

Signature of collective enhancement in nuclear level density

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Introduction

Our understanding of nuclear level density (NLD), which is an important ingredient in various statistical model calculations, is even today, far from satisfactory. In recent years several studies have been carried out both theoretically and experimentally to understand the functional dependence of nuclear level density on the key parameters, such as excitation energy, angular momentum and isospin. But one major issue which is yet to be resolved is the interrelationship between collective excitations and nuclear level density as a function of excitation energy (or temperature). In nuclei, coupling of collective rotation and vibration with the single particle excitations causes an enhancement in the level density. For nuclei with appreciable ground state deformation, most significant contribution to the collective enhancement comes from the rotational excitations, whereas in case of spherical nuclei, the collective enhancement is likely to be due to vibrational excitations. The collective contributions in NLD are expected to fade out at higher excitation energy due to gradual damping of long range correlations, which are mainly responsible for the collective enhancement. A critical temperature (T_c) at which the collective contributions are expected to be fade is proposed by Björnholm, Bohr and Mottleson, as given below,

$$T_c = \hbar\omega_0\beta_2 \sim 40A^{-1/3}\beta_2.$$

In the recent past, only a few experimental attempts [1, 2] have been made to look for the collective enhancement in nuclear level density and its subsequent fadeout at higher excitation energy. However no convincing idea on the existence of collective enhancement and its fade out were obtained from these analyses. In this paper to independently verify the status of collective enhancement we report a new

experiment where we have populated $^{169}\text{Tm}^*$, $^{185}\text{Re}^*$, and $^{201}\text{Tl}^*$ compound nuclei having widely different ground state deformations. The experiment was done at two energies to observe the variation, if any, of the level density parameter with energy.

Experimental Details

The present experiment was performed using ^4He ion beam of energies $E_{\text{lab}} = 40$, and 28 MeV (40 MeV and 30 MeV for ^{181}Ta target) from the cyclotron facility at Variable Energy Cyclotron Centre. Self-supporting foils of ^{181}Ta , ^{165}Ho (thicknesses ~ 1 mg/cm²) and, ^{197}Au (thickness ~ 500 $\mu\text{g}/\text{cm}^2$) were used as targets. The compound nuclei $^{201}\text{Tl}^*$ ($^4\text{He} + ^{197}\text{Au}$), $^{185}\text{Re}^*$ ($^4\text{He} + ^{181}\text{Ta}$) and $^{169}\text{Tm}^*$ ($^4\text{He} + ^{165}\text{Ho}$) were populated by the complete fusion reactions at the excitation energies, $E^* \sim 37$ and 26 MeV. The emitted neutrons were detected using four liquid-scintillator (BC501A) detectors of dimension $5'' \times 5''$. The neutron detectors were placed outside the scattering chamber at angles 90° , 105° , 120° and 150° with respect to the beam direction, at a distance of 150 cm from the target. The energy of the emitted neutrons has been measured using the Time of Flight (TOF) technique whereas neutron-gamma discrimination was achieved by both pulse shape discrimination (PSD) and time of flight. In the present experiment, the start of the time of flight was taken from a 50 element BaF_2 based low energy γ -detector array. The array was split into two blocks of 25 detectors each and was placed on the top and bottom of a thin wall reaction chamber (wall thickness ~ 3 mm) in staggered castle type geometry.

Results and Discussions

The neutron kinetic energy spectra for the three reactions as obtained from the corresponding time of flight spectra has been shown in Fig.1. Theoretical analysis of the experimental data was carried out using the statistical model code

GEMINI++ [3]. The evaporation of light particles has been treated using Hauser-Feshbach formalism with the level density function taken from the back shifted Fermi gas model.

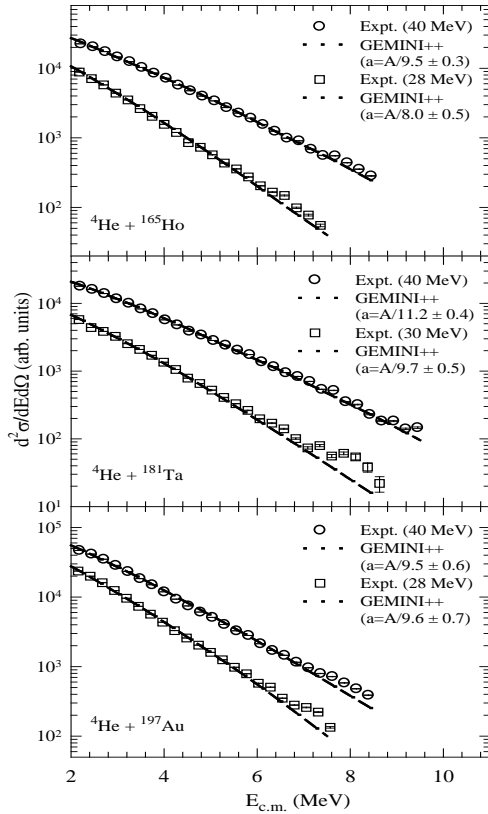


Fig. 1 Measured neutron energy spectra (symbols) for the ${}^4\text{He} + {}^{165}\text{Ho}$, ${}^{181}\text{Ta}$ and ${}^{197}\text{Au}$ system along with the GEMINI++ calculations (dashed lines).

The shapes of the neutron energy spectra were mostly sensitive to the value of level density parameter, which is estimated as $\tilde{a}=A/k$, where k is called the inverse level density parameter. The optimum values of k were extracted by fitting the experimental neutron spectra using the χ^2 minimization technique, which have been tabulated in Table I. It is observed (see Table I) that the best-fit values of the inverse level density parameter decrease from 9.5 ± 0.3 to 8.0 ± 0.5 for the ${}^4\text{He} + {}^{165}\text{Ho}$ system as the thermal excitation energy decreases from 35.7 to 24.8 MeV. Similar change (decrease) in k value from 11.2 ± 0.4 to 9.7 ± 0.5 has also been observed

for the ${}^4\text{He} + {}^{181}\text{Ta}$ system at the same excitation energy range.

TABLE I: Fitted inverse level density parameter (k) for different systems.

System	U (MeV)	k (MeV $^{-1}$)
${}^4\text{He} + {}^{165}\text{Ho}$	35.7	9.5 ± 0.3
	24.8	8.0 ± 0.5
${}^4\text{He} + {}^{181}\text{Ta}$	35.1	11.2 ± 0.4
	25.9	9.7 ± 0.5
${}^4\text{He} + {}^{197}\text{Au}$	36.1	9.5 ± 0.6
	24.8	9.6 ± 0.7

On the contrary, the k value remained almost same (9.5 ± 0.6 and 9.6 ± 0.7) at both excitation energies in case of ${}^4\text{He} + {}^{197}\text{Au}$ system. In other words, the above observation (the decrease of ' k ') suggests that there has been a relative enhancement in nuclear level density at lower excitation energy for the first two systems, whereas for the third system no such variation has been observed. The nature of variation as seen above may be directly linked with the deformation of the respective systems. The ground state deformations of the dominant daughter nuclei produced in ${}^4\text{He} + {}^{165}\text{Ho}$ ($\beta_2 \sim 0.284$ for ${}^{166,167}\text{Tm}$) and ${}^4\text{He} + {}^{181}\text{Ta}$ ($\beta_2 \sim 0.24$ for ${}^{182,183}\text{Re}$) reactions are significantly higher than those produced in ${}^4\text{He} + {}^{197}\text{Au}$ reaction ($\beta_2 \sim 0.044$ for ${}^{198,199}\text{Tl}$). The collective enhancement factors calculated using Ref. [1] for these systems indicate that there should be appreciable collective enhancement at the lower excitation energy in the two deformed systems ($K_{coll} \sim 80$) as compared to the nearly spherical third system ($K_{coll} \sim 1$). So, the observed variation of inverse level density parameter with excitation energy for the deformed systems is clearly a signature of collectivity induced modification (enhancement) of the level density, which is absent in case of nearly spherical system (${}^4\text{He} + {}^{197}\text{Au}$).

References:

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