Thermodynamic Properties of ^{59}Ni Using Nuclear Level Density as a Probe

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1. Introduction

In recent years, nuclear thermodynamics has become a prominent area of study, various temperature-dependent nuclear properties, such as the shapes of nuclei, widths of giant dipole resonances, and their fluctuation characteristics have been studied [1]. In this context, a particularly intriguing focus lies in the intricate phase transitions occurring within atomic nuclei. In macroscopic conductors, the pairing phase transition is identified by a sharp change in heat capacity at the transition temperature [2]. Conversely, in the case of a nucleus where the nuclear radius is significantly smaller than the pair coherence length, substantial fluctuations are anticipated to mitigate the sharp transition, resulting in a gradual "kink" resembling an "S-shape" in the heat capacity at the transition temperature [3]. Until now, these kind of pairing phase transitions in even-even nuclei due to breaking nucleonic Cooper pairs at a specific temperature have been reported [4, 5]. Recently, an S-shaped heat capacity has been found in the odd-odd ^{184}Re nucleus, suggesting the deformation-induced pairing [6]. A similar change in heat capacity was seen in even-odd ^{183,185}W nuclei [5]. Our previous work on ^{69}Zn, which also exhibit S shape heat capacity [7]. These studies motivated us for further investigations of pairing phase transition in odd-odd and even-odd systems in different mass regions, especially in nuclei crucial for nucleosynthesis during slow (s) and rapid (r) neutron capture processes.

2. Material and Methods

Here, different thermodynamic properties such as average energy, entropy, Helmholtz free energy and specific heat of ^{59}Ni nucleus have been investigated by using the nuclear level density (NLD) data, which have been experimentally extracted from the particle spectra, as discussed in Ref [8]. The experimental NLDs have been compared with those obtained within the microscopic 'Exact Pairing plus Independent-Particle Model' (EP+IPM) at finite temperature range [9]. The details of microscopic EP+IPM calculations are discussed in Ref. [9].

3. Results and Discussions

It is seen that the experimental NLD data as a function of excitation energy can well be explained by the microscopic EP+IPM calculations considering the deformed shape of ^{59}Ni (β_2~0.29) as shown in Fig. 1. It should be mentioned that the ^{59}Ni nucleus is spherical at

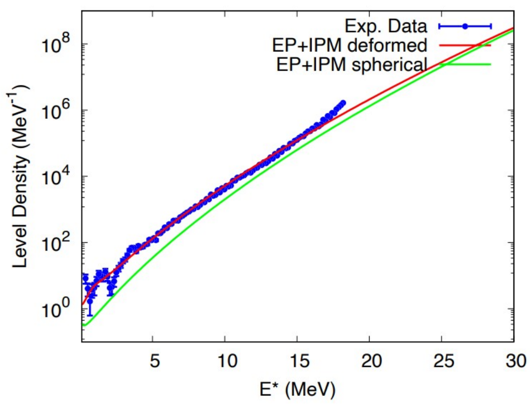

Fig. 1 NLDs as a function of excitation energy.

lowest spin, but it is deformed at high spin [10]. As the total NLD includes both the low and high spin, it is reasonable to consider its deformed shape, otherwise, the NLD data cannot be described. The best-matched EP+IPM NLDs are therefore used to evaluate the thermodynamic quantities as a function of temperature. Fig. 2 shows the heat capacities calculated using the best-matched EP+IPM NLDs in the temperature region of ~ 0.1−2.4 MeV. No kink or sudden

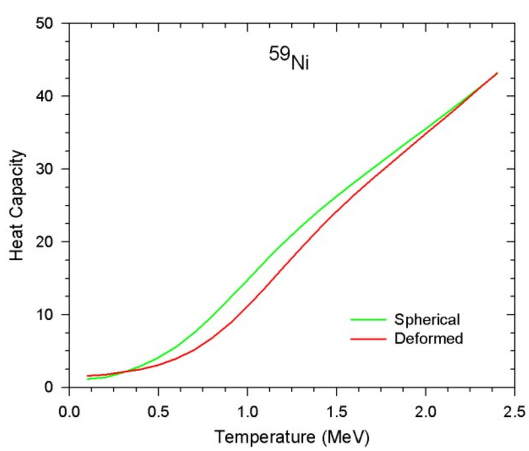

Fig. 2 The heat capacities calculated using the EP+IPM NLDs

drastic change in the heat capacity has been observed. Unlike nuclei with fully paired protons and neutrons (even-even), even-odd nuclei exhibit a more constrained response to thermal fluctuations. The observed constancy in heat capacity may result from the weakened pairing effects caused by the presence of an unpaired neutron, which restricts the emergence of phase transitions associated with heat capacity changes. This behavior highlights the complex interaction between nuclear shell structures and pairing forces, making even-odd isotopes an intriguing subject for further investigation in nuclear structure and thermodynamics. The detailed results will be presented at the symposia.

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