Investigating collective enhancement of nuclear level density using evaporation spectra

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Collective enhancement of nuclear level density has recently gained interest in experimental nuclear physics [1–8]. Due to the interplay between collective excitation and single particle energy levels, the nuclear level density at a given excitation energy and angular momentum is predicted to be higher than single particle level density which is known as collective enhancement of nuclear level density [9][10]. Nuclear level density $\rho(U, J)$ of a spherical nucleus having excitation energy U and angular momentum J can be expressed as [11]

$$\rho(U, J) = \frac{(2J+1)}{\sqrt{8\pi}\sigma^3} e^{\left\{-\frac{J(J+1)}{2\sigma^2}\right\}} \rho(U). \quad (1)$$

where $\rho(U)$ is the total state density independent of spin and σ is the spin cut-off factor. For a nucleus with axially symmetric deformation the level density at energy U and angular momentum J becomes

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

Here, $\rho_{int}(U)$ is total intrinsic state density due to single particle states and $\sigma_\perp$ is spin cut off factor perpendicular to the symmetry axis. $E_{rot}(K, J)$ in this equation is rotational energy of the nucleus. A comparison between equation 1 and 2 indicates that level density of a deformed nucleus is larger by a factor of $\approx \sigma^2$ since the value of $\sigma_\perp$ is comparable to σ. Similarly, presence of vibrational levels also causes enhancement of level density but the amplitude of the enhancement is small. As energy increases, the nucleus becomes spherical and the enhancement fades out gradually. The collective enhancement factor (σ^2) as well as the energy where collective enhancement fades out depend on nuclei property such as mass and ground state deformation. For highly deformed rare earth nuclei in the mass region of $150-170$ the value of σ^2 can be ≈ 100. Experimental evidence of of collective enhancement of nuclear level density and its fadeout was limited till last decade. First experimental evidence of CELD was reported by Junghans *et al.* [12] where enhanced level density was required to explain projectile like fragment yield distributions. In a later study by Komarov *et al.* [13], studied evaporated α-particle spectra from reaction ^{18}O+^{160}Gd were studied for investigating the effect of CELD on fusion evaporation spectra. However over an excitation energy range of $54 - 124$ MeV, no effect was observed and the measured α-particle spectra were well reproduced with statistical model without incorporating CELD. However in a few recent studies, evaporated neutron spectra showed evidence of CELD and its fadeout [1–3, 6].

In our recent studies we have investigated CELD and its fadeout using evaporated neutron and α-particle spectra [3, 5]. In these experiments we measured evaporated α-particles and neutrons for ^{11}B induced fusion reactions on number of targets. Evaporated particle spectra were measured for different beam energies in steps of $2 - 5$ MeV around the fusion barrier. Statistical model calculations were performed using CASCADE code. Fusion cross sections were taken from CCFULL code and was given as input to CASCADE. It was observed that no single value of level density parameter a could fit the α-spectra for all different beam energies. Hence, the value of inverse level density parameter $k(= 1/a)$ was varied to get best agreement between experimental data and CASCADE prediction. The value of k, when plotted as a function of

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excitation energy, showed a sudden increase over certain excitation energy. This kind of behaviour of k was reported earlier for neutron spectra and was attributed to the fadeout of CELD. In the statistical model code, an enhancement in the level density by a factor of K_{coll} was incorporated by taking $\rho(U) = \rho_{int}(U) * K_{coll}(U)$. Here $K_{coll}(U)$ is energy dependent enhancement factor and $\rho_{int}(U)$ is intrinsic level density. The form of $K_{coll}(U)$ was considered to be

$$K_{coll} = 1 + A_{en} \quad for\ U < U_{crit} \tag{3}$$

$$K_{coll} = 1 + A_{en} exp[(U - U_{crit})^2/2d_{crit}^2] \ for\ U > U_{crit}$$

where A_{en} is amplitude of enhancement, U_{crit} is critical energy value for CELD fadeout and d_{crit} is width of the CELD fadeout. With this form of K_{coll}, experimental spectra for different beam energies could be explained with a fixed value of k. Enhancement factor was extracted by fitting the experimental data with statistical model. For most of the studied nuclei, value of the enhancement factor was found to be $5 - 10$. The critical energy U_{crit}, where CELD fades out, was found to be $15-16.0$ MeV which is significantly small compared to the predicted value of 30 MeV. These values of K_{coll} and U_{crit} agrees well with reports where CELD factor was extracted from ^{4}He induced fusion reactions. These experimental results indicate that apart from neutron and γ-rays, α-particle spectra can also be good probe for investigating CELD and its fadeout.

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