

# Study of ${}^6,{}^7\text{Li}$ induced reactions on ${}^{235,238}\text{U}$ using Dynamical Cluster Decay Model

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## Introduction

Nucleon clusterisation has been extensively used to explain various nuclear phenomena within nuclear cluster models in which the nucleons are considered as cluster rather than free nucleons. The Nuclear reactions which involves weakly bound projectiles not only have the characteristic cluster structure but also their lower binding energies and a long tail in the density distribution that affects the fusion process. Such reactions mainly result in two independent fusion processes, i.e., complete (CF) and incomplete fusion (ICF). The different possible reaction mechanisms to study the breakup fusion process and its influence on the fusion mechanism are discussed in ref. [1]. To study these reactions the weakly bound nuclei, e.g.,  ${}^6,{}^7\text{Li}$  and  ${}^9\text{Be}$  involving  $\alpha+x$  cluster structure having 1.48, 2.45, and 1.67 MeV separation energies, respectively, are considered as the most relevant projectiles to investigate the role of the breakup on fusion mechanism. A lot of experimental and theoretical work has been carried out to understand the influence of weakly bound stable nuclei on the fusion process. Still, a clear identification of these factors is necessary to compare theoretical predictions of experimental data involving complete and incomplete fusion reactions. With this motivation, we have chosen fissile systems  ${}^{241,242,244,245}\text{Am}$  for which

experimental data is available in [2]. The present work conducts a comparative analysis of incomplete fusion (ICF) to investigate the fusion enhancement at near-barrier energies. Through this investigation, an attempt has been made to shed light on the impact of projectile breakup on fusion dynamics and to have better insight of segregation the CF and ICF processes. The existing experimental data has been reproduced for the specified energy range using the suitable neck length parameter  $\Delta R$  at comparable  $E_{c.m.}$  values within the collective clusterization approach of the dynamical cluster-decay model (DCM), which is based on quantum mechanical fragmentation theory (QMFT).

## Methodology

The Dynamical cluster decay model (DCM) [3] of Gupta and collaborators is worked out in terms of collective co-ordinates of mass (and charge) asymmetries. In terms of above said co-ordinates, for  $\ell$ -partial waves, the compound nucleus decay cross-section is given by

$$\sigma = \frac{\pi}{k^2} \sum_{l=0}^{l_{max}} (2l+1)P_0P; \quad k = \sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \quad (1)$$

Where,  $\mu = [A_1 - A_2/(A_1 + A_2)]m$ , is the reduced mass, with  $m$  as the nucleon mass and  $l_{max}$  is the maximum angular momentum. Where  $P$  is the barrier penetration probability and  $P_0$  is the preformation probability at a fixed  $R$  on the decay path. The  $P_0$  are evaluated by solving stationary Schrödinger wave

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TABLE I: The DCM-calculated ICF cross-section for  ${}^6\text{Li}$  induced reactions as considering the deformed fragmentation path.

Reaction	$E_{c.m.}(MeV)$	T(MeV)	$\ell_{max}(\hbar)$	$\Delta R(\text{fm})$	DCM $ICF(\text{mb})$	
					$\sigma_{ER}$	$\sigma_{fiss}$
${}^4\text{He} + {}^{235}\text{U} \rightarrow {}^{239}\text{Pu}^*$	18.33	0.721	118	1.02	$6.68 \times 10^{-8}$	5.4
${}^2\text{H} + {}^{235}\text{U} \rightarrow {}^{237}\text{Np}^*$	9.162	0.854	118	1.02	$3.03 \times 10^{-6}$	0.73
${}^4\text{He} + {}^{238}\text{U} \rightarrow {}^{242}\text{Pu}^*$	18.33	0.725	121	1.06	$3.56 \times 10^{-8}$	4.66
${}^2\text{H} + {}^{238}\text{U} \rightarrow {}^{240}\text{Np}^*$	9.242	0.826	121	1.06	$1.64 \times 10^{-6}$	0.5

equation and P calculated as the WKB tunneling probability. The structure information in  $P_0$  enters through the fragmentation potential  $V(\eta, R)$  [3].

## Calculations And Discussions

The analysis of heavy ion-induced fusion reactions across the Coulomb barrier has been performed within DCM for  ${}^{6,7}\text{Li} + {}^{235,238}\text{U}$  reactions populating compound nuclei (CN)  ${}^{241,242,244,245}\text{Am}^*$ . The calculations are performed by including deformation effects up to quadrupole deformation and with optimum orientations  $\theta_i^{opt}$ . With the inclusion of quadrupole deformation effects of two nuclei having optimum orientations and the effective lowering of the barrier (using the WKB quantum tunneling process), the cross-sections of  ${}^7\text{Li}$ -induced reactions are very well reproduced, indicating no ICF component in it, whereas, the data for  ${}^6\text{Li}$ -induced reactions remain unaddressed, suggesting ICF content in it. Thus, we have also fitted the ICF component for both possible ( ${}^2\text{H}$  and  ${}^4\text{He}$ ) channels formed after the breakup of  ${}^6\text{Li}$ .

The structural information of the compound nucleus is provided by the preformation probability ( $P_0$ ), is obtained from the calculated fragmentation potentials in the fragmentation process.  $P_0$  is assigned to each minimized fragment in the fragmentation process. The tunneling of these energetically favored fragments through the barrier is determined through the scattering potential and penetration probability of these fragments. Both of these quan-

tities are used in equation 1. to calculate cross-section values. Here, we have shown results for ICF only. As the projectile  ${}^6\text{Li}$  is a loosely bound nucleus and has small binding energy, thus, it breaks into  ${}^4\text{He}$  and  ${}^2\text{H}$ , which results in ICF. The energies of the resulting new projectile are modified for the calculations as per reference [4]. The ICF calculated cross-sections as reported in Table. I shows that the fission resulting from the fusion of  ${}^4\text{He}$  projectile is higher. Thus, we attempted to find the ICF components from the total cross-section value within the clusterization approach of DCM. Similar calculations are in progress to substantiate the predictability of model.

## References

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