Complete fusion suppression in weakly-bound projectile reactions in coupled channel calculations

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Introduction

Despite the fact that the sub-barrier fusion involving stable nuclei is well understood, there are conflicting results and predictions about enhancement or suppression of the fusion cross section around the Coulomb barrier when one of the collision partners is a weakly bound nucleus [1]. However, the role of breakup on fusion has been strongly deliberated both theoretically and experimentally. While Hagino *et al*. [2] predicted enhancement of fusion cross section at sub-barrier energies and reduction at above barrier energies, P. K. Rath *et. al.* [3] concluded that the suppression in complete fusion (CF) cross sections increases with the increase in the atomic number of targets. However, H. Kumawat *et. al.* [4] concluded that the CF suppression is observed irrespective of the target charge for reactions with weakly bound projectiles.

To resolve this controversy, we have calculated the suppression of the CF due to breakup of ^{6}Li as a projectile, systematically, with ^{28}Si, ^{144}Sm and ^{209}Bi as a light, a medium, and a heavy system, respectively. The coupled channel calculations are used to calculate the CF cross sections using CCFULL code [5].

Calculational details

In the present work, we include the couplings of low lying rotational states of ^{6}Li and ^{28}Si and Vibrational state of ^{144}Sm and ^{209}Bi. The values of the parameters such as deformation parameter β_λ, and excitation energy E_λ were taken from the Ref. [6-9] and are given in the table below.

The parameters of the Woods-Saxon form of the nuclear potential used in CCFULL for ^{6}Li + ^{28}Si (V_0 = 65.0 MeV, r_0 = 1.09 fm, a_0 = 0.6 fm), ^{6}Li + ^{144}Sm (V_0 = 48.8. MeV, r_0 = 1.12 fm, a_0 = 0.63 fm) and ^{6}Li + ^{209}Bi (V_0 = 107.4. MeV, r_0 = 1.12 fm, a_0 = 0.63 fm) are chosen to reproduce the fusion barrier V_B given in the corresponding references.

Nuclei	J^{π}	E_x (MeV)	β_λ
^{6}Li	3^{+}	2.186	0.72
^{28}Si	2^{+}	1.78	-0.407
^{144}Sm	3^{-}	1.81	0.21
	2^{+}	1.66	0.11
^{209}Bi	3^{-}	2.62	0.153
	5^{-}	3.09	0.11

Results and Discussion

Figures 1, 2 and 3 show the comparison of the calculated and experimental cross section of ^{6}Li + ^{28}Si, ^{6}Li + ^{144}Sm, and ^{6}Li + ^{209}Bi reactions respectively. As seen in these figs., dotted line is the result when the projectile and targets are assumed to be inert. Then we take the appropriate coupling of low lying excitation states of targets i.e. rotational excitation 2^{+} state for deformed ^{28}Si, vibrational excitation3^{-} and 2^{+} states for spherical ^{144}Sm, 3^{-} and 5^{-} states for spherical ^{209}Bi and low lying rotational state of 3^{+} for deformed ^{6}Li. These calculations over predict the measured fusion data over the entire energy range; these are denoted by blue dashed line in all three reactions. It clearly shows the large suppression of the complete fusion at energies near and above the barrier, which is due to the projectile nucleus having low threshold breakup energy.

However, it is interesting to note that the calculated cross sections agrees very well with the measured fusion cross section when multiplied by a factor over the entire energy range which is shown by blue solid line in Fig. 1, 2 and 3. These multiplying factor are 0.78, 0.65 and 0.64 for ^{6}Li + ^{28}Si, ^{6}Li + ^{144}Sm, and ^{6}Li + ^{209}Bi reactions respectively. This implies that there is an overall suppression of 21%, 35% and 36% of the fusion cross section in the entire energy range compared to the ones predicted by CC for ^{6}Li+^{28}Si, ^{6}Li+^{144}Sm, and ^{6}Li+^{209}Bi resp.

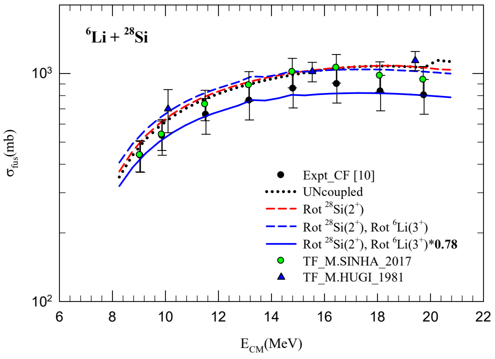

Fig. 1. Fusion cross sections for ^{6}Li + ^{28}Si system.

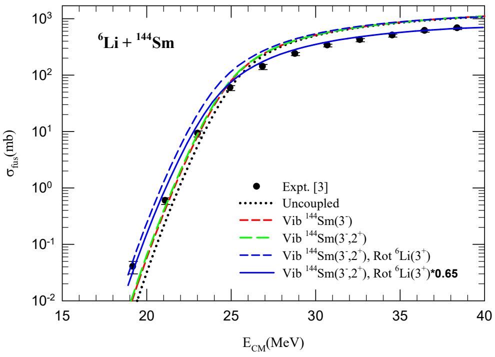

Fig. 2. Fusion cross sections ^{6}Li + ^{144}Sm system.

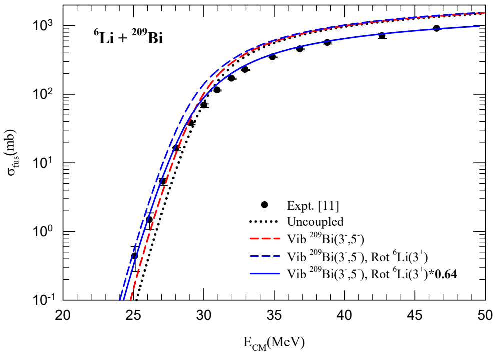

Fig. 3. Fusion cross sections ^{6}Li + ^{209}Bi system.

Fig. 4 shows the complete fusion suppression as a function of the atomic charge Z_T of the target for ^{6}Li + ^{28}Si, ^{6}Li + ^{144}Sm, and ^{6}Li + ^{209}Bi reactions. As seen in Fig. 4, suppression of CF cross section decreases almost linearly with the decreasing charge of the target. The suppression in CF cross section may be a direct consequence of the loss of incident flux due to the projectile breakup the charge field of the target.

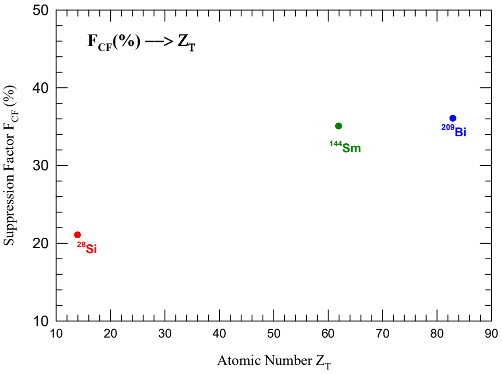

Fig. 4. The CF suppression F_{CF} (%) as a function of Atomic Number Z_T.

Conclusion

The present CC calculations for the ^{6}Li + ^{28}Si, ^{6}Li + ^{144}Sm, and ^{6}Li + ^{209}Bi reactions agree very well with the expt. fusion cross sections when multiplied by a suppression factor. A systematic comparison of fusion excitation functions for several reactions involving weakly stable projectile shows that the suppression in fusion is a common phenomenon and it increases with the increase in the target charge/atomic number.

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