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Role of rotational energy and deformations in the dynamics of $^{6}Li + ^{90}Zr$ reaction

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Abstract

In reference to recent experimental data, the dynamical cluster-decay model (DCM) has been applied to study the neutron evaporation residue (ER) cross sections of intermediate mass nucleus $^{96}Tc^{*}$ spread over a wide range of incident energy across the Coulomb barrier. In order to analyze the effect of rotational energy in the dynamics of $^{6}Li + ^{90}Zr$ reaction, the cross sections have been calculated using the sticking (I_S) and the non-sticking (I_{NS}) limits of moment of inertia with inclusion of quadrupole (β_2) deformation within optimum orientation approach. The effect of either of the two approaches on the angular momentum, and hence the rotational energy associated with it, is assessed through the fragment mass distribution, preformation factor and the barrier penetrability. Also, the role of deformations is studied through a comparative analysis of decay path for spherical and β_2 deformed fragmentation. The calculated evaporation residue cross sections show excellent agreement with the reported data at all incident energies for both spherical and β_2-deformed approach. Finally, the incomplete fusion (ICF) process observed due to loosely bound projectile ^{6}Li is addressed within the framework of DCM.

Keywords: Light nuclei; Evaporation residue; Sticking and non-sticking limit of moment of inertia; Deformations

1. Introduction

The vigorous research carried out to explore the nuclear structure and nuclear reaction dynamics eventually led to the discovery of loosely bound nuclei (e.g. $^{6,7}Li$, ^{9}Be). With this advent,

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there came surprising deviation from the conventional results which opened up new frontiers in nuclear physics. Since then, a lot of theoretical and experimental efforts are under way to explore the dynamics of composite systems formed in heavy ion reactions involving loosely bound nuclei. It is due to their exotic shape, size, peculiar internal structure, low breakup threshold and an extended matter distribution that such nuclei strongly influence the reaction mechanisms and thus bring a new set of challenges as compared to tightly bound nuclei. With these anomalous features, understanding the dynamics of loosely bound nuclei is of considerable importance and a lot of work has been devoted to the study of reactions involving such nuclei in the vicinity of the Coulomb barrier.

In a recent experiment [1] carried out to study the fusion of ^{6}Li projectile with medium mass ^{90}Zr target, the complete fusion cross sections, having major contribution from evaporation residue, have been measured over a wide range of incident energies varying from $E_{lab} = 14.9$–29.9 MeV (equivalently $E_{c.m.} = 13.9$–28.0 MeV) spread across the Coulomb barrier. In this reaction, the projectile ^{6}Li being loosely bound nucleus and the target ^{90}Zr, having a double shell closure with $N = 50$ and $Z = 40$ is expected to influence the decay of ^{96}Tc* system and thus play an important role in dynamics of the chosen reaction. With these prominent features it would be of interest to study the decay of $^{6}\mathrm{Li} + {}^{90}\mathrm{Zr}$ reaction in framework of dynamical cluster-decay model (DCM) [2–11]. So far DCM has been successfully applied to numerous systems varying from light to superheavy mass region for the decay channels involving evaporation residue (ERs; $Z_2 \leq 2$, $A_2 \leq 4$), intermediate mass fragments (IMFs; $2 \leq Z_2 \leq 10$, $5 \leq A_2 \leq 20$), near symmetric and symmetric fission fragments. Mostly, the decay cross sections have been estimated using sticking limit (I_S) of moment of inertia in which the rotation of two touching spheres is considered about their common center of mass. The choice of moment of inertia in sticking limit is attributed to the use of proximity potential of Blocki et al., [12] in DCM based calculations. On the other hand, for the fission fragment anisotropies it has been observed that DCM [7,13,14] approach favors the non-sticking limit (I_{NS}) where no intrinsic rotation of fragments is considered due to the small separation distance between them. However, with loosely bound ^{6}Li projectile having radius 10% larger than the normal systematics, an attempt has been made to analyze the comparative role of I_S or I_{NS} limit of moment of inertia, for the neutron evaporation residue decay channel observed in the reaction under consideration.

Apart from loosely bound projectile and semi-magic target nuclei, another interesting feature of this reaction is that the projectile involved and the compound nucleus formed are quadrupole deformed, owing to which, the deformations and orientations of decaying fragments could play a crucial role in the dynamics of chosen reaction. To explore the same, the decay of hot and rotating compound nucleus ^{96}Tc* is studied for spherical choice of fragmentation and with the inclusion of quadrupole (β_2) deformations having "optimum" orientations (θ_i^{opt}) [11].

In reactions induced by loosely bound nuclei, the projectiles are fragile, and can therefore, exhibit a range of phenomena (break-up being one of them) and thus lead to sizable effects on the dynamics of a reaction. It is well known that at higher energies when processes other than complete fusion become important, the fusion cross sections are found to drop below the total reaction cross section. An overall suppression of $34 \pm 8\%$ observed in the fusion cross sections of ^{96}Tc* nucleus [1] suggests the possibility of incomplete fusion (ICF) process. Evidently, for smaller systems lying in this mass region, the separation of complete fusion (CF) and incomplete fusion (ICF) cross section becomes difficult at both theoretical and experimental level. An attempt has been made to separate the CF and ICF components in framework of DCM by associating these processes with the angular momentum bins. The lower angular momentum states up to ℓ_{crit} are associated with CF process and higher ones with ICF process. This is because above ℓ_{crit}, the

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