A pocket formulae for fusion barriers using proximity potentials

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Introduction

In the low energy heavy-ion collisions, quasi-elastic scattering and fusion reactions have been studied in recent decades. These studies provide us an ample opportunity to extract the information about the nuclear structure and nucleus-nucleus interaction. One can also explore the mechanism of heavy-ion reactions at near barrier energies. Further, this information is of great importance for the synthesis of super-heavy nuclei. Since fusion is a low density phenomena, several theoretical models have been developed in recent past at microscopic/macroscopic level and have been robust against vast available experimental data [1–3]. Irrespective of the basis of a theoretical model, one always tries to parameterize the potential in terms of some known quantities like, the charges, masses and isospin of the colliding systems. Generally benchmark is always to compare with proximity potential [1]. Various authors have parameterized fusion barriers in terms of these quantities using different approaches. However, no such study is available using proximity potentials. With the availability of different versions of proximity potentials [1–3], it is of interest to parameterize the fusion barriers using these different versions of proximity potentials.

The Model

Different proximity potentials can be written as a product of geometrical factor and universal function $\Phi(\xi)$. According to the original version of proximity potential [1], interaction potential between two surfaces can be written as

$$V_N^{Prox\ 77}(r) = 4\pi\gamma b\overline{R}\Phi(\xi)\ \text{MeV}, \qquad (1)$$

where surface energy coefficient γ taken from the Lysekil mass formula (in MeV/ fm^2) is written as:

$$\gamma = \gamma_o\left[1 - k_s\left(\frac{N-Z}{A}\right)^2\right], \qquad (2)$$

here N, Z, and A refer to the combined system of the two interacting nuclei. Here, γ_0=0.9517 MeV/ fm^2 and k_s = 1.7826. With $\overline{R}$ is the mean curvature radius and $\Phi(\xi)$ is the universal function. We marked this potential as Prox 77.

With modified mass formula, the values of coefficients γ_0 and k_s are 1.2496 MeV/ fm^2 and 2.3, respectively, showing deeper alteration compared to above coefficients. This potential is marked as Prox 88.

In recent years, modifications over original proximity potential have also been suggested [2]. The prime aim behind this modification was the fact that assigned version of Prox 77 overestimates the experimental data by $\approx$ 4%. In the modified version, much attention is paid to improve the geometrical factor and surface energy coefficient γ. $\Phi(\xi)$ is also modified in this version. This potential is marked as Prox 00.

Results and Discussion

For the present study, all kind of reactions involving symmetric ($N = Z,\ A_1 = A_2$) as well as asymmetric nuclei ($N \gg Z,\ A_1 \ll A_2$) are considered. In all, 400 reactions covering almost whole of the periodic table are taken. Barrier positions were parameterized in terms of surface distance $s_B = R_B - C_1 - C_2$. We noted that s_B reduces with mass of the system indicating deeper penetration is needed

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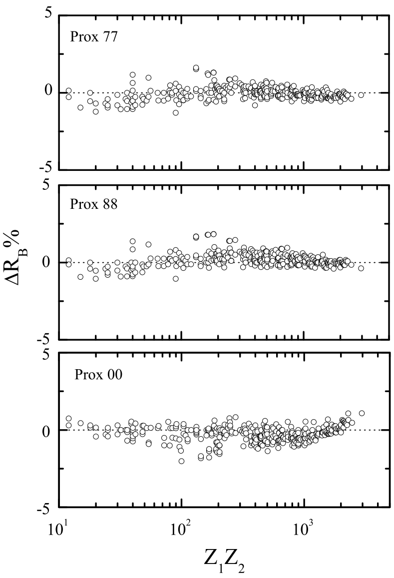

FIG. 1: The percentage difference ΔR_B % of parameterized values over exact value as a function of $Z_1 Z_1$.

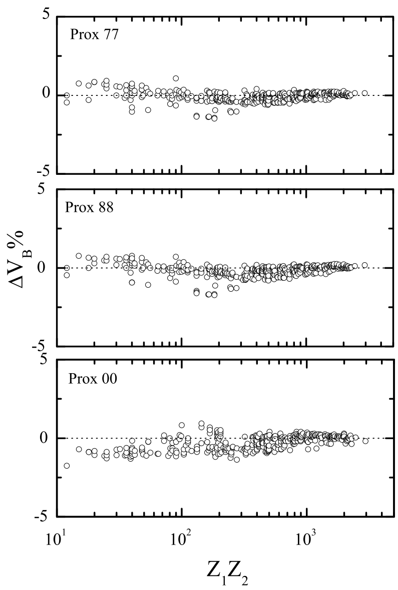

FIG. 2: Same as Fig. 1, but for ΔV_B % .

for heavier nuclei. By adding radii of two nuclei, one can compare the fusion barrier. All proximity potentials follow exponential parametrization [3]

$$s_B = a \exp[-b\,(x-2)^{1/4}], \tag{3}$$

where a and b are the constants having different values for different proximity potentials.

The quality of our parameterized fusion position can be judged by analyzing the percentage deviation defined as

$$\Delta R_B \ \% = \frac{R_B^{anal} - R_B^{exact}}{R_B^{exact}} \times 100. \tag{4}$$

We plotted in Fig. 1, the percentage deviation ΔR_B % verses $Z_1 Z_2$. Very encouragingly, we see that in all the three cases, our analytical parameterized forms give good results within $\approx \pm 1\%$. Further, we parameterize the fusion barrier heights V_B as [3]

$$V_B = \alpha[\frac{1.44 \cdot Z_1 \cdot Z_2}{R_B^{anal}}(1 - \frac{1}{R_B^{anal}})], \tag{5}$$

here α is a constant having different values for different proximity potentials. The second term in the above relation takes care of the deviations at lower tail of the fusion barrier heights. Again, the quality of our analytical parametrization is tested in Fig. 2 where percentage difference between exact and analytical values is in $\approx \pm 1\%$. This indicates that our analytical parameterized formulae are in close agreement with actual one [3].

Acknowledgments

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