Study of collective enhancement of nuclear level density using fusion evaporation reaction

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Introduction

Collective enhancement of nuclear level density (CELD) has recently gained interest after evaporation spectra showed evidence of fade-out of CELD [1–5]. The enhancement factor for axially deformed nuclei over the intrinsic level density is predicted to be σ^2 [6, 7] where, σ is spin cut off factor. For nuclei in 170 a.m.u. mass region σ^2 is of the order of 100. The enhancement vanishes with increase in energy as the nucleus becomes spherical. First experimental signature of CELD was found in the fission fragment yield distribution [8]. In recent years, fusion evaporation spectra of neutron, proton, α-particle and high energy γ-ray spectra have been used to study CELD and its fade-out [1–5]. In the mass region of $A \sim 170$, the enhancement factor (A_{en}) was found to be 10 which is significantly small compared to the initial prediction. The critical energy of fade-out (U_{crit}) was found to be near 15 MeV. For ^{171}Yb, a recent study showed large enhancement, $A_{en} = 40$ [9]. In this study we have populated ^{171,172}Yb via fusion evaporation channels and effect of CELD was studied.

Experiment

The experiment was carried out at BARC-TIFR pelletron using ^{11}B beam of energy in the range of $44-53$ MeV. Self-supporting target of ^{165}Ho of thickness 1mg/cm^2 was used. Four $E-\Delta E$ telescope detectors, made of silicon strip detectors of thicknesses 50 and 1500 μm were placed at angle of $\pm160°$,100°,120° with respect to the beam direction. Four single telescope detectors were also placed at angles of $50°, 60°, 70°, 80°$ with respect to beam direction for obtaining the angular distribution of the evaporated charged particles. Evaporated α-particles were taken from detectors placed at $\pm160°$ to minimize the contamination from direct reactions. Charged particles were identified using the energy losses in thin and thick detectors. Figure 1 shows two dimensional plot of energy loss in thin (ΔE) and thick detectors (E_{res}) at E_{beam} = 53 MeV. As can be seen from the figure, α-particles are clearly separable from other charged particles. A two dimensional cut was applied on on α-particles for further analysis.

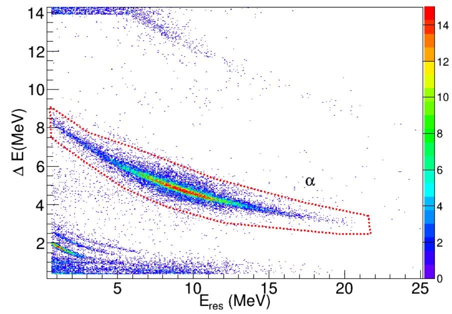

FIG. 1: ΔE vs E_{res} spectrum for beam energy of 46.5 MeV.

Result and Analysis

Evaporated α-particle spectra for each beam energy was compared with the statistical model code CASCADE and fusion cross sections were taken from CCFULL code. In the CASCADE calculation, the value of inverse level density parameter k was varied

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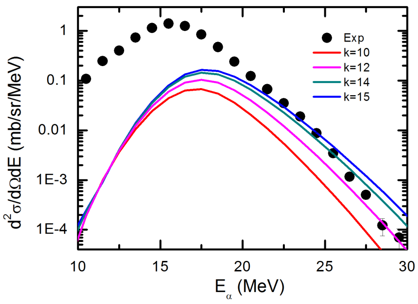

FIG. 2: Evaporated α-particle spectra for beam energy of 47 MeV along with CASCADE prediction for different k values.

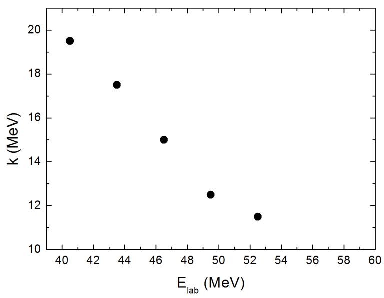

FIG. 3: Bestfit k as a function of beam energy.

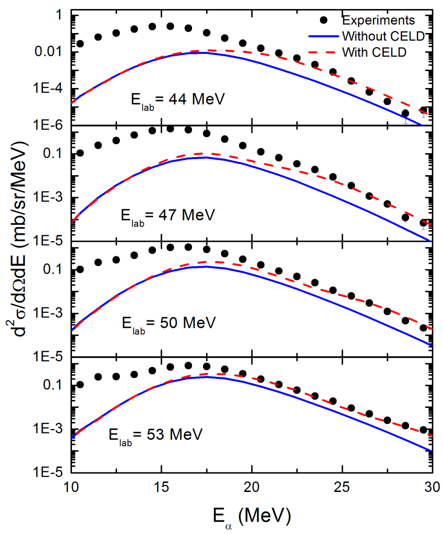

FIG. 4: Evaporated α-particle spectra are shown by symbols. Solid lines show CASCADE prediction ($k = 10.0$) without CELD. Dashed lines show calculations with CELD.

in order to get best-fit with the experimental data. In fig. 2, experimental and calculated spectra are shown for beam energy of 47 MeV. As can be seen in the figure that the low energy part ($E_\alpha < 17.0$ MeV) of the α-particle spectra is not reproduced by the CASCADE prediction. This was previously also observed for ^{12}C+^{159}Tb [5] and needs further investigation. Hence, only the higher energy α-particles were considered for extracting k. For other CN in this mass range, $k = 9.5 - 10.0$ were found to explain evaporation spectra [1, 5]. For reaction ^{11}B+^{165}Ho, high energy part of the α-particles spectra was under-estimated by $k = 10.0$ for all the beam energies and higher k value was needed as can be seen from fig.2. Best-fit k values as a function of beam energy is shown in figure 3. As can be seen from the figure, higher k was needed for explaining spectra at low beam energies. Similar behaviour of k was reported previously and was attributed to fade-out of CELD [1, 4, 5]. The CN ^{176}Hf populates residual nuclei ^{171,172}Yb after nα or α evaporation. Enhanced level density of ^{171,172}Yb for excitation energy $U < 20.0$ MeV results in an increase in the high energy α-particles yield and a higher k value is needed to explain the experimental spectra. When collective enhancement was included in the CASCADE calculation with $A_{en} = 5.0, U_{crit} = 17.0$, spectra for all the energies could be explained with single value of $k = 10.0$. Figure 4 shows experimental α-particle spectra for different beam energies. CASCADE prediction without and with CELD are shown by solid and dashed lines. The obtained value of A_{en} is significantly lower than that obtained for ^{171}Yb using transfer reaction [9] which needs further investigation.

References

[1] K. Banerjee *et al.* Phys. Lett. B 772, 105 (2017).
[2] D. Pandit *et al.* Phys. Rev. C 97, 041301(R) (2018).
[3] D. Pandit *et al.* Phys. Lett. B 816, 136173 (2021).
[4] G. Mohanto *et al.* Phys. Rev. C 100, 011602 (2019).
[5] G. Mohanto *et al.* Phys. Rev. C 105, 034607 (2022)
[6] A. Ignatyuk *et al.* Sov. J. Nucl. Phys. 29, 450 (1979).
[7] S. Bjornholm *et al.* Int. Conf. on the Phys. and Chem. of Fiss. 1, 367 (1973).
[8] A. Junghans *et al.* Nucl. Phys. A 629, 635 (1998).
[9] T. Santhosh *et al.* Phys Lett. B 841, 137934 (2023).