Fusion cross sections for ^{6}Li+^{209}Bi reaction in multi-body classical dynamical model

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Introduction

Heavy-ion fusion involving stable weakly bound nuclei are affected by their low binding energy, which can breakup near the fusion barrier. If all the projectile fragments are captured by the target nucleus then it is termed as complete fusion (CF). 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.

None of the models such as *CDCC*, *semi-classical couple channel* [1] or the *Classical trajectory models* [2,3] account for breakup following direct reactions in the ICF processes. We have developed a multi-body *Classical Dynamical Model* which demonstrated the possibilities for CF, ICF etc. in the same model [4, 5]. This model is also able to account [6] for a process equivalent to a direct reaction followed by breakup of the remaining unstable projectile fragment, leading to ICF process as reported in a recent experiment [7].

We present results of fusion cross sections calculations for ^{6}Li+^{209}Bi reaction using the multi-body classical dynamical model under various assumptions of rigid-body constraints on the projectile fragments.

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 is carried out in the 3S-CMD model [5] in 3-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.

We define complete fusion (CF) as an event in which both the projectile fragments are captured by the target nucleus for a sufficiently long interval of time, irrespective of whether they break-up (SCF) or not (DCF) before capture.

Barrier parameters (V_B, R_B, ω_B) for head-on collision (*b*=0) for a given E_{cm} and for a given initial orientation of the two nuclei are obtained from the dynamically generated ion-ion potential. Using these barrier parameters, fusion cross section is calculated using the Wong formula. The barrier parameters are obtained at every E_{cm}. A large number of Monte-Carlo sampled initial orientations are considered and orientation-averaged fusion cross section is calculated.

Incomplete fusion (ICF) is defined as an event in which only one of the projectile fragments or a part of the projectile is captured by the target nucleus after their break-up while the other fragment moves away from the target. Ion-ion potential is obtained as a function of the separation between the centre of masses of the target and the projectile-fragment that is captured. Barrier parameters determined from this ion-ion potential (*b*=0) are used in the Wong formula, as mentioned earlier, to calculate ICF cross section (σ_{ICF}). Total fusion (TF) cross section is calculated as $\sigma_{TF} = \sigma_{CF} + \sigma_{ICF}$.

Results and Discussion

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 of the 3S-CMD model.

Calculated CF cross sections for (*b*=0) in ^{6}Li+^{209}Bi reaction for the above cases are shown in figure-1. Calculated TF cross sections for (*b*=0) are shown in figure-2.

In the case-(a) there is complete lack of internal excitations in the rigid projectile which tends to lower fusion probability [6] and hence calculated CF cross sections are highly underestimated at lower energies as compared to the experimental data [8] and that for the case-(b).

CF cross sections in case-(b) are significantly enhanced at all the energies compared to that in case-(a). In case-(b), although the two fragments are not excited, the projectile is allowed to get excited and may even break up resulting in loss of flux for CF and, contributes to breakup events like ICF [6]. Thus the CF cross sections for case-(b) in figure-1 are less then the TF cross section for this case shown in figure-2.

Since, *d* in the projectile fragment itself has very low binding energy which can lead to its own breakup. Therefore, we consider case-(c) in which breakup of *d* results, additionally, in direct reaction process like *n*-stripping followed by breakup of the resultant unstable ^{5}Li→α+p with p scattered leading to ICF(α+n) equivalent to ICF(^{5}He) events [6]. This leads to significant reduction in CF cross sections compared to the calculation in which *d* is also kept rigid in case-(b). It is remarkable, however, that the TF cross sections for the case-(b) and case-(c) have almost same values at all the energies in figure-2.

Figure-2 also shows the total fusion cross section data of ref [8] which is obtained as a sum of the CF cross sections [8, table II] and, ICF cross sections [8, table VI] corresponding to the fusion products formed due to ICF as well as the products formed with the possibility of breakup of *d* leading to direct reaction process. It may be remarked that this experimental data can not distinguish between ICF and direct reaction products [8].

The calculated CF and TF cross sections in case-(c) give very good agreement with the experimental data.

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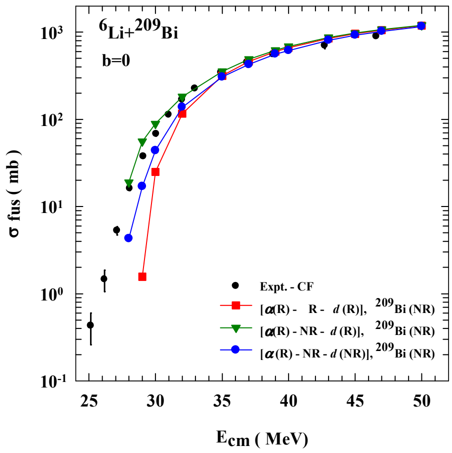

Figure 1: CF cross sections for ^{6}Li+^{209}Bi with *b*=0. R stands for rigid body and NR for non-rigid body.

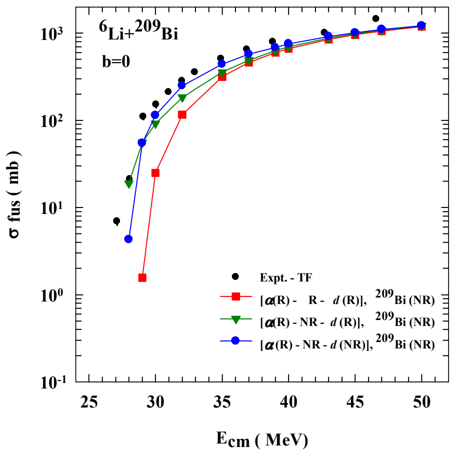

Figure 2: TF cross sections for ^{6}Li+^{209}Bi with *b*=0.

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