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Dipole strength in ^{80}Se below the neutron-separation energy for the nuclear transmutation of ^{79}Se

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Abstract. The γ-ray strength function (γSF) in ^{80}Se is an important parameter to estimate the neutron-capture cross section of ^{79}Se which is one of the long-lived fission products (LLFPs). Until now, the γSF method was applied for ^{80}Se only above the neutron-separation energy (S_n) and the evaluated ^{79}Se(n,γ) cross section has an instability caused by the GSF below S_n. We studied the dipole-strength distribution of ^{80}Se in a photon-scattering experiment using bremsstrahlung produced by an electron beam of an energy of 11.5 MeV at the linear accelerator ELBE at HZDR. The present photoabsorption cross section of ^{80}Se was combined with results of (γ,n) experiments and are compared with predictions usinmg the TALYS code. We also estimated the ^{79}Se(n,γ) cross sections and compare them with TALYS predictionms and earlier work by other groups.

1. Introduction

The γ-ray strength function (γSF) is an important parameter for the estimate of cross sections of photonuclear reactions and their inverse reactions for nuclear applications, such as nuclear medicine and nuclear engineering. In the past half century, the giant dipole resonance (GDR) has been investigated both, experimentally and theoretically via photonuclear reactions, by many researchers [1–11]. Recently, the behavior of the low-energy tail of the GDR below the neutron-separation energy (S_n) is paid attention for the nuclear application, because it strongly affects the estimate of neutron-capture cross sections. From the viewpoint of nuclear engineering, the capture cross section of ^{79}Se is important for the development of transmutation techniques for long-lived fission products (LLFPs). Because of the radioactive properties of ^{79}Se, the direct measurement is difficult [12–17]. To predict the ^{79}Se(n,γ) cross section, the dipole strength of ^{80}Se was measured using the (γ, γ') reaction at the bremsstrahlung facility γELBE at the Helmholtz-Zentrum Dresden-Rossendorf.

2. Experiment

The photoabsorption cross section of ^{80}Se was studied at the bremsstrahlung facility γELBE. Bremsstrahlung was produced by an electron beam of kinetic energy of E_e = 11.5 MeV with an average beam current of about 710 μA. The bremsstrahlung was produced by hitting a niobium foil of 7 μm thickness. The photon beam, collimated by a 2.6 m long aluminum collimator of 8 mm diameter at the entrance and 24 mm at the exit, has a flux of about 10^9 s^{-1} within 38 mm diameter at the target position. Scattered photons were measured with three HPGe detectors with efficiencies of about 100% relative to a NaI detector of 7.6 cm diameter and 7.6 cm length. All HPGe detectors were surrounded by escape-suppression shields of BGO detectors. One HPGe detector was placed horizontally at 90 degrees and the other two HPGe detectors were placed vertically at 127 degrees to the beam. The distance between the detectors and the ^{80}Se sample was 32 cm. The absolute photon flux was determined from intensities and known integrated scattering cross sections of five transitions in ^{11}B. The ^{80}Se sample had a mass of 1952.9 mg, was formed to a disk of 2 cm in diameter, and enriched to 99.9% in ^{80}Se. To obtain the integral scattering cross sections, the relative efficiencies of the detectors and the relative photon flux were determined by using GEANT4. For the determination of the absolute efficiencies of the HPGe detectors, we used ^{137}Cs, ^{154}Eu, and ^{226}Ra sources. To determine the scattering cross sections, the experimental spectrum was corrected for the detector response and absolute efficiency. To obtain the correct dipole strength distribution, inelastic transitions were subtracted from the spectrum and the ground-state transitions were corrected for their branching ratios b_0. In this study, we used the code γDEX [5,8,11], which uses statistical methods in analogy to the code DICEBOX [21], to calculate the intensities of branching transitions to low-lying excited levels and the branching ratios of

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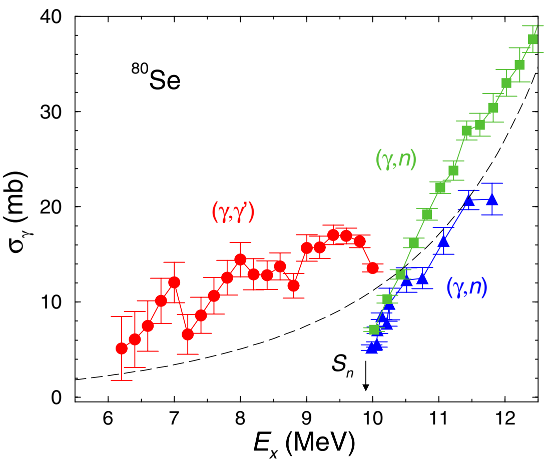

Figure 1. Photoabsorption cross sections for ^{80}Se (red circles) as a function of excitation energy. The present results smoothly connect to (γ,n) data taken from Ref. [15] (blue triangles) and Ref. [22] (green squares).

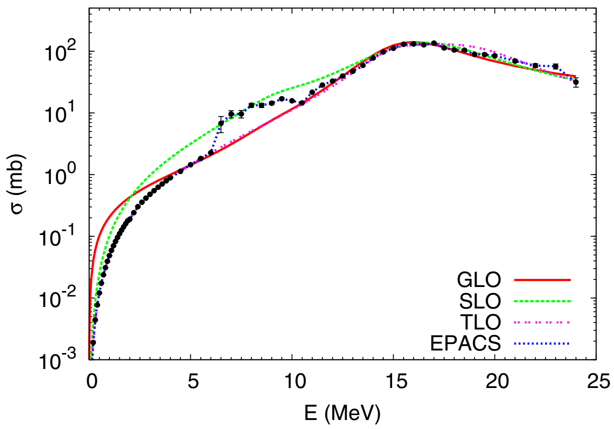

Figure 2. ^{80}Se photoabsorption cross sections as a function of excitation energy calculated using the code TALYS with various models for the input strength function.

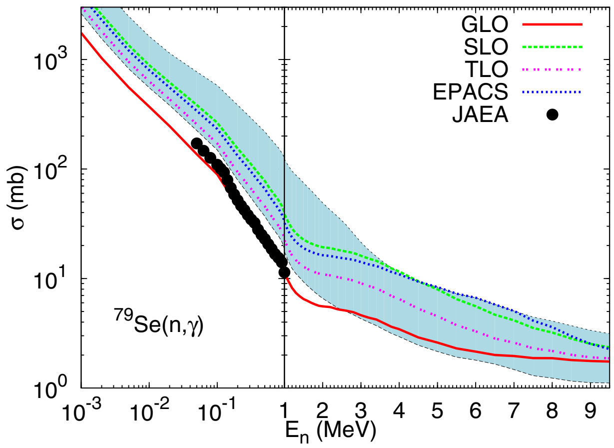

Figure 3. ^{79}Se neutron-capture cross sections as a function of neutron energy calculated using the code TALYS with various models for the input strength function. The uncertainties are shown a blue band which reflects the effect of various level density models. The earlier work in Ref. [17] is shown as black dot (JAEA).

the ground-state transitions. A detailed experimental description is reported elsewhere [18, 19].

3. Results

Figure 1 shows the photoabsorption cross section of ^{80}Se together with the photoneutron cross section taken from Refs. [15, 22]. The present cross sections below the neutron threshold smoothly connect to the (γ,n) cross sections. The present cross sections show three bumps at about 7, 8 and 9.5 MeV. To evaluate the neutron-capture cross section, an experimental photoabsorption cross section (EPACS) was constructed on the basis of the following components. i) $0 \leq E_\gamma \leq 6.2$ MeV: The TLO model is taken, because there is no experimental data in this energy region. ii) 6.2 MeV $\leq E_\gamma \leq$ 10.0 MeV: The photoabsorption cross section deduced from the present (γ, γ') experiment is used. At 10 MeV, the values from the (γ, γ') and (γ, n) channels were added to obtain the total absorption cross section. iii) $E_\gamma > 10.0$ MeV: The (γ, n) cross section taken from Ref. [22] is taken.

The result of EPACS was used as an input for the statistical calculation using TALYS [23] to estimate the neutron-capture reaction of ^{79}Se. For the nuclear level density we used the constant-temperature model. Figures 2 and 3 show the comparison of the present results with the standard Lorentz model (SLO), the generalized Lorentz model (GLO), and the TLO model. The uncertainties of cross sections from possible model selections of the nuclear level density in TALYS are shown as a blue band. The visible enhancement of γSF using EPACS results in a by about 55–98% larger neutron-capture cross section between 1 keV and 1 MeV compared with the TLO model. On the other hand, the GLO model usually leads to a lower neutron cross section than the other models. The present results are also compared with the earlier work [17]. In that work, the neutron capture cross section of ^{79}Se based on a γSF adjusted to photo neutron cross section of ^{80}Se data is lower than the present EPACS-based data by a factor of about three. A more quantitative discussion of the reason for this differences requires the knowledge of the γSF at energies below the neutron threshold, and the used level densities.

4. Summary

The photoapsorption cross section of ^{80}Se below the neutron-separation energy has been studied at the ELBE using maximum bremsstrahlung energy with 11.5 MeV. The measured γ-ray spectrum was corrected for the detector response and atomic background. The corrected γ-ray spectrum was used to estimate the photoabsorption cross sections of ^{80}Se using the γ-ray cascade simulations performed with the code γDEX. The γ-ray strength function obtained in this way was used as an input of the code TALYS to estimate the neutron-capture cross section of ^{79}Se. The present calculations have still uncertainties caused by model parameters such as level density and optical potential parameters.

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