Importance of direct reaction processes in ^{6}Li+^{209}Bi reaction

M. R. Morker, S. S. Godre*
Department of Physics, Veer Narmad South Gujarat University, Surat – 395007, India
* email: ssgodre@yahoo.com

Introduction

Heavy-ion fusion involving stable weakly bound nuclei may result in CF (complete fusion), or ICF (incomplete fusion) processes involving fusion of only one of the projectile fragments [1]. The projectile may also get scattered without breakup (NBUS) or after breakup (NCBU). In a recent experiment [2] it is observed that direct processes such as nucleon transfer leading to breakup of the remaining projectile contribute significantly to the ICF processes.

None of the models such as CDCC [3], semi-classical couple channel [4] or the Classical trajectory models [5] account for breakup following direct reactions in the ICF processes. The multi-body Classical Molecular Dynamics Model [6], apart from demonstrating CF, ICF events, is also able to account for a process equivalent to a direct reaction leading to ICF process. Probabilities for various events, $F(b)$, as a function of b and E_{CM} were studied for ^{6}Li+^{209}Bi reaction [7] which clearly demonstrated the importance of direct reaction process.

In the present contribution we analyse these result which are integrated over all possible impact parameters and discuss the importance of various events as a function of collision energy.

Calculation Details

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 and a soft-core Gaussian NN potential between all the nucleons as in ref. [6].

The dynamical collision is carried out in the 3S-CMD model [8] 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.

Events probabilities are calculated as $\boldsymbol{F}(\boldsymbol{b}) = \frac{\boldsymbol{N_{events}}}{\boldsymbol{N_{total}}}$; where $\boldsymbol{N_{total}}$ is total no of initially random orientations for given E_{CM} and b, and $\boldsymbol{N_{events}}$ is no of trajectories analyzed as DCF, SCF, ICF etc. events. We have analyzed simulated trajectories from b=0.0 fm to a maximum value $b_{\max}$, beyond which only scattering takes place. We have taken $b_{\max}$= 8.6, 7.0, and 5.0 fm for E_{CM} =50, 36 and 29 MeV respectively with Δb=0.2 fm with $\boldsymbol{N_{total}}$=500 at each value of b for E_{CM} =50 and 36 MeV, and 2000 for E_{CM}=29 MeV. Event probabilities for given E_{CM} are found as $\int_0^{b_{\max}} \boldsymbol{F}(\boldsymbol{b})\boldsymbol{db}$.

Results and Discussion

In all the calculations presented here, the bond between projectile fragments (d, α) as well as the target ^{209}Bi are kept non-rigid in stage-3 after R_{CM}=13 fm, while keeping α in the projectile fragment rigid. By allowing the d in the projectile fragment to be non-rigid, thereby allowing its own breakup, and comparing the results when it is kept rigid even in stage-3 near or inside the barrier, demonstrates the effect of direct reaction process in this reaction.

Probabilities of various events are shown in Fig.1 as staked bar-charts for the case when the d is kept rigid, like in many other calculations which consider the entire reaction essentially as a 3-body system. It can be noted that as E_{CM} is increasing DCF and SCF events increase. ICF events also increase as the collision energy increases.

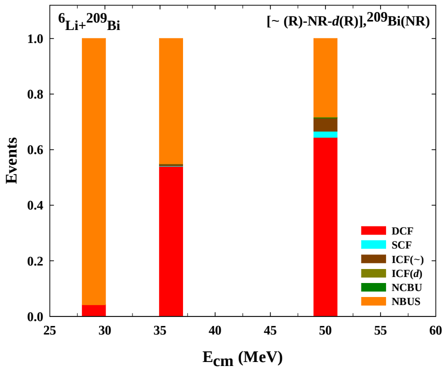

Fig. 1 All events for *d*-rigid

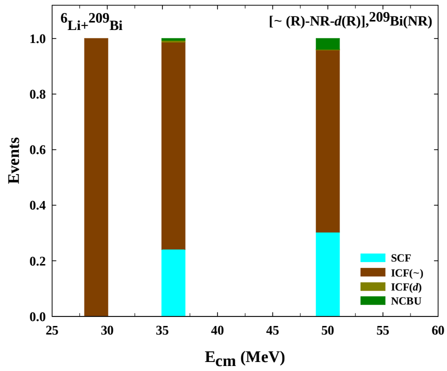

Fig. 3 Breakup events for *d*-rigid

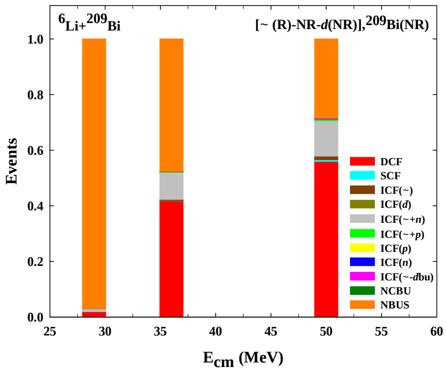

Fig. 2 All events for *d*-non-rigid

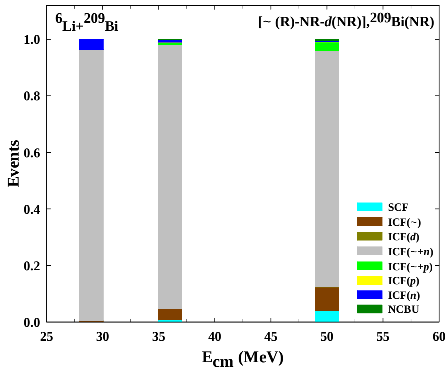

Fig. 4 Breakup events for *d*-non-rigid

Probabilities of various events when *d* is kept non-rigid are shown in Fig. 2, thus considering the entire reaction essentially as a 4-body system in which the *d* also may break up into *n* and *p*. Fig. 2 shows events ICF(~+*n*), capture of ~ and *n*, equivalent to ICF(^{5}He) or *n*-stripping followed by breakup of the resultant unstable ^{5}Li→~+*p* with *p* scattered. These events are seen even at the lowest energy and its relative importance increases as the collision energy increases. Also seen are ICF(~+*p*) events equivalent to *p*-stripping followed by breakup of the resultant unstable ^{5}He→~+*n* with *n* scattered. However, the relative strength of ICF(~+*p*) events is much smaller compared to ICF(~+*n*) events even at the highest energy considered here.

The relative strength of various events resulting only from breakup of the projectile into *d* and α in the case of *d* being kept rigid in Fig. 1 and breakup of *d* as well, into *n* and *p* as in Fig. 2 are shown in Fig. 3 and Fig. 4 respectively, normalized with the total no of breakup related events. Fig. 3 shows that the most prominent event that arises due to projectile breakup is ICF(~) in the case of *d*-rigid and ICF(~+*n*) in the case of *d*-non-rigid

Thus, the model calculations are able to account for all the possible reaction mechanisms in system involving weakly bound projectile.

References

[1] L F Canto *et al*, Phys Rep **424**, 1 (2006)
[2] D H Luong *et al*, Phys Rev C **88**, 34609 (2013)
[3] K Hagino *et al*, Phys Rev C **61**, 037602 (2000)
[4] H D Marta *et al*, Phys Rev C **89**, 034625 (2014)
[5] A Diaz-Torres *et al*, Phys Rev Lett **98**, 152701 (2007)
[6] M R Morker, S S Godre, EPJ Web of Conf **86**, 28 (2015)
[7] M R Morker, S S Godre, Proc Symp on Nucl Phys 59, 510 (2014)
[8] S S Godre, EPJ Web of Conf **86**, 12 (2015)