Experimental investigation on the temperature dependence of the nuclear level density parameter[†]

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Recently there have been ample experimental efforts to comprehend the spin dependence of the level density parameter $a = k^{-1}$. In a few measurements of angular momentum J gated neutron evaporation spectra in $A \sim 119$, 97, and 62, it was seen that the value of the inverse level density parameter k decreased with increasing J, which indicated that the level density increases with J. On the other hand, the values k extracted from the α evaporation spectra in the mass regions of $A \sim 180$ and 120 are either constant or increase with J. However, theoretical calculations for similar masses show that k should increase with J for all the systems. Thus, extremely exciting but conflicting experimental results on the spin dependence of the level density parameter motivate one to carry out further investigations.

This work reports on the angular momentum gated neutron evaporation spectra at different excitation energies (30 – 50 MeV) for the reaction $^4\mathrm{He} + {}^{93}\mathrm{Nb}$. The specific advantage of using a light-ion reaction is that the major residues are of similar nature and in our case they are $^{93-95}\mathrm{Tc}$, depending on the excitation energy of the compound nucleus. However, for excitation energies above 42 MeV, another channel contributes ($\sim 20\%$) due to $(\alpha, \alpha 2n)$ populating $^{91}\mathrm{Nb}$. Nevertheless, the deformations of all the nuclei populated in the decay chain are similar and of the order of $\beta \sim 0.05$. The shell effects are also very small and similar. Therefore, the neutron evaporation spectra will have the contribution from similar kind of nuclei only.

The experiment was performed at the Variable Energy Cyclotron Centre (Kolkata) using the α beam from the K-130 cyclotron. A self-supporting 1 mg/cm^2 thick target of 99.9% pure $^{93}\mathrm{Nb}$ target was used. Four different beam ($^4\mathrm{He}$) energies of 28, 35, 42, and 50 MeV were used to populate the compound nucleus $^{97}\mathrm{Tc}$ at the excitation energies of 29.3, 36.0, 43.0, and 50.4 MeV, respectively. The maximum populated angular momenta for fusion were 16, 18, 19, and 20$\hbar$, respectively. The evaporated neutrons from the compound nucleus were detected by a liquid organic scintillator (BC501A) based neutron detector that was placed at a distance of 1.5 m from the target position and at an angle of 125 degrees to the beam axis. The experimen-
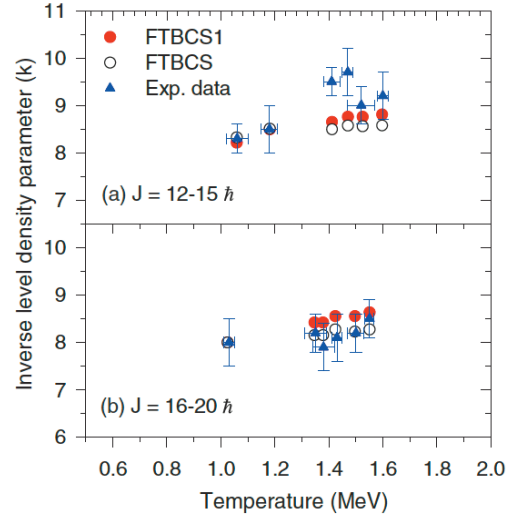
Fig. 1. Temperature dependence of k compared with the calculations of FTBCS and FTBCS1 theories.

tal data are compared with the predictions by several theoretical models including those by the finite temperature (FT) BCS and FTBCS1 theories. The latter[1] includes the effect due to quasiparticle-number fluctuations beyond the FTBCS theory.

As can be seen from Fig. 1, the increase of k with temperature T observed in the data is reproduced by the results of theoretical calculations within the FTBCS and FTBCS1 theories. The agreement is better for the higher J window, whereas for the lower J window the theory underestimates the two data points at $T = 1.41$ MeV ($J = 15\hbar$) and 1.47 MeV ($J = 13\hbar$). The FTBCS and FTBCS1 predict similar results, indicating that pairing reentrance effect, predicted by the FTBCS1 theory at finite T band J, might have a minor effect on k in this case. However, to have a thorough understanding of the effect of collectivity and pairing reentrance on the decrease of k with increasing J, much more theoretical and experimental studies are needed. Moreover, it may be noted that the effect of angular momentum on k is not observed for higher masses but is only apparent in low- and medium-mass $A \leq 120$ nuclei. Hence, more experimental data at both high- and low-mass regions are required to understand this behavior.

Reference

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