Decay of $^{213,217}$Fr* formed in $^{19}F+^{194,198}$Pt reactions using the dynamical cluster-decay model

Manoj K. Sharma$^1$,* Shefali Kanwar$^1$, Gudveen Sawhney$^1$, and Raj K. Gupta$^2$

$^1$School of Physics and Material Science, Thapar University, Patiala - 147004, INDIA, and
$^2$Department of Physics, Panjab University, Chandigarh - 160014, INDIA

Introduction

Fission excitation functions, i.e., fission cross-section $\sigma_{\text{fiss}}$ as a function of center-of-mass energy $E_{\text{c.m.}}$, or compound nucleus (CN) excitation energy $E_{\text{CN}}$, together with fission fragment angular distributions are measured for the $^{19}F+^{194,198}$Pt reactions forming the CN $^{213,217}$Fr* [1]. As expected, $\sigma_{\text{fiss}}$ for the more fissile CN $^{217}$Fr* is significantly larger over the entire measured energy range as compared to that for the less fissile $^{213}$Fr*. A significant contribution from the evaporation residue cross-section $\sigma_{\text{ER}}$ is also measured at some of the energies (three of six), giving the total fusion cross-section at these energies. The anisotropy data for $^{217}$Fr* (with $N=130$) are in good accord with the statistical saddle-point model (SSPM) over the entire energy range, except at the highest one energy. On the other hand, the anisotropy data for $^{219}$Fr* (with $N=126$) show noticeable deviations from SSPM calculations at a few energies. The authors of this work [1] associate this deviation with the magic neutron number of the CN, whereas in a recent work [2] some of us considered the possibility of a noncompound, quasifission (qf) component in the fission cross-section.

In this paper, we look for both the possibilities of the role of CN $N=126$ and the qf component, on the basis of the dynamical cluster-decay model (DCM) of Gupta and collaborators [2, 3]. We have carried out our calculations for the deformed fragments, using quadrupole, octupole and hexadecapole ($\beta_2$, $\beta_3$ and $\beta_4$) deformations, having "optimal" orientations of hot configuration [4]. Note that the DCM is applied for the first time to an odd-mass fissioning nuclear system with a significant $\sigma_{\text{ER}}$ contribution.

The Model

In DCM, we use the collective co-ordinates of mass asymmetry $\eta = (A_1 - A_2)/(A_1 + A_2)$ and relative separation $R$, which allow to define the CN decay cross-section, in terms of

*Electronic address: msharma@thapar.edu
FIG. 2: Comparison between the experimental [1] and calculated $\sigma_{\text{fiss}}$ and $\sigma_{\text{ER}}$ using the DCM for $^{213,217}\text{Fr}^\ast$.

the partial waves, as

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

(1)

with $\mu$ as the reduced mass and $l_{\text{max}}$, the maximum angular momentum, which could be taken as a free parameter or else fixed for the vanishing of the fusion barrier of the incoming channel, or for the light particle cross-section $\sigma_{\text{ER}}(l) \rightarrow 0$. $P_0$, the pre-formation 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 temperature dependent neck length parameter $\Delta R(T)$, defining the first turning point $R_0 = R_1(\alpha_1, T) + R_2(\alpha_2, T) + \Delta R(T)$ for the penetration process.

Calculations and Results

Fig. 1 shows the behavior of preformation probability $P_0$ as a function of the fragment mass for the decay of CN $^{213}\text{Fr}^\ast$ and $^{217}\text{Fr}^\ast$ at about the same $E_{\text{CN}} \sim 49$ MeV, and at the two extreme $\ell_{\text{min}}$ and $\ell_{\text{max}}$ values. The interesting result is a double-humped, asymmetric fission distribution for $^{213}\text{Fr}^\ast$ ($N=126$) and a triple-humped symmetric-asymmetric distribution for $^{217}\text{Fr}^\ast$ ($N=130$). This difference arises due their neutron number being different, resulting in different minima corresponding to either $Z=40$ or $N=50$, or both, in their fragmentation potentials. In terms of the contribution to fission cross-section, apparently, the symmetric fission (SF) component is small (or zero) for $^{213}\text{Fr}^\ast$ and non-zero for $^{217}\text{Fr}^\ast$. This difference in the structure of fragmentation potential or, equivalently, the preformation probability could be associated with the shell closure of neutrons in $^{213}\text{Fr}^\ast$.

Fig. 2 presents the comparison between our DCM calculated $\sigma_{\text{fiss}}$ and $\sigma_{\text{ER}}$ for both the $^{213}\text{Fr}^\ast$ and $^{217}\text{Fr}^\ast$ systems with the experimental data [1]. The near exact comparison between the calculations and data for both the cross-sections leaves no scope for the qf component in either of the two $\sigma_{\text{fiss}}$ data.

Summary and Conclusions

The calculated double-humped, asymmetric fission distribution for $^{213}\text{Fr}^\ast$ and a triple-humped symmetric-asymmetric distribution for $^{217}\text{Fr}^\ast$ point out to the possible role of magic $N=126$ in $^{213}\text{Fr}^\ast$, resulting in an almost zero contribution to the $\sigma_{\text{fiss}}$ due to the symmetric fission. The near exact comparisons between the $\sigma_{\text{fiss}}$ (as well as $\sigma_{\text{ER}}$) for both the CN give rise to no possibility of quasifission component in the fission cross-sections of either of the two systems.

References