Effect of entrance channel mass asymmetry and neck formation on nuclear reaction dynamics

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Introduction

The dynamical cluster-decay model (DCM) is having only one free parameter i.e. neck length parameter ΔR, which could be fixed uniquely for a particular set of reactions induced by the same projectile (loosely bound or stable) at chosen incident energy, E_{lab} (in MeV) [1]. For a given projectile at a fixed E_{lab} on different targets, we were able to calculate the total fusion cross section (σ_{fus}). The development for this dynamical model provides an opportunity to study those reactions which are not explored on experimental front. Recently, the nuclear reaction dynamics of the compound nuclei (CN) $^{60}Zn^*$, $^{60}Ni^*$ and $^{60}Fe^*$ formed in ^4He induced reactions on different targets ^{56}Ni, ^{56}Fe and ^{56}Cr, respectively, has been explored. These reactions have not been studied experimentally so far [2]. It is interesting to note that the entrance channel mass asymmetry (η_{in} = 0.8) is same for these ^4He induced reactions. It may further helps to reduce the degree of freedom for fixing the value of ΔR empirically i.e. ΔR^{emp}. For another set of reactions, study was made within DCM to fix the value of ΔR, with particular choice of η_{in} at chosen value of incident energy per nucleon (E_{lab}/A). We studied the decay of CN $^{75}Br^*$ and $^{79}Rb^*$ formed in the reactions ^{16}O+^{59}Co and ^{20}Ne+^{59}Co, respectively having $\eta_{in}\sim$ 0.5 at the same E_{lab}/A$\sim$3.1 MeV value [3]. We calculated the fusion cross section σ_{fus} for both the reactions at uniquely fixed ΔR and the results are compared nicely with the experimental data. It indicates that the size of the neck formed between two colliding nuclei leading to the formation of the compound nucleus depends on the η_{in}. Furthermore, yet another study established the role of η_{in} for the choice of ΔR-value. The reactions ^{27}Al+^{73}Ge, ^{27}Al+^{74}Ge, ^{27}Al+^{76}Ge and ^{28}Si+^{94}Zr having η_{in} = 0.46, 0.46, 0.48 and 0.54, respectively, were chosen to study its effect on ΔR through mass parameter $B_{\eta\eta}$ [4]. We have studied few more reactions with wide range of η_{in} values, but having energy per nucleon (E_{lab}/A) fixed, to further elaborate the relevance of neck formation in the compound nucleus reaction dynamics.

Methodology

The DCM [1–5], worked out in terms of collective co-ordinates of mass (and charge) asymmetries, for ℓ-partial waves, gives the compound nucleus decay cross-section as

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

P is penetrability of interaction barrier (of the preformed clusters with preformation probability P_0). The P_0 is obtained by solving the stationary Schrödinger equation in $\eta/B_{\eta\eta}$, at a fixed $R_a = R_1(\alpha_1,T)+R_2(\alpha_2,T)+\Delta R(T)$. The $B_{\eta\eta}$, representing the smooth hydrodynamical masses, is defined as

$$B_{\eta\eta} = \frac{AmR^2}{4}\left[\frac{v_t(1+\gamma)}{v_c}\right], \tag{2}$$

with, v_c=πR_c^2R, v_t=v_1+v_2 is the total conserved volume and

$$\gamma = \frac{R_c}{2R}\left[(2-\frac{R_c}{R_1}-\frac{R_c}{R_2}\right], \tag{3}$$

$$R_c = 0.4\times R_2 \tag{4}$$

is the radius for the homogeneous mass flow among the decaying fragments.

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TABLE I: The DCM calculated σ_{fus} for different reactions at $E_{lab}/A \sim 2.71$ MeV and ΔR=1.18 fm, and their comparison with the experimental data [6, 7].

							σ_{fus} (mb)	
Reaction	η_{in}	E_{lab} (MeV)	$E_{c.m.}$ (MeV)	E^*_{CN} (MeV)	T (MeV)	ℓ_{max} ($\hbar$)	DCM	Expt.
^{7}Be+^{27}Al→^{34}Cl*	0.58	19.0	15.08	38.19	3.315	31	949.6	858±94
^{7}Li+^{27}Al→^{34}S*	0.58	19.0	15.08	42.722	3.498	30	914.0	924±46
^{9}Be+^{27}Al→^{36}Cl*	0.5	24.39	18.29	41.96	3.365	37	1234.0	1163±106
^{9}Be+^{89}Y→^{98}Tc*	0.81	24.39	22.15	32.22	1.767	65	190.4	132±7
^{4}He+^{64}Zn→^{68}Ge*	0.88	10.84	10.20	13.599	1.409	39	175.5	155
^{16}O+^{24}Mg→^{40}Ca*	0.2	43.36	26.02	42.196	3.195	36	852.88	910±55
^{16}O+^{26}Mg→^{42}Ca*	0.2	43.36	26.84	44.436	3.195	36	819.68	860±54

Calculations and Discussions

Within DCM, an explicit relation between the ΔR and R_c has been shown [8], where R_c gives $B_{\eta\eta}$, which significantly affect the magnitude of σ_{fus} through P_0. Another study points out the variation of $B_{\eta\eta}$ with ΔR at different values of η_{in}, refer Fig. 1 of Ref.[4]. As η_{in} increases the magnitude of $B_{\eta\eta}$ starts rising, but the converse is true for the variation of $B_{\eta\eta}$ with ΔR. The work presented in Ref.[4] also suggests that for the reactions having same η_{in} and E_{lab}/A value, an unique choice of ΔR^{emp} could address the respective σ_{fus}. In order to further explore these findings we have studied few more reactions. The calculated σ_{fus} for the reactions under study and their comparison with the experimental data [6, 7] is shown in the Table I.

The DCM calculated results for different reactions having range of η_{in} values, having same value of E_{lab}/A, are in good comparison with the data. However, there is one interesting point to note that the value of ΔR is same for all the reactions presented in Table I. This observation encourages us to analyze variety of reactions to establish a systematics for the neck length parameter. We hope to finish the further work by the time of presentation.

References

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