Dynamical effects of Si-isotopes induced reactions at similar centre of mass energies $E_{c.m.}$

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 lower-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}Si+^{12}C populating $^{40,42}Ca^*$ [3] with Z=20 shell closure and neutron number gradually moving away from N = 20 neutron shell closure has been investigated within DCM at energies above and below Coulomb barrier. The cross-sections for ^{30}Si+^{12}C are reproduced using neck length parameter (ΔR) at the different energies. The empirically fitted values of ΔR are used to predict the fusion cross-sections at similar centre of mass energies $E_{c.m.}$ for ^{28}Si+^{12}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}Si+^{12}C has been addressed through barrier lowering parameter which is the in-built property of the model.

*Electronic address: roopisaini87@gmail.com

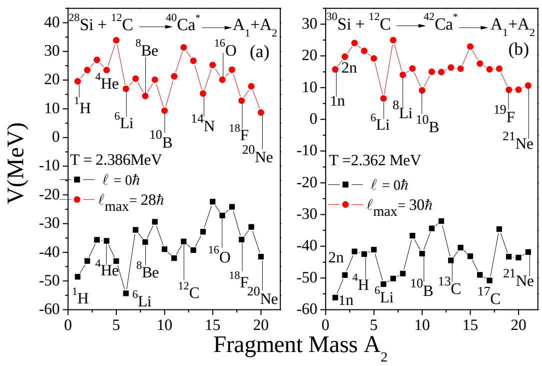

FIG. 1: The fragmentation potential $V(MeV)$ as a function of fragment mass number A$_2$, calculated for two extreme ℓ-values, for the CN $^{40}Ca^*$ and $^{42}Ca^*$ at $E_{c.m.}$ = 9.5 MeV and ΔR = -0.7 fm, for deformed fragmentation paths.

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 ℓ-partial waves, the compound nucleus decay cross-section is given by

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

Where, $\mu = [A_1 - A_2/(A_1 + A_2)]m$, is the reduced mass, with m as the nucleon mass and ℓ_{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 equation and P calculated as the WKB tunneling probability. The structure information in P_0 enters through the fragmentation potential $V(\eta, R)$ as given in Fig. 1.

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 $\ell = 0\hbar$, 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 ℓ 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 (ΔV_B) values, which is difference between the top of the barrier V_B and actual potential V_{R_a} 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 (ΔV_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

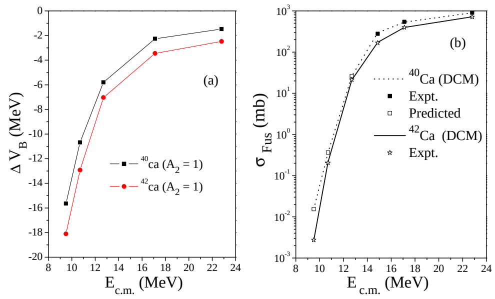

FIG. 2: (a)ΔV_B as a function of $E_{c.m.}$ and (b) The fusion cross section, σ_{Fus} calculated at comparable center of mass energies for $^{40,42}Ca^*$ within DCM and are compared with available experimental data where applicable for deformed fragmentation.

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 ΔV_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.

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