Total cross-section for the reactions induced by weakly bound nuclei

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Introduction

Over the course of several decades, a great deal of research has been done in the reactions involving weakly bound stable and unstable nuclei. Special interests has been devoted to these reactions as the involved nuclei are composed of a tightly bound core plus one or two nucleons orbiting far around the core. At energies close to the Coulomb barrier, these reactions results into fusion, where a compound nucleus is formed, and incomplete fusion [1]. ^{6,7}Li and ^{9}Be are considered as the most relevant projectiles to investigate the role of the breakup on fusion mechanism owing to their α+x cluster structure and lower separation energies. A lot of experimental and theoretical work has been carried out to understand the influence of weakly bound stable nuclei on the fusion process.

In our recent work the plausible segregation of CF (complete fusion) and ICF (Incomplete Fusion) was also made in heavy mass region within the formalism of Dynamical Cluster Decay Model (DCM)[2]. This work is aimed at theoretical analysis of the total cross sections for the reactions above coulomb barrier in light mass region for which experimental data is available in [3]. The work conducts a comparative analysis to investigate the dynamics involved using weakly bound nuclei with increasing target mass. In present work, preliminary calculations are performed for ^{6,7}Li on ^{64}Zn using existing experimental data by employing the suitable neck length parameter ΔR at comparable and above the barrier $E_{c.m.}$ values within DCM, which is based on quantum mechanical fragmentation theory (QMFT).

Methodology

The Dynamical cluster decay model (DCM) [4] 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 ℓ-partial waves, the compound nucleus decay cross-section is given by

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

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 equation and P calculated as the WKB tunneling probability.The structure information in P_0 enters through the fragmentation potential $V(\eta, R)$ [4].

Calculations And Discussions

The analysis of heavy ion-induced fusion reactions above the Coulomb barrier has been performed within DCM for ^{6,7}Li+^{64}Zn reactions populating compound nuclei (CN) ^{70,71}As* . 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

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

Reaction	$E_{c.m.}(MeV)$	T(MeV)	$\ell_{max}(\hbar)$	ΔR(fm)	DCM (mb) σ_{ER}	σ_{fiss}	Expt. (mb)
^{7}Li +^{64}Zn→ ^{71}As*	∼22	2.27	35	1.72	684	1.33×10^{-4}	656±56
	∼31	2.515	35	1.87	1000	4.31×10^{-5}	1002±69
	∼39	2.717	36	1.96	1214	1.6	1254±81
^{6}Li +^{64}Zn→ ^{70}As*	∼22	2.17	35	1.72	602	3.1×10^{-1}	597±45
	∼31	2.43	35	1.87	976	5.05×10^{-1}	984±64
	∼39	2.644	36	1.96	1173	1	1166±71

lowering of the barrier (using the WKB quantum tunneling process), the cross-sections of ^{7}Li-induced reactions are reproduced, for given set of excitation energies by fitting the neck length parameter ΔR. The reproduced data indicates absence of ICF component in it. Using same set of conditions, the data for ^{6} Li-induced reactions are addressed, suggesting no ICF content in it also. Therefore, we expect that the ICF is not as important for light systems, at energies above the barrier, as it is for the heavy ones. It is to be noted here that values of ΔR is uniquely fixed for particular set of reactions at fixed energy and it increases with increasing energy. The same set of conditions are used for reaction induced by different projectile on same target to check the possibility of ICF in it (check [2] for more details).

To calculate cross-section we have used eq 1. in which the structural information of the compound nucleus is provided by the preformation probability (P_0), and the tunneling of these energetically favored fragments through the barrier is determined through the scattering potential and penetration probability (P) of these fragments. Both of these quantities are used to calculate cross-section values. The calculated cross-sections as reported in Table I. We have also mentioned the σ_{fiss} values for each set of energy values. Similar calculations are in progress to study the effect of increasing mass of target on the fusion dynamics and to substantiate the predictability of model.

References

[1] A. Diaz-Torres and I. J. Thompson, Phys. Rev. C **65**, 024606 (2002), A. Diaz-Torres, I. J. Thompson, and W. Scheid, Nucl. Phys. A **703**, 83 (2002); **533**, 265 (2002).

[2] Rupinder Kaur, BirBikram Singh , Maninder Kaur, Manoj K. Sharma and Pushpendra P. Singh *et al.* Phys. Rev. C **108**, 034611 (2023).

[3] I. Padron, P. R. S. Gomes, R. M. Anjos, J. Lubian, *et al.* Phys. Rev. C **66**, 044608 (2002).

[4] R. K. Gupta *et al.*, PRC **71**, 014601 (2005); R. Kaur *et al.* Phys. Rev. C **98**, 064612 (2018); Phys. Rev. C **101**, 034614 (2020); Phys. Rev. C **101**, 044605 (2020); Phys. Rev. C **108**, 034611 (2023).