Nuclear level densities and gamma-ray strength functions in samarium isotopes

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The spectroscopic properties of excited nuclei provide information on the internal structure of these highly dense, many-body quantum systems. Low-energy excitation regime is treated differently compared to the high- energy quasi-continuum region. In the latter, the quantities such as discrete energy levels are replaced by nuclear level densities (NLD) and transition probabilities are defined as γ-ray strength functions (γSF) which are aver- age reduced radiation or absorption probabilities at any given photon energy E_γ. Both of these observables also form important inputs for Hauser-Feshbach calculations predicting the astrophysical neutron capture rates. Therefore, a comprehensive understanding of NLD and γSF is required for an insight on the astrophysical processes driving the synthesis of nuclei in our universe.

The NLDs are often described by phenomenological analytical formulas built on the first principles of the Fermi gas model. In order to explain the shape of the γSF, phenomena such as giant electric dipole resonances are commonly adopted to fit the enhanced dipole transition probability at energies around 12-17 MeV. A relatively recent observation of the strength enhancement in the energy range below 3-4 MeV shows two features in the γSF: an enhancement at low energies, *upbend*, and a bump around 3-4 MeV corresponding to the scissors mode in deformed nuclei. While the strength of the *upbend* and the scissors mode is a small contribution to the γSF, it has a significant impact on capture and photodissociation reaction rates. TALYS calculations shown in Ref. [1] highlight the profound effect of the observed low-energy strength enhancement on the neutron capture rates. An increase of 3 orders of magnitude in the rates is predicted for Sm iso- topes lying at the neutron drip line provided a similar enhancement exists in that region. Measuring the γSF in nuclei close to the neutron drip line is still a far-fetched goal, however a systematic study of the evolution of low-energy *upbend* in stable members of an isotopic chain is required to have a clear picture of the conclusions made in Ref. [2] and to further extrapolate the properties of the γSF to the less explored neutron-rich regions. In this paper, the systematic study of the evolution of the γSF at low energies was extended to ^{147,149}Sm nuclei which are closer to the $N = 82$ shell.

The experiment was performed at the Cyclotron Institute of Texas A&M University, where two 98(1)% isotopically enriched samarium targets, ^{148}Sm and ^{150}Sm, 0.8 mg/cm^2 and 1.1 mg/cm^2 thick, respectively, were bombarded by a 1.0 nA of 28 MeV proton beam from the K- 150 cyclotron. The reaction products were detected by the Hyperion array [3] that consists of 12 HPGe Clover- type γ-ray detectors combined with ΔE-E STARS telescope for charged particle identification and energy measurement. The telescope comprised two segmented silicon detectors, 140 μm (ΔE) and 1000 μm (E) thick. Each of the detectors was a disk, 72 mm in diameter, with a 22 mm in diameter opening for the beam in the center. The disk was divided into 24 concentric 1 mm wide rings and into 8 segments in the angular direction. The ΔE-E system was placed 18 mm behind the target, providing an angular coverage for particle detection of 30-58 degrees. The design of the telescope allowed for identification of the light ion charged particle reaction products (protons, deuterons and tritons) and an energy resolution of 130 keV FWHM for detected deuterons. The clover γ-ray detectors were positioned approximately 21 cm from the target at 45, 90, and 135 degrees with respect to the incident beam axis. Using standard γ-ray calibration sources, an energy resolution of 2.6 keV and 3.5 keV FWHM was obtained at 122 keV and 963 keV, respectively. The absolute photopeak efficiency of the Clover array was measured to be 10% at 130 keV [3]. Only the γ rays coincident with a particle were recorded, which provided data required to build the particle-γ matrices for the Oslo method.

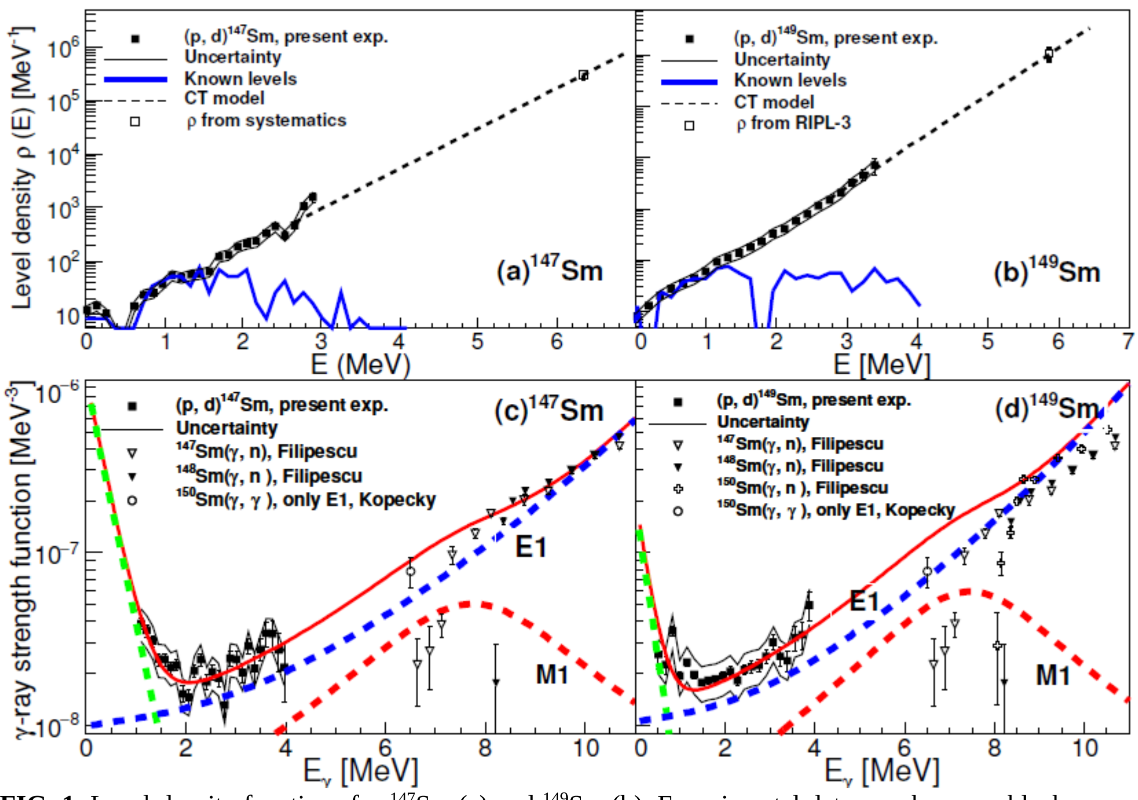

FIG. 1. Level-density functions for ^{147}Sm (a) and ^{149}Sm (b). Experimental data are shown as black squares. The dashed line corresponds to the constant-temperature approximation extrapolating to (S_n) (open squares). The solid line is the known level density in the low-energy discrete region. Experimentally deduced -ray strength functions are shown in (c) and (d). For comparison, the analytical approximations for the E1 strength (blue dashed lines) and M1 strength (red dashed lines) as well as their sums (red solid lines) are shown.

Level densities and γ-ray strength functions were extracted from particle-γ coincidence data for ^{147,149}Sm nuclei using the Oslo method is shown in Fig. 1. As in the previous study of the Sm nuclei, the low-energy upbend in the γSF has been observed at energies below 2 MeV. No structure that could be attributed to the scissors mode has been observed, which is consistent with the lack of deformation of the studied nuclei. The results of this work are consistent with the previous measurements of the statistical properties of the Sm nuclei [1]. Moreover, the total M1 strength in the γ-ray energy range of 0-5 MeV remains fairly constant across the isotopic chain as it was predicted by Schwengner et al [2]. Shell model calculations for the lowest 60 levels for spin 1/2 - 13/2 were carried out, which reproduce the gross structure of the experimental level densities (exponential increase with excitation energy) and of the γ-ray strength functions (development of a minimum at a transition energy of about MeV caused by the emergence of a scissors resonance with the onset of deformation).

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