Effect of incident channel properties on the fusion dynamics

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Introduction

Consistent efforts have been made in last few decades to discover new stable elements by fusing a heavy ion beam with stable target. Indeed, the fusion process is found to be inhibited by various factors specially at sub barrier energies. In low energy region, the interacting nuclei may not be able to penetrate the Coulomb barrier and hence demanding the change in reaction partners, that favor the quantum mechanical tunnelling of barrier by inducing barrier lowering effects. The Coulomb factor Z_1Z_2 is found to be the main ingredient that hinder the formation of equilibrated compound system and give rise to some competing non compound nucleus mechanisms. The higher value of Z_1Z_2 reduces the fusion probability and results in the formation of dinuclear system. The fusion-evaporation residue which is clear signature of compound nucleus formation is hindered for higher values of Z_1Z_2, followed by fission and quasi fission processes. However, it doesn't mean that the fusion of heavier system is impossible. It gives us motivation to find a feasible way that leads to the formation of compact and equilibrated compound systems in heavy mass region. To rectify this problem, charge asymmetry η_Z of incident channel plays an important role in the reaction dynamics, as it lowers the Coulomb barrier and increases the fusion probability.

The present work is aimed to analyze the consequences of Coulomb effect i.e. Z_1Z_2 effect is explored within the reactions operating for different projectiles and fixed target nuclei. Here, we have worked on $^{12}C,^{16}O,+^{92}Zr$ reactions[1], forming the compound systems ^{104}Pd and ^{108}Cd. The calculations are based on extended Wong model[2] wherein proximity potential is calculated using SIII Skyrme force derived from Skyrme energy density formalism. The preliminary calculations show that the fusion hindrance is observed at sub barrier region for the reaction with higher Z_1Z_2 values and lower mass asymmetry (η_Z). The drastic behavior in sub barrier cross sections is further clarified from the irregular variation of angular momentum values i.e. ℓ_{max} values with increase in incident energy.

Methodology

In extended Wong model [2], the total fusion cross section is calculated as

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

where ℓ_{max} is determined empirically for the best fit of experimental data and P_ℓ is defined as penetration probability given by the Hill Wheeler[3],

$$P_\ell = \left[1+\exp\left(\frac{2\pi(V_B^\ell - E_{c.m.})}{\hbar\omega_\ell}\right)\right]^{-1} \quad (2)$$

with V_B^ℓ is the barrier height, and $\hbar\omega_\ell$ is the curvature that can be obtained at empirically optimized ℓ values.

Calculations and Results

The fusion evaporation cross sections of $^{12}C,^{16}O,+^{92}Zr$ reactions are calculated in the vicinity of Coulomb barrier using the extended Wong formula. The results are compared with experimental data as shown in Fig

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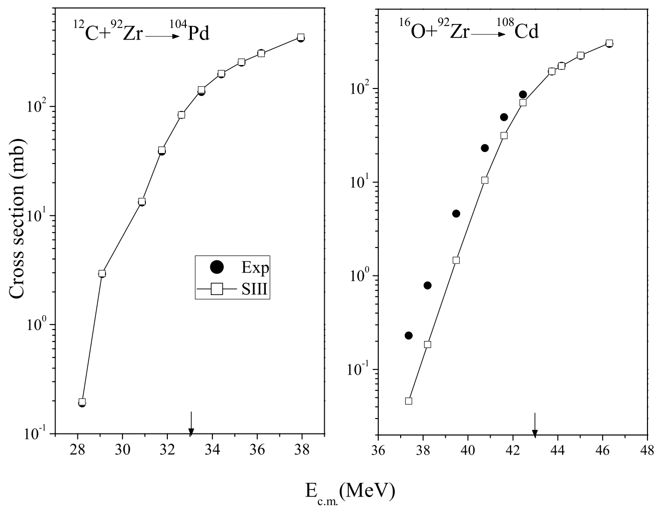

FIG. 1: The fusion excitation function of (a) $^{12}C +^{92} Zr$ and (b)$^{16}O +^{92} Zr$ reactions is compared with the available experimental data. Here, the down arrow represents the Coulomb barrier of each reaction.

1. The fusion excitation function of ^{12}C+^{92}Zr reaction with Z_1Z_2=240 and Coulomb barrier at V_C = 33.13 MeV, is prescribed in Fig 1(a). It is apparent from the figure that SIII force fits the data nicely at all the available energy range, following the smooth variation of angular momentum values (ℓ_{max} values) with respect to center of mass energies. The factors such as deformations and orientation are duly incorporated in the calculation. In order to examine the role of Coulomb factor in the reaction dynamics, calculations are also performed with relatively heavier projectile beam i.e. ^{16}O, interacting with same target i.e. ^{92}Zr. The colliding nuclei have Z_1Z_2= 320 and Coulomb barrier, V_C at 43.33 MeV, across which the fusion excitation function of $^{16}O +^{92} Zr$ reaction has been calculated using the SIII Skyrme force. In Fig 1(b), the theoretical cross-sections of $^{16}O +^{92} Zr$ reaction exhibit fusion hindrance phenomena at sub barrier energies. It is further indicated from the irregular variation of angular momentum ℓ_{max} values. This deviation in the cross section seems to arise due to higher Z_1Z_2 product. As, both the reactions have negative ground state Q_{2n} value, so the possibility of neutron transfer effect is minimal. This shows that Coulomb factor or equivalently charge or mass asymmetry plays important role in fusion dynamics and is considered as one of the main reason behind the fusion hindrance experienced at below barrier region. It would be of further interest to explore reaction dynamics with wider range of Z_1Z_2 product and generalize the possible impact on fusion hindrance.

References

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