Deformation effects on fusion cross-sections using various proximity potentials

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Introduction

The fusion of colliding nuclei and related phenomena has always been of central interest. The collision of two massive nuclei holds a special place in nuclear reaction mechanism as a large number of nucleons are involved in the interaction process. The knowledge of nucleus-nucleus interaction potential acts as an essential ingredient in the analysis of fusion-fission dynamics. The total interaction potential is sum of the centrifugal term, the long range Coulomb repulsive force and short range nuclear attractive force. The centrifugal and Coulomb part of the interaction potential are well known, however nuclear interaction part is not clearly understood as yet. Various versions of proximity potentials are available, all these are based on the proximity force theorem, according to which the nuclear part of the interaction potential can be taken as the product of a factor depending on the mean curvature of the interaction surface and a universal function (depending on the separation distance) and is independent of the masses of colliding nuclei.

Recently, authors of Ref. [1] have carried out a comparison of different proximity potentials by considering colliding nuclei to be spherical and the fusion cross-sections of selected reactions were explained by Bass 80, AW 95 and Denisov DP potentials at above barrier energies however the comparison was not good at below barrier energies. Here, we study the effect of deformation and orientation degree of freedom on fusion cross-sections for ^{16}O+^{92}Zr, ^{16}O+^{112}Sn, ^{16}O+^{186}W, ^{48}Ca+^{154}Cm, ^{48}Ca+ ^{96}Zr reactions using various proximity potentials (i.e. Prox 77, Prox 88, Bass 80 and Denisov DP) within Wong formula [2] and compare our calculations with experimental data spread on either side of Coulomb barrier. It is to be noted here that out of eight reactions investigated for fusion cross-section in Ref. [1], only two reactions i.e. ^{16}O+^{112}Sn and ^{48}Ca+ ^{96}Zr are considered here, as in other reactions the target and projectile are spherical and hence are not important in context of present study.

From calculations it is clear that with inclusion of deformations the fusion cross-sections are improved for majority of nuclear interaction potentials at below barrier energies. We observe that for O- and Ca- based reactions, Prox 77 fits the experimental data nicely at sub-barrier energies and overestimates the data at above barrier energies. In order to resolve the problem of over estimation of data, one can use the extended-Wong model [3] and can deduce maximum value of angular momentum ℓ_{max} at various energies.

Theory

The total interaction potential is defined as the sum of the deformation, orientation dependent Coulomb potential, proximity potential and angular momentum dependent potential, i.e.

$$V_T^\ell(R) = V_C(R, Z_i, \beta_{\lambda i}, T, \theta_i) + V_P(R, A_i, \beta_{\lambda i}, T, \theta_i) + V_\ell(R, A_i, \beta_{\lambda i}, T, \theta_i). \quad (1)$$

The temperature effects in both the V_C and V_P are introduced via the radius vectors of two nuclei, as follows:

$$R_i(\alpha_i, T) = [R_{0i}(1 + 0.0007T^2)][1 + \sum_\lambda \beta_{\lambda i} Y_\lambda^{(0)}(\alpha_i)] \quad (2)$$

For details of different versions of nuclear potentials used here one can see Ref. [1].

The fusion cross-section calculated using the Wong formula [2] for deformed and ori-

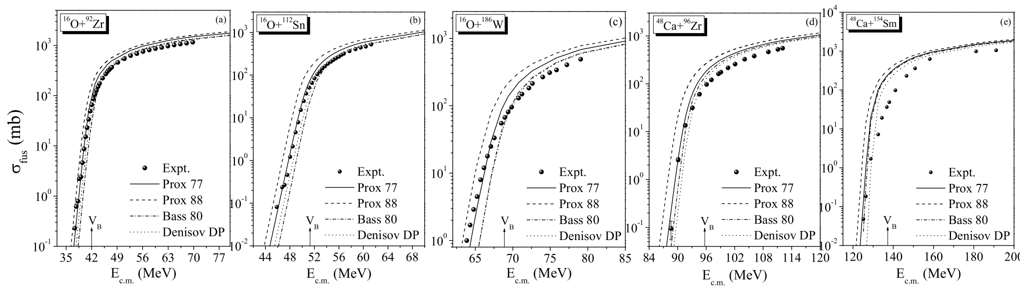

FIG. 1: Comparison of fusion cross-sections calculated using various nuclear proximity potentials with in the Wong formula for (a) ^{16}O+^{92}Zr (b) ^{16}O+^{112}Sn (c) ^{16}O+^{186}W (d) ^{48}Ca+^{96}Zr (e) ^{48}Ca+^{154}Sm reactions, as a function of $E_{c.m.}$. The upward arrow point out the Coulomb barrier of the reaction.

ented nuclei, colliding with $E_{c.m.}$, is

$$\sigma(E_{c.m.}, \theta_i) = \frac{{R_B^0}^2 \hbar\omega_0}{2E_{c.m.}} \ln\left[1 + \exp\left(\frac{2\pi}{\hbar\omega_0}(E_{c.m.} - V_B^0)\right)\right] \quad (3)$$

which on integrating over the orientation angles θ_i gives the fusion cross-section

$$\sigma(E_{c.m.}) = \int_{\theta_i=0}^{\pi/2} \sigma(E_{c.m.}, \theta_i) sin\theta_i d\theta_i. \quad (4)$$

Calculations and Results

Fig. 1 (a), Fig. 1(b) and Fig. 1(c) show the fusion cross-section of ^{16}O-based reactions i.e. ^{16}O+^{92}Zr, ^{16}O+^{112}Sn and ^{16}O+^{186}W, using nuclear interaction potentials Prox 77, Prox 88, Bass 80 and Denisov DP, with in the Wong formula. The barrier energies for above reactions are indicated by the upward arrows in Fig. 1. With the inclusion of deformation and orientations effects the comparison of experimental data of fusion cross-sections and calculated one improves for all proximity potentials at below Coulomb barrier energies. It is to be noted here that ^{16}O+^{112}Sn reaction was also considered in Fig. 8 of Ref. [1], and our comparison improves at below barrier energies as compare to calculations shown in that work. More specifically, Prox 77 seems to give better results at below barrier energies and Denisov DP and Bass 80 compete with each other at above barrier energies giving better comparison with available data and Prox 88, having lowest barrier height, overestimates the data at all energies.

Fig. 1 (d) and Fig. 1 (e) show the comparison of calculated fusion cross-sections for Ca-based reactions with experimental data for the above mentioned proximity potentials. For these reactions experimental data is available for above as well as below the Coulomb barrier. Prox 77 and Bass 80 explain the experimental data nicely at below barrier energies. It is clear from the comparison of our calculations (Fig. 1(d)) for ^{48}Ca+^{96}Zr reaction with the one shown in Fig. 7 of Ref. [1], that the comparison with available data improves with inclusion of deformation and orientation with in the Wong formula at below barrier energies. Thus from the above cases of O- and Ca-based reaction, we can say that fusion cross-sections are significantly affected with the inclusion of deformations and orientations and such effects are of extreme importance particularly at below barrier energies.

References

[1] I. Dutt, and R. K. Puri, Phys. Rev. C **81**, 064609 (2010); *ibid* **81**, 064608 (2010).
[2] C. Y. Wong, Phys. Rev. Lett. **31**, 766 (1973).
[3] R. Kumar, M. Bansal, S. K. Arun, and R. K. Gupta, Phys. Rev. C **80**, 034618 (2009).