Experimental investigation on temperature dependence of nuclear level density parameter

Balaram Dey[1*], Deepak Pandit[1], Srijit Bhattacharya[2], Debasish Mondal[1], S Mukhopadhyay[1], Surajit Pal[1], A De[3], K. Banerjee[1] and S. R. Banerjee[2]
[1]Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata – 700064, INDIA
[2]Deptartment of Physics, Barasat Govt. College, Kolkata-700 124, INDIA
[3] Department of Physics, Raniganj Girls' College, Raniganj-713358, INDIA
* email: balaram.dey@vecc.gov.in

The knowledge of nuclear level density (NLD) is extremely crucial as an input parameter in the study of nuclear reaction cross sections, nuclear reaction rates which are needed for astrophysical calculations, fission or fusion reactor design etc. Along with that, they also provide information about the thermodynamic quantities such as temperature and entropy as well as pairing correlations in the nuclear structure study. However, the knowledge of NLD parameter as a function of excitation energy, angular momentum for different nuclear shapes is in large part phenomenological. The most commonly used analytical expression for calculating NLD is based on the work of Bethe [1] for a system of non-interacting fermions. The backshifted Fermi gas model of NLD for a spherical nucleus A at excitation energy E* and angular momentum J used in statistical model code CASCADE is given by

$$\rho(E^*, J) = \frac{(2J+1)}{12}\left(\frac{\hbar^2}{2I_0}\right)^{3/2}\sqrt{a}\,\frac{\exp(2\sqrt{aU})}{U^2} \quad (1)$$

Here $U = E^* - E_{rot} - \delta p$ is the available thermal energy. E_{rot}, δp and I_0 are the rotational energy, paring energy and effective moment of inertia, respectively. The nuclear level density parameter a is related to the single particle level density in the region of the Fermi energy and is correlated to the mass of the nucleus as a = A/k. Recently, several groups have shown the effect of angular momentum on the NLD parameter experimentally, but the temperature dependence of the NLD parameter has not been studied extensively. Although, different theoretical and semi-empirical models on the temperature dependence of NLD parameter exist, only a few experimental data are available on the temperature dependence of NLD parameter [2]. For the success of any theoretical work or model, a wealth of experimental data is needed for a wide range of excitation energy and different mass ranges. Early experimental works [3, 4] supported the increasing NLD parameter with temperature in A~160 region. On the other hand, recent experiment of Chbihi et al [5] reported weaker dependence of a on T for lighter A ~ 128 system. These contradicting results deserve further investigation on the measurement of NLD as a function of temperature in a uniform way. Since, NLD parameter depends on both the angular momentum and temperature, it is very important to separate the two effects in order to understand their individual contribution. In this work, angular momentum gated T-driven inverse NLD parameter is investigated for medium mass nuclei (A~100) by measuring the evaporated neutrons along with the γ-multiplicity in ^{4}He + ^{93}Nb reactions. These experimental results provided the motivation to examine different theories available to the temperature dependence of the level density parameter.

The experiment was performed at VECC, Kolkata using alpha beam from the K-130 cyclotron. A self supporting 1 mg/cm2 thick target of 99.9% pure ^{93}Nb target was used. Four different beam (^{4}He) energies were used to populate the compound nucleus ^{97}Tc at the excitation energies of 29.3, 36.0, 43.0 and 50.4 MeV, respectively. The evaporated neutrons from the compound nucleus were detected by a liquid organic scintillator (BC501A) based neutron detector [7]. Along with the BC501A neutron detector, a 50 element low energy γ-multiplicity filter [8] was also used to estimate the angular momentum populated in the compound nucleus as well as to get a fast start trigger for neutron time-of-flight (TOF) measurement. The TOF spectrum was converted to energy spectrum using the prompt gamma peak as a time reference. The details of experiment and analysis part are discussed in [9].

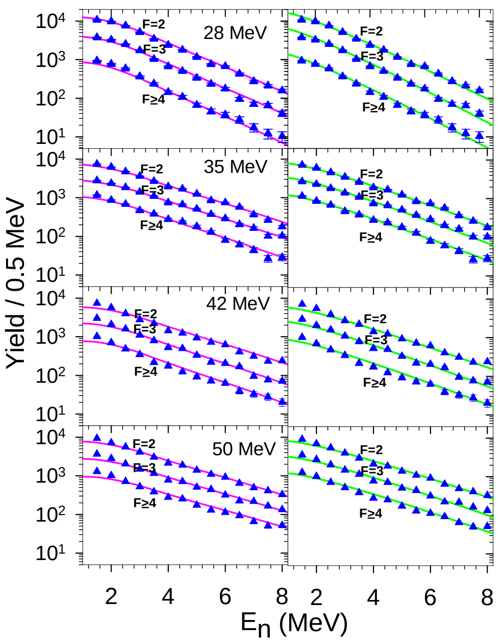

Fig.1. Experimental neutron energy spectra (symbols) at different angular momenta and excitation energies compared with CASCADE calculation (left panel) and Maxwellian (right panel) to extract the level density parameter and temperature, respectively.

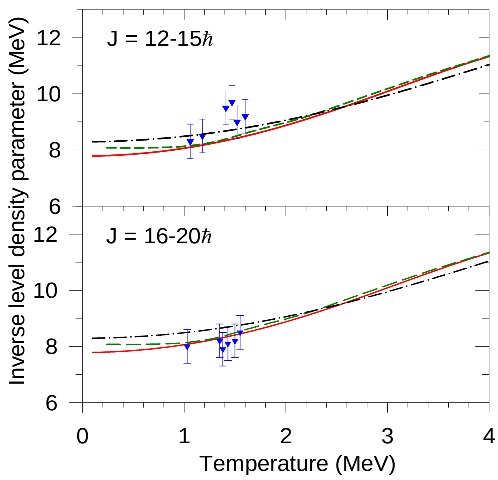

Fig. 2. The inverse level density parameter (symbols) compared with different theoretical models Shlomo (continuous line), Lestone (dashed line) and Mughaghab (dot-dashed line) for two angular momentum window

The experimental neutron energy spectra were compared with the statistical model code CASCADE to extract the inverse level density parameters. The average temperatures of the populated compound nucleus for different excitation energies were calculated by fitting the experimental data with Maxwellian function ($\sqrt{E}e^{-E/T}$). The neutron energy spectra along with the CASCADE calculation and the Maxwellian are shown in Fig 1. Finally, the inverse LD parameter as a function of temperature for two angular momentum windows have been compared with the three different theoretical calculations Shlomo [2] (continuous line), Lestone [10] (dashed line) and Mughaghab [11] (dot-dashed line) shown in Fig 2. The Shlomo calculation has been taken from literature for A=110 mass. The other two were calculated for A=97 mass using the formula given in Ref [10, 11]. It needs to be mentioned that none of the theoretical calculation includes J effect. As can be seen, the inverse level density parameter increases with increase in temperature (Fig 2). However, the data at higher angular momenta match very well with the calculations but are at disparity at low angular momenta. This outcome was unexpected since the calculations do not include J effect and, thus, data and theoretical calculation should have matched at lower J. The results indicate that the level density is suppressed at lower angular momenta compared to the Fermi gas model. As a matter of fact, this new data clearly indicate towards the fact that the angular momentum effect should also be included in calculations when T dependence of level density parameter is studied.

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