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Investigating the strength of the scissors mode in ^{151}Sm

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Abstract.
Change in nuclei deformation leads to changes in statistical properties such as the nuclear level density (NLD) and γ-ray strength function (γSF). The NLD and γSF of ^{151}Sm were extracted using the Oslo method. The strength of the scissors resonance (SR) and its centroid energy for ^{151}Sm were found to be 2.13 ± 0.60 μ_N^2 and 2.48 ± 0.25 MeV, respectively. These results were used to place the SR of ^{151}Sm and its magnetic dipole strength $B(M1)_{SR}$ into the context of previously measured Sm isotopes.

1. Introduction

When the nucleus is excited, one or more of its particles moves to higher energy levels, and upon de-excitation, a nucleon or γ-ray is released, sometimes both. The γ-rays emitted can be measured individually if they have been emitted from discrete levels. In the continuum region, the spacing between the levels is decreased such that levels cannot be resolved and studied individually. The NLD exhibits the number of levels per energy bin or per unit excitation energy. The γSF expresses the average strength of γ-ray decay from high excitation energies to lower levels and is directly proportional to the transition probability, and it can be used to study resonances.

The SR is characterised by strong M1 transitions and the strength of the SR, $B(M1)_{SR}$ is proportional to the square of the ground-state deformation parameter [1]. Initially, even-even nuclei were considered the best candidates for exhibiting well-developed SR modes. It soon became apparent that this mode is also found in even-odd and odd-odd systems, even though its intensity might be significantly fragmented making it difficult to detect [2, 3]. The SR is usually observed in the γ energy range of 2 - 4 MeV in rare earth nuclei [4, 5]. In this work, the reaction ^{152}Sm(d,tγ)^{151}Sm was used to investigate the γSF, NLD and $B(M1)_{SR}$ in ^{151}Sm.

2. Experimental details

The experiment was conducted at the Oslo Cyclotron Laboratory, where a self-supporting ^{152}Sm target was impinged with a pulsed deuteron beam of 13.5 MeV at an average intensity of 0.2 nA. The target had a thickness of 2.9 mg/cm^2 and was 98.27% enriched. The $^{152}\mathrm{Sm}(d,t\gamma)^{151}\mathrm{Sm}$ reactions populated the residual nucleus. The data were collected for approximately 5 days (120 hours) including calibration runs on a ^{28}Si target.

The silicon particle telescope (SiRi) [6] was used to identify particles in coincidence with γ-rays detected by CACTUS [7], which is an array of 26 5in.×5in. NaI(Tl) scintillation detectors. The SiRi array consists of 8 silicon detector chips, with each chip segmented into 8 strips. This amounts to 64 ΔE-E silicon detectors that were placed at backward scattering angles between 126° to 140°. The detector chips have thicknesses of 130 μm for the front and 1500 μm for the back detectors, respectively. A 10 μm thick aluminium foil was placed in front of the detector to shield it from electrons emitted during the reaction. The energy resolution of SiRi was 120 keV at FWHM. The array covers a solid angle of 16 - 17 % of 4π. CACTUS has a total efficiency of $\approx$ 14.1 % and an energy resolution of $\approx$ 7 % FWHM for a 1332 keV γ -ray transition. To suppress X-rays a 2 mm thick copper absorber is placed in front of each NaI(Tl). To avoid crosstalk between detectors, a 3 mm thick lead shield was used around each NaI(Tl) detector.

3. Data analysis and Discussion

The data were analysed using the Oslo method [8, 10], a technique used to simultaneously extract the NLD and γSF. The starting point of the Oslo method is the raw particle-γ coincidence matrix, which is then unfolded [11] using the detector's response function. The unfolded matrix undergoes the first generation iterative procedure [12], resulting in the primary γ-ray matrix, P(E$_x$, E$_\gamma$). The NLD and γSF are extracted from the first generation coincidence P(E$_x$, E$_\gamma$) matrix using the ansatz [13, 14]:

$$P(E_x, E_\gamma) \propto \rho(E_x - E_\gamma)\mathcal{T}(E_\gamma), \tag{1}$$

where $\rho(E_x - E_\gamma)$ is the nuclear level density at the final levels and $\mathcal{T}(E_\gamma)$ is the γ-ray transmission coefficient which is dependent only on the γ-ray energy assuming validity of the generalised Brink-Axel hypothesis [15, 16]. To improve the extraction of $\rho(E_x - E_\gamma)$ and $\mathcal{T}(E_\gamma)$, a χ^2 minimization is performed between the experimental $P(E_i, E_\gamma)$ and theoretical $P_{th}(E_i, E_\gamma)$ [8] first generation matrices. Since the iterative procedure gives an infinite number of solutions, the definite solution is found by normalizing the parameters $\rho(E_x - E_\gamma)$ and $\mathcal{T}(E_\gamma)$ [8] using:

$$\widetilde{\rho}(E_x - E_\gamma) = \rho(E_x - E_\gamma)A\ exp\ [\alpha(E_x - E_\gamma)], \tag{2}$$

and

$$\widetilde{\mathcal{T}}(E_\gamma) = \mathcal{T}(E_\gamma)B\ exp\ (\alpha E_\gamma). \tag{3}$$

The parameters A and B are constants and α is the slope transformation factor, these are normalised to the s-wave average resonance spacing, the total average radiative width and known discrete states.

3.1. The scissors resonance

The Oslo method type experiments are only capable of extracting the SR built on excited states in the quasi-continuum [17]. The magnetic dipole strength, $B(M1)_{SR}$ was calculated with [18]:

$$B(M1)_{SR} = \frac{27(\hbar c)^3}{16\pi} \int f_{SR}^{SLo}(E_\gamma)d(E_\gamma). \tag{4}$$

A standard Lorentzian function (SLo) was used to fit the γSF Fig 1 (left) in the energy range of the SR and integrated over the distribution. The $B(M1)_{SR}$ was found to be 2.13 ± 0.60 μ_N^2

and the centroid energy to be 2.48 ± 0.25 MeV. The ^{151}Sm $B(M1)_{SR}$ data were compared to results of other Sm isotopes [1, 9, 17] in Fig 1 (right).

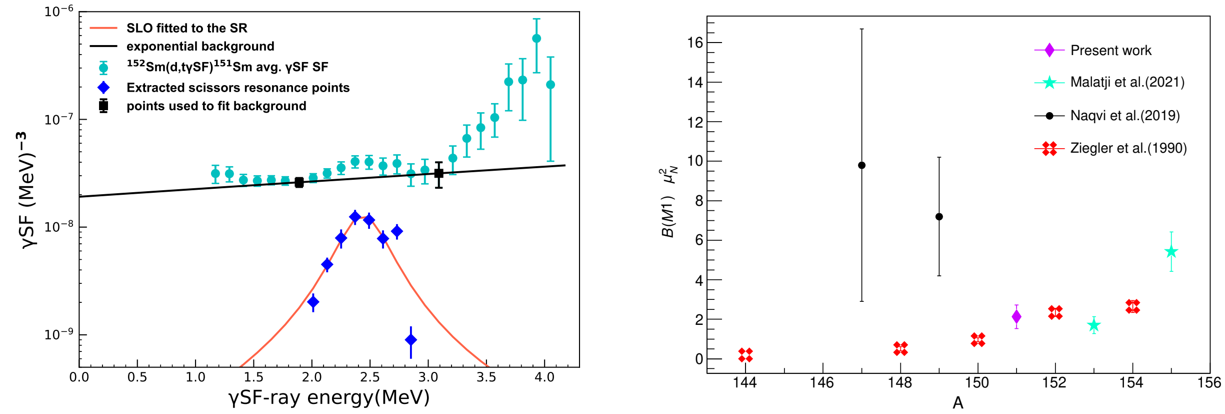

Figure 1. The extracted SR of ^{151}Sm (left), the experimental γSF is fitted by the Standard Lorentzian function (SLo). (right) is the $B(M1)_{SR}$ against atomic mass number A. The $B(M1)_{SR}$ for ^{144,148,150,152,152}Sm is taken from Ref [1], ^{147,149}Sm from Ref. [9] and ^{153,155}Sm from Ref. [17].

4. Summary and Outlook

The statistical properties of the ^{151}Sm nucleus were studied experimentally for the first time through the (d,tγ) reaction. The $B(M1)_{SR}$ of ^{151}Sm was extracted and compared with that of other isotopes of samarium [1, 9, 17] see Fig.1 (right). The results of this work are in agreement with previous work on the $B(M1)_{SR}$, it's proportional to deformation squared. Moreover, the data from [9] are significantly larger than the other measurements on Fig.1 right and does not follow the same trend hence further investigation should be conducted.

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