Dynamical effects of Si-isotopes induced reactions at similar centre of mass energies \( E_{\text{c.m.}} \).

Rupinder Kaur\(^1,\)\(^*\), Varinderjit Singh\(^2\), Maninder Kaur\(^2\), BirBikram Singh\(^3\), and B.S. Sandhu\(^1\)

\(^1\)Department of Physics, Punjabi University, Patiala-147002, India.
\(^2\)Department of Physics, I.K.G. Punjab Technical University, Kapurthala-144603, India. and
\(^3\)Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib-140406, India.

**Introduction**

The study of the complex phenomena observed in sub-barrier energies through fusion of isotopic chain of reactions is topic of interest in nuclear physics. A number of authors have theoretically investigated the sub-barrier fusion phenomena using different models to explain fusion enhancement and fusion hindrance phenomenon [1]. Since dynamics of fusing nuclei play a key role in the fusion mechanism, it will be interesting to study the fusion enhancement/hindrance for low-mass nuclei using the dynamical cluster decay model (DCM) [2] to get a better insight of the fusion process.

With this motivation, fusion of \( ^{28,30}\text{Si}^{+12}\text{C} \) populating \( ^{40,42}\text{Ca}^* \) [3] with \( Z=20 \) shell closure and neutron number gradually moving above \( N = 20 \) neutron shell closure has been investigated within DCM at energies above and below Coulomb barrier. The cross-sections for \( ^{30}\text{Si}^{+12}\text{C} \) are reproduced using neck length parameter \( \Delta R \) at the different energies. The empirically fitted values of \( \Delta R \) are used to predict the fusion cross-sections at similar centre of mass energies \( E_{\text{c.m.}} \) for \( ^{28}\text{Si}^{+12}\text{C} \). The predicted fusion cross-section values are in good agreement with the experimental measurements. Also, the fusion cross-sections has been predicted for energies far below the barrier. The hindrance phenomenon observed at sub barrier energies \( ^{30}\text{Si}^{+12}\text{C} \) has been addressed through barrier lowering parameter which is the in-built property of the model.

**Methodology**

The DCM [2] 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 \( \ell \)-partial waves, the compound nucleus decay cross-section is given by

\[
\sigma = \frac{2}{k^2} \sum_{l=0}^{l_{\text{max}}} (2l + 1) P_0 \pi \left( \frac{2\mu E_{\text{c.m.}}}{\hbar^2} \right)
\]

(1)

Where, \( \mu = [A_1 - A_2/(A_1 + A_2)]m \), is the reduced mass, with \( m \) as the nucleon mass and \( l_{\text{max}} \) 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
Calculations and Discussions

The analysis of heavy ion induced fusion reactions across coulomb barrier has been performed within the DCM for $^{28,30}$Si+$^{12}$C reactions populating compound nuclei (CN) $^{40,42}$Ca*, respectively. To understand the possible structure of the decaying CN $^{40,42}$Ca* formed in the $^{28,30}$Si+$^{12}$C reaction, fragmentation potential has been calculated for various fragments/clusters formed inside the CN. The calculated fragmentation potentials have been plotted with respect to fragment mass in the decay of $^{40,42}$Ca* at similar $E_{c.m.}$, as shown in Fig. 1(a and b) which describes the fragmentation for the extreme values of angular momentum values. At $\ell = 0h$, the contribution of the LPs or ERs(evaporation residues) is more prominent than the intermediate mass fragments and symmetric fission fragments, which otherwise start appearing at higher $\ell$ values. The tunneling of these energetically favored fragments through the barrier is determined through the scattering potential and penetration probability of these fragments. The barrier modification ($\Delta V_B$) values, which is difference between the top of the barrier $V_B$ and actual potential $V_R$, used for penetration is plotted as a function of $E_{c.m.}$ is plotted for the dominant decay channel at highest value of angular momenta, shown in Fig. 2(a). It can be noticed that the lowering of barrier increases as $E_{c.m.}$ decreases for both the compound systems, which signifies the lower cross-sections at lower energy values. It also indicates that the lowering of barrier values ($\Delta V_B$) required in case of $^{40}$Ca* is lesser than that of $^{42}$Ca* at all values of $E_{c.m.}$. Thus, the quantum tunneling of fragments/clusters in case of $^{40}$Ca* through the barrier is less hindered as compared to compound nucleus $^{42}$Ca*. Therefore, less hindrance threshold is observed in $^{40}$Ca* in comparison to $^{42}$Ca*, at lower energy values. Finally, the calculated fusion excitation values are plotted as function of $E_{c.m.}$ in Fig. 2(b). It can be observed that the calculated fusion excitation values are in agreement with the available experimental data. Also, it can be seen that the cross section values of $^{40}$Ca* are larger in comparison to $^{42}$Ca*. Also, it can be clearly noticed that the cross sections of $^{42}$Ca* (solid line) decrease very steeply at the lowest energies in contrast to $^{40}$Ca* (dotted line). These observations can be understood through the lower $\Delta V_B$ values of fragments/clusters from compound nucleus $^{40}$Ca* and possibly its double shell closure in comparison to that of compound nucleus $^{42}$Ca* which may lead to enhanced cross section values.

References