Significance of neck length parameter in ^{32}S induced fusion reactions

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Introduction

The dynamics of heavy ion induced reactions give a pathway to number of interesting characteristics of atomic nuclei. The heavy ion fusion reactions are observed to be strongly influenced by the nuclear structure of the interacting nuclei and the intrinsic properties associated with them. The exclusive studies have been made to study the effects of nuclear shape, structure and angular momentum etc. The neck length of two interacting nuclei also play a significant role in the reaction dynamics. In low energy reactions when two nuclei come close to each other, there is a interplay between, electrostatic force of repulsion and attractive nuclear force. Once this strong nuclear interaction overcomes the Columbic repulsion, there is a formation of neck between the nuclei which held them together and is referred as neck length parameter "ΔR".

In recent studies, Gupta and Collaborators successfully addressed the interaction barrier modification characteristics in term of "ΔR", within the dynamical cluster decay model (DCM) formalism [1]. In DCM, both the relative motion of heavy ions and intrinsic excitations lead to neck formation, treated quantum mechanically. Interestingly, it has been worked out that the empirically fitted ΔR^{emp} simply results in the corresponding 'barrier lowering' ΔV_B^{emp} for the given reaction, i.e., 'barrier lowering' is an inbuilt property of the DCM. Very recently, the fusion cross section σ_{fus} induced by loosely bound (LB) projectile, with the same energy, on different targets have been studied [3]. It is important to note that the value of ΔR is

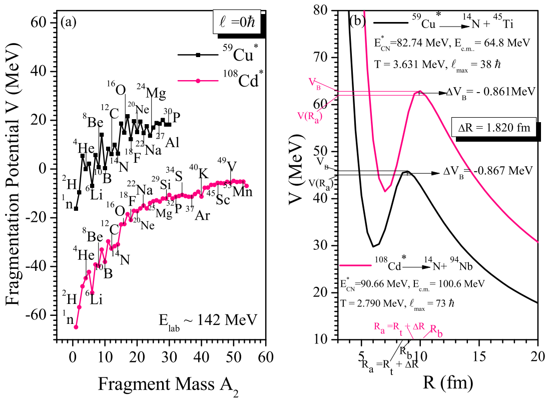

FIG. 1: (a) The fragmentation potentials for the compound nuclei formed in ^{32}S induced reactions at E_{lab}~142 MeV, for ℓ=0 $\hbar$. (b) The Scattering potentials for the respective exit channels of the CN with the ^{6}Li decay, at the respective ℓ_{max} values.

fixed empirically for the given projectile at a given choice of projectile energy. The σ_{fus} for all other reactions induced by the same projectile at fixed incident energy on different targets are calculated/ predicted using the same ΔR^{emp}. Present work is a further attempt to establish the predictability of the DCM, while studying the reactions induced by the stable projectile ^{32}S at fixed incident energy E_{lab}~142 MeV on different targets [2].

Methodology

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

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

Where, $\mu = [A_1A_2/(A_1+A_2)]m$, is the reduced mass, with m as the nucleon mass and

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TABLE I: The DCM calculated σ_{fus} for the ^{32}S induced reactions at $E_{lab} \sim$ 142 MeV with $\Delta R^{emp.}$=1.820 fm and their comparison with the experimental data. The barrier modification factor $\Delta V_B = V(R_a) - V_B$ at the respective ℓ_{max} values of the compound systems given here for the respective exit channels with the ^{14}N decay.

Reaction	$E_{c.m.}$ (MeV)	E^*_{CN} (MeV)	T (MeV)	ℓ_{max} ($\hbar$)	$\Delta V_B(MeV)$	$\sigma_{fus.}$ (mb) DCM	Expt.
^{32}S+^{27}Al→^{59}Cu*	64.98	82.745	3.631	38	-0.867	1086.46	1070 ± 20 [2]
^{32}S+^{76}Ge→^{108}Cd*	10.63	90.655	2.790	73	-0.861	917.53	890 ± 90 [2]

ℓ_{max} is the maximum angular momentum. The preformation probability P_0 is obtained by solving the stationary Schrödinger equation in η, at a fixed $R = R_a$.The penetrability P, calculated as the WKB tunneling probability, is

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

The parameter ΔR fixes the first turning point R_a of the barrier penetration, refereeing to the actually used barrier height V(R_a), consequently to the concept of barrier lowering $\Delta V_B(\ell)$ as shown in Fig.1(b).

Calculations and discussions

Fig. 1(a) gives the fragmentation potentials of ^{59}Cu* and ^{108}Cd* nuclei at $\ell = 0\hbar$, for ^{32}S induced reactions at $E_{lab} \sim$ 142 MeV. We see that with heavy mass target ^{76}Ge (Table I), the magnitude of fragmentation potential becomes lower at $\ell = 0\hbar$ in comparison to the light mass target ^{27}Al. This happens because the temperature T of compound nucleus (CN) decreases with increase in the mass of target. Hence, the CN ^{108}Cd* lying lower in fragmentation potential (being energetically more stable) has lower decay probability than ^{59}Cu*, i.e., the heavier CN has lower decay probability, so the σ_{fus} for latter is more as compared to the former. Fig. 1(b) presents the first and second turning points of the scattering potential at the respective ℓ_{max} values of the CN ^{59}Cu* and ^{108}Cd* for the ^{14}N decay channel. We see that the barrier modification factor remains almost constant for ^{59}Cu* and ^{108}Cd*, particularly, at the respective ℓ_{max} values. It may be noted that the empirically fitted neck length parameter ΔR^{emp} determines the characteristics of barrier lowering component. It is relevant to mention here that these observations are similar to our recent study of the reactions induced by LB projectiles [3].

The calculated σ_{fus} is shown in Table I for ^{32}S induced reactions. The total σ_{fus} is calculated by taking the contribution of light particles, intermediate mass fragments and fusion-fission fragments. In one reaction the value of ΔR^{emp} is fixed empirically for a given projectile at a given E_{lab}. This ΔR^{emp} is then further used to calculate the σ_{fus} for another reaction leading to ^{108}Cd*, having the same projectile and E_{lab} value. Interesting enough, we are successful to meet the experimental value [2] of the σ_{fus} for this reaction with ΔR^{emp}=1.820 fm fixed earlier for the reaction having the same projectile and E_{lab} value. Hence it is concluded that the unique value of neck length parameter ΔR can address all reactions having the same projectile (stable or LB) and E_{lab} value.

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