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THERMAL AND ELECTROMAGNETIC PROPERTIES OF THE LIGHT VANADIUM ISOTOPES ^{50,51}V*

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The level densities and radiative strength functions (RSFs) in ^{50,51}V have been experimentally measured using the (^{3}He, $\alpha\gamma$) and (^{3}He,^{3}He$'\gamma$) reactions, respectively. From the level density thermodynamic properties such as entropy and temperature can be extracted. The microcanonical heat capacity shows negative branches. The gross properties of the RSF are described by the giant electric dipole resonance. At γ energies below 3 MeV, the RSFs show an unexpected enhancement.

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1. Introduction

In the case of macroscopic systems, temperatures are measured by bringing the system into thermal contact with a thermometer. Such a method is of course not applicable for microscopic systems like an atomic nucleus. Here, every thermometer will, due to its size, act as a heat bath when brought into contact with the system under study. Therefore, thermal properties of nuclei have to be measured indirectly.

The Oslo Cyclotron group has developed a method to extract first-generation (primary) γ-ray spectra at various initial excitation energies. From such a set of primary spectra, nuclear level density and radiative

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strength function (RSF) can be extracted [1]. These two functions reveal essential nuclear structure information such as pair correlations and thermal and electromagnetic properties.

At the Oslo Cyclotron Laboratory one-particle transfer reactions are utilized to extract simultaneously the level density and radiative strength function of the nucleus under study. In the vanadium experiments a self-supporting ^{51}V target was used to measure particle-γ coincidences for ^{50,51}V with the CACTUS multi-detector array [2]. The reactions of interest were ^{51}V(^{3}He$, \alpha\gamma$)^{50}V and ^{51}V(^{3}He$, ^3$He$'\gamma$)^{51}V.

The experimental extraction procedure and the assumptions made are described in Ref. [1] and references therein. For each initial excitation energy E, determined from the ejectile energy, γ-ray spectra are recorded. These spectra are the basis for making the first generation (or primary) γ-ray matrix [3], which is factorized according to the Brink–Axel hypothesis [4, 5] as $P(E, E_\gamma) \propto \rho(E - E_\gamma)\mathcal{T}(E_\gamma)$. Here, ρ is the level density and $\mathcal{T}$ is the radiative transmission coefficient.

The ρ and $\mathcal{T}$ functions can be determined by an iterative procedure [1] through the adjustment of each data point of these two functions until a global χ^2 minimum with the experimental $P(E, E_\gamma)$ matrix is reached. The obtained functions must then be normalized according to the procedure described in Ref. [1].

2. Level density and thermal properties

From the level density the entropy can be deduced since the microcanonical entropy is given by $S(E) = k_{\rm B} \ln \Omega(E)$, where the multiplicity Ω is directly proportional to the level density by $\Omega(E) = \rho(E)/\rho_0$. The normalization constant ρ_0 is adjusted to ensure that when $T \to 0$, also $S \to 0$ in the case of even–even nuclei. Fig. 1 shows the microcanonical entropy of ^{50,51}V.

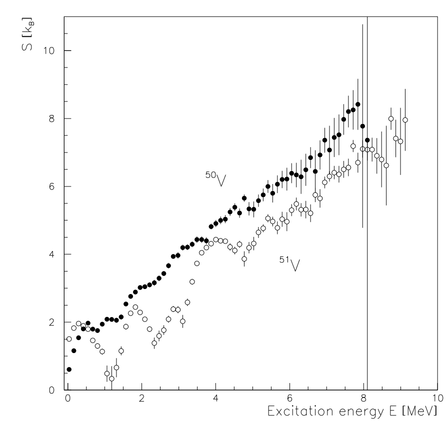

Fig. 1. Microcanonical entropy of ^{50,51}V.

The odd–odd nucleus ^{50}V displays a smoother entropy curve than the neighbouring isotope ^{51}V. Above 5 MeV excitation energy the entropy difference between the two nuclei is about $\sim 1k_{\mathrm{B}}$, which can be due to the unpaired neutron in ^{50}V.

Assuming that the thermodynamic relation $T(E) = \left(\frac{\partial S}{\partial E}\right)^{-1}$ holds even for very small systems such as a nucleus, a "temperature" can be found for the nuclei ^{50,51}V, see upper part of Fig. 2. Large statistical fluctuations are expected to appear since the system contains few particles; at ~1 MeV excitation of ^{50}V, the temperature reaches 3 MeV. The heat capacity is given in the microcanonical ensemble by $C_V(E) = \left(\frac{\partial T}{\partial E}\right)_V^{-1}$ and is displayed in the lower part of Fig. 2. The most striking feature is the negative branches. This phenomenon is also seen in multifragmentation experiments and has been suggested as a signature of a first-order phase transition [6].

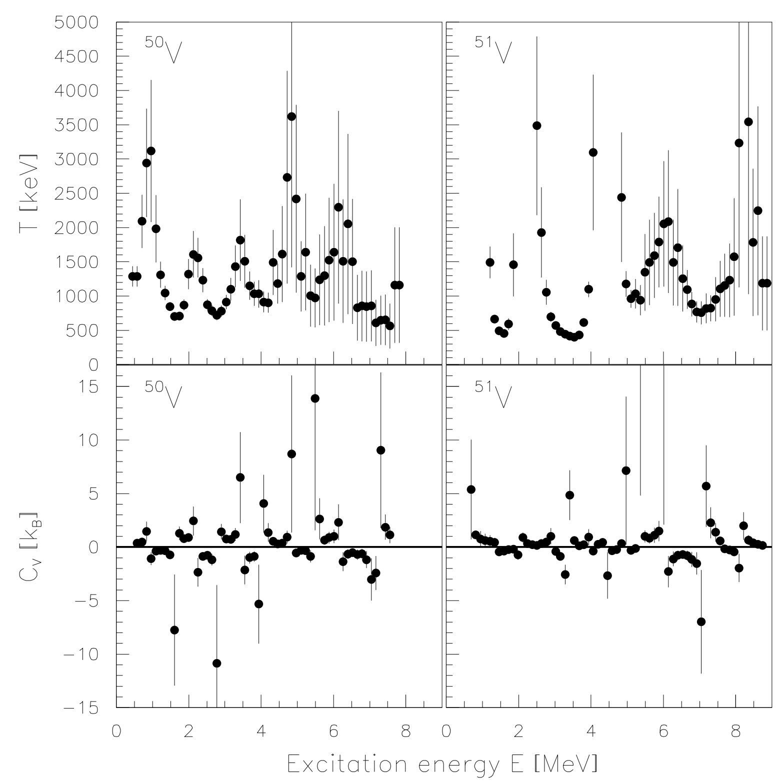

Fig. 2. Upper panels: Microcanonical temperature of ^{50}V (left) and ^{51}V (right). Lower panels: Microcanonical heat capacity of ^{50}V (left) and ^{51}V (right).

3. Radiative strength functions

From the normalized radiative transmission coefficient $\mathcal{T}$ found in section 2 the radiative strength function (RSF) can be found from the relationship [7]

$$f(E_\gamma) \;=\; \frac{1}{2\pi E_\gamma^3} B\mathcal{T}(E_\gamma)\,,$$

where a method to determine the normalization constant B is given in Ref. [7]. The experimental RSFs of the nuclei ^{50,51}V are shown in Fig. 3. They generally follow the tail of the giant electric dipole resonance, except for the low γ-energy region. In this region an unexpected enhancement of the RSFs is found. This enhancement is also seen in the iron isotopes ^{56,57}Fe [8] and in molybdenum isotopes.

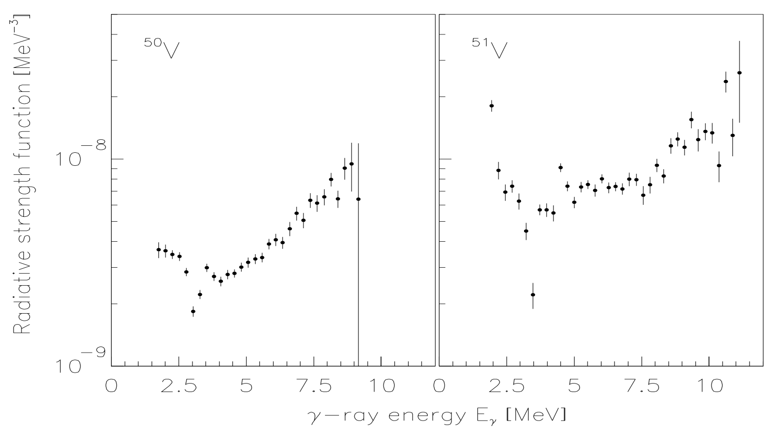

Fig. 3. Normalized RSFs for ^{50}V (left panel) and ^{51}V (right panel).

4. Summary and conclusions

The results of a new set of experiments on vanadium isotopes have been reported. The odd–odd nucleus ^{50}V seems to have $1\,k_{\rm B}$ more entropy than the odd–even ^{51}V above 5 MeV of excitation energy. The temperature and heat capacity extracted for the two nuclei display large fluctuations, and even negative branches in the heat capacity are seen. The gross properties of the RSFs are described by the tail of the GEDR, but a large and unexplained enhancement of the RSFs for low γ-energies is also seen. This new feature, called a soft pole, might correspond to the excitation energy of some new, robust collective low-frequency oscillation.

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