Impact of the shell effects in Nuclear Level Density

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Introduction

The advancemnent of experimental techniques, to extract the nuclear level density (NLD) [1, 2] and to measure the thermodynamical properties of the excited nuclei, have opened up a new platform to explore the response of the nuclear systems subjected to the thermodynamical changes and consequently the structural changes that impact the nuclear level density and emission spectra of the decaying nuclear systems. Measurements of the damping of shell effects on NLD parameter with the excitation energy and the fadeout of collective enhancement of NLD with shape transitions [1–3] have indicated the significance of shell structure in NLD variations. On the theoretical front, the enhancement of NLD and the fluctuation in inverse LD parameter 'K' due to shape transition were found to be evident in deformed nuclei [4] but absent in closed shell nuclei. Since a part of the excitation energy is used up in overcoming the shell effects, the spherical and deformed nuclei respond to the excitations differently. This points towards the importance of the deformation, shape effects and most importantly the shell correction which is around $\approx 4 - 10$ MeV for magic nuclei and is large enough to impact the NLD in a major way. Therefore one must consider the shell effects while evaluating the excitation energy and NLD.

Brief description of work

We use the Statistical Model [4, 5] along with a triaxially deformed Nilsson potential including the shell correction in Macroscopic-Microscopic approach. We compute entropy and minimize the free energy $F = E - TS$ for Nilsson deformation parameters β and γ which give equillibrium deformation and shape of the excited nucleus. To evaluate the nuclear level density ($\rho(U_{th})$) of the residual nucleus, the internal excitation energy (U_{th}) of the residual nucleus is computed as U_{th} = E^* - E_{rot} -S_n - E_n where E_n is the average kinetic energy of the outgoing neutron, E^* is the total excitation energy available to the system due to the reaction process which is shared between the rotational energy (E_{rot}), neutron separation energy (S_n) and E_n. Our formalism has been very effective in reproducing and interpreting the data [4, 7] very well. To see the impact of shell correction, we use separation energy $S_N{}^{cor}$ (which includes microscopic corrections) and $S_N{}^{LDM}$ (which uses Macroscopic mass formula) for evaluating U_{th} and consequently NLD. We choose decay of the doubly magic ^{78}Ni and highly deformed ^{83}As compound nuclei.

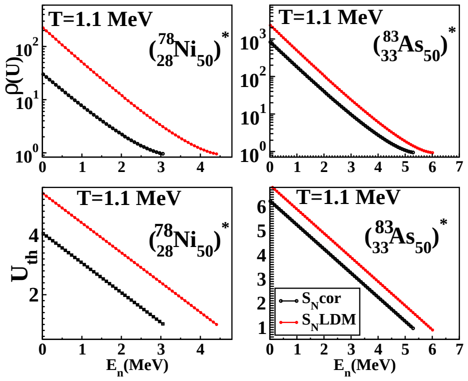

FIG. 1: plot of (a) NLD ($\rho(U_{th})$ (b) U_{th} vs the energy of outgoing particle E_n for (i) ^{78}Ni (ii) ^{83}As. Two curves in each panel correspond to calculations using $S_N{}^{cor}$ and $S_N{}^{LDM}$ respectively.

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Results and Discussion

Fig.1 shows the impact of including shell correction energy while evaluating U_{th} and NLD ($\rho(U_{th})$. Higher shell correction energy in doubly magic ^{78}Ni reflects in the large gap between the U_{th} curves and also in NLD ($\rho(U_{th})$ curves in ^{78}Ni as compared to the small gap between respective curves in well deformed ^{83}As (fig. 1). Enhancement of level density in deformed nucleus than in spherical is evident. In Fig. 2, we have plotted our computed NLD of an odd ^{69}As and neighbouring even -even ^{70}Ge nuclei along with data given in Ref. [6]. We compute the range of excitation energies (3 to 24 MeV) given in Ref. [6], using our formalism using T= 0.95 to 2.0 MeV by incorporating microscopic corrections and our calculated proton separation energy [5]. At low T, ^{69}As being more deformed than ^{70}Ge shows enhanced level density, NLD curves are apart from each other indicating the prevalent shell effects. At higher excitation energy the deformation drops to zero and the NLD curves almost converge at higher excitation showing the quenching of shell effects and pairing although pairing effects are not prominent at T> 0.8 MeV hence are not included in the present calculations. Our excitation energy and NLD variation show good match with that of available data [6]).

Conclusion

The significance of shell effects and the quenching of shell effects with the excitation energies on NLD is studied. Since the residual excitation energy (U_{th}) after particle evaporation has significant dependence on the separation energy S_N, the accurate determination of the value of S_N is essential for which the inclusion of shell correction energy is important. Excitation energy and NLD are shown to be impacted significantly by the shell effects, shell correction energy. The magic nucleus and deformed nucleus respond to excitation differently which gets reflected in NLD. Large deformation in odd-Z ^{69}As than even-even ^{70}Ge, contributes more to the level density but convergence of NLD curves with increasing excitation indicates the quenching of shell effects.

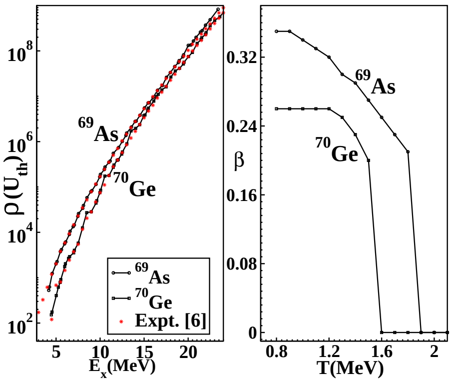

FIG. 2: (a) Our computed NLD ($\rho(U_{th})$ for ^{69}As and ^{70}Ge for the excitation energies given in Ref. [6] along with the $\rho(U_{th})$ data from ref. [6] which show excellent match. (b) β for T corresponding to the excitation energies used for calculating NLD.

Acknowledgments

M. Aggarwal acknowledges support from SERB (DST) under WOS-A scheme.

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