Search for fadeout of collectivity in nuclear level density

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Nuclear level density (NLD) is an essential ingredient in nuclear reaction code to calculate reaction cross-sections. Nuclear level density is generally described semi empirically using Fermi Gas model. Fermi Gas model does not however account for the microscopic effects such as shell structure, pairing correlation and collective excitation in the nuclear level density. These are generally incorporated phenomenologically in this model. Collective excitation has a significant effect on nuclear level density particularly for deformed nuclei. For nuclei with appreciable ground-state deformations, it has been conjectured by Ignatyuk et al. [1] that, at low excitation energies, there should be collective enhancement of NLD due to the coupling of the rotational as well as the vibrational degrees of freedom with the single particle degrees of freedom. The enhanced level density $\rho(E^*, J)$ may be expressed as $\rho(E^*, J) = \rho_{int}(E^*, J)K_{coll}(E^*)$, ρ_{int} being the single particle level density and K_{coll} the collective enhancement factor.

In our earlier study [2] we have observed the signature of collectivity in nuclear level density by the statistical model analysis of the measured neutron spectra from $^{201}Tl^*$, $^{185}Re^*$, and $^{169}Tm^*$ compound nuclei, having different ground-state deformations. The values of the inverse level density parameter ($k = A/\tilde{a}$), extracted at two excitation energies ($E^* \sim 37$ and 26 MeV) were observed to decrease substantially at the lower excitation energy (~26 MeV) for nuclei having large ground-state deformation (residues of $^{185}Re^*$ and $^{169}Tm^*$), whereas for near-spherical nuclei (residues of $^{201}Tl^*$), the k value remained unchanged at the two energies. The nature of variation as seen above is primarily due to the collective excitations which is correlated with deformation of the respective nuclei. It is well known that collective excitations gradually deplete with excitation energy, due to weakening of long range correlations. However it is still not experimentally observed at what excitation energy this fadeout occurs. Bjornholm [3] suggested critical temperature $T_c = 40A^{-1/3}\beta_2$ at which fade out is expected, here β_2 is the ground state nuclear quadrupole deformation parameter and A is the mass number. To search for any such signature, we have recently performed an experiment where we populated three compound nuclei $^{173}Lu^*$ ($^4He + ^{169}Tm$), $^{185}Re^*$ ($^4He + ^{181}Ta$) and $^{201}Tl^*$ ($^4He + ^{197}Au$) in the excitation energy range ~ 22 – 56 MeV. The ground state deformations β_2 for ^{173}Lu, ^{185}Re and ^{201}Tl are 0.286, 0.221, -0.044 respectively. The critical temperatures for the three reactions are 1.55 MeV ($^4He + ^{181}Ta$), 0.3 MeV ($^4He + ^{197}Au$) and 2.05 MeV ($^4He + ^{169}Tm$).

Evaporated neutron energy spectra were measured through time of flight technique using four liquid scintillator based neutron detectors [4] placed at backward angles 90°, 110°, 120° and 150°, placed at a distance of 150 cm from the target position. A 50 element BaF_2 detector array [5] was used as start detector for the above time of flight measurement. The measured time of flight energy spectra were converted to neutron energy spectra. The neutron energy spectra in centre of mass frame were compared with the neutron spectra calculated using statistical model code GEMINI++ [6]. Inverse level density parameter has been extracted by χ^2 minimization of these two respective plots. Fig 1 shows the measured neutron energy spectra along with the statistical model fit for $^4He + ^{181}Ta$ system in the excitation energies range ~ 27 to 52.6 MeV. Extracted values of inverse level density parameter are given in the graph. Fig 2 shows the neutron energy spectra for $^4He + ^{169}Tm$ in the excitation energy range ~ 27 to 51.8 MeV. The k values extracted for ^{4}He + ^{181}Ta varies from 9.0 ± 0.5 to 11.5 ± 0.5 with the change in excitation energy from 27.2 to 41.8 MeV, at 51.6 MeV, k value was found to be 11.0. The k values for the reaction ^{4}He + ^{169}Tm varies from 7.5 ± 0.5 to 10.0 ± 0.5 as the excitation energy changes from 27.3 MeV to 51.8 MeV.

From the preliminary analysis of the data it appears that there is a sharp change in inverse level density parameter k with excitation energy for the two deformed system reported here. This indicates a relative decrease in nuclear level density with excitation energy. Further analysis for all three nuclei in all the excitation energies are in progress, which will be reported during symposium.

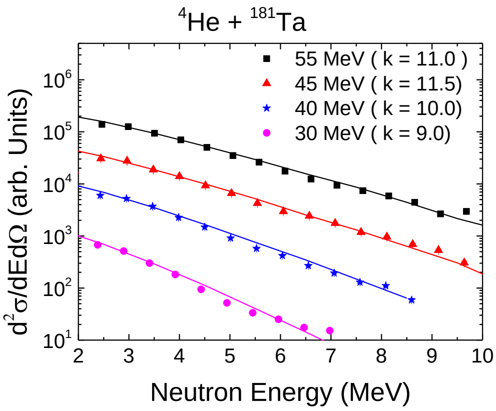

Fig 1 Measured neutron energy spectra (symbol) along with statistical model fit (solid line) for different lab energies for ^{4}He +^{181}Ta system.

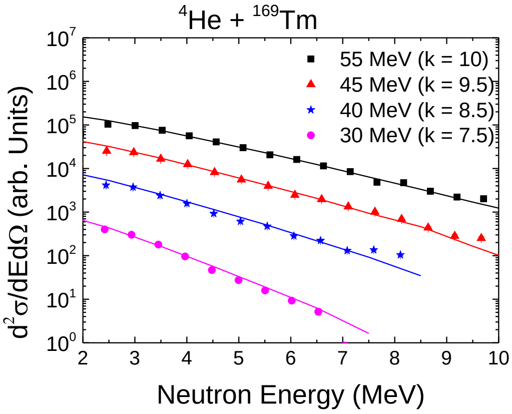

Fig 2 Same as Fig. 1 for ^{4}He + ^{169}Tm system.

References

[1] A. V. Ignatyuk, K. K. Istekov, and G. N. Smirenkin, Sov. J. Nucl. Phys. **29**, 450 (1979).

[2] Pratap Roy et.al., Phys. Rev. C 88 (2013) 031601(R).

[3] S. Bjormholm et. al., Proceedings of the International Conference on the Physics and Chemistry of Fission, Rochester, New York, 1973 (IAEA, Vienna, 1974), Vol. 1, p. 367.

[4] K. Banerjee et al., Nuclear Instruments and Methods in Physics Research Section A 608, 440 (2009).

[5] Deepak Pandit et al., Nuclear Instruments and Methods in Physics Research Section A 624, 148 (2010).

[6] R. J. Charity, Phys. Rev. C **82**, 014610 (2010).