Temperature tuned dynamical cluster decay model applied to the binary breakup of $^{181}Re^*$ formed in $^{12}C +^{169} Tm$ reaction

C. Kokila* and M. Balasubramaniam
Department of Physics, Bharathiar University, Coimbatore - 641046

Introduction

The study of the fission of highly excited nuclei remains a topic of great interest.The description of fission cross section and fission probabilities in induced fission, that involves the entrance channel, the transmission through the fission barrier and the competition with other exit channels, is a field of continuous activity. The Dynamical Cluster-decay Model (DCM) of Gupta and collaborators [1, 2] has been used to study the binary breakup of various compound nuclei formed in low energy nuclear reaction. In DCM, the temperature for all the binary channels in the decay is considered same corresponding to the excitation energy of the compound nucleus, E^*_{CN}. However, the choice of keeping the same temperature for all the decay products results in excitation energies whose sum differs with that of the total excitation energy E^*_{CN}.

Thus, in this work we report for the first time, a temperature tuned dynamical cluster decay model with specific temperature for each channel. For our study we have considered the very recently reported binary decay of $^{181}Re^*$ compound nucleus formed through the entrance channel $^{12}C +^{169} Tm$ reaction [3] wherein 26 fission like events with charge numbers $32 \leq$ Z ≤ 49 were identified at three different excitation energies corresponding to the incident energies of $E_{lab} \approx$ 6.4, 6.9 and 7.4 A MeV with the angular momentum values $\approx 37\ \hbar$, $\approx 41\ \hbar$, and $\approx 45\ \hbar$, respectively. Further, a broader and symmetric mass distribution, manifesting their production through compound nuclear process is reported.

*Electronic address: `ckokilaphysics@gmail.com`

Model Decscription: DCM

In DCM, the equations of motion for the binary breakup of hot and rotating compound nucleus are solved in the the mass asymmetry, $\eta = (A_1 - A_2)/(A_1 + A_2)$ and the relative separation coordinate, R. The binary fragmentation potential $V(\eta)$ at a fixed R is defined as

$$V(\eta) = -\sum_{i=1}^{2}\left[BE_{LDM}(A_i,T)\right] + \sum_{i=1}^{2}\delta U_i(T) + E_C(T) + V_P(T) + V_\ell(T)$$

with 1 and 2 referring respectively to light and heavy fragments. Here, instead of keeping the same temperature for all channels, the temperature for each channel is tuned such that $E^*_{CN} = E^*_1 + E^*_2$, where the individual exictation energies are evaluated as $E^*_i = B.E(T)_i - B.E(T = 0)_i$ with $i = 1,\ 2$. $BE_{LDM}(A_i,T)$ are the Krappe's temperature dependent binding energy, and δU_i are the shell corrections, which vanishes to zero exponentially with T. $E_C(T) = Z_1Z_2e^2/R(T)$ is the Coulomb potential, with $R_i(T) = 1.16\left(1 + 7.63\times10^{-4}T^2\right)A_i^{1/3}$ and touching point is defined as $R_t = R_1 + R_2 + \Delta R$. The nuclear potential is evaluated as

$$V_P(T) = 4\pi\bar{R}(T)\gamma b(T)\phi\left[s(T)\right]$$

with $\bar{R}(T)$, $\phi\left[s(T)\right]$, and γ respectively, as the inverse of the root mean square radius of the Gaussian curvature, the universal function and the nuclear surface energy constant.

The centrifugal potential is

$$V_\ell(T) = \frac{\hbar^2\ell(\ell+1)}{2I_S(T)}$$

where the moment of inertia is evaluated at the complete sticking limit.

The decoupled approximation to R and η motion can be used to evaluate respectively the penetration probability P and preformation probability P_0. P_0 is obtained by solving the stationary Schrödinger equation governing the η coordinate at $R = R_t$ as,

$$P_0(A_i) = |\psi[\eta(A_i)]|^2 \sqrt{B_{\eta\eta}} \frac{2}{A}$$

with $B_{\eta\eta}$ as the hydrodynamical mass parameter. The penetration probability P can be evaluated using the WKB approximation at a fixed η as

$$P = \exp\left[-\frac{2}{\hbar}\int_{R_a}^{R_b} \{2\mu\,[V(R) - Q_{eff}]\}^{1/2} dR\right]$$

R_a and R_b are the first and second turning point satisfying, $V(R_a) = V(R_b) = Q_{eff}$. The decay cross-section is defined in terms of the partial waves as,

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

with $E_{c.m.}$ as the incident energy.

Results and Discussion

The calculated fragmentation potential energies, preformation probabilities clearly indicates, a stronger and broader minimum and maximum respectively in the symmetric region as shown in Fig. 1 (a) and (b) respectively. It is to be mentioned that, the potential energies, preformation probabilities and cross-sections are computed only for the restricted mass window of 75 to 106 as reported in the Ref. [3].

Thus, the cross section also inturn reflects a broader and symmetric distribution for all the energies considered for the study. In the calculations, a constant neck length distance is considered for all the binary channels. We find that the experimental cross-sections are lying between our theoretical results for the range of neck length parameter between 0.9 and 1.0 fm. We have not attempted for fitting to the data, which can be done by considering different neck length parameter for different channels. Thus, the temperature tuned DCM is found to fairly reproduces the experimental trend of the mass distribution.

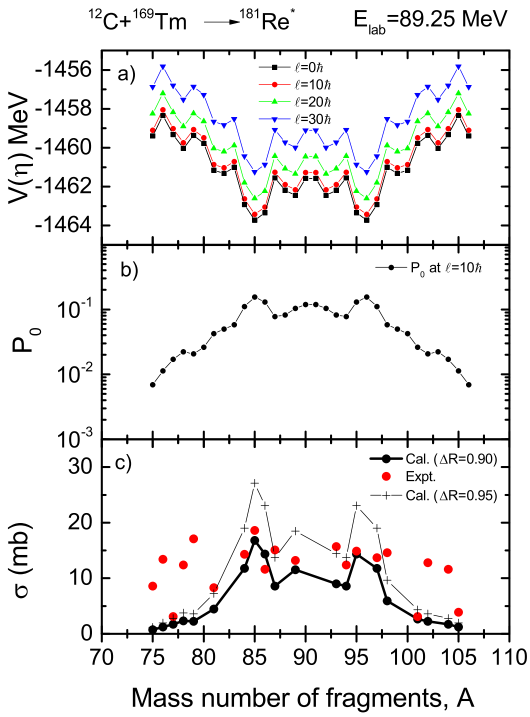

FIG. 1: (a) Fragmentation potential for different ℓ-value (b) Logarithmic plot of preformation probability at $\ell = 10\hbar$ and (c) Comparison of cross section with experimental data for $E_{lab} = 89.25MeV$

Acknowledgments

One of the authors C. Kokila, acknowledges the INSPIRE Fellowship awarded by DST.

References

[1] R. K. Gupta *et. al.*, Phys. Rev. C **65**, 024601 (2002)

[2] C. Karthikraj *et. al.*, Phys. Rev. C **86**, 014613 (2012)

[3] Arshiya Sood *et. al.*, Phys. Rev. C **96**, 014620 (2017)