Dependence of neck-length parameter on entrance channel mass asymmetry of heavy ion induced reactions

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Introduction

The heavy ion reaction mechanisms, particularly, the formation of the Compound Nuclei (CN) and their subsequent decays have attracted the interest of experimentalist as well as theoreticians for last many decades. The fusion of heavy ion low energy reactions is strongly influenced by the formation of CN at the initial stage of reaction at which a significant amount of kinetic energy is converted into excitation energy. The formation of CN is affected by the distance R between the center of two colliding nuclei along with neck-length (ΔR) and mass asymmetry $\eta_A = (A_1 - A_2)/(A_1 + A_2)$ or charge asymmetry $\eta_Z = (Z_1 - Z_2)/(Z_1 + Z_2)$. The well developed dynamical cluster-decay model (DCM) of Gupta and collaborators is worked out in terms of these collective coordinates [1]. The ΔR of two interacting nuclei or decaying fragments, in the binary decay of CN, plays an important role in the reaction dynamics.

In our previous studies, it has been worked out that the empirically fitted ΔR_{emp} simply results in the corresponding potential barrier lowering ΔV_B for a given reaction, which is an in-built property of DCM. Recently, the relevant role of ΔR is analyzed in view of the predictability of the DCM [2]. The fusion cross section σ_{fus} induced by the same loosely bound projectile, with same incident energy, has been studied, while fixing ΔR_{emp}. The σ_{fus} for all such reactions were estimated/ predicted by using the same value of ΔR_{emp}. We extended this study successfully further for stable projectile ^{32}S*, also at fixed E_{lab}=142 MeV on different targets [2].

In the present work, further emphasis is put to reduce the degree of freedom for fixing the value of ΔR. We have analyzed particular choice of entrance channel mass asymmetry η_A to fix the value of ΔR for different CN formed through different reactions at the fixed value of incident energy per nucleon (E/A). We have studied here 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_A\sim$0.5 for each case, at the same incident energy $E/A \sim$3.1 MeV. We have calculated the σ_{fus} for ^{75}Br* by fixing ΔR_{emp}=1.536 fm. The σ_{fus} for ^{79}Rb* has been calculated using the same value of ΔR_{emp}. For both the reactions, the DCM calculated σ_{fus} are in reasonable agreement with the experimental data [3].

Methodology

The DCM is worked out in terms of collective co-ordinates of mass (η_A) (or charge η_Z) asymmetry, and relative separation R. Then, for ℓ-partial waves, the compound nucleus decay cross-section is

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

where, μ is reduced mass, with m as nucleon mass and ℓ_{max}, the maximum angular momentum, fixed for vanishing light particles LP cross-section $\sigma_{LP}\rightarrow$ 0. The preformation probability P_0 is obtained by solving the stationary Schrödinger equation in η, at a fixed $R = R_a$, and penetrability P is WKB integral

$$P = \exp[\frac{-2}{\hbar}\int_{R_a}^{R_b}\sqrt{2\mu[V(R)-Q_{eff}]}dR] \quad (2)$$

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TABLE I: The DCM calculated σ_{fus} for ^{16}O+^{59}Co and ^{20}Ne+ ^{59}Co reactions (having each η_A∼0.5) at E_{lab}/A ∼3.1 MeV and for ΔR_{emp}=1.536 fm, compared with the experimental data.

Reaction	$E_{c.m.}$ (MeV)	E^*_{CN} (MeV)	T (MeV)	ℓ_{max} ($\hbar$)	$\sigma_{fus.}$ (mb) DCM	Expt.
^{16}O+^{59}Co→^{75}Br*	38.89	41.03	2.280	43	523.2	523.4 [3]
^{20}Ne+^{59}Co→^{79}Rb*	46.92	48.45	2.407	47	463.2	563.2 ± 74.86 [3]

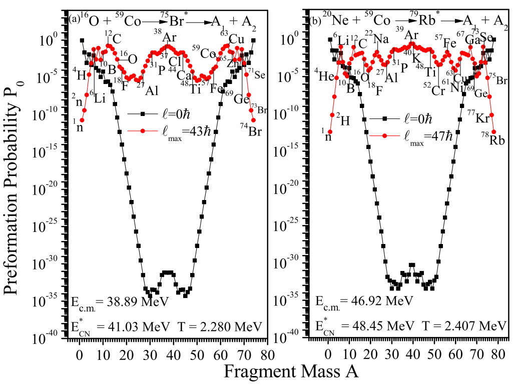

FIG. 1: The $P_0(A)$ for the compound systems ^{75}Br* and ^{79}Rb* at ℓ=0 $\hbar$ and ℓ_{max}.

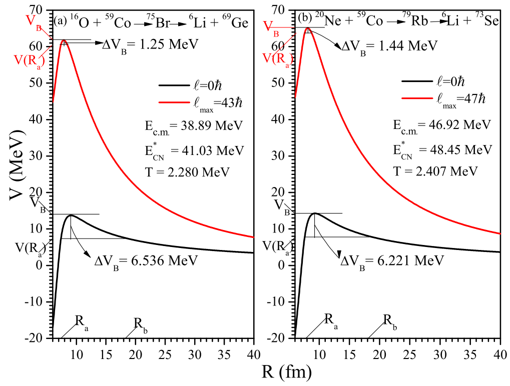

FIG. 2: The V(R) of ^{75}Br* and ^{79}Rb* for the respective ^{6}Li exit channels, at ℓ=0 $\hbar$ and ℓ_{max}.

The ΔR fixes the first turning point R_a of the barrier penetration, referring to the actually used barrier height V(R_a), and consequently to the concept of barrier lowering $\Delta V_B(\ell)$.

Calculations and discussions

The main motive of present work is to study the effect of entrance channel mass asymmetry (η_A) in fixing the value of ΔR, the only parameter of DCM. The η_A for both the reactions ^{16}O+^{59}Co and ^{20}Ne+^{59}Co, forming CN ^{75}Br* and ^{79}Rb*, is ∼0.5 and also E_{lab}/A ∼ 3.1 MeV. Fig.1 shows the preformation profile for the decay of CN ^{75}Br* and ^{79}Rb* at ℓ=0$\hbar$ and the respective ℓ_{max} values. The LPs are more favorable at ℓ=0$\hbar$ but intermediate mass fragments (IMFs) starts competing strongly at ℓ_{max} for both the reactions. One more observation is that both ^{6}Li and ^{12}C give comparable yields in the decay of both CN ^{75}Br* and ^{79}Rb*. We have taken ^{6}Li as the decay mode for both the CN, to compare as well as present the barrier modification effects in both cases.

Fig. 2 gives the first and second turning points for the scattering potentials $V(R)$ of ^{75}Br* and ^{79}Rb* CN with exit channels ^{6}Li+^{69}Ge and ^{6}Li+^{73}Se, respectively, at ℓ=0$\hbar$ and ℓ_{max} values. The barrier lowering potential ΔV_B is also shown in Fig. 2. We notice that ΔV_B remains almost constant in both cases. Preliminary results show that ΔV_B is comparable for the decay of these CN, having same η_A and same E/A value. Table 1 presents the DCM calculated σ_{fus}, in reasonable agreement with the data [3]. The study is in progress for a few more reactions having same η_A and E/A.

References

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