Description of fusion and quasi-fission processes using one-dimensional Langevin dynamical model

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Introduction

Heavy ion induced nuclear reaction consists of two successive dynamical time evolutions. In the first step, the projectile is captured by the target to form a dinuclear system (DNS). Subsequently, the DNS either decays via quasi-fission or equilibrates to a compound nucleus through fusion process. In this course of evolution diffusion of nucleons among the target and projectile nuclei takes place. The fate of an event is decided based on the direction of mass flow. Specifically, fusion occurs when the projectile is completely absorbed within the target nucleus resulting the mass-asymmetry to be unity.

Model

At a particular beam energy, the fusion cross-section is given by

$$\sigma_{CN} = \sum_{l=0}^{l_{max}} \sigma_c(l) P_{CN}(l), \quad (1)$$

where σ_c is the capture cross-section. The fusion probability P_{CN} is calculate by solving a one-dimensional stochastic Langevin dynamical model. Within this model,

$$P_{CN} = \left(\frac{N_{fus}}{N_{tot}}\right)_l, \quad (2)$$

where N_{fus} is the no of fused events out of a total of N_{tot} Langevin events with initial angular momentum l. We have used the target-projectile mass-asymmetry, $\alpha = \frac{A_1-A_2}{A_1+A_2}$, as the collective coordinate in the dynamical calculation. The expression for the driving force is given by,

$$V = B_T + B_P + V_C + V_N - B_{CN} \quad (3)$$

where V_C, V_N are Coulomb and Nuclear potential, respectively [1]. B_T, B_P, and B_{CN} represents the binding energies of the target, projectile, and compound nucleus, respectively. The Langevin equations are solved within the high friction limit [2].We consider an event to be complete fusion when α reaches a predefined value close to unity. Otherwise, if α reduces to zero, we count the event as quasi-fission.

Results and discussion

Due to the competition between fusion and quasi-fission, probability of the fusion process increases as the mass asymmetry of the entrance channel increases whereas quasi-fission dominates for more symmetric systems. We consider ^{16}O+^{208}Pb, ^{48}Ca+^{208}Pb and ^{50}Ti+^{208}Pb reactions for the present study. The α of these three systems varies widely to distinguish the effect due to non-compound reactions. In the present calculation, the shape of the target and projectiles are always considered to be spherical. We have plotted V in Fig. 1. For different charge fractions between the target and projectile, corresponding neutron numbers are obtained by optimizing the potential along N/Z. Since the N/Z for the three composites are different, we obtain different potential energy curve for each reaction.

The reaction ^{16}O+^{208}Pb is more asymmetric compared to the ^{48}Ca+^{208}Pb, ^{50}Ti+^{208}Pb. The initial value of α is large for ^{16}O+^{208}Pb

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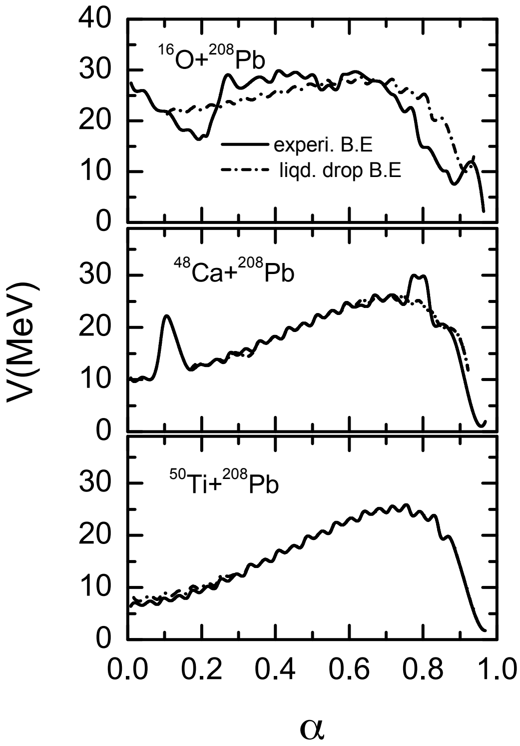

FIG. 1: Variation of V along α.The solid and dashed lines corresponds to experimental and liquid drop binding energies, respectively.

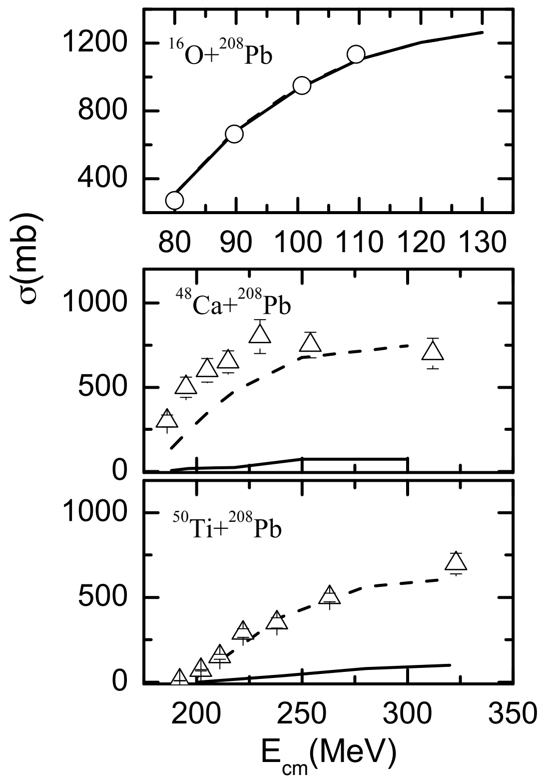

FIG. 2: Variation of σ_c (dashed lines) and σ_{CN} (solid lines) for different beam energies. Experimental values are shown by circle [4] and triangle [5].

and, therefore, it is more probable to undergo complete fusion. However, ^{48}Ca+^{208}Pb and ^{50}Ti+^{208}Pb reactions are known to contribute mostly in quasi-fission channel as the values of α are comparatively small. We have calculated σ_{fus} for the three reactions and plotted in Fig. 2 as a function of center of mass energy. The calculated and experimental σ_c are shown in this figure. The details of the calculation of σ_c is described in [3].Evidently, for the ^{16}O+^{208}Pb reaction, the σ_{CN} is close to σ_c, whereas the σ_{CN} for the other two reactions are strongly suppressed due to quasi-fission.

In conclusion, we have presented a simplistic dynamical model to calculate fusion cross-sections in heavy-ion induced reactions. This model can be implemented for a faster estimation of entrance-channel effects.

References

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