RADIATIVE STRENGTH FUNCTIONS OF WARM NUCLEI IN THE $1f_{7/2}$ SHELL*

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The level densities of ^{50,51}V and ^{44,45}Sc have been extracted using the (^{3}He,$\alpha\gamma$) and (^{3}He,^{3}He$'\gamma$) reactions, respectively. Also the radiative strength functions of ^{50,51}V will be presented. The high γ-energy part of the measured strength functions fits well with the tail of the giant electric dipole resonance. A significant enhancement over the predicted strength in the region of $E_\gamma \leq 3$ MeV is observed. This feature is, at present, without any theoretical explanation.

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1. Introduction

Nuclear level densities and radiative strength functions (RSFs) are essential quantities for nuclear structure studies. However, the level density is difficult to determine experimentally at high excitation energies, when there are more than ~ 100 levels per MeV. Also the RSF is scarcely known at low γ-ray energies. The Oslo Cyclotron Group has developed the so-called Oslo method, which gives the opportunity to extract the level density and RSF of warm nuclei [1]. With the multidetector system CACTUS [2] at the Oslo Cyclotron Laboratory (OCL), this extraction can be done in one and the same experiment from primary γ spectra.

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We report on experiments done on the nuclei ^{44,45}Sc and ^{50,51}V at the OCL. All of the investigated nuclei have their protons and neutrons in the $f_{7/2}$ shell, which is isolated from other orbitals by the N, $Z = 20$ and 28 shell gaps. As within every major shell, the presence of only one parity for single-particle orbitals in the low-spin domain means that transitions of $E1$ type will be suppressed. The low-energy tail of the giant electric dipole resonance (GEDR) is relatively weak for the investigated nuclei; hence, possible fine structures and nonstatistical effects might stand out in the RSF.

2. Experimental method

The experiments were done at the OCL using a beam of ^{3}He ions with energy 30 MeV on the ^{51}V target and 38 MeV on the ^{45}Sc target. Particle-γ coincidences for the (^{3}He,$\alpha\gamma$) and (^{3}He,^{3}He$'\gamma$) reactions were measured with the CACTUS multi-detector array [2]. The charged ejectiles were detected using eight Si ($\Delta E - E$) particle telescopes placed at an angle of 45° relative to the beam. An array of 28 collimated NaI γ-ray detectors with a total efficiency of $\sim 15\%$ surrounded the target and the particle detectors.

The recorded particle-γ coincidences were sorted into $E_x - E_\gamma$ matrices by gating on the ejected ^{3}He or α particle. The γ spectra were unfolded using the known response functions of the CACTUS array [3]. To obtain the γ spectra containing only the first γ rays in a cascade, a subtraction method is applied [4].

3. Level densities and radiative strength functions

The level density and RSF are found from the primary γ-ray spectra through an iterative procedure [1] based on the generalized Brink–Axel hypothesis [5, 6]

$$P(E, E_\gamma) \propto \rho(E - E_\gamma)\mathcal{T}(E_\gamma)\,.$$

Here $P(E, E_\gamma)$ is the normalized primary γ-ray matrix, $\rho(E - E_\gamma)$ is the level density at the final energy $E_{\mathrm{f}} = E - E_\gamma$, and $\mathcal{T}(E_\gamma)$ is the γ-ray transmission coefficient. The level density is normalized to known, discrete levels at low excitation energy, and at the neutron (or proton) binding energy using neutron (proton) resonance data. The γ-ray transmission coefficient is normalized utilizing experimental data on the average total radiative width $\langle \Gamma_\gamma \rangle$ at $E = B_n$, and then transformed to RSF by the relation $\mathcal{T}(E_\gamma) = 2\pi \sum_{XL} E_\gamma^{2L+1} f_{XL}(E_\gamma)$, where X denotes the electromagnetic character, L is the multipolarity, and f_{XL} is the RSF.

The obtained level densities of ^{44,45}Sc and ^{50,51}V are shown in Fig. 1. It is apparent from Fig. 1 that the odd–odd nuclei ^{50}V and ^{44}Sc have an overall larger level density than the odd–even ^{51}V and ^{45}Sc. Also, the level density of ^{51}V shows much more structures than the others, an effect of the closed $N = 28$ neutron shell in this nucleus.

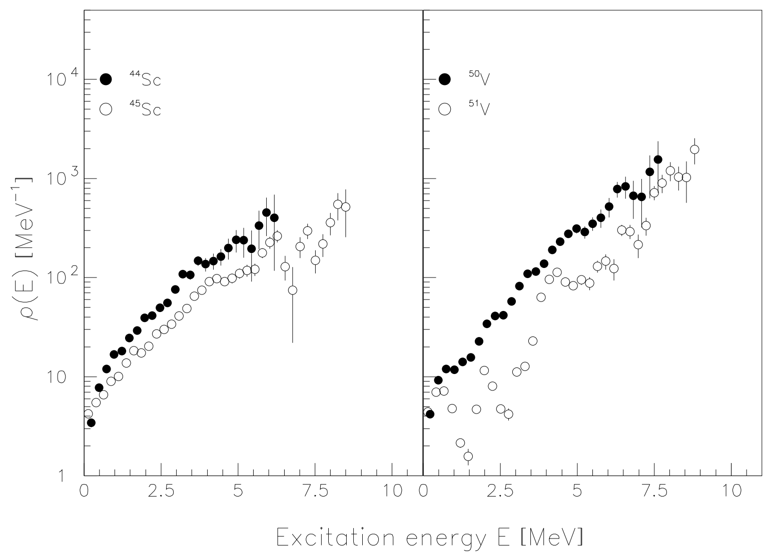

Fig. 1. Level densities of ^{44,45}Sc (left) and ^{50,51}V (right).

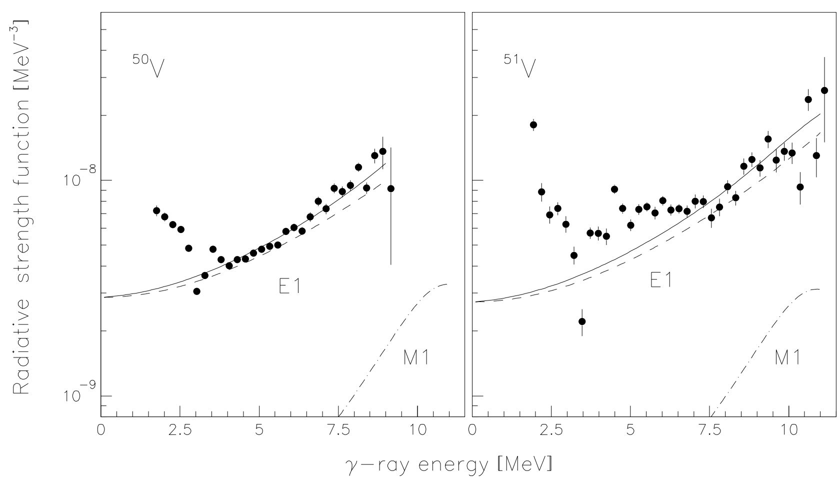

Fig. 2. Normalized RSFs of ^{50,51}V. The dashed and dash-dotted line show the extrapolated tails of the giant $E1$ and giant $M1$ resonance, respectively. The solid line is the summed strength for the giant dipole resonances.

The RSFs of ^{50,51}V displayed in Fig. 2 have several interesting features. First, the part of the RSF with $E_\gamma \geq 5$ MeV seems to fit well with the low-energy part of the giant electric dipole resonance (GEDR) of ^{51}V. Here, the RSFs are compared to the Kadmenskiĭ, Markushev and Furman (KMF) model [7] for the $E1$ strength. In this model, the Lorentzian GEDR is modified in order to reproduce the nonzero limit of the GEDR for $E_\gamma \to 0$ by means of a temperature-dependent width of the GEDR. Secondly, a peculiar enhancement in the γ strength below $E_\gamma \sim 3$ MeV is apparent for both nuclei [8]. This behaviour has been seen in other nuclei such as some Mo [9, 10] and Fe [10, 11] isotopes, where it has been shown to be present in the whole excitation-energy region. In the case of the ^{57}Fe RSF, the feature has been confirmed by an $(n,2\gamma)$ experiment [11]. However, even the temperature dependence included in the KMF model fails to reproduce the observed increase of the RSFs. As of today, no theory can explain the physical origin of these observations. The RSFs of ^{44,45}Sc are still under investigation.

4. Summary

The experimental level densities of ^{44,45}Sc and ^{50,51}V have been extracted using the Oslo method. The difference between level densities of odd–odd and odd–even nuclei is apparent. The RSFs of ^{50,51}V show an enhancement at $E_\gamma \leq 3$ MeV. The underlying physics of this behaviour is not yet understood.

REFERENCES

[1] A. Schiller *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A447**, 498 (2000).

[2] M. Guttormsen *et al.*, *Phys. Scr.* **T32**, 54 (1990).

[3] M. Guttormsen *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A374**, 371 (1996).

[4] M. Guttormsen *et al.*, *Nucl. Instrum. Methods Phys. Res.* **A255**, 518 (1987).

[5] D.M. Brink, Ph.D. thesis, Oxford University, 1955.

[6] P. Axel, *Phys. Rev.* **126**, 671 (1962).

[7] S.G. Kadmenskiĭ, V.P. Markushev, V.I. Furman, *Yad. Fiz.* **37**, 277 (1983) [*Sov. J. Nucl. Phys.* **37**, 165 (1983)].

[8] A.C. Larsen *et al.*, *Phys. Rev.* **C73**, 064301 (2006).

[9] M. Guttormsen *et al.*, *Phys. Rev.* **C71**, 044307 (2005).

[10] S. Siem *et al.*, *Acta Phys. Pol. B* **36**, 1089 (2004).

[11] A. Voinov *et al.*, *Phys. Rev. Lett* **93**, 142504 (2004).