80}\mathrm{Se}(\gamma,n)^{79}\mathrm{Se}$. Fig. 2 shows $< \sigma_{n\gamma} v >$ as a function of the stellar temperature in units of keV. The result with the BSFG-Lorentz model parameters is similar to that of Bao and Käppeler [13], whereas the reaction rate is enhanced with the combinatorial-QRPA model parameters. The difference in the two model calculations stems from their different behaviors of the E1 γ strength function below the neutron separation energy and the nuclear level density. Implications of the present reaction rates for the stellar condition for the weak s-process component will be investigated in the future.

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