Fission dynamics of superheavy nuclei formed in Uranium induced reactions

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Introduction

The compound nuclear system follows symmetric fission if the competing processes such as quasi-elastic, deep inelastic, quasi-fission etc are absent. The contribution of quasi-fission events towards the fusion-fission mechanism depends on the entrance channel asymmetry of reaction partners, deformations and orientations of colliding nuclei beside the dependence on energy and angular momentum [1]. Usually the ^{209}Bi and ^{208}Pb targets are opted for the production of superheavy nuclei with Z_{CN}=104-113. The nuclei in same mass/charge range can also be synthesized using actinide targets + light projectiles (i.e. asymmetric reaction partners) via hot fusion interactions. These actinide targets are prolate deformed which prefer the compact configurations at above barrier energies, indicating the occurrence of symmetric fission events [1]. Here an attempt is made to address the dynamics of light superheavy system (Z_{CN}=104-106), formed via hot fusion reaction involving actinide targets.

In order to look for the fission dynamics of actinide based reactions, ^{238}U target with lighter projectiles ^{26}Mg, ^{27}Al, and ^{30}Si are chosen for the present work. The ^{238}U-induced hot fusion reactions leading to ^{264}Rf*, ^{265}Db*, and ^{268}Sg* are investigated at comparable energy of 50±1 MeV in the framework of the dynamical cluster decay model (DCM). Although the main focus is on the study of ^{265}Db* nucleus but the results are generalized by including the decay mechanism of ^{264}Rf* and ^{268}Sg* compound systems. The calculations are carried out for the static and dynamical choices of deformed fragments using the hot optimum orientations.

The Model

The dynamical cluster decay model [2] based on fragmentation theory is worked out in terms of mass or charge asymmetry, relative separation $\bar{R}$, neck parameter, deformation and orientation. In terms of these parameters and with proper inclusion of temperature effects, the fragmentation potential $V_T(\eta$,R) reads as

$$\begin{aligned} V_T(\eta,R) &= -\sum_{i=1}^{2} B_i(A_i,Z_i,\beta_{\lambda i}) + V_C(Z_i,\beta_{\lambda i},\theta_i) \\ &\quad + V_P(A_i,\beta_{\lambda i},\theta_i) + V_\ell(A_i,\beta_{\lambda i},\theta_i) \quad (1) \end{aligned}$$

Using above potential, the Schrödinger wave equation is solved in η-coordinates at fixed R=R_a to get the preformation probability (P_0). The barrier penetrability (P) of the decaying fragments is worked out using WKB approach. The compound nucleus decay cross-sections for ℓ-partial waves is calculated as given in [2]. The deformations ($\beta_{\lambda i}$) used in the present work are static as well as dynamic deformations, the static one are taken from the theoretical estimates of Möller and Nix [3]. The temperature dependence in deformations is included through $\beta_{\lambda i}$(T) = $\exp(-T/T_0)\beta_{\lambda i}(0)$.

Calculations and Results

As mentioned above, the present analysis is carried out to study the ^{238}U-induced reaction leading to lighter superheavy nuclei such as ^{264}Rf*, ^{265}Db*, and ^{268}Sg*. The fission data is addressed within the framework of dynamical cluster decay model (DCM) by including the hot optimum orientations (θ_i) and quadrupole (β_{2i}) deformations of the fragments. The calculated fission cross-sections show nice agrement with the experimental data [1]. Fig.1 is plotted to observe the mass distribution of ^{264}Rf*, ^{265}Db* and ^{268}Sg* nuclei at excitation energy of 50±1 MeV using static and dynamic deformations. Symmetric

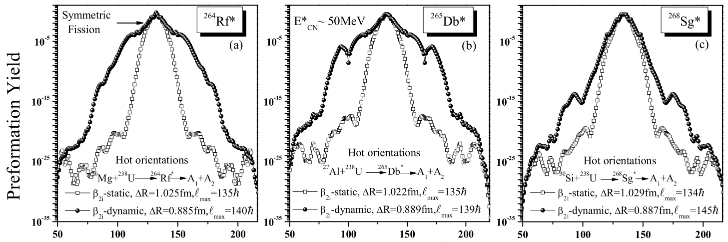

FIG. 1: Variation of preformation probability as a function fragment mass (A$_i$) with the use of static and dynamic deformation for (a)$^{264}Rf^*$, (b)$^{265}Db^*$, and (c) $^{267}Sg^*$ nuclei.

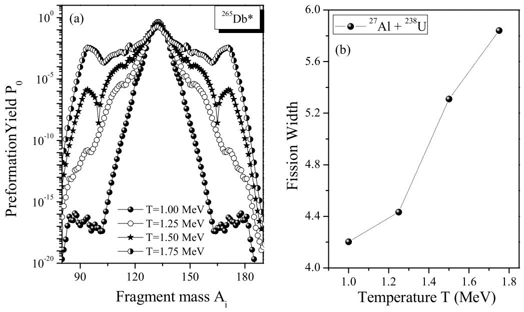

FIG. 2: (a) Preformation yield plotted as a function of fragment mass with the use of dynamical deformations at different temperature and (b) variation of fission width as a function of temperature (and hence energy).

fission fragmentation is observed for both the cases, but the difference lies in the fact that for the dynamic deformations, the structure of the asymmetric fission and heavy fragment mass (HMF) regions is significantly modified. Relatively broader fragmentation peak is observed for the dynamic choice of deformations. Broadly speaking, at such excitation energy (∼50MeV), the shell effects play silent role, so no asymmetric peak is observed across magic daughter. As mentioned earlier, for the fusion of highly asymmetric systems, the effect of Coulomb re-separation are expected to be small owing to the prevailing strength of attractive surface tension. Therefore the reactions of actinide targets with lighter projectiles favor the symmetric distribution in the fission region. It is relevant to mention that similar results are obtained with the inclusion of the higher order deformations which are not shown here to avoid repetition.

Fig.2 is plotted to explore the exclusive role of dynamic deformations on the preformation yield of fission region for ^{265}Db* nucleus. Fig.2(a) shows that with increase in the temperature, the distribution of the fragments gets modified from a sharp peaked structure to a broader state. At the highest temperature (T=1.75 MeV), more fragments contribute toward the symmetric fission region, as compared to that for lower incident energy or temperature. In order to explore this further, the gaussian widths of the symmetric distribution of the fragments (equivalently fission fragments) are plotted in Fig.2(b). Minimum width observed for the lowest temperature, clearly suggest that the more symmetric yield is obtained at lower temperature (T=1.0 MeV), which gets broader with rise in temperature. We are in the process to expand this analysis for heavier superheavy systems so as to comment on the distribution of fragments in the fission region.

References

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