Oblate/prolate deformed shapes of the fusion partners at different relative orientations

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Introduction

The shape, mass and radius are fundamental properties of a nucleus. The shape of the nuclei participating in a reaction affects the barrier height, which is of great significance for the synthesis of super-heavy elements. It is expected that collisions involving deformed nuclei can result in different properties of dynamical processes compared to spherical ones. Moreover, due to distinct differences in the overlap region of deformed nuclei, collisions of aligned deformed nuclei may provide a clearer and deeper insight of reaction. Along with the deformed shapes, the relative orientations of the two colliding nuclei may contribute appreciably towards their fusion probability. So it is quite interesting to see how different (oblate/prolate) quadrupole deformations in the Coulomb potential affect the total interaction potential in the inner region and to study the role of deformation at different orientations of the colliding nuclei in the fusion dynamics.

Methodology

We employ Aage Winther(AW) 95 to study the role of deformed Coulomb potential at different orientations of the colliding nuclei in the fusion process. The nuclear part of the interaction potential $V_N(R)$ between two colliding surfaces is written as

$$V_N(R) = -\frac{V_0}{1+exp(\frac{R-R_0}{a})} MeV, \quad (1)$$

with $R_0 = R_1 + R_2$ and

$$V_0 = 16\pi \frac{R_1 R_2}{R_1 + R_2}\gamma a \quad (2)$$

The surface diffuseness parameter is expressed as

$$a = \Big[\frac{1}{1.17(1+0.53(A_1^{-1/3}+A_2^{-1/3}))}\Big] fm. \quad (3)$$

The effective sharp radius R_i is given by

$$R_i = 1.20 A_i^{1/3} - 0.09\ fm. \quad (4)$$

For further details, reader is referred to Ref. [1]. In the present study, the nuclear potential is assumed to be independent of deformation effects. The expression for the deformed Coulomb potential $V_C(R,\theta)$ between two colliding nuclei as given by Wong [2] is

$$\begin{aligned} V_C(R,\theta) &= \frac{Z_1 Z_2 e^2}{R} \\ &+ \sqrt{\frac{9}{20\pi}}\frac{Z_1 Z_2 e^2}{R^3}\sum_{i=1}^{2} R_i^2 \beta_{2i} P_2(cos\theta_i) \\ &+ \frac{3}{7\pi}\frac{Z_1 Z_2 e^2}{R^3}\sum_{i=1}^{2} R_i^2 [(\beta_{2i} P_2(cos\theta_i)]^2, \end{aligned} \quad (5)$$

where θ_i is the angle between the symmetry axis of the *ith* nucleus and the collision axis and R_i being the effective sharp radius of *ith* nucleus. The parameter β_{2i} [3] corresponds to quadruple deformation parameter for *ith* nucleus.

Adding Coulomb potential to nuclear part, we get the total interaction potential which, for zero value of orbital momentum is given by

$$V_T(R) = V_N(R) + V_C(R,\theta). \quad (6)$$

Since the colliding nuclei may have many possible orientations, therefore, we take $\theta_1 = 0^0$ and θ_2 varies from 0^0 to 90^0.

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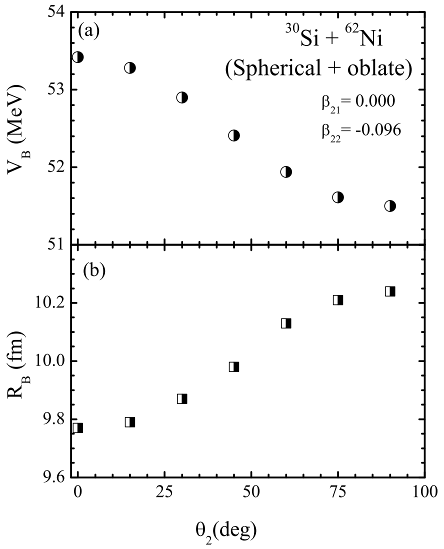

FIG. 1: The upper panel (1(a)) displays fusion barrier heights (half-filled circles) as a function of θ_2 and the lower panel (1(b)) represents barrier positions (half-filled squares) as a function of θ_2 for the reaction of ^{30}Si + ^{62}Ni. Here, the projectile is spherical and the target is oblate-deformed.

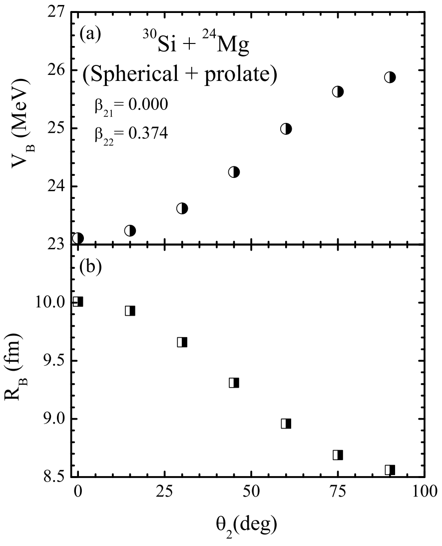

FIG. 2: Same as Fig. 1, but for the reaction of ^{30}Si + ^{24}Mg. Here, the projectile is spherical and the target is prolate-deformed.

Results and Conclusions

In order to study the effect of different shapes (oblate/prolate) at different orientations of colliding nuclei in the fusion dynamics, we have considered the reactions of ^{30}Si + ^{62}Ni and ^{30}Si + ^{24}Mg.

From figure 1, it is clear that in case of reaction (^{30}Si + ^{62}Ni) involving spherical projectile ($R_x = R_y = R_z$) and oblate-deformed target ($R_x = R_y > R_z$), the barrier heights V_B decrease and barrier positions R_B increase with increasing value of the orientation of target nucleus (θ_2). Also, collision along the polar axis (short axis) finds lowest barrier whereas collisions along the equatorial axes results in maximum repulsion.

In figure 2, we notice that the fusion barrier heights V_B increase and barrier positions R_B decrease in case of reaction (^{30}Si + ^{24}Mg) involving spherical projectile and prolate-deformed ($R_x = R_y < R_z$) target with increasing value of the orientation of target nucleus (θ_2). In this case, the prolate-deformed target finds maximum height of fusion barrier while colliding along its shortest axis (side collision) with the spherical projectile and lowest barrier height while colliding along the longest axis (tip collision). Hence, the barrier heights as well as barrier positions are shape-dependent and also depend upon the orientations of the colliding nuclei.

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References

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