A three-body classical dynamics model for study of effect of weakly bound projectile breakup on heavy-ion fusion

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Introduction

Heavy-ion fusion reactions above and near the fusion barrier involving tightly bound projectile/target nuclei have been of considerable interest for many years. Recent developments have made it possible to study reactions involving nuclei far from stability, specially the ones which are weakly bound. Breakup of stable weakly bound nuclei is an important process in their collision with other nuclei [1-4].

For such unstable nuclei the fusion process can be affected by their low binding energy, which can cause them to breakup before reaching the fusion barrier. After the breakup, if all the breakup fragments are captured by the target then it is termed as a 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 significantly change the nature of the reaction products, fusion probabilities and distribution of barriers. It is therefore important to understand the effects of breakup of weakly bound nuclei on the fusion process.

Breakup reactions are studied using Continuum Discretized Couple-Channel (CDCC) method [5] and a semi-classical couple channel approximation [6]. More recently a classical trajectory model [7] has been used to study fusion of weakly bound nuclei. In this model the projectile is considered as a two-body system which interacts with each other by an assumed weak potential and the breakup is initiated by a breakup probability function. Thus the two-body projectile and the target system is a three-body classical point-particle system evolving under a given set of interaction potentials between each pair. Nuclei being treated as point particles, a very important degree of freedom, i.e., the deformation and consequential reorientation [8] of the entire projectile system is neglected in this model. Moreover the interaction potentials are not obtained self-consistently.

In the present paper, development of a new simple classical trajectories model is presented for reactions involving weakly bound projectiles which also overcome the difficulties stated above. This model is an extension of the CRBD-model used in the study of the reorientation effect [8].

Calculation Details

Individual nuclei are constructed using a static potential energy minimization procedure [8]. The given number and the type of nucleons are randomly placed in a sphere. The potential energy of this random distribution of nucleons is cyclically minimized with respect to small displacements of individual nucleon coordinates. A soft-core Gaussian form of NN-potential is chosen for interaction between nucleons, along with the usual Coulomb interaction. Parameters of the NN-potential P4 [8] which reproduces g.s. properties of many nuclei are chosen.

Weakly bound nuclei can be constructed as a cluster of tightly bound nuclei [9] as discussed above. In order to maintain initially defined clusters, nucleon coordinates of the individual clusters are rigid-body constrained. Thus a weakly bound nucleus can be constructed as a cluster of two or more rigid nuclei in such a manner that the entire cluster has the desired properties of the corresponding projectile nucleus. Thus, the interaction between the projectile fragments is generated self-consistently. We can also consider a projectile/target nucleus, where desired, as consisting of a rigid core nucleus plus one or many nucleons. This has the possibility of mimicking the halo nuclei as well. Relaxation of the rigid-body constraints at appropriate stages can take care of excitation of target and projectile fragments.

Initially the target and the clustered projecttile system are placed along their respective Rutherford trajectories at a large distance for a given initial condition for collision. Coupled classical equations of motion for the translational and rotational degrees of freedom for the three-body (or more) system are numerically solved to obtain the trajectories of the respective centre of mass and orientation of the principle axes of the respective rigid-bodies. All the rigid-bodies move under the influence of the ion-ion potential and the torques generated by interaction between all the nucleons in the combined system.

Results & Discussions

Using the above model we have simulated ^{6}Li+^{209}Bi collision. The weakly bound ^{6}Li projectile is constructed as a cluster of a ^{2}H and a ^{4}He with the separation between the two chosen with the potential energy (-1.446 MeV) corresponding to the experimentally observed breakup threshold energy [1]. ^{2}H, ^{4}He and ^{209}Bi are strongly bound nuclei obtained by the static minimization procedure as described earlier.

In the present simulation of ^{6}Li+^{209}Bi collision we have treated ^{2}H and ^{4}He as rigid-bodies and the ^{2}H - ^{4}He cluster representing the projectile is dynamically evolved as a rigid-body till the target-projectile separation is close to their barrier top (~ 13.0 fm). At this separation the rigid-body constraint is removed for further evolution of the entire system. The target nucleus ^{209}Bi is not rigid-constrained.

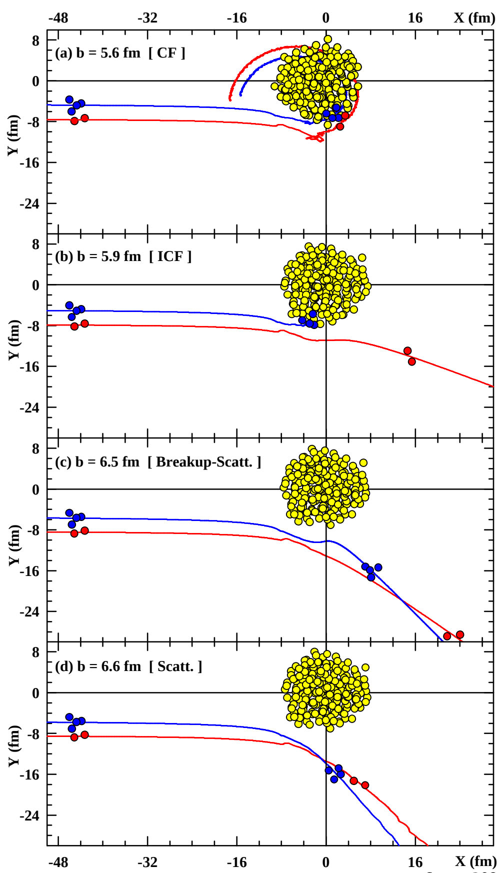

Fig. 1: Dynamic simulation of ^{6}Li+^{209}Bi reaction for E_{cm}=42.7MeV; (a)-(d) for different impact parameters, b showing various reactions.

Figure-1 shows the ^{6}Li+^{209}Bi collision at E_{cm} = 42.7 MeV and different impact parameters b resulting in complete fusion (CF) in fig.1(a), incomplete fusion (ICF) in fig.1(b); where ^{4}He is captured after breakup of the projectile, scattering with projectile breakup in fig.1(c) and scattering without breakup in fig.1(d).

The model presented here, thus looks promising for the study of Heavy-Ion collisions involving weakly-bound nuclei. Further calculations are underway and will be presented.

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