Phenomenological study of total reaction cross section

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Introduction

During recent years, studies on the total reaction cross section have been pursued both theoretically and experimentally as it provides crucial information on the nuclear processes. The total reaction cross section is the sum of the cross sections of a number of processes, out of which fusion is the most dominant (≈ 74 %) [1]. Above the Coulomb barrier, fusion is well understood in terms of the single barrier penetration model (SBPM). Application of SBPM and making minor approximations, Wong's formula is obtained and it has been used by a number of authors for a qualitative understanding of fusion. Because of close proximity between the total reaction and fusion cross sections, there have been attempts to obtain a phenomenological understanding of total reaction cross section above the Coulomb barrier in terms of the Wong's formula. In this paper we develop a phenomenological formula for understanding the total reaction cross section for reactions induced by three types of projectiles, viz., tightly bound, loosely bound and radioactive halo projectiles.

Formalism

Wong's formula for the study of reaction cross section is given by [2],

$$\sigma_R = \frac{R_b^2 \hbar\omega_0}{2E_{cm}} ln\Big\{1 + exp\Big[\frac{2\pi(E_{cm} - E_b)}{\hbar\omega_0}\Big]\Big\} \quad (1)$$

where, R_b and E_b are the position and height of the Coulomb barrier, respectively. R_b and E_b can be expressed as,

$$R_b = k_b(A_P^{1/3} + A_T^{1/3}) \quad fm \quad (2)$$

$$E_b = \frac{Z_P Z_T e^2}{k_r(A_P^{1/3} + A_T^{1/3})} \quad MeV \quad (3)$$

where, A_P and A_T are the atomic masses and Z_P and Z_T are the atomic numbers of the projectile and target, respectively. k_b and k_r are unknown constants. Wong's formula forms the basis for the Gomes' reduction procedure, where the cross section is divided by the square of $(A_P^{1/3} + A_T^{1/3})$ and the energy is divided by $Z_P Z_T/(A_P^{1/3} + A_T^{1/3})$. The reduced formula is given by [2],

$$\sigma_{red} = \frac{k_b^2 \epsilon_0}{2E_{red}} ln\Big\{1 + exp\Big[\frac{2\pi(E_{red} - V_{red})}{\epsilon_0}\Big]\Big\} \quad (4)$$

where,

$$V_{red} = E_b \frac{A_P^{1/3} + A_T^{1/3}}{Z_P Z_T e^2} = \frac{1}{k_r} \quad (5)$$

The values of the constants k_b and k_r can be obtained from the best fit of the reduced experimental reaction cross-section at various energies. According to the study conducted in [3, 4], the following facts are reported. For tightly bound projectile (^{16}O), the best fitting can be done with $k_b = 1.56$, $k_r = 1.65$ and ϵ_0=0.14. For loosely bound projectiles (^{6}Li, ^{7}Li, ^{7}Be and ^{9}Be), the Wong's model fit can be done with $k_b = 1.64$, $k_r = 1.76$ and ϵ_0=0.34. For radioactive halo projectiles (^{6}He and ^{8}B), the fitting can be done with $k_b = 1.79$, $k_r = 1.83$ and ϵ_0=0.49. For determination of the theoretical barrier parameters , we use three proximity type nuclear potentials, viz., the Bass, Aage Winther and the Akyuz Winther potentials [2].

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TABLE I: Values of the deviations (K_1 and K_2) for the three types of systems. Values in the last two columns indicate the average values of the deviations for the three potentials.

System	Bass potential		Aage Winther potential		Akyuz Winther potential		Average	
	K_1	K_2	K_1	K_2	K_1	K_2	K_1	K_2
Tightly bound	-0.0400	0.0660	-0.0452	0.0638	-0.0400	0.0572	-0.0417	0.0623
Loosely bound	-0.0491	0.0537	-0.0412	0.0459	-0.0495	0.0524	-0.0466	0.0507
Halo	-0.0618	0.1297	-0.0650	0.1271	-0.0722	0.1250	-0.0663	0.1273

Results and Discussions

The empirical barrier parameters (E_R and R_R) for generation of reaction cross-section are determined from Eqs. (2) and (3) and using the values of k_b, k_r and ϵ_0 for the three categories of reactions. All the twelve reactions of [3, 4] have been considered for the determination of barrier parameters. The theoretical values of the barrier parameters (E_B and R_B) are evaluated using the three nuclear potentials and the results are given in Table 1 of Ref. [2]. The deviations (K_1 and K_2) of the theoretical barrier parameters (E_B and R_B) with respect to the empirical barrier parameters (E_R and R_R) are evaluated.

$$K_1 = \frac{E_R - E_B}{E_B} \quad ; \quad K_2 = \frac{R_R - R_B}{R_B} \qquad (6)$$

Now, that the deviations of the barrier parameters are known, hence a phenomenological formula for the total reaction cross section is attempted,

$$\sigma_R = \frac{R_R^2 \hbar\omega_0}{2E_{cm}} ln\Big\{1 + exp\Big[\frac{2\pi\{E_{cm} - E_R\}}{\hbar\omega_0}\Big]\Big\} \qquad (7)$$

where, $E_R = E_B + E_B^{'}$ and $R_R = R_B + R_B^{'}$ are the empirical barrier parameters for generation of reaction cross-section. $E_B^{'}$ and $R_B^{'}$ are the corrections to be applied to the theoretical barrier parameters (E_B and R_B) for obtaining the empirical barrier parameters. In terms of the deviations (K_1 and K_2) the corrections are given by,

$$E_B^{'} = K_1 E_B \quad ; \quad R_B^{'} = K_2 R_B \qquad (8)$$

Average values of the deviations (K_1, K_2) are shown in Table 1 for the three systems and also for the three potentials. The average values in the last two columns are compiled after taking the average of the deviations for the three potentials. The signs of K_1 (- ve) and K_2 (+ ve) suggests that the barrier height (E_B) is lowered, whereas the barrier position (R_B) is increased and the overall effect is to increase the reaction cross section with respect to the SBPM cross section. It is noted that the values of K_1 and K_2 are large for reactions induced by halo projectiles and this is a consequence of the dominance of processes like transfer and breakup which results in an increase of the total reaction cross section.

Conclusion

A new phenemenological formula is introduced for the explanation of reaction cross section for reactions induced by three types of projectiles, viz., tightly bound, loosely bound and radioactive halo projectiles. The formula is based upon the Wong's formula in which the barrier parameters are expressed in terms of the theoretical barrier parameters plus a small correction term. From the results it is observed that the correction term for reactions induced by halo projectiles is large compared to reactions induced by tightly bound and loosely bound projectiles.

References

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