Decay of Z=112 isotopes and related orientation effects across the Coulomb barrier

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Introduction

The probability of compound nucleus formation using above/below barrier collisions in the superheavy mass region is mainly associated with deformations and orientations of the reaction partners. This is because, at above barrier, the projectile can hit the equatorial region of the target, hence form the most compact nuclear structure on the way to compound nucleus formation. On the other hand, at the sub-barrier region the interaction is limited to the polar collisions where the probability for the re-separation of the reaction partners is high. In context to the decay of such composite systems, the symmetric fission mass distribution is observed in the above barrier region which changes to asymmetric mass fragment distribution governing less fusion probability, when the incident energy is reduced to sub-barrier region [1, 2].
Keeping this in mind, we have studied the comparative role of orientation degree of freedom for $^{40,48}Ca+^{238}U\rightarrow^{278,286}112^*$ [1] reactions using the dynamical cluster decay model (DCM)[2–4]. The calculations for above mentioned reactions are done in reference to the experimental data of [1] using quadrupole deformations within optimum orientation approach at comparable energies of $E_{c.m.} = 230$ (above barrier) MeV and 180 MeV (below barrier). For DCM, orientations play extremely important role since polar, "non-compact" and equatorial, "compact" configurations are obtained, respectively for large interaction radius with lowest barrier and smallest interaction radius with higher interacting barrier [3]. The calculations for fission cross-sections are made by taking proton magic Z=120 and N=184 in view of [4].

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The Model

The dynamical cluster decay model (DCM) [2–4], works in terms of the collective coordinates of mass (and charge) asymmetries (η and η_Z), and the relative separation R. Using partial waves analysis, the compound nucleus decay cross-section are calculated in terms of preformation factor P_o and penetrability P. The penetrability P is estimated using WKB approximation.
The preformation probability P_0, which imparts structure information of the decaying nucleus, is obtained by solving the stationary Schrödinger equation in η, at a fixed R=R_a

$$\left[-\frac{\hbar^2}{2\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}\frac{1}{\sqrt{B_{\eta\eta}}}\frac{\partial}{\partial\eta}+V_R\right]\psi^\omega = E^\omega_\eta\psi^\omega$$

with ω=0,1,2,3... referring to ground-state (ω=0) and excited-state solutions, with the ground state P_0 given as

$$P_0 = |\psi(\eta(A_i))|^2\frac{2}{A_{CN}}\sqrt{B_{\eta\eta}}, \qquad (2)$$

and for a Boltzmann-like function,

$$|\psi|^2 = \sum_{\omega=0}^{\infty}|\psi^\omega|^2\exp(-E^\omega/T) \qquad (3)$$

Calculations and Results

Generally, the collision of incoming reaction partners along the polar axis form a non compact nuclear structure at below barrier energies, whereas compact nuclear shape is preferred for above barrier equatorial collisions.

Firstly, to understand the fragment mass

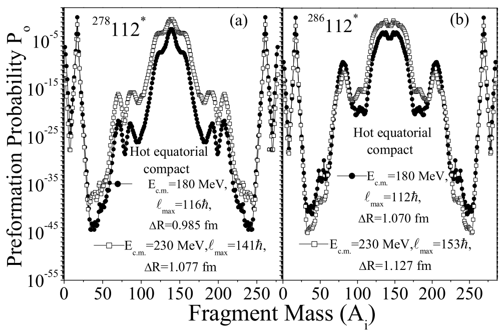

FIG. 1: Variation of preformation probability as a function of fragment mass for ^{40,48}Ca+^{238}U→^{278,286}112* reactions at $E_{c.m.}$ =180 and 230 MeV using hot equatorial configuration.

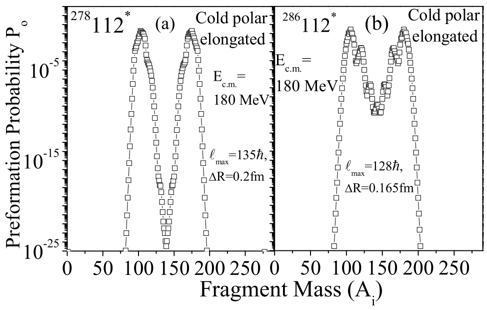

FIG. 2: Variation of preformation probability as a function of fragment mass for ^{278,286}112* isotopes at $E_{c.m.}$ =180 MeV using cold polar configuration.

distribution across the barrier, Fig.1 is plotted at $E_{c.m.}$ = 230 MeV (above barrier) and 180 MeV (below barrier) for ^{278}112* and ^{286}112* using hot equatorial configuration. It is clear from Fig.1 that symmetric fragment mass distribution is dominant for both nuclei which further confirms the fact that fusion-fission is the dominant decay mode in chosen reactions. For isotopic comparison of Z=112, it is clear that the fragments with $A/2{\pm}16$ are contributing towards the fission cross-sections, and the symmetric fragments show more prominence for lighter isotope ^{278}112*. In addition to this, small asymmetric secondary-peaks are also emerging in the region of $A_2\sim$ 70-85 for both the nuclei. But their effective contribution towards fission cross-section is negligibly small. Interestingly, the emergence of such peaks in this mass region at below barrier energies is suggested in [1].

To address these secondary-peaks further, the polar elongated configurations are taken into account for sub-barrier region. It is clear from Fig.2 that asymmetric fission is dominant when the hot equatorial configuration is replaced by cold polar configuration. With cold polar elongated configuration the fragments with A_2=93-116 and A_2=96-125 contribute towards fission cross-sections of ^{278}112* and ^{286}112* respectively. The symmetric fragments show negligible contribution, which starts increasing marginally for neutron rich isotope of Z=112. The appearance of these asymmetric peaks seem to suggest that QF component may contribute at below barrier region. It is relevant to mention here that the observed mass-asymmetry for probable QF is smaller than the one anticipated in DCM based calculations for chosen reaction. Henceforth it would be of interest to include the higher order deformation effects for overall understanding of dynamics involved.

One may conclude from above discussion that orientation degree of freedom plays indispensable role to understand the dynamics of superheavy nuclei.

Acknowledgments

We are thankful to DST, New Delhi, for the financial support to this work.

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