Evidence of Large Collective Enhancement of Nuclear Level Density

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Nuclear Level Density(NLD) is an essential input parameter in the Hauser-Feshback or Weisskopf-Ewing evaporation model calculation often used to obtain nuclear reaction cross sections. Thus, the NLD is employed to estimate the low energy astrophysical reaction rates[2], study of giant resonances, reaction rate relevant for energy and isotope production for medical applications etc,.

Even-though the NLDs are extensively studied both experimentally and theoretically over the years, the effects of collective enhancement of the NLD for different mass regions are less understood.

Bohr and Mottelson have derived NLD formula for an axially deformed nucleus [3], given as,

$$\rho(E_X, J) = \sum_{K=-J}^{J} \frac{1}{\sqrt{8\pi}\sigma_\perp} e^{\frac{-K^2}{2\sigma^2}} \rho_{int}(E_X - E_{rot}),$$

When the above formula is compared to the level density of spherical nuclei, an enhancement factor of $\sigma_\perp^2$ is obtained. $\sigma_\perp$ is perpendicular spin cut of the parameter describing the width of the spin distribution along the perpendicular axis. $\sigma_\perp \approx 11\sqrt{T(MeV)}$(for Lanthanides), T is nuclear temperature, implies a rotational enhancement factor of about 100 at nucleon binding energies.

Recent Finite-temperature relativistic Hartree Bogoliubov model [4] calculations showed an enhancement factor of ~ 40 in the mass region $A = 160$-170. Shell Model Monte Carlo(SMMC) calculations shows the fade out of rotational enhancement around 20-30 MeV[5]. Many experiments have been carried out to find the collective enhancement character in deformed nuclei in the mass region A $\approx$ 160-200 [6–8].

The purpose of the present work is to extract the collective enhancement factor in ^{171}Yb by comparing the calculated (statistical model) level density with the experimental level density extracted from measured neutron evaporation spectra.

The experiment was carried out at 14UD BARC-TIFR pelletron accelerator with weakly bound ^{7}Li pulsed beam of energy 40 MeV bombarded on self supported ^{169}Tm target of thickness 2.72 mg/cm2. The compound nucleus ^{172}Yb is populated using breakup/transfer of triton from ^{7}Li to target nucleus. Two ΔE-E telescope strip detectors of 5 cm$\times$5 cm dimension were placed at about 10 cm from the target center used for charged particle detection. An array of 15 liquid scintillation(LS-EJ301) detectors was used for neutron detection.

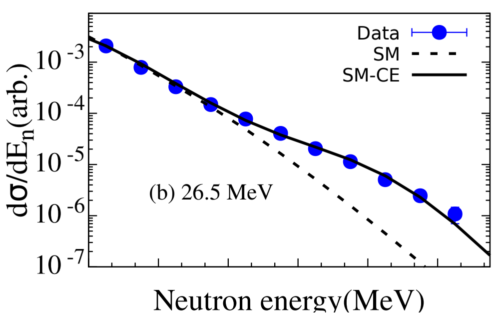

FIG. 1: Comparison of neutron spectra with Statistical Model calculation using the level density parameter A/8.5 MeV^{-1}. Solid line show calculation with collective enhancement (SM-CE) and dashed line is without collective enhancement (SM).

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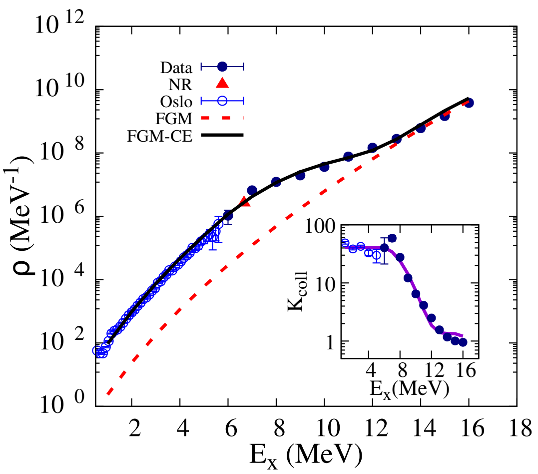

FIG. 2: The NLD obtained as a function of excitation energy using Oslo data [10] and present experiment, normalized to the level density at the neutron resonance point(NR). The dashed red line shows intrinsic level density from Fermi gas model(FGM) and black solid line shows Fermi gas level density with collective enhancement(FGM-CE).

The statistical model(SM) analysis of measured neutron spectra with the level density parameter A/8.5 MeV^{-1} has been performed. A/8.5 MeV^{-1} was opted by fitting the low energy neutron spectra($<$ 6MeV) where the slope is fairly constant as shown in Fig.1. Any deviation in the slope from A/8.5 MeV^{-1} is attributed to the contribution from collective degrees of freedom known as collective enhancement. The total nuclear level density can be written as $\rho_{tot} = \rho_{int} K_{coll}$, where K_{coll} includes both rotational and vibrational enhancement contributions.

In the CASCADE model this collective enhancement factor K_{coll} was included as a Fermi function given as,

$$K_{coll} = 1 + A_{en}.\frac{1}{1 + e^{\frac{(E-E_{cr})}{D_{cr}}}} ,$$

where A_{en} is the collective enhancement factor. The sensitivity of the level density parameter was studied by varying the inverse level density parameter with k= 8.5± 0.2 MeV. By the analysis of all three excitation energies from the three alpha bins, the collective enhancement and fade-out energy were found to be 40±3 and 14±1 MeV respectively.

The experimental level density was obtained using the following scaling technique[9],

$$\rho_{exp}(E_X) = \frac{(d\sigma/dE_n)_{exp}}{(d\sigma/dE_n)_{fit}} \rho_{fit}(E_X),$$

The extracted level density was then combined with Oslo data[10] as shown in Fig 2. The inset shows collective enhancement with E_X obtained from the combined data sets. A large collective enhancement factor of ∼40 is observed for the first time which corroborates with theoretical predictions.

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