Role of surface energy coefficient on the fusion barrier characteristics of ^{16}O induced reactions

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Introduction

The fusion dynamics of the colliding nuclei and related properties has always attracted the attention of the scientific community working on the heavy ion induced reactions. The fusion properties depend on the total interaction potential between the two colliding nuclei, which is defined as the sum of Coulomb potential, centrifugal potential, and the nuclear potential. Although the Coulomb and centrifugal potentials are well established, but the characteristics of nuclear potential depend on various complex nuclear properties. Over the past few decades, significant efforts have been made to understand the nuclear potential, as it plays a critical role in determining the fusion cross-sections as well as subsequent decay cross-sections. From the literature, it is evident that the proximity potential has emerged as one of the widely used interactions for the analysis of the nuclear potential. The proximity potential was formulated by Blocki et al., marked as Prox-77 [1]. Over the past years, various improvements have been made in proximity formula in order to study the fusion barrier and fusion cross-sections accurately. The authors of [2] have modified the Prox-77 by introducing a new surface energy coefficient γ, which resulted in reasonable predictions of fusion cross-sections across a range of center-of-mass energies.

In the present work, we intend to investigate the influence of temperature independent and temperature dependent surface energy coefficient on the fusion barrier characteristics and corresponding fusion cross-sections. Here, the ℓ-summed Wong model incorporated with quadrupole deformation, and associated optimum orientations [3] is used to calculate the fusion cross-sections (σ_{fus}). The investigation of σ_{fus} is done for the $^{16}O+^{176}Yb$ reaction, as a function of center of mass energies ($E_{c.m.}$) lying across the Coulomb barrier and the obtained results are compared with the experimental data of σ_{fus} [4].

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Methodology

The fusion cross-sections are calculated using the ℓ- summed Wong Model [5] which reads as

$$\sigma_{fus} = \frac{\pi}{k^2}\sum_{\ell=o}^{\ell_{max}}(2\ell+1)P_\ell(E_{c.m}, \theta_i), \qquad (1)$$

where $k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}}$, μ is the reduced mass, $\hbar\omega_B$ is curvature, ℓ_{max} is the maximum angular momentum calculated by sharp cut-off approximation method.

The attractive nuclear potential is calculated by using the proximity force which is marked as Prox-77 [1] and given as

$$V_N(R, A_i, \beta_{\lambda i}, \theta_i) = 4\pi\bar{R}\gamma b\Phi(s_0), \qquad (2)$$

where, $\bar{R}$ is the mean curvature radius, 'b' is the surface thickness. γ is the surface energy coefficient and $\Phi(s_0)$ is the universal function dependent on the minimum separation distance s_0. Here, the surface energy coefficient γ is depending on two parameters γ_0, the surface energy constant and k_s the surface-asymmetry constant, and is written as [6]

$$\gamma = \gamma_0[1 - k_s A_s^2], \qquad (3)$$

Here, A_s is the mass asymmetry parameter of the formed compound nucleus. The values of constants γ_0=0.9517 MeV/fm^2 and k_s= 1.7826 (γ labelled as γ_1). The other pair of γ_0, k_s are suggested by the authors of [2] reads as γ_0=1.460734 MeV/fm^2 and k_s= 4.0 (γ labelled here as γ_2). The thermal effect on γ at (T) w.r.t. barrier temperature (T_B) [6] is given as

$$\gamma(T) = \gamma(T=0)\left[1 - (\frac{T-T_B}{T_B})\right]^{\frac{3}{2}}, \qquad (4)$$

where, $\gamma(T=0)$ is calculated by using the equation 3.

Results and Discussion

The present study examines the role of the surface energy coefficient (γ) on the fusion barrier

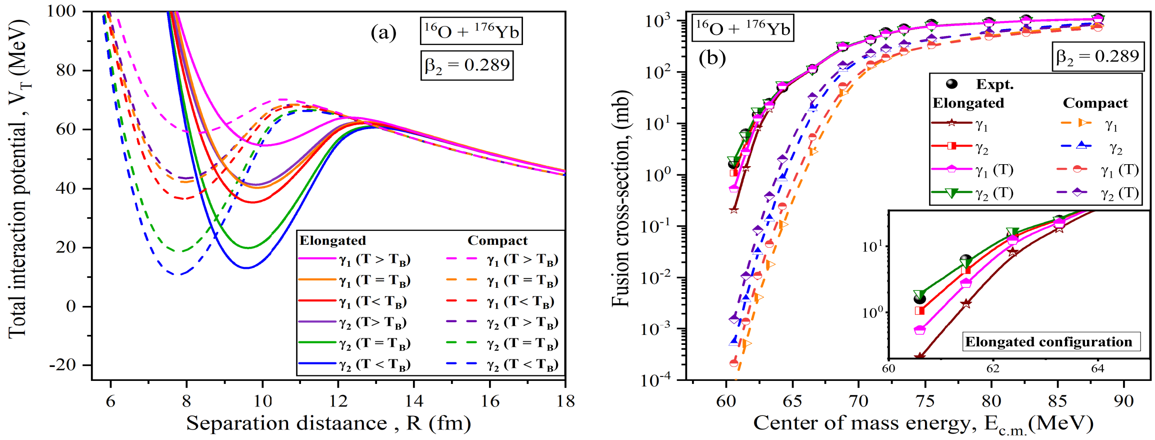

FIG. 1: (a) is plotted for scattering potential of ^{16}O+^{176}Yb, and (b) shows the fusion cross-sections of same reaction. The results are plotted for different choices of surface energy coefficients and optimum orientations of the deformed target.

characteristics and corresponding cross-sections for the reaction ^{16}O+^{176}Yb, taking into account quadrupole (β_2) deformation and related orientations of the target nuclei. The three values of γ are considered as γ_1, γ_2 and $\gamma(T)$ as mentioned earlier. Firstly, the scattering potential for the reaction ^{16}O+^{176}Yb is displayed in Fig. 1 (a). It is noted that the barrier height (V_B) for the elongated configuration is lower than that for the compact, attributable to the higher separation distance in the elongated configuration compared to the compact. The characteristics of scattering potential are influenced by various choices of γ. Specifically, as we move from γ_1 to γ_2, the V_B decreases while the pocket depth increases. Additionally, when considering the temperature effects associated with both γ_1 and γ_2, the pocket depth deepens at lower temperature, whereas it becomes shallower at higher temperature.

The ℓ-summed Wong model, incorporating the quadrupole deformations and the associated orientations using various values of γ, is employed to calculate the fusion cross-sections (σ_{fus}) for the aforementioned reaction. The obtained cross-sections are then compared with experimental data [4]. From the Fig. 1 (b), it is observed that elongated configurations lead to rise in the fusion cross-sections due to reduced barrier heights in comparison to the compact configuration. It may be noted that the elongated configuration provide a better agreement to experimental data at energies above the barrier for all γ values, some discrepancies are found at below the coulomb barrier energies, particularly for γ_1 case. Further, when the temperature dependence of γ_1 and γ_2 is included, the cross-sections get enhanced at below barrier region (pl. see inset of fig. 1(b)). The $\gamma_2(T)$ gives a relatively better agreement with data. Similar results are observed for the other ^{16}O induced reactions.

In summary, the fusion cross-section obtained from the ℓ-summed Wong model with the elongated configuration with temperature-dependent γ provides better agreement with data at energies below the Coulomb barrier.

Acknowledgments

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