THERMAL QUENCHING OF PAIR CORRELATIONS AND γ-STRENGTH FUNCTIONS IN ^{148,149}Sm*

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The level densities and γ-strength functions of the almost spherical ^{148}Sm and ^{149}Sm nuclei have been extracted. The temperature curve, derived within the framework of the micro canonical ensemble, shows structures, which we associate with the break up of Cooper pairs. The nuclear heat capacity is deduced within the framework of the canonical ensemble and exhibits an S-shape as a function of temperature indicating a phase transition. The results are compared to the results for well deformed ^{161,162}Dy and ^{171,172}Yb isotopes.

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1. Introduction and experimental details

The Oslo Cyclotron group has developed a method to simultaneously extract the level density and γ-strength function, over a wide excitation energy and γ-energy region, from measured γ-ray spectra [1]. The main advantage of utilizing γ-rays as a probe for level density is that the nuclear system is likely to be thermalized prior to the γ-emission. A long-standing problem in experimental nuclear physics has been to observe the transition from a superfluid state, at the ground state, to a normal (Fermi gas) state at higher temperature.

The experiments were carried out at the Oslo Cyclotron Laboratory. The (^{3}He,$\alpha\gamma$) and (^{3}He,^{3}He')-reactions were employed on a ^{149}Sm self-supporting target, with the 45 MeV ^{3}He-beam delivered by the MC-35 cyclotron. The charged particles and γ-ray were recorded with the detector array CACTUS. From the reaction kinematics the measured ejectile energy

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can be transformed to excitation energy E. Thus, each coincident γ-ray can be assigned to a γ-cascade originating from a specific excitation energy.

For each excitation energy E the NaI γ-ray spectra are unfolded. Then the first-generation (primary) γ-ray matrix is extracted [2]. The resulting matrix $P(E,E_\gamma)$, describing the primary γ-spectra obtained at initial excitation energy E, is factorized according to the Brink-Axel hypothesis [3] by $P(E,E_\gamma) \propto \rho(E-E_\gamma)F(E_\gamma)$. The method and the assumptions behind the factorization of this expression are described in Ref. [1].

2. Results

The γ-strength functions of ^{148}Sm and ^{149}Sm are compared with the γ-strength functions of ^{161,162}Dy and ^{171,172}Yb [4] in Fig. 1. The bump around 3 MeV in the γ-strength functions of ^{161,162}Dy and ^{171,172}Yb was first referred to as the pygmy resonance [4]. According to systematic inves-

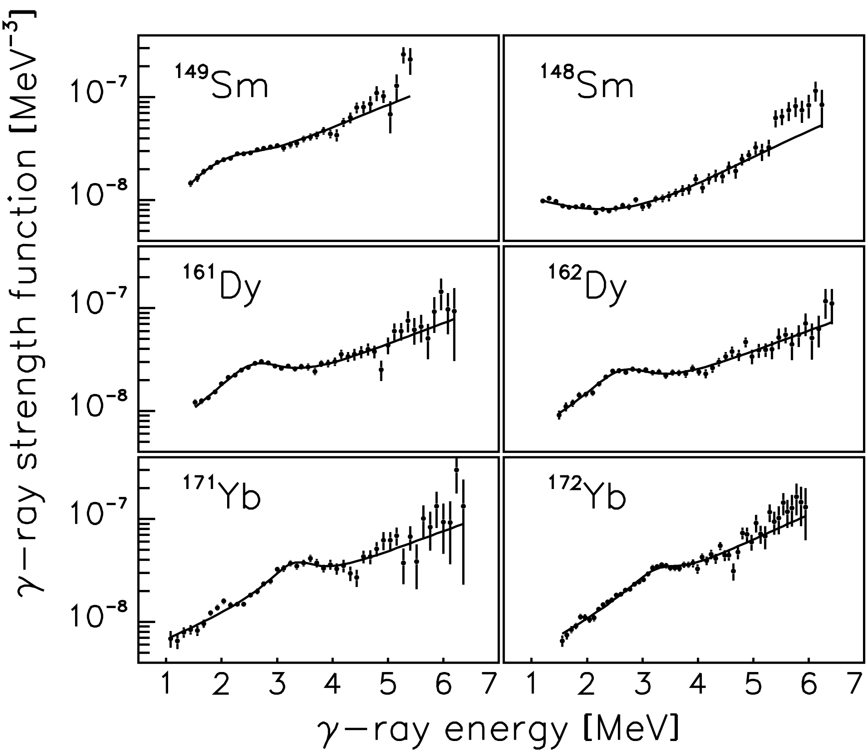

Fig. 1. The γ-strength functions for ^{148,149}Sm, ^{161,162}Dy and ^{171,172}Yb. The solid lines represent a fit to the experimental data using a Kadmenskiĭ GEDR model and a Lorentzian spin flip GMDR model, and a pygmy resonance [4].

tigations of the pygmy resonance parameters in the rare earth nuclei [5] it should appear around 1.7 MeV for ^{148,149}Sm. However, recent investigations of Dy and Yb isotopes [6] indicate that this bump can be interpreted as due to the scissors mode built on exited states. The fact that the γ-strength function for ^{149}Sm shows a bump between 2–3 MeV supports the interpretation as the scissors mode built on exited states. The ^{148}Sm γ-strength function is more difficult to understand. It might be that shell effects in ^{148}Sm hide the fine structure in the γ-strength function. After establishing the level density as a function of excitation energy — see Fig. 2, we can explore other thermodynamical parameters of the nuclei. The measured level density $\rho(E)$ is proportional to the number of states accessible to the nuclear system, in this reaction, at excitation energy E. The entropy $S(E)$ in linear scale will be the "same" curve as $\rho(E)$ in log scale. The microcanonical temperature is given by $T(E) = 1/(\partial S/\partial E)_V$. The deduced temperature spectra exhibit pronounced bump structures, as shown for ^{148,149}Sm in Fig. 3. The bump structures are interpreted as the breaking of nucleon pairs, and, at higher energies, the possible quenching of pair correlations [7]. The reminiscence of the quenching process is distributed over a wide excitation energy region, which is difficult to observe and interpret in the microcanonical ensemble.

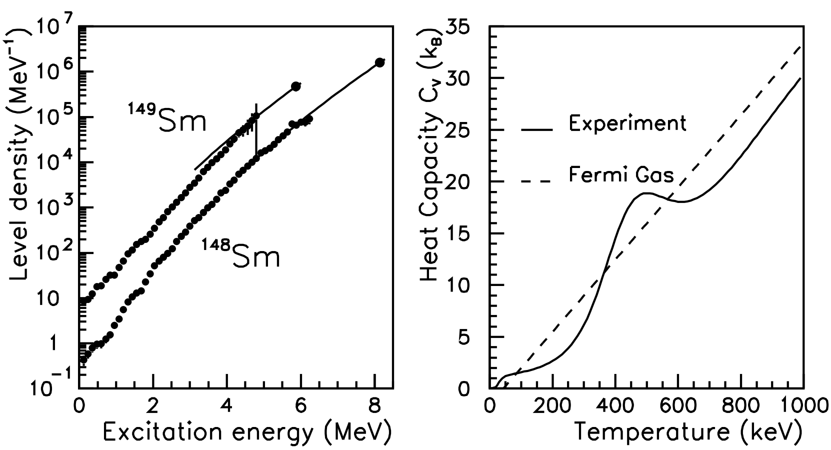

Fig. 2. Left: The level densities for ^{148}Sm and ^{149}Sm. The filled circles are experimental data. The solid lines are a Fermi gas predictions (von Egidy) for the level densities (made to go through the experimental ρ(Bn)). Right: The heat capacity for ^{149}Sm derived within the canonical ensemble.

The heat capacity determined within in the canonical ensemble can be used as a "thermometer" for the quenching of pair correlations. The canonical heat capacity exhibits an s-shape as a function of temperature for ^{149}Sm see Fig. 2. This is interpreted as the onset of new degrees of freedom orig-

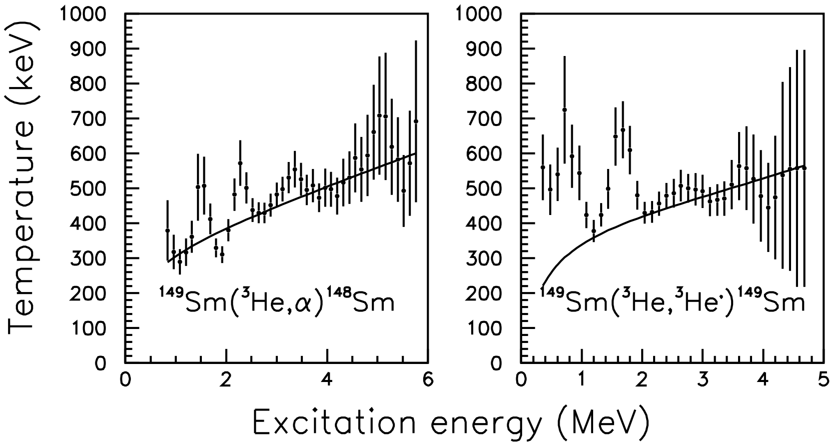

Fig. 3. The temperature curve for ^{148}Sm and ^{149}Sm derived within the micro canonical ensemble (filled circles) and canonical ensemble (solid line).

inating from the breaking of Cooper pairs [8]. The critical temperature for the quenching of pair correlations is found at $T_{\rm c} = 0.45$ MeV for ^{148}Sm and $T_{\rm c} = 0.52$ MeV for ^{149}Sm, in the same range as for the deformed rare earth nuclei [8].

3. Conclusions

The level density and the γ-strength function have been extracted experimentally for ^{148}Sm and ^{149}Sm. The bump between 2–3 MeV in the γ-strength function of ^{149}Sm is interpreted as due to the scissors mode built on exited states. From the level densities thermodynamical quantities such as temperature and heat capacity were found. Structures in the microcanonical temperature are interpreted as the onset of new degrees of freedom as the result of breaking up Cooper pairs. The s-shape in the heat capacity curves, found within the canonical ensemble, indicates the pairing-phase transition, and a critical temperature for the quenching of pair correlations is found. The method was developed for well deformed nuclei and has now been successfully adopted to the more spherical Sm nuclei. Recently a (^{3}He,α)-reaction experiment on ^{28}Si was performed and new experiments on Mo nuclei were carried out in December 2000.

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