Influence of fragment deformation and orientation on compact configuration of odd-Z superheavy nuclei

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Introduction

The synthesis of heavy and superheavy nuclei is generally carried out by using hot and cold fusion reaction mechanisms. It has been noticed that, the cold fusion reactions occur at relatively low excitation energies ($E^*_{CN} \sim$ 10-20 MeV) whereas, the hot fusion reactions occur at excitation energies of $E^*_{CN} \sim$ 30-50 MeV. The fusion mechanism is quit different in both the processes. In the cold fusion process, the interaction of spherical targets (Pb and Bi) with deformed light mass projectiles occurs. On the other hand, the fusion of deformed actinide targets with spherical ^{48}Ca projectile characterize the hot interaction processes. Hence the deformations and orientations of targets and projectiles play extremely important role in the superheavy fusion process. From very general prospective, one can expect that heavy element production in heavy ion reactions is most favorable when the interaction configuration is compact. It is therefore of interest to investigate the behavior of deformations (β_{2i} and β_{4i}) and orientation degree of freedom for a chosen reaction.

In view of above, using extended fragmentation theory [1], firstly, the comparative analysis of two isotopes of Z=113 formed in hot and cold fusion processes is carried out to check the effect of reaction mechanism on the compactness of compound systems. It is relevant to mention that relatively lighter superheavy systems are synthesized using cold fusion process whereas the the one with Z $\geq$ 112 seem to prefer the hot fusion route. Therefore hot vs cold processes comparison are of huge significance near Z = 112. Beside this, the influence of increase in charge and mass on compact configuration of odd mass superheavy nuclei is also investigated.

Methodology

The extended fragmentation theory [1], is expressed in terms of collective coordinates of mass and charge asymmetries i.e. η_A and η_Z, relative separation R, multipole deformations $\beta_{\lambda i}$ (λ=2, 3, 4), and the relative orientations θ_i (i=1,2) of two nuclei. Using the relative separation R and η-coordinates, fragmentation potential V(η, η_Z, R) is defined as:

$$\begin{aligned} V_R(\eta,\eta_Z,R) \;=\; & \sum_{i=1}^{2}[V_{LDM}(A_i,Z_i,\beta_{\lambda i})]+\sum_{i=1}^{2}[\delta U_i] \\ & +V_C(R,Z_i,\beta_{\lambda i},\theta_i,) \\ & +V_P(R,A_i,\beta_{\lambda i},\theta_i,) \end{aligned} \quad (1)$$

The deformation parameters ($\beta_{\lambda i}$) of the nuclei are taken from the tables of Möller *et al.* [2]. The orientations are fixed by minimization of potential in the η_A co-ordinates as in [3]. The deformation and orientations effects are included through radius vectors, as stated below:

$$R_i(\alpha_i) = R_i\Big[1+\sum_{\lambda}\beta_{\lambda i}Y_{\lambda}^{(0)}(\alpha_i)\Big] \quad (2)$$

Calculations and Results

The present analysis is carried out to aggrandize the work of [3] which illustrate the role of deformations and orientations on even superheavy nuclei. Here, we extend this analysis for odd superheavy nuclei. It is relevant to note that the temperature and angular momentum effects are not included in the present analysis.

In Fig. 1, the variation of barrier height (V_B) with orientation angle (θ_i) for entrance channels of $^{285}113^*$ and $^{279}113^*$ compound nuclei formed respectively in ^{237}Np + ^{48}Ca $\rightarrow$ $^{285}113^*$ and ^{209}Bi + ^{70}Zn $\rightarrow$ $^{279}113^*$ reactions is presented. Since $^{285}113^*$ compound nucleus is formed via spherical projectile and deformed target, so it is expected to form a equatorial compact (ec) configuration however, the formation of $^{279}113^*$ is done via deformed projectile and weakly deformed target,

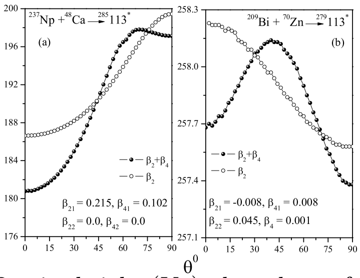

FIG. 1: Barrier height (V_B) plotted as a function of orientation angle (θ) for (a) $^{285}113^*$ formed in hot fusion reaction and (b) $^{279}113^*$ formed in cold fusion reaction.

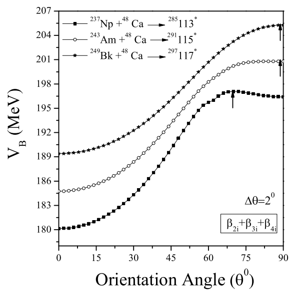

FIG. 2: Variation of barrier height (V_B) as a function of orientation angle (θ) for various ^{48}Ca based reactions forming the compound systems with Z= 113-117.

so it responds to belly-to-belly compact (bbc) configuration [3]. If we look at Fig. 1(a), it is clear that when deformations are included upto quadrupole (β_{2i}) alone, the compact angle is at 90^0, showing ec configuration, but after the inclusion of higher order deformations i.e. upto hexadecupole ($\beta_2 + \beta_3 + \beta_4$), compact angle shifted from 90^0 to 70^0 and configuration is no longer ec but becomes not-equatorial compact (nec). Similar observations are drawn when $^{285}113^*$ nucleus is replaced with $^{279}113^*$ as shown in Fig. 1(b). It may be observed that, for $^{279}113^*$ nucleus formed in ^{209}Bi-induced cold fusion reaction, compact angle show large deviations from optimum orientation. With β_{2i} deformation, compact angle is obtained at $\theta_c = 0^0$, but presence of deformations upto β_{4i}, changes the compact configuration to be around $\theta_c = 40^0$ resulting in not belly-to-belly configuration (nbbc). It is important to mention here that, the cold elongated configuration of hot and cold fusion reactions is insensitive to the presence of higher order deformations and corresponding elongated angle remain same as obtained for β_{2i}-optimum orientations.

Further, the comparative analysis of odd nuclei i.e. $^{285}113^*$, $^{291}115^*$, and $^{297}117^*$ formed in hot fusion reactions, is carried out in Fig. 2. From this figure one can interpret that for $^{285}113^*$, compact configuration is obtained at orientation angle $\sim 70^0$ indicating that it is the case of non equatorial compact (nec) configuration. But as Z increases, equatorial compact (ec) configuration shifts towards higher compact angle i.e. 90^0. This is possibly due to the reason that with increase in Z from 113 to 117, quadrupole deformations (β_{2i}) of target nuclei increases from 0.215 to 0.235 and hexadecapole deformations (β_{4i}) decreases from 0.102 to 0.04. So for higher Z nuclei, the values of β_{2i} is significantly large as compare to β_{4i}, therefore the effect of β_{4i} is negligible on compact configuration and hence compact angle is obtained at 90^0, similar to the one observed for β_{2i}-optimum orientations. These results are in accordance with the study made for even compound nuclei [3]. We are in the process to analyze the exclusive role of octupole (β_{3i}) deformations on the compact configuration.

Acknowledgments

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