# Complete versus incomplete fusion in $^{6}$Li+$^{144}$Sm reaction

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## Introduction

The effect of breakup of the loosely bound projectile on fusion is a topic of current interest. In a recent article [1], it has been reported that the complete fusion (CF) cross section for $^{6}$Li+$^{144}$Sm is found to be suppressed by about 32% compared to the coupled channel calculation as well as other reactions forming the same compound nucleus but involving strongly bound projectiles. The reason for this suppression is attributed to the loss of incident flux due to the breakup of $^{6}$Li ($\rightarrow\alpha$+d) prior to the fusion. In such a situation, one of the breakup fragments ($\alpha$ or d) gets fused with the target leading to incomplete fusion (ICF) or partial fusion. So, there can be three different scenarios: (i) the projectile as a whole is captured by the target leading to CF, (ii) only one of the breakup fragments gets captured leading to ICF, and (iii) both of the breakup fragments get captured also contributing to CF. It would be interesting to investigate the experimental CF and ICF cross section and compare them with the theoretical estimation to understand the underlying connection between breakup and fusion for the above system.

## Results and discussion

The evaporation residue (ER) cross sections corresponding to the capture of individual breakup fragments of the projectile i.e., d+$^{144}$Sm and $\alpha$+$^{144}$Sm channels for $^{6}$Li+$^{144}$Sm reaction have been measured at near barrier energies by activation technique [2]. In the present work, the ICF cross section was obtained by summing the detected cross sections for d-capture and $\alpha$-capture, and shown in Fig. 1. Since the cross section does not include all possible evaporation residue channels corresponding to alpha- and d-capture, the values of the ICF can be considered as the lower limit. They are compared with CF cross sections of Ref [1] as shown in Fig. 1. It can be seen that the measured ICF cross sections are significant as compared to the complete fusion (CF) cross sections. The large ICF cross section clearly indicates that due to low breakup threshold, the projectile ($^{6}$Li) in the field of target nucleus breaks into $\alpha$ and d resulting in a loss of flux in the entrance channel. This explains why there is a large suppression (~32%) of CF cross section as observed in Ref. [1]. It is also interesting to see that ICF dominates over CF at sub-barrier energies.

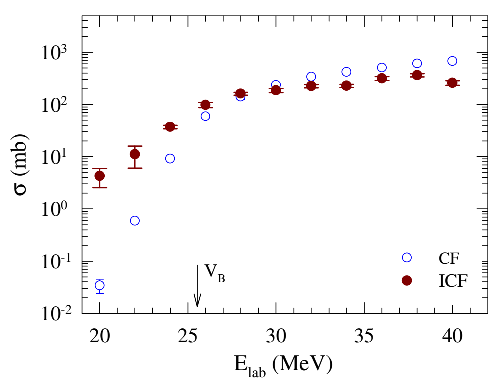


Fig. 1. Complete and incomplete fusion cross sections

To see the behaviour of total fusion (TF) with energy as compared to complete fusion, the ratio of measured total (CF+ICF) cross section to CF cross section is obtained and shown as filled circles in Fig. 2. It shows that the ratio is almost constant for energies above the barrier, but it increases sharply with the decrease of energy at sub-barrier region. This is mainly due to the existence of Coulomb breakup which leads to the increase in ICF at sub-barrier energies. The CF and ICF cross sections for $^{6}$Li+$^{209}$Bi, $^{7}$Li+$^{209}$Bi and $^{9}Be+^{208}Pb$ systems are available in Ref [3]. The ratio of TF to CF are obtained and also shown in Fig.2 as open circles, open diamonds and filled triangles respectively. It can be seen that the trend of all the above systems is similar to that of the present system. Especially, the ratios for $^{6}Li+^{209}Bi$ system being very close to the present data implies that the breakup probability at a particular energy (normalized with the barrier $V_B$) is independent of the target.

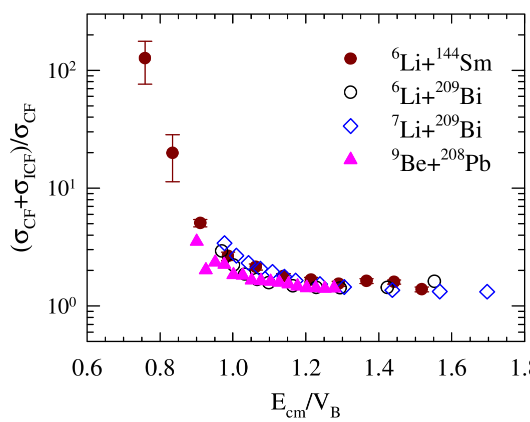

Fig. 2. Ratio of total fusion to complete fusion

To compare the measured CF and ICF with theoretical results a 3-dimensional classical dynamical model [4] calculation was done. However, this model calculates the CF and ICF cross sections only for energies above the barrier. It uses a local probability breakup function that fits the breakup cross sections as a function of distance of closest approach at sub-barrier energies where the breakup is influenced only by Coulomb field. Continuum discretized coupled channel (CDCC) calculations have been performed to calculate the breakup cross section at sub-barrier energies using FRESCO[5]. In the breakup coupling, $^{6}Li$ is considered as a cluster of α and *d*, and the breakup is assumed to be through the inelastic (both resonant and non-resonant) states in the continuum of $^{6}Li$. The differential cross sections thus obtained are then rewritten as a function of $R_{min}$, i.e., the distance of closest approach. The local breakup probability function, $A\exp(-\alpha R_{min})$, that fits the sub-barrier breakup cross sections is obtained with $A=3.75\times10^{3}$ and $\alpha=0.922$. These values were used to calculate the cross sections for CF and ICF at above barrier energies, and are shown respectively as solid and dashed lines in Fig. 3. It can be seen that the calculations are reasonably close to the data and explain both CF and ICF simultaneously.

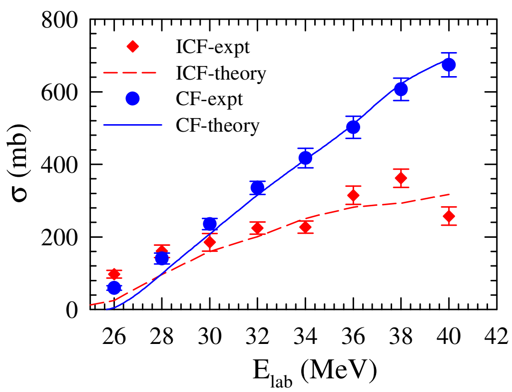

Fig. 3. CF and ICF @ $E>V_B$

## Summary and conclusions

The incomplete fusion cross section was obtained by summing all the ER channels corresponding to the capture of both breakup fragments i.e., α and *d*. The comparison of total fusion and complete fusion for several systems showed similar trend in energy. It was observed that the breakup probability of a projectile at a particular energy (normalized with the barrier $V_B$) is independent of the target. A 3-dimensional classical dynamical model calculation could explain simultaneously the measured CF and ICF cross sections at energies above the barrier.

## References


[1] P. K. Rath et al., Phy. Rev C **79**, 051601(R) (2009).

[2] P. K. Rath et al., DAE Symp. Nucl. Phys. **53**, 477 (2008).

[3] M. Dasgupta et al., Phys. Rev. C **70**, 024606 (2004).

[4] A. Diaz Torres, Phys. Rev. Lett. **98**, 152701 (2007).

[5] I. J. Thompson, Comp. Phys. Rep. **7** (1988) 167.