Complete and incomplete fusion probabilities for $^{6}Li+^{209}Bi$ reaction in multi-body classical dynamical model calculation

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Introduction

Heavy-ion fusion involving weakly bound but stable nuclei are affected by their low binding energy, which can cause them to breakup near the fusion barrier. If all the projectile fragments are captured by the target nucleus then it is termed as complete fusion (CF), irrespective of whether they break-up (SCF) or not (DCF) before being captured. However, if only some of the fragments are captured then it is termed as an incomplete fusion (ICF). Such ICF processes can lead to suppression of fusion probabilities. A recent experiment [1] has shown that direct processes such as 1- or 2- nucleon transfer reactions leading to breakup of the remaining projectile; contribute significantly to the ICF processes.

None of the model calculations such as *CDCC*, *semi-classical couple channel* [2] or the *Classical trajectory models* [3] account for breakup following direct reactions in the ICF processes. We have developed a 3-body (or more) *Classical Dynamical Model* which demonstrated the possibilities for CF, ICF etc. in the same model [4, 5]. This model is also able to account for a process equivalent to a direct reaction followed by breakup of the remaining unstable projectile fragment leading to ICF process.

In this paper we present a detailed study of the calculated probabilities of various possible events in $^{6}Li+^{209}Bi$ reaction to understand the various break-up and capture mechanisms using the multi-body classical dynamical model.

Calculation Details

Nucleon distribution in each tightly bound nucleus is obtained by the *STATIC* code with a soft-core Gaussian form of NN-potential along with the usual Coulomb interaction [5]. The weakly-bound ^{6}Li is constructed making use of the stable ^{2}H and ^{4}He with the potential energy between the fragments equal to -1.467 MeV.

The dynamical collision simulation is carried out in the 3S-CMD model [5] in three stages: (1) Rutherford trajectory calculation up to R_{cm}= 2500 fm for given E_{cm} and b; (2) thereafter, assuming the two nuclei as rigid bodies, using CRBD model calculation; (3) the rigid-body constraints at about R_{cm}= 13 fm are relaxed and the trajectories of all the nucleons are computed as in CMD model calculation. If one or both the projectile fragments are further constrained to be rigid, then it is dynamically evolved as in the CRBD-model calculation.

To analyse various event probabilities we have calculated the fractions, $F(b)$, for given impact parameter b defined as a ratio of $N_{event}(b)$ to $N_{total}(b)$. We have calculated it for b = 0-7 fm considering 500 initially random orientations for each b at E_{cm}= 50 MeV.

We consider various assumptions of rigid-body constraints on the projectile fragments and the bond between them, *viz*, (a) ^{6}Li (rigid-body); (b) both α and d are rigid but free to move with respect to each other for R_{cm}<13 fm; (c) same as in (b) but allowing d also to breakup. Target ^{209}Bi is non-rigid in all above cases in stage-3.

Results and Discussion

Figure-1 shows $F(b)$ for case-(b). As b increases, the relative angular momentum of the projectile fragments increases leading to rise in the events following breakup (ICF+NCBU). However, for larger value of b the trajectories do not come very close to the target and $F(b)$ for events following breakup again decreases. The field of the target nucleus and the angular momentum of the projectile are both responsible for breakup of the projectile. For CF events, DCF is the major component but SCF events are also present in some numbers. ICF(α) with α-capture, is negligible at low b and rises at higher b. Surprisingly, ICF(d) with d-capture is almost negligible (not shown). Scattering following breakup

(NCBU) is also negligible. Thus in the scenario where breakup does occur, either both the fragments are captured (SCF), or α is captured.

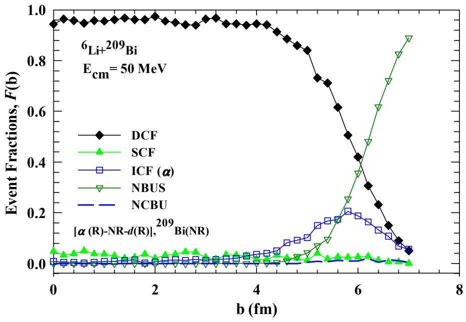

Figure 1: Fractions of different events for ^{6}Li+^{209}Bi at E_{cm}= 50 MeV for d-rigid (case-b).

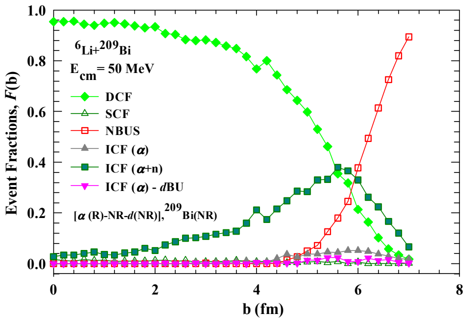

Figure 2: Fractions of different events for ^{6}Li+^{209}Bi at E_{cm}= 50 MeV for d-non-rigid (case-c).

Figure-2 is similar to figure-1 but for the case-(c). Apart from breakup of ^{6}Li into α and d fragments, we now allow the d also to breakup. Figure-2 shows events ICF(α+n) equivalent to ICF(^{5}He) or n-stripping followed by breakup of the resultant unstable ^{5}Li→α+p with p scattered. The ICF(α+n) distribution is much broader and larger as compared to ICF(α) in figure-1. Moreover, ICF(α+n) is substantially large compared to events ICF(α) in figure-2. This is in conformity with the recent experimental observation in [1] which shows the importance of direct reaction processes in complete fusion suppression at higher energies. ICF(d) in this case is also negligible. Some cases show ICF(α), following breakup of ^{6}Li, into α and d, as well as breakup of d into p and n (ICF(α)-dBU) without capture of either of them.

Figure-3 shows $F(b)$ for CF, ICF, and TF (Total fusion=CF+ICF) for the three cases. Remarkably, TF in cases (b) and (c) are almost identical which implies that the differences in ICF are responsible for the CF values to be different in the two cases. As there is no break-up in case-(a), we see that CF in this case is very close to TF in other cases. A small difference may be attributed to complete lack of internal excitations in the rigid projectile which tends to lower fusion probability. This discussion is in conformity with the experimental observation of suppression of complete fusion at higher energies as compared to the case where there is no breakup [6].

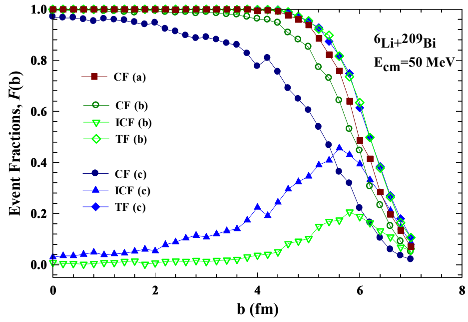

Figure 3: CF, ICF & TF probabilities for ^{6}Li+^{209}Bi at E_{cm}= 50 MeV for three cases, a, b, & c.

Similar calculations at lower energies E_{cm}= 36 and 29 MeV shows that this suppression diminishes as energy is lowered; and internal excitations in case-(b) and case-(c) leads to ehancement of CF at lower energies. Due to enhanced ICF events in case-(c) even at lower energy, CF is reduces below the value for the case-(b).

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