On collective enhancement of nuclear level density

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Introduction

Nuclear Level Density(NLD) is a fundamental property of the atomic nucleus and an essential input for statistical models like Hauser-Feshbach calculations. Understanding how the magnitude of NLD changes with parameters like excitation energy, angular momentum, parity etc is very crucial for practical applications like calculation of reaction rates in astrophysics[1], synthesis of heavy elements, design of nuclear reactors etc. Many nuclei are deformed in its ground state and for a deformed nuclei in addition to intrinsic level density, the residual interactions of nucleons gives off collective degrees of freedom. The total NLD is written as $\rho_{tot} = \rho_{int} K_{coll}$. K_{coll} includes both rotational and vibrational enhancement contribution. Using statistical methods Bethe derived NLD formula to be proportional to $e^{2\sqrt{aE_x}}$, where **a** is the level density parameter. Two interesting problems regarding NLD are contribution of magnitude of collective enhancement to the intrinsic NLD, and the transition region where the collective nature dies off. Bohr and Mottelson [2] calculated collective enhancement factor for a deformed nuclei and is of the order $\sigma_\perp^2$ ($\sigma_\perp \approx 10$ for A $\approx$ 170), but various recent measurements on collective enhancement resulted about one order of magnitude less than this prediction.The calculations show that the shape transition from deformed to spherical happens at temperature T $\approx$ 1.7 MeV which is about 60 MeV excitation energy for A $\approx$ 170 nuclei having $\beta_2 \approx 0.3$. But the recent experimental studies on neutron evaporation spectra from A $\approx$ 160-200 indicated the fade out region around 15 MeV excitation energy (T $\approx$ 0.8 MeV) [3–6] much below the predicted transition region.

In the recent work using finite- temperature relativistic Hartree-Bogoliubov model of [7], the calculated collective enhancement K_{coll} in mass region $A = 160\text{-}170$ is about ≈ 40. Also in [8] using microscopic level density model a similar magnitude of collective enhancement has been calculated.Though the experimental enhancement factor from the recent measurements is well below the predicted value, it is necessary to populate compound nucleus using different techniques and measure the collective level density contribution for practical statistical model applications. The aim of the present measurement is to study the rotational enhancement of the nuclear level density(NLD) in ^{171}Yb and its fade out with E_x. The statistical model analysis of the measured neutron spectra from ^{172}Yb, populated through the breakup-fusion reaction of ^{7}Li with ^{169}Tm will reveal the fade out of rotational enhancement with E_x.

Experimental Details

Self supported ^{169}Tm target of thickness 2.72 mg/cm^2 was bombarded with weakly bound ^{7}Li pulsed beam of energy 40 MeV.The desired compound nucleus was populated in incomplete fusion reaction of weakly bound ^{7}Li where predominantly triton fuses with target to form ^{172}Yb. At 40 MeV, the most probable excitation energy is 26.5 MeV. Three ΔE-E telescope strip detectors (5 cm$\times$5 cm dimension) placed at about 10 cm from the target at mean angles $\pm 60^\circ$ and 140° used for charged particle detection. The neutron time of flight(TOF) technique is used to measure the neutron energy using an array of 15 liquid scintillation(LS-EJ301) detectors.The LS ar-

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ray having the angular coverage range 58° to 143° is placed at 72.5 cm from the target center and there is a 16° separation between each detector. Neutron-gamma discrimination is done by both TOF and pulse shape discrimination (PSD) methods. The neutrons were detected in coincidence with charged particles.

Results and Discussion

The emission of evaporated neutrons depends on nuclear temperature (T) of the residual nuclei and the T is related to excitation energy by the relation $T = \sqrt{U/a}$ where a is nuclear level density parameter which is in turn used in NLD formula.

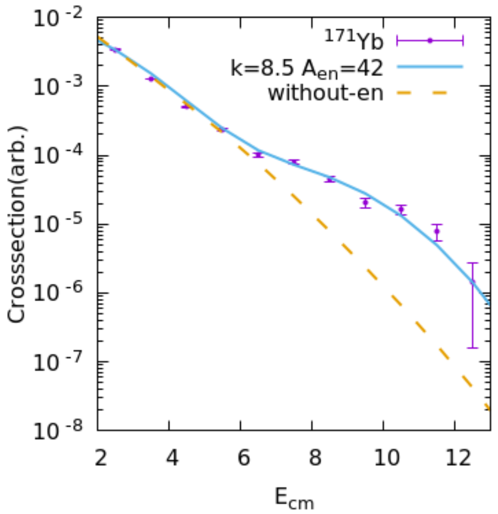

FIG. 1: solid line shows the CASCADE fitting with enhancement, dashed line is without enhancement. k=8.5 was used in both cases.

Evaporated neutron energy spectra (gated with alpha energy bin to populate compound nucleus at a particular excitation energy) in the center of mass frame was compared with the modified statistical model code CASCADE. As shown in the Fig.1. the magnitude of contribution of collective enhancement to the intrinsic NLD is emulated using a Gaussian function multiplied by the enhancement factor. Inverse level density parameter k, critical energy U_{cr}, and the enhancement factor A_{en} have been used as free parameters in the collective enhancement function. FIG.1 shows the CASCADE fitting with and without enhancement factor(without-en) at the compound nucleus excitation energy 26.5 MeV. k=8.5 is chosen by finding the best fit to the low energy data points upto 6 MeV. In the present measurement, it is found that the enhancement factor for ^{171}Yb is as high as 42 which is considerably larger than the several other recent measurements in near mass region [3–6] but in agreement with recent microscopic level density calculations [7, 8]. Physical parameters pertaining to the collective enhancement of NLD have been derived within the frame work of the statistical model decay of compound nucleus which will eventually shed light on magnitude of collective enhancement and its fade-out with excitation energy.

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