Direct reaction processes in ^{7}Li+^{209}Bi reaction in multi-body classical molecular dynamics model calculation

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Introduction

Heavy-ion reactions involving weakly bound nuclei may result in CF or ICF(x) where x is only part of the projectile fragments which are captured [1]. The projectile may also get scattered without breakup (NBUS) or after breakup (NCBU). In coincident measurements of breakup fragments of $^{6-7}$Li, it is observed that direct processes such as nucleon transfer leading to breakup of the remaining projectile contribute significantly to the ICF processes [2].

None of the models such as CDCC [3], semi-classical CC [4] or the classical trajectory models [5] account for breakup following direct reactions in the ICF processes. The multi-body Classical Molecular Dynamics model [6-9], apart from demonstrating CF, ICF events, is also able to account for processes equivalent to direct reactions leading to ICF processes. Event fractions for various events, $F(b)$, as a function of b and E_{CM} were studied for ^{6}Li+^{209}Bi reaction [7,8] and probabilities of various events as a function of E_{CM} [7,9] was studied in this model which clearly demonstrated the importance of the direct reaction process.

In the present contribution we present similar study for ^{7}Li+^{209}Bi reaction.

Calculation Details

The weakly-bound ^{7}Li is constructed by making use of the stable ^{3}H and ^{4}He with the potential energy between these fragments equal to -2.47 MeV, and a soft-core Gaussian NN potential between all the nucleons as in ref. [6]. The ground state configuration of nucleons in the stable ^{3}H, ^{4}He, and ^{209}Bi are generated by a potential energy minimization code *STATIC* [10].

Dynamical simulation of ^{7}Li+^{209}Bi collision is carried out in the 3S-CMD model [10, 11] in the following 3-stages: (1) Rutherford trajectory calculation up to R_{CM}= 2500 fm for given E_{CM} and b; (2) thereafter, assuming ^{7}Li and ^{209}Bi as rigid bodies, using CRBD model calculation [12]; (3) the rigid-body constraints are relaxed at about R_{CM}=13 fm near the barrier and the trajectories of all the nucleons are computed as in CMD model calculation. In the present calculation one of the projectile fragments (^{4}He) is further constrained to be rigid and it is dynamically evolved as in the CRBD-model calculation.

The rigid-body constraint on the bond between the projectile fragments (^{3}H-^{4}He), as well as on the target ^{209}Bi, and ^{3}H are relaxed in the stage-3. Relaxation of rigid-body constraint on ^{3}H in the projectile fragment allows its own possible breakup to demonstrate the effect of direct reaction processes in this reaction where ^{7}Li is treated as a 4-body system in stage-3.

Events fractions, F(b) are calculated as F(b)=$\boldsymbol{N_{events}}$ /$\boldsymbol{N_{total}}$; where $\boldsymbol{N_{total}}$ is total number of initially random orientations for given E_{CM} and b, and $\boldsymbol{N_{events}}$ is number of trajectories analyzed as DCF, SCF, ICF *etc*. events. Trajectories for b=0-b_{max} are analyzed with b_{max}= 5.2, 7.4, and 9.6 fm for E_{CM} =29, 36, and 50 MeV respectively with Δb=0.2 fm. We have considered $\boldsymbol{N_{total}}$= 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

$$\left(\frac{1}{(\boldsymbol{b}_{\max}/\Delta\boldsymbol{b})+1}\right)\int_{0}^{\boldsymbol{b}_{\max}} \boldsymbol{F}(\boldsymbol{b})d\boldsymbol{b} \qquad \ldots(1)$$

Results and Discussion

Figure-1 shows F(b) as a function of b for E_{CM}=50 MeV. Apart from events like DCF, SCF *etc*, this figure shows 1n- and 2n- stripping reactions leading to ICF(n) and ICF(2n) events respectively. This figure also shows events ICF(α+2n) which are equivalent to 2n-stripping followed by breakup of the resultant unstable

^{5}Li→α+p with α-captured and p-scattered. Events ICF(α+n), equivalent to 1n-stripping, ICF(d) and ICF(^{6}Li) are also seen but very few in numbers. Contribution of ICF(t) events is also small as ^{3}H breaks up in most of the cases. No events are seen for ICF(α) and ICF(p).

Similar calculations for E_{CM}= 36 & 29 MeV shows reduction in events following breakup.

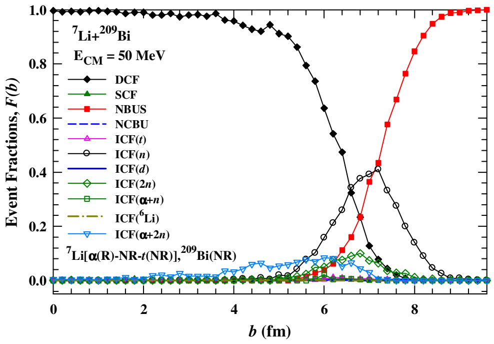

Fig. 1: Fraction of different events for ^{7}Li+^{209}Bi

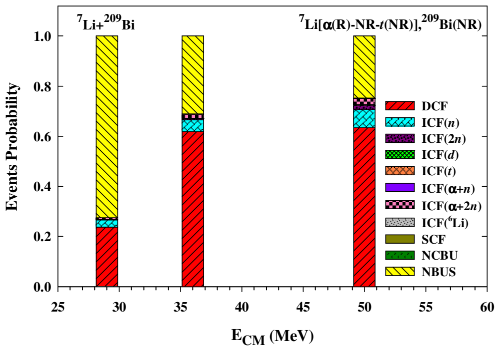

Fig. 2 Event probabilities for all the events

Calculated event-probabilities (eq.-1) for various possible events are shown as staked bar-charts in figure-2 for E_{CM}= 29, 36, and 50 MeV. Apart from events such as DCF, SCF *etc*, this figure also shows events ICF(n), ICF(2n), ICF(α+n) and ICF(α+2n) which are, as mentioned above, equivalent to direct reaction process. These events are seen even at the lowest energy considered here, and their relative importance increases as the collision energy increases. However, the relative strength of ICF(α+2n) events is much smaller compared to ICF(n) events even at the highest energy considered here. Probability of ICF(α+p) events corresponding to p-stripping is found to be zero in this case.

The relative strength of various events resulting only from the breakup of the projectile into ^{3}H and ^{4}He and breakup of ^{3}H as well, into *2-n* and p as in Fig. 1 and 2 are shown in Fig. 3, which are normalized with the total number of breakup related events. Figure-3 shows that the most prominent events that arises due to direct reaction processes in the present calculations are ICF(n), ICF(2n), and ICF(α+2n) events.

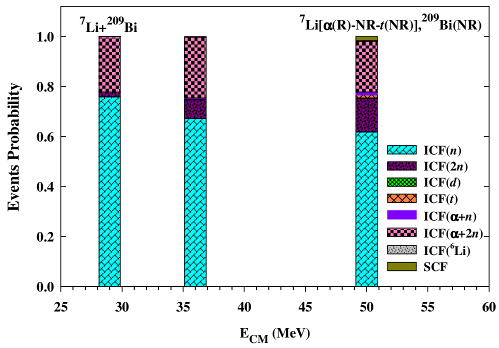

Fig. 3 Relative probabilities for breakup events

Conspicuous by its absence in the present calculations is the p-pickup reactions which could lead to formation of ^{8}Be and its subsequent breakup up into 2-α as in ref [2].

Thus, the model calculations are able to account for all the possible reaction mechanisms except the p-pickup in ^{7}Li+^{209}Bi reaction, which may be due to the lack of shell effects in the present classical calculations.

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