Study of fusion barriers of reactions induced by loosely bound projectiles

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Introduction

In recent years a lot of experimental work has been done on nuclear reactions induced by loosely bound projectiles. This is due to the breakup properties of these projectiles (^{6}Li, ^{7}Li and ^{9}Be). For example, ^{6}Li can breakup into a deuteron and an α-particle having a breakup threshold energy of 1.48 MeV [1]. The theoretical side of this huge amount of experimental work is largely unexplored. In this work we would be studying the fusion barrier parameters for such reactions. Two factors which are very crucial in the study of fusion barrier and cross section is the nuclear potential, and the deformation properties of the target. For the nuclear potential eight different versions of the nuclear proximity potential are chosen and their predictions are compared. Also a comparison of the results (with and without deformation) for the highly deformed target (^{152}Sm) is also done. It needs to be mentioned that the extraction of fusion barrier parameters using global proximity potentials has been extensively done for reactions induced by tightly bound projectiles, and such work hasn't yet been pursued for loosely bound systems.

Formalism

The interaction potential between the target nuclei and the projectile can be written as the sum of nuclear, Coulomb and centrifugal potentials. Hence,

$$V = V_C(r) + V_N(r) + \frac{\hbar^2 l(l+1)}{2\mu r^2} \qquad (1)$$

r is the distance between the centres of the target and projectile, l is the angular momentum quantum number, and μ is the reduced mass of the system. Assuming the size of the projectile to be much smaller than the radius of the target nucleus, r_c, the Coulomb potential V_C(r) can be approximated by the relation ,

$$V_C = \begin{cases} \frac{Z_1 Z_2 e^2}{2r_c}(3 - \frac{r^2}{r_c^2}) & \text{if } r \leq r_c, \\ \frac{Z_1 Z_2 e^2}{r} & \text{if } r > r_c \end{cases} \qquad (2)$$

where Z_1, Z_2 are the atomic numbers of the target and projectile. For ℓ=0 the maximum or peak value of the potential V is called the Coulomb or the fusion barrier. The respective values of V and r are called the height (V_B) and position (R_B) of the Coulomb barrier. The nuclear proximity potentials chosen for our study are the two versions of the Blocki proximity potential (Prox 77 and Prox 88) [2], three versions of the Bass potential (Bass 73, Bass 77 and Bass 80), the Christensen and Winther potential (CW 76), the Broglia and Winther potential (BW 91), and the Aage Winther potential (AW 95) [1].

Results

The fusion barrier heights and positions are determined by applying the rules of calculus for finding the maxima of a function. Hence,

$$\left.\frac{dV(r)}{dr}\right|_{r=R_b} = 0 \quad ; \left.\frac{d^2V(r)}{dr^2}\right|_{r=R_b} \leq 0 \qquad (3)$$

where, V is determined from Eq. (1). Values of V_B and R_B have been determined for all the eight nuclear potentails, and for thirteen number of reactions induced by the projectiles ^{6}Li, ^{7}Li and ^{9}Be on the targets ^{89}Y, ^{124}Sn, ^{159}Tb, ^{144}Sm, ^{152}Sm, ^{208}Pb and ^{209}Bi. The results are compared with empirical values of

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	Prox 77	Prox 88	Bass 73	Bass 77	Bass 80	CW 76	BW 91	AW 95
σ_{V_B}	4.66	2.85	8.03	2.73	1.89	2.39	2.04	2.02
σ_{R_B}	4.65	3.24	3.33	2.95	2.05	2.04	1.94	2.19

TABLE I: Standard deviations of theoretical barrier parameters with respect to the empirical barrier parameters calculated for each potential [1].

	Prox 77	Prox 88	Bass 73	Bass 77	Bass 80	CW 76	BW 91	AW 95
V_B	25.36	24.82	22.32	24.87	24.11	24.36	24.51	24.25
R_B	9.88	10.11	10.58	10.12	10.47	10.45	10.36	10.48

TABLE II: Height and position of the Coulomb barrier for ^{6}Li+^{152}Sm after applying correction for the deformed target.

V_B and R_B and details are given in [1]. It is found that all the potentials could reproduce V_B and R_B quite satisfactorily for all the reactions (except ^{6}Li+^{152}Sm). Inorder to compare the predictions of the various potentials, the standard deviation of theoretical with respect to empirical values have been calculated, and the results are shown in table I. From the results we can conclude that the best potentials for reproducing the values of V_B and R_B are Bass 80 and BW 91, respectively, as they have the minimum values of standard deviations.

For the reaction, ^{6}Li+^{152}Sm, it is found that the deviations of the theoretically values with respect to the empirical values are unusually large. This is due to the fact that the target ^{152}Sm has a large static deformation. For the above reaction we apply the correction to the Coulomb potential for the deformed target nucleus [3],

$$V_c(r,\theta) = \frac{Z_1 Z_2 e^2}{r} + \sqrt{\frac{9}{20\pi}} \frac{Z_1 Z_2 e^2}{r^3} \sum_{i=1}^{2} R_i^2 \beta_{2i} P_2(cos\theta_i) + \left(\frac{3}{7\pi}\right) \frac{Z_1 Z_2 e^2}{r^3} \sum_{i=1}^{2} R_i^2 [\beta_{2i} P_2(cos\theta_i)]^2 \quad (4)$$

The deformation parameter of the target nucleus (^{152}Sm) is taken as β_2=0.26 [1] and the projectile (^{6}Li) is assumed spherical. As the Coulomb potential is dependent upon the orientation of the target nucleus, hence, the effective Coulomb potential is found by averaging over all possible orientations. The new values of the barrier parameters for the reaction ^{6}Li+^{152}Sm are shown in table II. When compared to the old values that are calculated without applying the above correction [1], it is found that the new values are closer to the empirical values [1].

Conclusion

The barrier parameters of thirteen number of reactions induced by loosely bound projectiles have been determined. For the nuclear potential eight different versions of the nuclear proximity potential have been taken into consideration. From the results we find that the potentials Bass 80 and BW 91 have slight edge over the other potentials in reproducing the values of V_B and R_B, respectively. For the reaction, ^{6}Li+^{152}Sm, the barrier parameters are recalculated because of the fact that the target has a high static deformation. The new values of the barrier parameters are in good agreement with the empirical values.

References

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