Influence of non-coplanar orientation on fusion barrier characteristics of heavy-ion induced nuclear reactions

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Introduction

In literature, many studies [1–5] have advocated the inclusion of the non-coplanar orientation, ϕ, as it significantly influences the fusion barrier characteristics. In [2], the authors studied the ^{150}Nd+ ^{150}Nd and ^{180}Hf+^{86}Kr projectile-target combinations to study the variation in the total interaction potential V_T after incorporating the non-coplanar orientation ϕ, ranging from 0^o to 90^o. The study showed that the non-coplanar orientation lead to a increase in the total interaction potential and the potential pocket. The studies [1, 2, 5] on the non-coplanar orientation ϕ provide the necessity of studying such interactions. However, most of the studies are focused on the coplanar compact configurations, that are associated with the orientations corresponding to maximum barrier height V_B and the minimum barrier separation R_B with the value of non-coplanar orientation restricted up to 90^o, without addressing the full range of ϕ (0^o-360^o).

In the present work, we have re-examined the system ^{150}Nd+ ^{150}Nd and ^{180}Hf+^{86}Kr, employing the reference [2]. We use the same formalism as of $\phi = 0$, substituting the radius parameter $R_i(\alpha_i)$ for the out-of-plane nucleus (where i = 1 or 2) with the projected radius parameter $R_i^P(\alpha_i)$ in the definitions of both the mean curvature radius $\bar{R}$ and the shortest distance s_0. This approach allows us to investigate the effects of non-coplanar orientation ϕ, at fixed polar orientation θ with different order of deformations. We aim to determine whether the total interaction potential V_T exhibits symmetry around a specific value of non-coplanar orientation, similar to the behavior observed in polar orientation θ. Also, the variation of the barrier height V_B with ϕ has been studied with different orders of deformation for the rotation of non-coplanar orientation ϕ. These results may serve as a framework for a better understanding of the barrier characteristics and related fusion cross-sections.

Methodology

The shape of the nuclear surface for higher-order deformation (up to β_4) can be described in terms of the nuclear radius vector $R_i(\alpha_i)$ using the spherical harmonic function, as given below

$$R_i = R_{0i}\left[1 + \sum_{\lambda=2,4}^{i=1,2} \beta_{\lambda i} Y_{\lambda i}^{(0)}(\alpha_i)\right] \quad (1)$$

For the non-coplanar $\phi \neq 0$ analysis, the projections into the plane of the other nucleus are given as

$$R_i^P(\alpha_i) = R_i(\alpha_i)\cos\phi \quad (2)$$

and

$$R_j^P(\delta_j) = R_j(\delta_j)\cos(\phi - \delta j) \quad (3)$$

where i=j=1 or 2 (See [2] for more). To study the variation in the coplanar orientation degree of freedom, the barrier characteristics V_B and R_B at $\ell = 0$ have been calculated using the total interaction potential V_T given as

$$V_T(R) = V_C(R, Z_i, \beta_{\lambda i}, \theta_i, \phi) + V_N(R, A_i, \beta_{\lambda i}, \theta_i, \phi) \quad (4)$$

where V_C and V_N are the Coulomb and nuclear potential respectively. While the V_C is taken from [1], the nuclear potential is obtained using the Proximity potential given by J. Blocki *et. al*[6].

$$V_N(R, A_i, \beta_{\lambda i}, \theta_i, \phi) = 4\pi\bar{R}\gamma b\Phi(s_0) \quad (5)$$

here, $\bar{R}$ is the mean curvature radius, γ is the surface energy constant, 'b' is the surface thickness having value 0.99 fm, and Φ is the universal function dependent on s_0 which is the minimum separation distance among the surfaces of two colliding nuclei.

Results and Discussion

In this study, we have re-examined the ^{150}Nd+ ^{150}Nd and ^{180}Hf+^{86}Kr reactions, to examine the effects of non-coplanar orientation ϕ, along with

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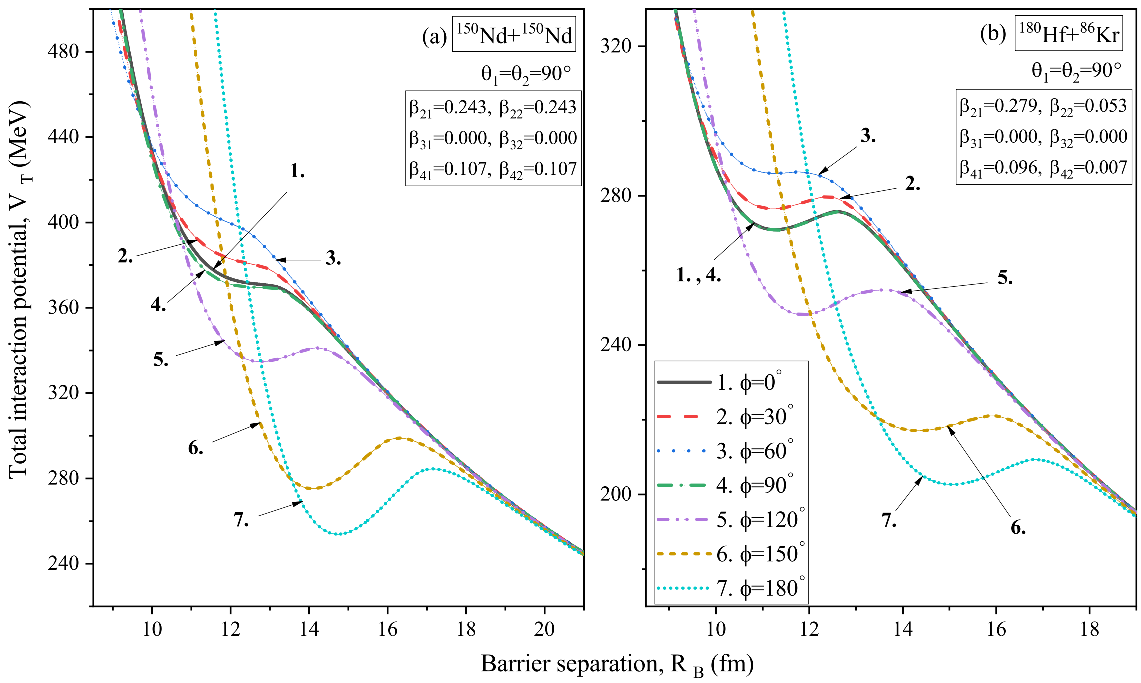

FIG. 1: (Color online) Graphical representation of variation in the total interaction potential V_T w.r.t the barrier separation R_B for different values of non-coplnar orientations varied from 0^o to 360^o at fixed coplanar orientation θ.

deformation up to hexadecapole (β_4), at fixed polar orientation θ, on the total interaction potential V_T and the barrier characteristics V_B and R_B. In present work, rather than limiting the range of non-coplanar orientation to 90^o, we have extended it to 360^o. This broader range revealed that non-coplanar orientations yield symmetrical values of V_T around 180^o. As illustrated in Fig.1, the height of the V_T first increases and then decreases in response to variations in ϕ from 0^o to 180^o. This behavior can be attributed to the further compression or elongation of the interaction radius resulting from the non-coplanar orientation ϕ signifying a complex relationship between ϕ and the total interaction potential V_T and the related barrier characteristics. The observed modifications in the potential barrier V_T, in contrast to the coplanar ($\phi = 0$) scenario, offer new insights into the dynamics of heavy-ion induced reactions. Such modifications are expected to have significant impact on the fusion reaction cross-sections. These results underscore the importance of considering non-coplanar orientations up to 180^o for a more comprehensive understanding of the dynamics of heavy-ion induced fusion reactions, and help in achieving better agreement with the experimental results.

References

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