Fusion-fission of $^{215}\text{Fr}^*$ nucleus using the Dynamical Cluster-decay Model

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Introduction

For the successful formation of heavy nuclei, deep understanding of fusion-fission process of the compound nucleus formed in low energy heavy ion reaction is essential. A number of factors and properties influence the fusion-fission process and hence need be handled with proper care in order to make meaningful predictions regarding the behavior of a nuclear system. Considering the importance of these factors (to be discussed in the following), we have done an extensive study on the fusion-fission excitation functions of $^{215}\text{Fr}^*$ formed in $^{18}\text{O}+^{197}\text{Au}$ reaction.

It has been reported in Ref. [1] that, the systems having entrance channel mass asymmetry ($\alpha = (A_T - A_P)/(A_T + A_P)$) smaller than the Bussinaro-Gallone mass asymmetry ($\alpha_{BG}$) show preference for pre-equilibrium or quasi-fission, compared to the ones with larger mass asymmetry. These observations are made in reference to the variance of measured anisotropies with respect to the standard saddle-point statistical model (SSPM) anisotropy predictions. In other words, the difference in measured and SSPM based anisotropies indicate the possibility of quasi-fission in addition to normal fission process.

The decay of $^{215}\text{Fr}^*$, formed in $^{18}\text{O}+^{197}\text{Au}$ reaction over a wide range of energy, has been studied using the Dynamical Cluster-decay Model (DCM) of Gupta and collaborators [2]. The DCM provides an effective alternative to the statistical Hauser-Feshback analysis and the statistical fission models, and hence used successfully to understand the cross-sections for Evaporation Residues, Intermediate Mass Fragments, Fusion-Fission and Quasi Fission processes. We have carried out the calculations using quadrupole deformed ($\beta_2$) considerations alone, using the “optimum” orientations for hot (compact) configurations in the fragmentation process.

The Model

The DCM, based on the well-known quantum mechanical fragmentation theory, including the effects of deformations and orientations of the two incoming or outgoing nuclei, contains the effects of angular momentum $\ell$ and temperature $T$. Using partial waves, the compound nucleus decay cross-section is

$$\sigma = \pi \frac{l_{\text{max}}}{k^2} \sum_{l=0}^{l_{\text{max}}} (2l + 1) P_0 P, \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}},$$

(1)

with $\mu$ as the reduced mass and $l_{\text{max}}$, the maximum angular momentum, fixed for the vanishing of the fusion barrier of the incoming channel, or else for the light-particles cross-section $\sigma_{ER} \to 0$. $P_0$, the preformation probability, is the solution of stationary Schrödinger equation in mass asymmetry coordinate $\eta$ and $P$ is the WKB penetrability of the preformed fragments or clusters in $R$-motion. The only parameter of the model is the $T$-dependent neck-length parameter $\Delta R(T)$. The fission anisotropy is also calculated for the DCM based parameters, within the SSPM approach [3].

Calculations and discussion

In the present work, we have calculated the fission cross-sections for the decay of $^{215}\text{Fr}$.
FIG. 1: (a) Fission cross-sections $\sigma_{\text{fission}}(E_{\text{c.m.}})$ calculated on DCM using $I_S$ limit, compared with experimental data and (b) The DCM calculated anisotropies using $I_{NS}$ limit, compared with SSPM calculations and experimental data on anisotropy, for decay of compound nucleus $^{215}\text{Fr}^*$.

($\alpha_{BG}=0.855$) compound system formed in $^{18}\text{O}+^{197}\text{Au}$ ($\alpha=0.833$) channel in reference to recent experimental data [4]. Hence, this is a case of $\alpha < \alpha_{BG}$, and should prefer quasi-fission process [1]. However, our DCM calculated fission cross-sections ($\sigma_{\text{fission}}$) in Fig. 1(a) show an excellent agreement with the experimental data at all reported centre of mass energies, thereby providing no signature of quasi-fission or any other non-compound nucleus decay process in the decay of $^{215}\text{Fr}$. Note that here the DCM calculated anisotropies are for use of moment-of-inertia in the non-sticking limit $I_{NS}$ ($=\mu R^2$). Thus, the DCM-based anisotropies are compared with SSPM and experimental data at a relatively much smaller value of angular momentum $\ell_{\text{max}}$-value.

Concluding, within the DCM, the non-sticking moment-of-inertia is found more appropriate for the anisotropy calculations whereas the sticking moment-of-inertia is more appropriate for obtaining the fission cross-sections which involves a larger limiting value $\ell_{\text{max}}$ and hence a smaller neck-length parameter $\Delta R$ required for the proximity potential ($\leq 2\text{fm}$).

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References