Systematic study of the fusion barriers for helium projectile fusing with targets in the mass range 12≤A≤233

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Introduction

Nuclear physics deals with the study of structure of nuclei as well as interactions among these nuclei and their nucleons. This study is quite helpful in the formation of super-heavy elements, which are synthesized either by cold fusion reactions or by hot fusion reactions. Fusion barriers play significant role in deciding the fate of a fusion reaction. These fusion barriers can be derived from the total interaction potential, which is sum of attractive nuclear potential and repulsive Coulomb potential. Our aim is to give pocket formulae, which can be used to directly estimate the barrier parameters. With this aim in our mind, we parameterize the fusion barriers for helium induced reactions using various proximity potentials. For the present analysis, proximity potentials like proximity 1977 (Prox 77), proximity 1988 (Prox 88), modified proximity 1988 (Mod Prox 88), proximity 2000 (Prox 00), modified proximity 2000 (Prox 00DP) and proximity 2010 (Prox 2010) are employed.

Methodology

Proximity potential is based on the principle that when two nuclear surfaces approach each other within a small distance of 2 to 3 fm, then these surfaces actually face each other across the small gap or crevice and result in strong attraction. This strong attraction cannot be due to the surface energy term alone. The additional forces responsible for this attraction are called proximity forces. In the original version of proximity potential, the nuclear potential $V_N(s)$ was expressed as:

$$V_N(s) = 2\pi\overline{R}\int e(s)ds \text{ MeV}. \qquad (1)$$

where $\overline{R}$ is the reduced radius and 2π being the proportionality factor. The quantity $e(s)$ is the interaction potential per unit area between two flat surfaces made of semi-infinite nuclear matter and s is the distance between the surfaces of the colliding nuclei. For details of proximity potentials like Prox 77, Prox 88, Mod Prox 88, Prox 00, Prox 00DP and Prox 2010, the reader is referred to Ref. [1].

Results and Conclusions

For present analysis, we have considered helium induced reactions with target varying from carbon to uranium. In Fig. 1(a), the barrier positions R_B calculated using these proximity potentials are parameterized in terms of following relation

$$R_B^{Par} = aX_1 + b, \qquad (2)$$

where $X_1 = A_2^{1/3}$. Here, a and b are constants having different values (mentioned in Fig. 1(a)) for different versions of proximity potential. A linear increase in the barrier positions with increase in the mass of the target nuclei is observed. This is due to the reason that heavier the target, more is the Coulomb repulsion and this effect is counterbalanced by increase in the barrier position in order to make the fusion possible. In figure 1b, the barrier heights calculated using different versions of proximity potentials are parameterized using the expression

$$V_B^{Par} = cX_2, \qquad (3)$$

where $X_2 = Z_1Z_2/R_B^{Par}$. The value of constant c for different cases is mentioned in Fig.

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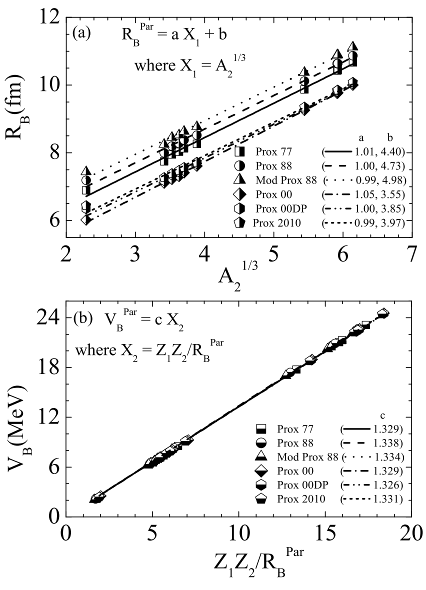

FIG. 1: The upper panel displays the fusion barrier positions R_B as a function of $A_2^{1/3}$. The lower panel represents the fusion barrier heights V_B as a function of $\frac{Z_1 Z_2}{R_B^{Par}}$.

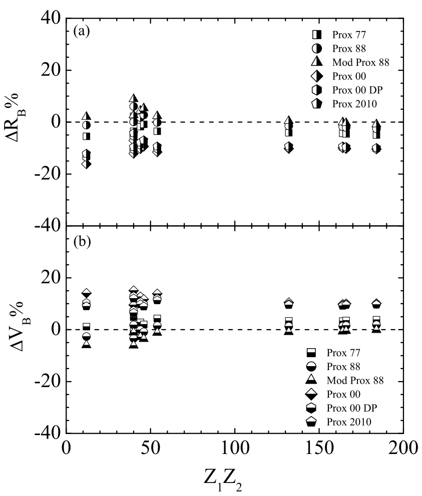

FIG. 2: Variation of percentage differences for fusion barrier positions (upper panel) and barrier heights (lower panel) with $Z_1 Z_2$.

1(b). The barrier heights are found to increase linearly with $\frac{Z_1 Z_2}{R_B^{Par}}$. Because, heavier is the target nuclei, higher is the Coulomb barrier.

In order to check the accuracy of these parameterized relations, we display the percentage difference in Fig. 2(a) and 2(b), which are given by

$$\Delta R_B\% = \frac{R_B^{Par} - R_B^{emp}}{R_B^{emp}} \times 100, \qquad (4)$$

and

$$\Delta V_B\% = \frac{V_B^{Par} - V_B^{emp}}{V_B^{emp}} \times 100. \qquad (5)$$

Here, R_B^{Par} and V_B^{Par} are the values calculated using parameterized forms (Eq. 3 and 4, respectively) and R_B^{emp} and V_B^{emp} are empirical values taken from Ref. [2]. We find that parameterized forms derived using Prox 77 can reproduce the actual barrier positions and barrier heights within ±6% and ±5%, respectively. Whereas, in rest of cases, this deviation is large. So the ideal parametrization (using Prox 77) for helium induced reactions is given by

$$R_B^{Par} = 1.01 A_2^{1/3} + 4.40, \qquad (6)$$

and

$$V_B^{Par} = 1.329 \frac{Z_1 Z_2}{R_B^{Par}}. \qquad (7)$$

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