Study of deformation and orientation effect in capture process using 2D Langevin dynamical model

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Introduction

Heavy-ion induced reactions provide the opportunity to synthesize heavy and superheavy elements. Substantial theoretical and experimental progresses have been made in this field. In superheavy nuclei formation, relatively heavy projectiles are involved and the process depends critically on the intricated characteristic of the reaction mechanism. The process consists of two consecutive dynamical evolutions. First, a compact dinuclear shape is formed during the capture, and, in the second stage, either it decays through quasifission or it equilibrates to a compound nucleus. The initial stage i.e., the capture process is influenced by different reaction parameters. One of the important quantity is the deformations of the colliding target and projectile, respectively. In the case of deformed nuclei, it is indispensable to define relative orientations (α_1 and α_2) for precise estimation of capture cross-section. In the present work, we systematically investigated the effect of deformation on the capture process using a 2-dimensional Langevin dynamical model [1].

Theoretical Model

The expression of capture cross-section is given by

$$\sigma_c = \frac{\pi\hbar^2}{2\mu E_{c.m.}} \sum_{\ell=0}^{\infty}(2\ell+1)T_\ell = \int_0^\ell \frac{d\sigma_c(\ell)}{d\ell} d\ell \tag{1}$$

here T_ℓ is capture probability, calculated by counting the no of captured events.

$$T_\ell = \frac{N_{cap}}{N_{tot}} \tag{2}$$

where N_{cap} is the no of captured events out of N_{tot}, total no events considered for a particular ℓ. To calculate N_{cap}, we solved the 2D Langevin equations in the deformation space of $(r, \theta, \alpha_1, \alpha_2)$, where r defines the distance between the center of mass of the colliding nuclei, θ is the angle subtended by r on the plane of reaction and α_1 and α_2 signify relative orientations of target and projectile, respectively. The driving potential is obtained by applying LDM [2]. To incorporate fluctuation-dissipation in the dynamics, we implement the surface friction model [3]. The capture cross-section is calculated for each value of θ as a function of energy, and obtained the average capture cross-section by averaging over all orientations.

Results

For the present study we consider two reactions (i) ^{50}Ti+^{238}U (ii) ^{48}Ca+^{244}Pu. In Fig. 1, we plotted the variation of potential energy as a function of the distance between the colliding nuclei for different orientations. The driving potential is obtained for spherical and deformed target projectile configurations incorporating the orientations of colliding nuclei. In the Fig. 1, we have calculated the potential energy for 0°-0°, 60°-60°, 90°-90° orientations, respectively. For ^{48}Ca+^{244}Pu reaction, ^{48}Ca is spherical and quadrupole deformation for ^{244}Pu is 0.293, and for ^{50}Ti+^{238}U reaction, the quadrupole

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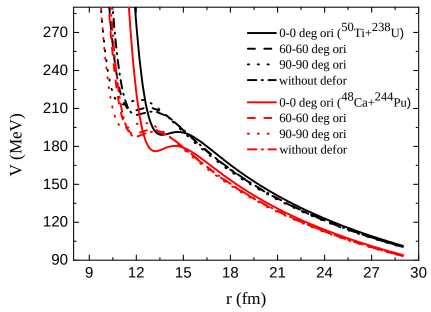

FIG. 1: Variation of potential energy with r for ^{50}Ti+^{238}U and ^{48}Ca+^{244}Pu reactions.

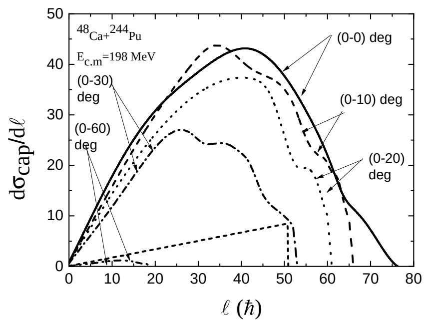

FIG. 2: Variation of $d\sigma_{cap}(\ell)/d\ell$ with ℓ for ^{48}Ca+^{244}Pu.

deformations for ^{50}Ti and ^{238}U are 0.166 and 0.275, respectively. Comparing the results obtained for spherical and deformed configurations, one can infer that the height of barrier for the deformed cases especially for 0°-0° orientation is lower than the spherical and other deformed configurations. Next, In Fig. 2, we demonstrated the calculated $d\sigma_{cap}(\ell)/d\ell$ corresponding to different orientations. We have compared the calculated capture cross-section with experimental data [4] in Fig. 3. In the calculation of capture cross-section, we incorporate both target projectile deformation. For the deformed target projectile, the barrier height decreases in comparison with the spherical case. Hence, capture probability increases in the case of the deformed target

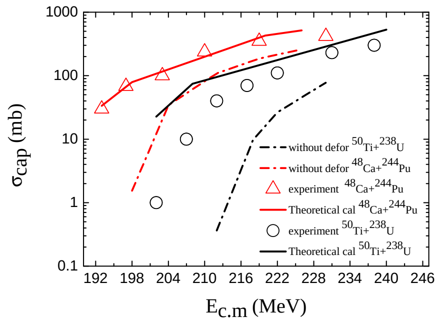

FIG. 3: Capture cross sections calculated from Langevin dynamics are compared with experimental data.

projectile. We observed that the agreement between the experiment and results obtained from our model calculation is good. For spherical targets and projectiles, the model calculated capture cross-section is much lower than the experimental data.

Conclusion

In conclusion, we have studied theoretically the effect of deformation and orientation in capture process using a 2-D Langevin dynamical model. We can also conclude that the deformation and orientation of target and projectile have significant effects in the capture process and it is essential to include these effects in the calculations.

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