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Photon strength functions in ^{177}Lu: Study of scissors resonance in high-spin region

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Abstract. The nucleus ^{177}Lu is characteristic by an unusually high value of the thermal-neutron capturing state spin, $J = 13/2$, and by distinct low-energy rotational bands built on the $7/2^+$ ground state and the $9/2^-$ level at 150 keV. The γ cascades connecting the capturing state with the members of these bands carry unique information about the role of identical $M1$ scissors-mode resonances, built according to Brink hypothesis assumingly on each energy level, even in conditions of fast nuclear rotation. With this motivation we measured a set of spectra of two-step γ cascades following the thermal neutron capture in ^{176}Lu. The measurement was performed at neutron beam of the LWR-15 Reactor in Řež. From the analysis of these spectra the common parameters of the scissors resonances were deduced. The obtained results are discussed.

1 Introduction

Photon strength functions (PSF) are essential quantities for the statistical description of γ decay of highly-excited nuclear levels. During the last decades considerable efforts were devoted to deeper understanding of the behavior of PSFs at γ-ray energies below the neutron threshold. Several new phenomena in statistical γ decays were observed and, in part, understood, e.g. the occurrence of scissors-mode (SM) in $M1$ PSF. However, many questions are still open.

The method of two-step cascades (TSCs) proved to be a powerful tool for studying PSFs. Here we report the results on PSFs obtained from analysis of spectra of TSCs following the thermal neutron capture in ^{176}Lu. The spin and parity $J^\pi = 13/2^-$ of the neutron capturing state enabled us to investigate the SM coupled to excited levels with high spin in strongly deformed nucleus ^{177}Lu.

2 Experiment and data analysis

The ^{176}Lu(n,γ)^{177}Lu measurement was performed using the HPGe $\gamma-\gamma$ coincidence setup installed at the LWR-15 research reactor in Řež [1]. A 2 g sample of natural Lu was exposed to a neutron flux of 3×10^6 cm^{-2}s^{-1}. The spectrum of γ-ray energy sums is shown in Fig. 1. The spectra of TSCs, in particular the ones populating the 9/2, 11/2 and 13/2 members of ^{177}Lu low-lying rotational bands with opposite parities, $7/2^+$[404] and $9/2^-$[514], were reconstructed from the coincidence data and were subject of the main analysis.

To interpret our data in terms of PSFs, many independent simulations of TSC spectra were performed using the DICEBOX algorithm [2] under various model assumptions about the shape and size of $E1$, $M1$ and $E2$ PSFs. This algorithm embodies the basic postulates of the extreme statistical model, takes into account the existing data on the level system of ^{177}Lu and reflects all specificities of the experiment, in particular roles of $\gamma-\gamma$ angular correlation and parasitic veto effects. Simulated TSC spectra were compared with their experimental counterparts.

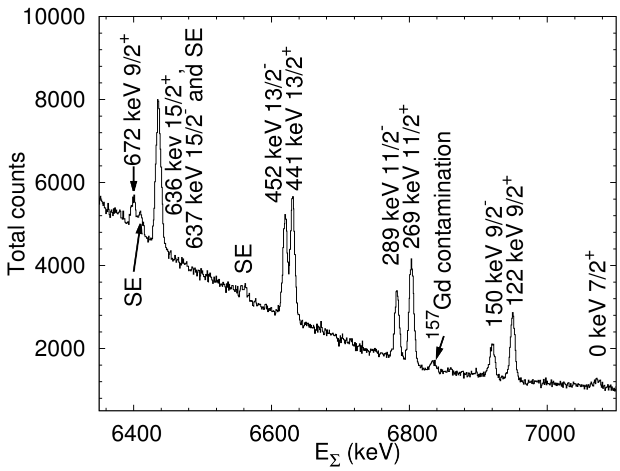

Figure 1. Spectrum of γ-ray energy sums from neutron capture in ^{176}Lu. Energies and values of J^π of all ^{177}Lu levels populated from neutron capturing state via TSCs are shown.

3 Results and conclusions

From the comparison between experimental and simulated TSC spectra, shown in Fig. 2, it follows that with-

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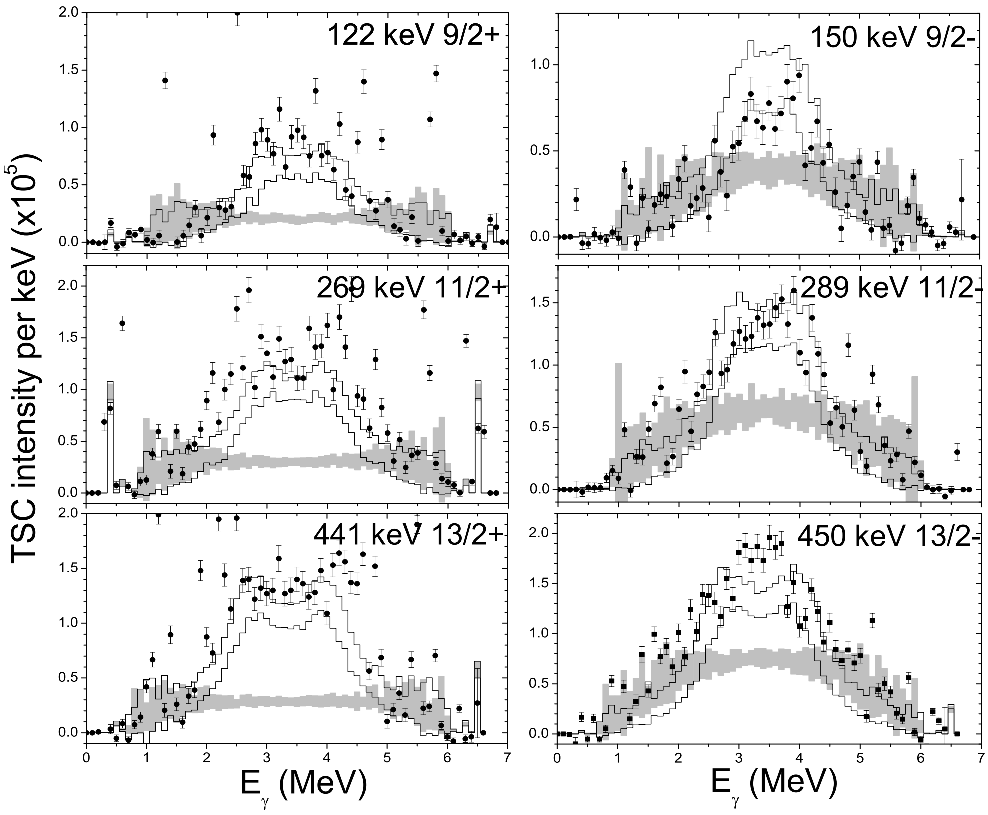

Figure 2. Comparison between the data and simulations. Points with error bars – experimental TSC spectra; the gray areas – predictions of TSC spectra based on validity of Kadmenskij-Markushev-Furman (KMF) model for E1 PSF, spin-flip (SF) model for $M1$ PSF and the giant quadrupole electric (GQE) model for E2 PSF; the regions between solid lines – predictions when contribution of scissors mode with parameters $E_{SM} = 4.0$ MeV, $\Gamma_{SM} = 1.0$ MeV and $\sum B(M1)\uparrow = 24.5\,\mu_N^2$ is added to the $M1$ PSF. Corridors of simulated TSC intensities represent the Porter-Thomas uncertainties.

out adding the SM contribution to the $M1$ PSF a set of widely used models for $E1$, $M1$ and $E2$ photon strengths alone, specifically the KMF, SP and GQE respectivelly, cannot provide a satisfactory agreement between the data and simulations. We arrived at the same conclusion with other alternative choices of the convetional models [3].

In our simplified interpretation the SM, expressed as a broad bump in the mid of TSC spectra, is responsible for a significant or even dominating part of the total strength of the TSC spectra. Further, we found that this bump cannot be attributed to any additional resonance-like component of the $E1$ or $E2$ photon strength. A strong role of SM in the cascade γ decay of neutron capturing state of ^{177}Lu is beyond any doubt.

The best description of the TSC spectra was achieved by assuming a common scissors resonance with parameters $E_{SM} = 4.0$ MeV, $\Gamma_{SM} = 1.0$ MeV and $\sum B(M1)\uparrow = 24.5\,\mu_N^2$. It is evident that the values of energy and total reduced $M1$ strength are extremely high compared to what has been found for a large number of odd deformed rare-earth nuclei from previous experiments [4–6]. At the same time the agreement between the experimental and simulated TSC spectra is far from being ideal.

Furthermore, the experimental spectra for positive parity final states exhibit large fluctuations of TSC intensities, which may reflect the persisting colectivity of the levels in quasicontinuum. In view of the magnitude of these fluctuations it is unlikely to achieve an acceptable agreement between the measured and predicted TSC spectra, even when the SM contribution to the $M1$ PSF is postulated as a function of quantum numbers J and K and/or excitation energy.

Both these very interesting phenomena are planned to be further investigated.

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