# Role of different surface energy coefficients and nuclear radii in the study of heavy-ion fusion reactions

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## Introduction

The ion-ion interaction potential plays a very significant role in heavy-ion collisions involving different colliding nuclei at all incident energies [1–3]. The choice of the potential and its form to be adopted is one of the most challenging task when one wants to compare the experimental data with theory. One has seen a large interest in the recent times where many of new potentials and their parameterizations have been proposed [2, 3]. The common among these approaches is the fact that it is almost mandatory for all these potentials to justify their approaches and its utility by comparing it with proximity potential. One should keep in the mind that original form of the proximity potential [1], overestimates the data by $\approx 4\%$. Its modified version is also not able to explain the data completely [2]. Due to vast utility of these phenomenological potentials, it is necessary to study the role of different ingredients of the potential. It is clear from the literature that various parameters used in these potentials are chosen quite arbitrary. The universal function used in such potentials have been parameterized by various authors from time to time in large variety of forms [2]. Whereas less attention is being paid to other two parameters of the potentials namely, surface energy coefficient and nuclear radius. Here, we attempt to discuss the role of these two important parameters used in original proximity potentials and ultimately in fusion barriers.

## The Model

In original version of proximity potential [1], labeled as Prox 77, $V_N(r)$ can be written as

$$V_N(r) = 4\pi\overline{R}\gamma b\Phi\left(s\right) \text{ MeV}, \tag{1}$$

where $\Phi\left(s\right)$ $(s = r - C_1 - C_2)$ is the universal function and $\overline{R}$ is the reduced radius. The surface energy coefficient $\gamma$ ( in MeV/ fm$^2$) was taken from the work of Myers and Świątecki which reads as

$$\gamma^{MS} = 0.9517\left[1 - 1.7826\ I^2\right], \tag{2}$$

with $I = \left(\frac{N-Z}{A}\right)$; N, Z and A refer to the combined system of two interacting nuclei. Möller and Nix refitted the new mass formula and obtained a new set of constants given as

$$\gamma^{MN} = 1.2496\left[1 - 2.3\ I^2\right]. \tag{3}$$

In recent version of proximity potential, Myers and Świątecki, selected $\gamma$ that takes care of the neutron skin $t_i$ of the interacting nuclei in the following way

$$\gamma^{MS-N} = \frac{1}{4\pi r_0^2}\left[18.63 - Q\frac{\left(t_1^2 + t_2^2\right)}{2r_0^2}\right]. \tag{4}$$

In another attempt, based on the Yukawa-plus-exponential model, Krappe and Nix and Sierk (KNS) fitted $\gamma$ as

$$\gamma^{KNS} = 1.2402\left[1 - 3.0\ I^2\right]. \tag{5}$$

The nuclear radii on the other hand, also been used in the literature arbitrarily. In Prox 1977 [1], radius has the following form

$$R^{Prox77} = 1.28A^{1/3} - 0.76 + 0.8A^{-1/3} \text{ fm}, \tag{6}$$

whereas new form of radius quite similar to the one used in the modified version of proximity potential with slightly different constants include also the relative neutron excess I as

$$R^{Prox00N} = 1.2332A^{1/3} + 2.8961A^{2/3} - 0.18688A^{1/3}I \text{ fm}. \tag{7}$$

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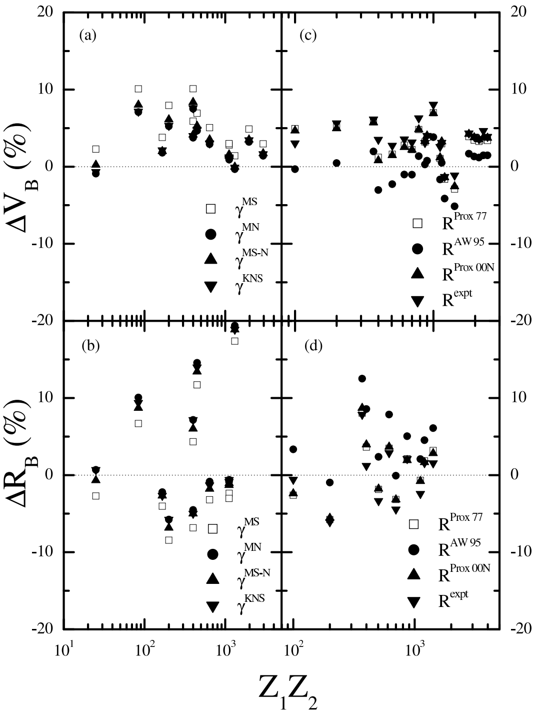


FIG. 1: Percentage deviation of $\Delta V_B$ (%) and $\Delta R_B$ (%) as function of $Z_1Z_1$ for different $\gamma$ and radii using Prox 77 (preliminary results).

It is noted here that, in modified version of proximity potential both experimental as well as theoretical compilations have been used to calculate the radius. We denote experimental values as $R^{expt}$. For the present study, we also used the radius due to Aage Winther which reads as

$$R^{AW95} = 1.20A^{1/3} - 0.09 \text{ fm}. \qquad (8)$$

In total, we employ here four different versions of $\gamma$ as well as radii.

## Results and Discussion

Firstly, we calculated the total interaction potential by adding Coulomb part to Eq. (1). Then, we estimated the fusion barriers using the above mentioned combinations of $\gamma$ and R in Prox 77. We have analyzed as many as 200 reactions involving symmetric as well as asymmetric nuclei. It is observed that $\gamma^{MN}$ leads to lesser barrier heights compared to $\gamma^{MS}$ because of its deeper nuclear potential [2]. We quantify our outcome with the help of following percentage deviation defined as:

$$\Delta V_B \ (\%) = \frac{V_B^{theor} - V_B^{expt}}{V_B^{expt}} \times 100. \qquad (9)$$

In Fig. 1, we plotted these percentage deviations $\Delta V_B$ (%) and similarly $\Delta R_B$ (%) as a function of $Z_1Z_2$. Further from Fig. 1(a), we see that $\gamma^{MN}$ and $\gamma^{KNS}$ are equally good in reproducing the experimental outcome, whereas $\gamma^{MS-N}$ deviates slightly. In Fig. 1(b), more deviations are visible for fusion barrier positions. In Fig 1.(c), we choose $\gamma^{KNS}$ in Prox 77 and changes above mentioned radii one by one. Here, we notice that different radii versions can yield barrier heights and positions difference by $\pm10\%$ and $\pm15\%$ respectively [3]. Further, interestingly, we see that if we use radius formula $R^{AW95}$ in proximity formula, the deviations are very close to zero line, however more deviations are seen in the case of positions. Alternatively, if we use new radius formula $R^{Prox00N}$, then results are better in both the cases. It is clear from the above study that, the effects of these two technical parameters i.e. the surface energy coefficients $\gamma$ and radius parameter are quite significant of the order of 10-15% and one should be very careful while choosing these parameters.

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