Correlation among neck length parameter and entrance channel mass asymmetry

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Introduction

Recently, it has been observed that within the dynamical cluster decay model (DCM), the value of empirically fitted $\Delta R_{emp}$ can be fixed uniquely for a particular set of reactions induced by the same projectile (loosely bound or stable) at the same incident energy $E_{lab}$ (in MeV) [1]. Interestingly, for a given projectile at a fixed $E_{lab}$ on different targets, we are able to calculate/predict the total fusion cross section ($\sigma_{fus}$) for numerous reactions under study. This work has been provided an excellent platform to analyze those reactions which are yet to get experimental consideration due to limited availability of incident beam. The DCM has been applied to explore the nuclear reaction dynamics of the CN $^{60}Zn^{*}$, $^{60}Ni^{*}$ and $^{60}Fe^{*}$ formed in the reactions $^4He+^{56}Ni$, $^4He+^{56}Fe$ and $^4He+^{56}Cr$ respectively, which have not been explored experimentally so far due to the non-availability of the stable targets [2]. It is to be noted here that entrance channel mass asymmetry ($\eta_n = 0.8$) is same for all the $^4He$ induced reactions. It further helps to reduce the degree of freedom for fixing the value of $\Delta R_{emp}$.

In one of our recent work, particular choice of entrance channel mass asymmetry has been taken to fix the value of neck length ($\Delta R$), for different compound nuclei (CN) formed through different reactions at fixed value of incident energy per nucleon (E/A). In that work, we had 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 $\eta_n \sim 0.5$ for each case at the same E/A $\sim 3.1$ MeV [3]. We calculated the fusion cross section $\sigma_{fus}$ for both the reactions at same value of $\Delta R$ and the results were nicely compared 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 $\eta_n$.

The motivation behind the present work is to establish the role of $\eta_n$ on the $\Delta R$-value. We have chosen the reactions $^{27}Al+^{73}Ge$, $^{27}Al+^{74}Ge$, $^{27}Al+^{76}Ge$ and $^{28}Si+^{94}Zr$ having $\eta_n = 0.46, 0.46, 0.48$ and 0.54, respectively, to study its effect on $\Delta R$ through $B_{\eta\eta}$. We have calculated the $\sigma_{fus}$ of all the reactions by fixing the value of $\Delta R_{emp}$-value.

Methodology

The DCM [1–4], worked out in terms of collective co-ordinates of mass (and charge) asymmetries, for $^\ell$-partial waves, gives the compound nucleus decay cross-section as

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

(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 $R_0 = R_1(\alpha_1, T) + R_2(\alpha_2, T) + \Delta R(T)$, $\Delta R$ is the only free parameter of DCM. The $B_{\eta \eta}$ represents the smooth hydrodynamical masses, is defined as

$$B_{\eta \eta} = \frac{AmR^2}{4} \left[ \frac{v(1+\gamma)}{\upsilon_0} \right] .$$

(2)
TABLE I: The DCM calculated $\sigma_{fus}$ for different reactions at $E_{lab}/A \sim 3.1$ MeV and their comparison with the experimental data.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>$\eta_{in}$</th>
<th>$E_{cm}$ (MeV)</th>
<th>$E_{c.m.}$ (MeV)</th>
<th>$T$ (MeV)</th>
<th>$\ell_{max}$ (h)</th>
<th>$\Delta R$</th>
<th>$\sigma_{fus}$ (mb)</th>
<th>DCM</th>
<th>Expt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{27}<em>{13}$Al$^{+82}$Ge$^{100}</em>{15}$Rh$^*$</td>
<td>0.46</td>
<td>61.10</td>
<td>58.19</td>
<td>2.334</td>
<td>71</td>
<td>1.608</td>
<td>308.55</td>
<td>309.0±22</td>
<td></td>
</tr>
<tr>
<td>$^{27}<em>{13}$Al$^{+72}$Ge$^{101}</em>{15}$Rh$^*$</td>
<td>0.46</td>
<td>61.32</td>
<td>58.12</td>
<td>2.321</td>
<td>71</td>
<td>1.608</td>
<td>291.00</td>
<td>292.3±34</td>
<td></td>
</tr>
<tr>
<td>$^{27}<em>{13}$Al$^{+79}$Ge$^{103}</em>{15}$Rh$^*$</td>
<td>0.46</td>
<td>61.75</td>
<td>59.37</td>
<td>2.322</td>
<td>71</td>
<td>1.577</td>
<td>363.43</td>
<td>364.0±11</td>
<td></td>
</tr>
<tr>
<td>$^{28}_{12}$Si$^{+94}$Zt$^{122}$Xe$^*$</td>
<td>0.54</td>
<td>66.60</td>
<td>43.19</td>
<td>1.822</td>
<td>72</td>
<td>1.180</td>
<td>2.140</td>
<td>2.160±0.31</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 1: The variation of $B_{\eta\eta}$ with $\Delta R$ for the decay of CN $^{100}$Rh$^*$, $^{101}$Rh$^*$, $^{103}$Rh$^*$ and $^{122}$Xe$^*$ formed in the reactions having $\eta_{in} = 0.46, 0.46, 0.48$ and 0.54, respectively.

with, $v_0 = \pi R_c^2 R$, $v = v_1 + v_2$ is the total conserved volume and

$$\gamma = \frac{R_c}{2R} \left( \frac{2 - R_c}{R_1} - \frac{R_c}{R_2} \right), \quad (3)$$

$$R_c = 0.4 \times R_2 \quad (4)$$

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

Calculations and Discussions

Within DCM, it is shown explicitly that there is a relation between the $\Delta R$ and $R_c$ [5]. The $R_c$ gives $B_{\eta\eta}$, which has a significant effect on the $\sigma_{fus}$ through $R_0$. Fig. 1 shows the variation of $B_{\eta\eta}$ with $\Delta R$ at different values of $\eta_{in}$. Quite evidently, the value of $B_{\eta\eta}$ depends upon $\eta_{in}$. As $\eta_{in}$ increases the value of $B_{\eta\eta}$ starts rising. But the converse is true for the variation of $B_{\eta\eta}$ with $\Delta R$ i.e. the value of $B_{\eta\eta}$ decreases with increase in the value of $\Delta R$. It shows that the larger value of $R_c$ through $B_{\eta\eta}$ requires a smaller value of $\Delta R$ or vice-versa. A larger value of $R_c$ means, the radius of cylinder will be larger and flow of the nucleons requires a smaller neck i.e. smaller $\Delta R$. If $R_c$ is smaller, the mass flow requires relatively larger neck. It means that as $B_{\eta\eta}$ increases (which inturn depends on the value of $\eta_{in}$), the neck of the interacting nuclei i.e. $\Delta R$ feels restricted.

The calculated $\sigma_{fus}$ for the reactions under study are given in the Table I. The DCM calculated $\sigma_{fus}$ are very well compared with the available experimental data [6] at same incident energy per nucleon ($E_{lab}/A$) for all the reactions. These calculations have been made by fitting the value of $\Delta R_{emp}$. It is important to note that, for the reactions having same $\eta_{in}$, the value of $\Delta R_{emp}$ also remains unchanged in order to address their respective $\sigma_{fus}$.

References