Suppression of fusion cross-sections in reactions using loosely bound projectiles

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Introduction

In recent years, breakup and fusion reactions, near the Coulomb barrier, of weakly bound (stable or unstable) nuclei led to a strong theoretical [1] and experimental [2,3] activity. This is now due to the availability of Radioactive Ion Beams (RIB) of unstable exotic nuclei, having weakly bound nucleons. Experimentally, however, such studies are limited due to their low intensities, and high intensity beams of stable nuclei like ^{6}Li and ^{7}Li, having large breakup probabilities, are being used [2,3] as references for developing and testing the, so called, Breakup and Fusion models (BFM). It is relevant to mention here that in such reactions, the complete fusion (CF) is associated with the capture of all the projectile-constituents by the target, whereas incomplete fusion (ICF) occurs when only a part of the projectile is captured by the target and the remaining part escapes; thus total fusion (TF= CF+ ICF) is a sum of these two components. In the present day scenario, these studies would probably play important role for producing exotic nuclei near the drip lines and the super-heavy nuclei of current interest.

In the present work, we have carried out a study on the suppression of fusion cross-sections in the reactions ^{6}Li+^{144}Sm and ^{7}Li+^{159}Tb, due to the weakly bound projectiles with low breakup thresholds, forming compound nucleus (CN) ^{150}Tb and ^{166}Er, respectively. The results are compared with the experimental data [2] for both the reactions. Furthermore, in order to investigate the role of breakup and fusion in ^{6}Li+^{144}Sm and ^{7}Li+^{159}Tb reactions, calculations are also performed for the experimentally studied ^{20}Ne+^{133}Cs, ^{12}C+^{141}Pr and ^{4}He+^{162}Dy reactions [2], having strongly bound projectiles, forming CN ^{153}Tb and ^{166}Er, respectively. Here, it is to be noted that ^{6}Li has lower breakup threshold, in comparison to that for ^{7}Li [3].

Methodology

We have used the one dimensional Barrier Penetration Model (BPM) based Wong formula [4] for fusion cross-section. The nucleus-nucleus interaction potential is a combination of the repulsive Coulomb potential and the attractive nuclear proximity potential,

$$V = Z_1Z_2e^2/R + V_P,$$

where $V_P = 4\pi\,(C_1C_2/C_1+C_2)\,\gamma\, b\, \Phi(s_0)$ (1)

from [5], with the surface thickness b = 0.99 fm and the nuclear surface tension coefficient

$$\gamma = 0.9517[1-1.7826((N-Z)/A)^2]\ \mathrm{MeV\ fm}^{-2}, \quad (2)$$

or another version from [6]

$$\gamma = 1.2496[1-2.3((N-Z)/A)^2]\ \mathrm{MeV\ fm}^{-2}, \quad (3)$$

known as the 'proximity 1988', giving a stronger attraction. The universal function Φ in Eq. (1), independent of the geometry of nuclear system, is

$$\Phi(s_0) = -1/2(s_0 - 2.54)^2 - 0.0852(s_0 - 2.54)^3$$
$$= -3.437\exp(-s_0/0.75), \quad (4)$$

respectively, for $s_0 \leq 1.2511$ and ≥ 1.2511. Here s_0 is in units of surface thickness b. Süssmann central radii C_i are related to sharp radii R_i as $C_i = R_i - b^2/R_i$, with $R_i = 1.28A_i^{1/3} - 0.76 + 0.8A_i^{-1/3}$.

Wong formula for fusion cross-sections, at energies near the barrier, is given as [4],

$$\sigma_f = R_B^2\, \hbar\omega/2E_{c.m.} \ln\{1+\exp[2\pi(E_{c.m}-V_B)/\hbar\omega\}, \quad (5)$$

where, $\hbar\omega$ is curvature of the inverted parabola, R_B and V_B are the barrier position and barrier height, respectively. $E_{c.m.}$ is the centre-of-mass energy for target-projectile system.

Results and Discussions

Fig. 1(a) gives the interaction potentials for ^{6}Li+^{144}Sm, ^{12}C+^{141}Pr, ^{20}Ne+^{133}Cs and Fig 1(b) for ^{7}Li+^{159}Tb, ^{4}He+^{162}Dy reactions. In each case, the solid lines represent the results for the use of Eq. (2), and the dashed lines for use of Eq. (3), for the nuclear surface tension coefficient γ. It is evident from these plots that, owing to deeper pocket, Eq. (3) gives a stronger attraction in comparison to the use of Eq. (2). Also, V_B as well as R_B increase with the increase in mass of the projectile, relevant for calculating the fusion cross-section σ_f in Eq. (5).

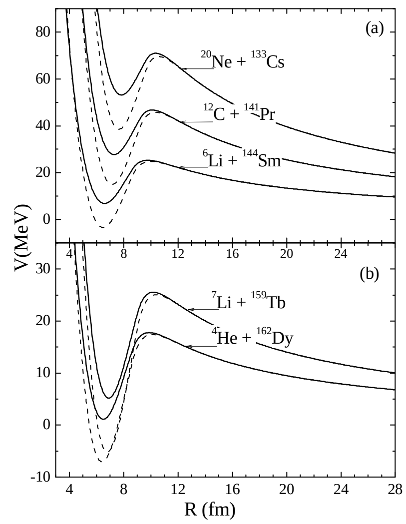

Fig. 1 *Scattering potential V as a function of the inter-nuclear distance R for (a) $^{6}Li+^{144}Sm$ and $^{20}Ne+^{133}Cs$, $^{12}C+^{141}Pr$ reactions, and (b) $^{7}Li+^{159}Tb$ and $^{4}He+^{162}Dy$ reactions. Solid lines represent the results obtained by using nuclear surface tension co-efficient γ given by Eq. (2), while dashed lines for using Eq. (3).*

Fig. 2(a) presents the reduced fusion cross-sections $\sigma_f / \pi R_B^2$ as function of $E_{c.m} / V_B$ for (a) ^{6}Li+^{144}Sm reaction forming CN ^{150}Tb, together with for two other reactions ^{20}Ne+^{133}Cs and ^{12}C+^{141}Pr forming the CN ^{153}Tb; the later two reactions having the strongly bound projectiles. For the weakly bound projectile ^{6}Li, we observe 36% suppression in σ_f (compared to 32% in the case of coupled channel (CCFULL) calculations [2]). Also, for incident energies $>1.7V_B$, we notice that the comparison with experimental data is not so good for ^{20}Ne+^{133}Cs and ^{12}C+^{141}Pr reactions, which is not the case with CCFULL calculations [2]. Fig. 2(b) presents the results for ^{7}Li+^{159}Tb reaction, forming CN ^{166}Er. Here again we observe similar effects as in Fig. 2(a) with 20% suppression in σ_f (compared to 26% in case of CCFULL [2]) in comparison to the ^{4}He+^{162}Dy reaction forming the same CN. For ^{6}Li+^{144}Sm, the comparison with experimental data is good with the choice of γ given by Eq. (2) whereas the ^{7}Li+^{159}Tb reaction favors Eq. (3) with stronger attraction. In this later case, the preference for Eq. (3) is probably due to the higher charge of the target nucleus.

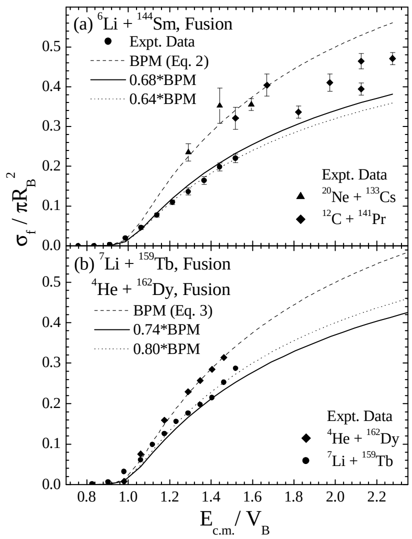

Fig. 2 *The calculated reduced cross sections $\sigma_f / \pi R_B^2$ as a function of $E_{c.m} / V_B$ compared with the experimental data.*

Summary and Conclusions

Our preliminary results of higher percentage of suppression in the case of ^{6}Li induced reaction, in comparison to ^{7}Li induced, seems to be due to the lower breakup threshold. As for the role of different γ's, a few more cases need be studied before drawing any final conclusion. The difference of our results with CCFULL may be due to our non-inclusion of the deformation and orientation effects of target and projectile nuclei. Work is in progress in this direction.

References

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