A comparative study of different proximity-type potentials using asymmetric colliding nuclei

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Introduction

The study of fusion reactions involving nuclei with neutron excess captured central place in the current days research. This renewed interest is due to the advent of nuclei with extreme neutron/proton ratio in fusion reactions using radioactive-ion beams.

Considerable experimental and theoretical efforts have been devoted in recent years to understand the mechanism of asymmetric reactions like $^{4-6}$He $+^{209}$ Bi (with $\mathrm{A_s} = \left[\frac{(\mathrm{N-Z})}{(\mathrm{N+Z})}\right] = 0.202 - 0.209$, where N and Z refer to the combined system of two nuclei.), $^{4-6}$He $+^{238}$ U ($\mathrm{A_s} = 0.223 - 0.230$), ^{6}Li $+^{208}$ Pb ($\mathrm{A_s} = 0.206$), $^{6-7}$Li $+^{209}$ Bi ($\mathrm{A_s} = 0.200 - 0.204$), $^{9-10}$Be $+^{209}$ Bi ($\mathrm{A_s} = 0.202 - 0.205$), $^{16-18}$O $+^{112-124}$ Sn ($\mathrm{A_s} = 0.094 - 0.183$) etc. Fusion barriers evaluated within different approaches [1–4] for the same colliding system differ considerably especially when one nucleus is very heavy and another is light. Interesting systematic features have been observed and a large number of studies have been under taken using macroscopic/microscopic models [4]. The phenomenological form of the proximity potential [1] is backbone of all such studies. In recent years, various modifications and improvements over the original proximity potential and other parameterized proximity potentials have been proposed by various authors within the proximity concept [2–4]. Many of these modifications are based on introducing isospin effects either through the surface energy coefficients or nuclear radii leading to different potentials. Here, we are interested to test these potentials in the isospin plane and to see how asymmetry parameter affects the fusion barriers.

The Models

All proximity potentials are based on the proximity force theorem, according to that, *"the force between two gently curved surfaces in close proximity is proportional to the interaction potential per unit area between the two flat surfaces"*. According to Ref. [1], interaction potential, $V_N(r)$ between the two flat surfaces can be written as

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

here $\overline{R}$ and $\Phi\left(s\right)$ are known as reduced radius and the universal function, respectively. It was noted that both of the above factors are independent of isospin content [1]. However, factor γ, surface energy coefficient, is responsible for the relative neutron/proton excess of the projectile and target in the following way

$$\gamma = \gamma_0\left[1 - k_s A_s^2\right]. \qquad (2)$$

In original version, $\gamma_0 = 0.9517$ (MeV/ fm^2) and $k_s = 1.7826$. Later on, Due to better mass formulas and new experimental data, the above constants were refitted by various authors in a large variety of forms resulting in different potentials. Similarly, nuclear radius is also chosen quite arbitrarily. Recently, we modify the proximity potential 2000 [3] and one due to Denisov (Denisov DP) by using latest radius formula [4]. Along with basic proximity potentials (i.e. Prox 77, Prox 88, Prox 00, and Prox 00DP), other parameterizations due to Bass (Bass 80), Ngô (Ngô 80), and Winther (AW 95) are also used. In total, eight different potentials are undertaken. More detailed study is presented in Ref. [4].

Results and Discussion

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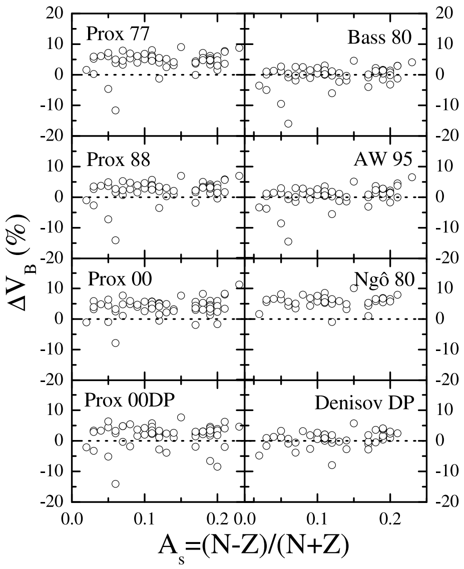

FIG. 1: Percentage difference of theoretical fusion barrier heights over empirical one as a function of A_s using different proximity potentials.

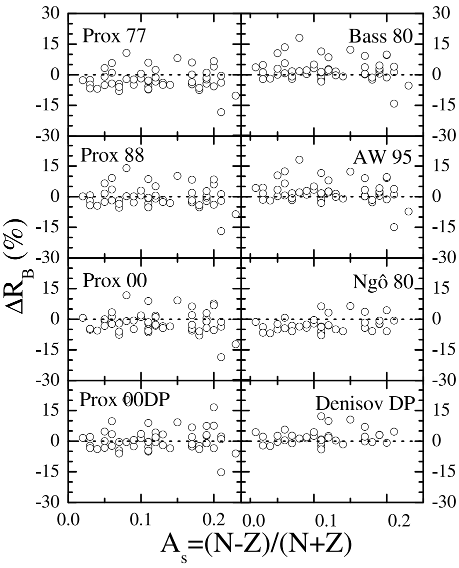

FIG. 2: Same as Fig. 2, but for fusion barrier positions.

As a first step, we calculated the nuclear part of the ion-ion interaction potential using different proximity potentials and then by adding Coulomb potential total ion-ion interaction potential is calculated.

The fusion barrier height and position are obtained using condition

$$\frac{dV_T(r)}{dr}|_{r=R_B} = 0; \frac{d^2V_T(r)}{dr^2}|_{r=R_B} \leq 0. \quad (3)$$

The height of the barrier yield V_B, the barrier position is marked as R_B.

We take here only experimentally studied reactions with mass between 19 and 294 and asymmetry parameter A_s between 0.02 and 0.23. The surface energy coefficient is the main force behind introducing isospin dependence in the potential. It is important to note that Prox 00 and Prox 00DP has isospin dependent radius with slightly different constants are less sensitive toward A_s [4]. In Fig. 1, we plotted percentage deviation of the exact fusion barrier heights from available empirical estimates as a function of A_s defined as

$$\Delta V_B\ (\%) = \frac{V_B^{theor} - V_B^{expt}}{V_B^{expt}} \times 100. \quad (4)$$

No systematic trend with A_s is visible here. Further, we note that Bass 80, AW 95, and Denisov DP reproduce empirical fusion barrier heights within ±5%, whereas, other need ±10% to reproduce same. A comparison of the fusion barrier positions outcome are presented in Fig. 2. Due to large uncertainty in the fusion barrier positions, all models are able to reproduce it within ±15% on the average. It is clear from the above study that no definite trend and conclusion can be drown on the basis of asymmetry parameter.

Acknowledgments

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