S-shaped heat capacity in an odd-odd deformed nucleus[†]

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A long-standing problem in nuclear physics is the experimental observation of the pairing phase transition in atomic nuclei. Thermodynamic properties such as superfluidity and pairing phase transition are well-established facts in infinite nuclear matter.[1)] However, these properties digress from infinite nuclear matter to finite nuclei owing to statistical fluctuations in the order parameter. Therefore, the gradual transition from strongly correlated paired states to unpaired ones in atomic nuclei may not be as evident as in infinite matter.[1)] This induces a high degree of interest in the study of nuclear thermodynamics, especially in the energy domain of neutron binding.

The study of thermodynamics of finite nuclei involves the reliable extraction of experimental nuclear level density (NLD). The experimental determination of NLDs has been difficult in the past owing to the absence of suitable experimental techniques. Recently, the thermal properties of different nuclei were measured by the Oslo group using a new technique, called the Oslo method, and the S-shaped canonical heat capacity was extracted, signalizing the pairing phase transition around the critical temperature $T_c = 0.5$–1.0 MeV.[2,3)] However, this method is limited to a low excitation energy E^* (below the particle threshold) and angular momentum J (only a few multiples of $\hbar$). This limitation in E^* and J has recently been overcome by measuring the NLD from the evaporated particle spectra in compound nuclear reactions.[3)] In addition, thus far, most of the thermal properties have been studied in nuclei where the shell effect (δS) is very small (less than $\sim$1 MeV). The mass region exhibiting a large shell effect ($\delta S \sim 10$ MeV) has rarely been studied; and thus, it is very important to investigate how the thermodynamic properties behave because of the large effect of nuclear shells. In this work, the NLDs and, consequently, the nuclear thermodynamic quantities (TQs) for four different nuclei, ^{184}Re, ^{200}Tl, ^{211}Po, and ^{212}At, are estimated to understand the shell and deformation effects on the TQs.

Figure 1 shows the free energy F, average energy $\overline{E}$, entropy S, and heat capacity C as functions of T. F and $\overline{E}$ behave smoothly with varying T for all the nuclei. However, S and C show different variations with T. The difference in entropy appears primarily because of

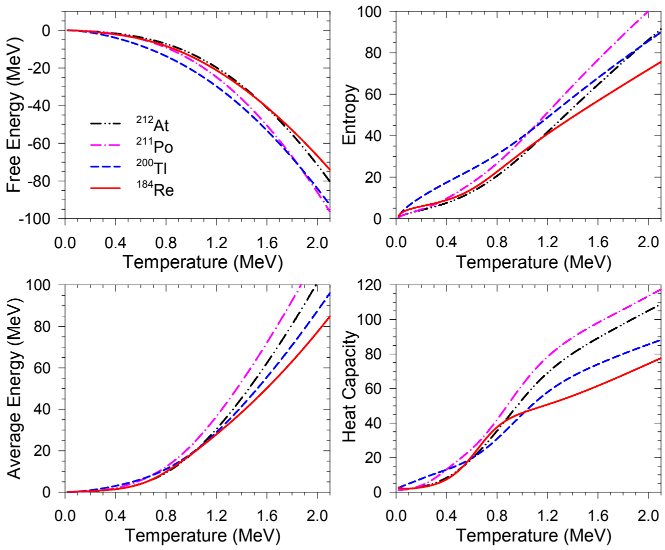

Fig. 1. TQs as functions of temperature obtained using the EP+IPM level densities for $J = 12\ \hbar$.

the different shell structures of the nuclei at low T since they show a smooth variation at higher T (above $T =$ 1.6 MeV), where the shell structures are predicted to be melted. Most noteworthy is the nature of the heat capacity of ^{184}Re, which is completely different from those of the other three nuclei. There is a pronounced bump (S-shape) in the heat capacity of ^{184}Re at $T \sim 0.8$ MeV, which is close to the critical temperature T_c, where the pairing gap collapses, as predicted by the conventional BCS theory. This S-shape in the heat capacity is interpreted as a fingerprint for a pairing transition in nuclei. The heat capacities of ^{211}Po, ^{212}At, and ^{200}Tl do not show the pronounced S-shape structure, as expected for odd-odd and odd-even nuclei. In order to understand the S-shaped heat capacity in such odd-odd deformed nuclei, the exact neutron and proton pairing gaps have been calculated as functions of T, as discussed in detail in Ref. 4). It has been shown that S-shape of the heat capacity observed in the odd-odd deformed ^{184}Re nucleus at $J = 12\ \hbar$ is only due to the change in pairing gaps caused by the change in deformation.

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References

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