Large Collective Enhancement of Nuclear Level Density in ^{161}Dy

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Introduction

The nuclear level density(NLD) is a measure of how many quantum states are available for a nucleus at a given excitation energy. It is important for understanding nuclear reactions, especially those involving highly excited nuclei. One way to estimate the nuclear level density is to use the Fermi gas model, which treats the nucleons as independent particles moving in a mean field potential. However, this model neglects the effects of nuclear deformation and collective motion, which can enhance the level density significantly.

To gain a deeper understanding of collective motion in nuclei, one can examine the NLDs at specific excitation energies where statistical principles can be applied. If collective motion is observed, it indicates the existence of additional degrees of freedom for low-energy excitations. This, in turn, can lead to a significant increase in the overall NLD [1].

Jie Zhao et. al. [2] utilized the Finite-temperature relativistic Hartree Bogoliubov model and found that there is an increase of approximately 40 times in the mass range of A = 160-170. Another work, using the Shell Model Monte Carlo (SMMC) calculations, demonstrated that the rotational enhancement diminishes at around 20-30 MeV. Numerous experiments have been conducted to investigate the collective enhancement properties in deformed nuclei within the mass range of approximately A ≈ 160-200, as reported in [3–6].

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Experiment

The experiment was carried out at the 14UD BARC-TIFR pelletron accelerator. A weakly bound ^{7}Li pulsed beam with an energy of 40 MeV was directed towards a self-supported ^{159}Tb target, which had a thickness of 2.8 mg/cm2. The compound nucleus ^{162}Dy is populated using breakup/transfer of triton from ^{7}Li to target nucleus. To detect charged particles, two ΔE-E telescope strip detectors, each measuring approximately 5 cm×5 cm, were positioned around 10 cm away from the center of the target. An array of 15 liquid scintillation(LS-EJ301) detectors was used for neutron detection.

Statistical model analysis

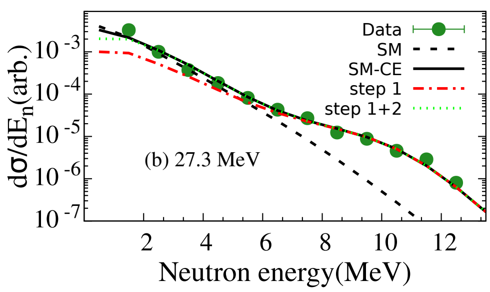

FIG. 1: Comparison of neutron spectra with Statistical Model calculation using the level density parameter A/8.5 MeV^{-1} is shown. The solid line represents the calculation with collective enhancement (SM-CE), while the dashed line represents the calculation without collective enhancement (SM). Contributions from the first and second step evaporation are also shown.

The neutron TOFs were converted into neutron energy spectra using appropriate Jacobian factor. The efficiency of neutron detectors as a function of incident energy and threshold were estimated using a Monte Carlo simulation. To assess the potential presence of collective enhancement in the neutron spectra, we conducted a comparison between the experimentally measured neutron spectra and the statistical model code CASCADE as shown in Figure.1. The CASCADE code has the feasibility to include collective enhancement(K_{coll}) explicitly, and is modeled as,

$$K_{coll} = 1 + A_{en}(1 + \exp[(E - E_{cr})/d_{cr}])^{-1}$$

The value of k = A/8.5 MeV^{-1} was obtained by fitting the low-energy neutron spectra (< 6 MeV). Subsequently, the parameters of the enhancement function were adjusted to reproduce the experimental data. The optimal parameters were determined by simultaneously fitting the three excitation energies obtained from three energy bins of alphas, resulting in a maximum collective enhancement factor of 42±2. Additionally, the values of E_{cr} and d_{cr} were determined to be 8.5±0.5 MeV and 1.2±0.2 MeV, respectively. Figure 2 shows the enhancement factor as a function of excitation energy extracted from the ratio of level density with Kcoll (collective enhancement) included in the CASCADE calculations to the Fermi gas model + constant temperature model(CT+FGM), denoted as CASCADE. The enhancement extracted from Oslo data combined with present measured enhancement is also shown.

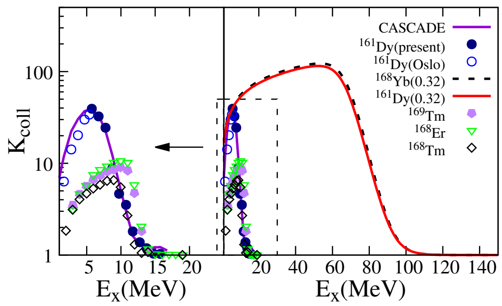

FIG. 2: The figure illustrates the enhancement factor as a function of excitation energy, obtained by comparing the level density calculations incorporating Kcoll (collective enhancement) in the CASCADE model to the constant temperature + Fermi gas model (CT+FGM), referred to as CASCADE. The figure further includes experimental enhancement factors for various nuclei [5].

Conclusion

In our study, we investigated the nucleus ^{162}Dy through an incomplete fusion reaction and analyzed the resulting neutron evaporation spectra. By comparing the experimental data with statistical model calculations, we observed a significant deviation, indicating the presence of collective enhancement. To address this deviation, we proposed an excitation energy-dependent collective enhancement based on the suggestion by Hansen and Jensen. By incorporating this collective enhancement, we were able to successfully explain the experimental data. Furthermore, our statistical model analysis revealed a maximum collective enhancement of 42±2, with fade-out observed at around 15 MeV. These findings highlight the importance of considering collective enhancement in statistical model calculations and implications for nuclear reactions, affecting the rates of neutron capture, fusion reactions, and nucleosynthesis processes in stars.

We thank the PLF staff for smooth running of the machine and target laboratory staff for targets.

References

[1] A. Bohr, B.R. Mottelson, Nuclear Structure, vol. 1, Benjamin, New York, 1969

[2] Jie Zhao,et al., Phys. Rev.374 C 102, 054606(2020).

[3] T. Santhosh, et. al., Phys. Lett. B 841, 137934 (2023)

[4] K. Banerjee, et al., Phys. Lett. B 772 (2017) 105.

[5] Deepak Pandit, et al., Phys. Rev. C 97 (2018) 041301(R).

[6] G. Mohanto, et al., Phys. Rev. C 100 (2019) 011602(R).