Comparative study of different nuclear potentials in fusion of ^{48}Ca+^{96}Zr above and below the Coulomb barrier

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Introduction

The knowledge of nucleus-nucleus interaction potential is an essential ingredient in the analysis of nuclear scattering and fusion-fission dynamics. From the literature it is clear that no experiment can extract information about fusion barriers directly. All experiments measure fusion cross-sections and then with the help of theoretical models, one can extract the fusion barriers. Theoretical models are helpful in understanding the nuclear interactions at a microscopic/macroscopic level. 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 is well known, whereas nuclear part is not clearly understood as yet. The nuclear part can be calculated by taking different proximity potentials. These proximity potentials are the benchmark and backbone for majority of microscopic/macroscopic fusion models.

Here, we study the effect of different nuclear interaction potentials with deformations upto hexadecapole (β_4) included, on the fusion cross-section for ^{48}Ca+^{96}Zr reaction [1] and compare our calculations with experimental data available for energies above as well as below the Coulomb barrier. The nuclear potentials used in present analysis are, the three versions of proximity potential, i.e. Prox 1977, 1988 and 2000, Bass potential and a modified version of the Denisov potential, which have been used in similar comparative study [2], but only by taking spherical interactions into account. We observe that deformations play important role in this illustrative reaction within Wong formula [3]. The comparison of experimental data with that of calculated ones is improved, specially at below barrier energies, when nuclei are considered deformed.

Theory

The nuclear interaction potential, V_N, between two surfaces can be written as:

$$V_N(s_0(T)) = 4\pi\bar{R}\gamma b(T)\phi(s_0(T)), \qquad (1)$$

where $\bar{R}(T)$ is the mean curvature radius and Φ is the universal function.γ is the surface energy coefficient which has two parameters γ_0 and k_s. Different versions of nuclear potentials used here are following:

1. Proximity 1977 (Prox 1977)

For this proximity potential the universal function is given by,

$$\Phi(s_0) = \begin{cases} -\frac{1}{2}(s_0(T)-2.54)^2 - 0.0852(s_0(T)-2.54)^3 \\ -3.437exp(-\frac{s_0(T)}{0.75}) \end{cases} \qquad (2)$$

respectively, for $s_0(T) \leq 1.2511$ and $s_0(T) \geq 1.2511$. In this, γ_0 and k_s were taken to be 0.9517 Mev/fm^2 and 1.7826 resp.

2. Proximity 1988 (Prox 1988)

Later on, Möller and Nix [4] improved the mass formula and due to this the value of coefficients γ_0 and k_s were changed, leading the values = 1.2496 MeV.fm^{-2} and 2.3, respectively. Its universal function is same as for Prox 1977.

3. Proximity 2000 (Prox 2000)

The universal function for this is given by,

$$\Phi(\xi) = \begin{cases} -0.1353 + \sum_{n=0}^{5}[c_n/(n+1)](2.5-\xi)^{n+1} \\ \quad for 0 < \xi \leq 2.5, \\ -exp((2.75-\xi)/0.7176) \\ \quad for \xi \geq 2.5, \end{cases} \qquad (3)$$

where $\xi = R - C_1 - C_2$ The values of different constants c_n were c_0=-0.1886, c_1=-0.2628, c_2=-0.15216, c_3=-0.04562, c_4=0.069136, and c_5=-0.011454.

4. Bass 1980

The universal function for this is given by,

$$\Phi(s) = [0.033exp(\frac{s}{3.5}) + 0.007exp(\frac{s}{0.65})]^{-1}. \tag{4}$$

For more details see Ref. [2].

5. New Denisov Potential

Denisov performed numerical calculations and parameterized the potential based on 7140 pair within semimicroscopic approximation. For universal function and more details see Ref. [2].

$WongFormula$

The fusion cross-section is calculated using the Wong formula [3] for deformed and oriented nuclei, colliding with $E_{c.m.}$, is

$$\sigma(E_{c.m.},\theta_i) = \frac{{R_B^0}^2\hbar\omega_0}{2E_{c.m.}} \ln\left[1+\exp\left(\frac{2\pi}{\hbar\omega_0}(E_{c.m.}-V_B^0)\right)\right] \tag{5}$$

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

$$\sigma(E_{c.m.}) = \int_{\theta_i=0}^{\pi/2} \sigma(E_{c.m.},\theta_i) sin\theta_i d\theta_i. \tag{6}$$

Calculations and Results

Here, we study the effect of deformations on fusion cross-sections using different proximity potentials within Wong formula for ^{48}Ca+^{96}Zr reaction. It is clear from Fig.1, that deformations play significant and important role in the fusion process of ^{48}Ca+^{96}Zr reaction. With the inclusion of deformations, comparison of calculated cross-section with experimental data is improved significantly as compared to the case of spherical nuclei (see Fig.7 (a) of [2] for comparison). It is clear from Fig. 1 that Prox 1977 is comparatively better than others at energies below the Coulomb barrier. The cross-section for Denisov and Bass 80, both are also close to the experimental data. Prox 1988 overestimates the experimental data and Prox 2000 fits the data only

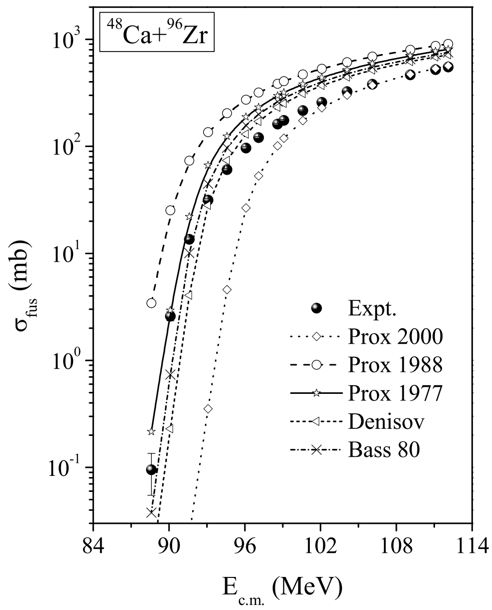

FIG. 1: Comparison of the experimental data of the fusion cross-section for ^{48}Ca+^{96}Zr with the calculated ones with in Wong formula using various proximity potentials used.

at higher center of mass energies and underestimate at below barrier energies. For spherical case [2] Bass 80 and Denisov, both are better than Prox 1977 but none is fitting the data at below barrier energies.

Thus it is concluded that with effect of deformations included, Prox 1977 is better than the others nuclear potentials in the context of ^{48}Ca+^{96}Zr reaction. Further calculations are on, in order to make some generalized statement by studying the role of different nuclear potentials in a variety of heavy ion reactions.

References

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