Systematic study of the fusion barriers using different versions of surface energy coefficients

Aditi Toshniwal[1]* and Raj Kumari[2]
[1]S. V. National Institute of Technology, Surat - 395007, India
[2]Department of Physics, Panjab University, Chandigarh - 160014, India

Introduction

The study of heavy-ion collisions at low energies (*i.e.* $E < 10$ MeV/nucleon) has been attracting a lot of attention since last few decades. This interest is due to synthesis of super-heavy elements in cold fusion reactions. The total interaction potential between the colliding nuclei is the sum of the long range Coulomb repulsion and short range nuclear attraction. Recently, many efforts have been put in this direction to explain the accurate form of the nuclear part of the interaction potential. In this series of recent attempts, the proximity potential is very popular for its simplicity and numerous applications in different fields. It was noted that the original proximity potential overestimates the experimental data on fusion barrier heights by 4 %. In recent years, several refinements and modifications have been proposed over original proximity potential to improve it [1]. In Ref. [2], Dutt and Puri revealed that surface energy coefficient as well as nuclear surface diffusion affected the nuclear potential as well as fusion barriers. In present study, it would be interesting to use different forms of surface energy coefficient γ (taken from different proximity potentials) in the original proximity potential (*i.e.* Prox 77) and to see which value of γ will yield the fusion barriers closer to the experimental data, while keeping the effective sharp radius R_i constant.

Methodology

In the original version of the proximity potential (Prox 77), the nuclear part of the interaction potential $V_N(R)$ between two approaching nuclei with central separation R is given by

TABLE I: The values of γ_0 and k_s taken from different potentials are displayed.

Coefficients	Prox77	MN1976	Prox88	Prox2010	Mod-Prox88
γ_0	0.9517	1.460734	1.2496	1.25284	1.65
k_s	1.7826	4.0	2.30	2.345	2.30

$$V_N(R) = 4\pi\gamma b\overline{R}\Phi(\frac{R-C_1-C_2}{b})\ MeV, \quad (1)$$

where b, C_i, $\overline{R}$ and Φ are the surface width, central radii, reduced radius and universal function, respectively. The effective sharp radius (R_i) is taken as

$$R_i = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3} fm\ (i = 1, 2). \quad (2)$$

The surface energy coefficient γ is written as

$$\gamma = \gamma_0\Big[1 - k_s\Big(\frac{N-Z}{A}\Big)^2\Big], \quad (3)$$

here γ_0 and k_s are the surface energy coefficient and surface asymmetry constant, respectively. The different values of γ_0 and k_s, taken for the present analysis are displayed in Table 1. For all proximity potentials (γ-values)[1] used in the present analysis, except Prox 2000, the form of surface energy coefficient γ is same (as given by Eq. 3). In case of Proximity 2000, γ is taken in terms of neutron skins of colliding nuclei [1].

Results and Discussions

The present study is conducted using two different reaction series, keeping the target

---

*Electronic address: `adi.aditi2008@gmail.com`

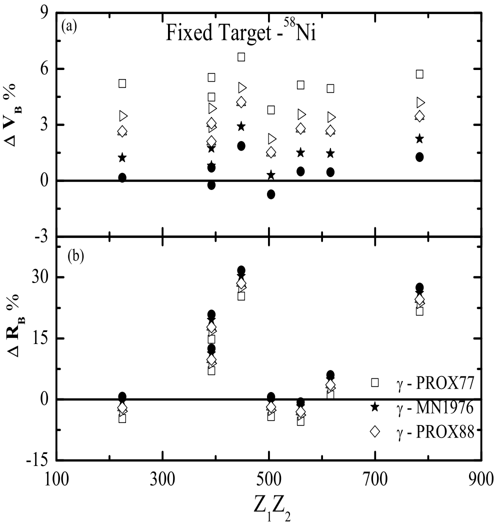

FIG. 1: (a) The upper panel displays the percentage deviation $\Delta V_B(\%)$ and (b) lower panel displays $\Delta R_B(\%)$ as a function of the $Z_1 Z_2$ for fixed target (^{58}Ni) reaction series.

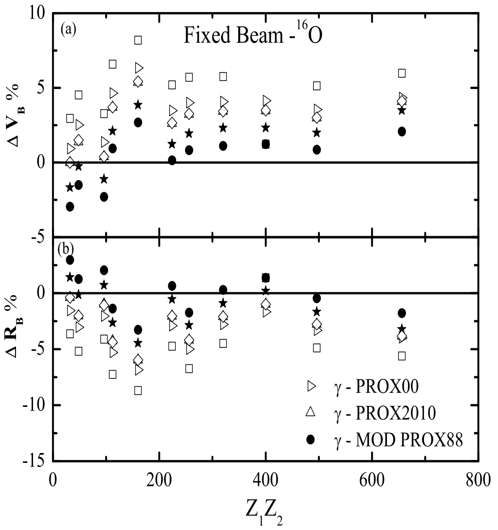

FIG. 2: Same as Fig. 1, but for fixed beam (^{16}O) reaction series.

(^{58}Ni) fixed in first and taking fixed beam (^{16}O) in second. In Fig. 1, we display the percentage deviation of barrier heights (a) and barrier positions (b) calculated using different γ values over the experimental data, given by

$$\triangle V_B(\%) = \left(\frac{V_B^{theor} - V_B^{expt}}{V_B^{expt}}\right) \times 100, \quad (4)$$

here, V_B^{theor} are calculated using different γ values and the experimental data is taken from Refs. [1, 3]. The calculations for $\Delta R_B(\%)$ are also done in similar manner. It is clear from Fig. 1 that in case of barrier positions, all γ values yield nearly similar results. However, in case of barrier heights, γ-Mod-Prox88 yields results much closer to experimental data. The average deviation for the fusion barrier heights is least *i.e.* 0.5% in case of γ-Mod-Prox88 followed by 1.52% in case of γ-MN1976. However, for rest of γ-values, average deviation is comparatively large. Earlier, Dutt [2] showed that γ-MN1976 gives the minimum deviation. But the use of γ values of Modified proximity 88 yields much improved results.

In Fig. 2, we notice that for fixed beam (^{16}O) case, the average deviations for the fusion barrier heights are 1.03% in case of γ-Mod-Prox88 and 0.14% in case of γ-MN1976 and that for fusion barrier positions are 1.1% in case of γ-Mod-Prox88 and 0.21% in case of γ-MN1976. From both these cases (fixed target and fixed beam), we conclude that the surface energy coefficient γ of Modified proximity 88 can be now a better choice followed by γ-MN1976 of Möller and Nix.

The authors are thankful to Professor Rajeev K. Puri for fruitful discussions on the present work.

References

[1] I. Dutt and R. K. Puri, Phys. Rev. C 81, 064609 (2010); *ibid.* C 81, 064608 (2010); R. Kumar and M. K. Sharma, Phys. Rev. C 85, 054612 (2012).

[2] I. Dutt and R. K. Puri, Phys. Rev. C 81, 047601 (2010).

[3] K. Siwek-Wilczyńska and J. Wilczyński, Phys. Rev. C 69, 024611 (2004); E. F. Aguilera *et al.*, Phys. Rev. C 52, 3103 (1995).