Three-body classical dynamical model calculation of fusion cross section for ^{6}Li+^{209}Bi reaction involving weakly-bound projectile

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Introduction

Heavy-ion fusion reactions above and near the fusion barrier have been of considerable interest for many years. Breakup of stable weakly bound nuclei is an important process in their collision with other nuclei [1-2]. For such weakly-bound 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.

In ref. [3] we have presented a three-body classical dynamics model to simulate such break-up reactions and showed possibilities for CF, ICF as well as scattering with and without breakup in the same model. The ^{6}Li projectile nucleus is constructed as a weakly-bound cluster of ^{2}H and ^{4}He. In ref. [3] the target and the projectile nuclei were treated as rigid-bodies and the rigid-body constraint on the projectile fragments was relaxed when they approach the barrier-top and classical trajectories of the 3-body system were calculated using the Classical Rigid-Body Dynamics (CRBD) model [4].

Recently, realizing the importance of the target and projectile excitations at distances very close to the barrier, a new 3-Stage Classical Molecular Dynamics (3S-CMD) was developed which could account for the long-range Coulomb re-orientation effect of the deformed nucleus (CRBD-model) as well as account for all the intrinsic degrees of freedom (CMD-model); reducing the computational time and accumulation of numerical errors. In this paper we present the results of complete fusion cross section calculations for ^{6}Li+^{209}Bi in the 3-body, 3S-CMD approach.

Calculation Details

Nucleon distribution in each tightly bound nucleus is first obtained by the *STATIC* code [5] in which the total potential energy of an initially random distribution of nucleons is cyclically minimized. We have used a soft-core Gaussian form of NN-potential given by [5]

$$V_{ij}(r_{ij}) = -V_0\left(1-\frac{C}{r_{ij}}\right)\exp\left(-\frac{r_{ij}^2}{r_0^2}\right)$$

along with the usual Coulomb interaction with the potential parameters V_0 = 710 MeV, C= 1.88 fm, r_0= 1.15 fm in the present study. Calculated ground state properties for the nuclei considered in the present work are given in table-1.

	Calculated		Experimental	
	(B.E.) Mev	**R (fm)**	**(B.E.) Mev**	**R (fm)**
^{2}H	2.069	1.000	2.225	2.100
^{4}He	14.481	1.317	28.296	1.690
^{6}Li (^{2}H+^{4}He)	18.017	1.934	31.990	2.540
^{209}Bi	1606.155	5.553	1640.000	5.520

Table 1: Ground state properties of the nuclei generated with new potential and *STATIC.*

The weakly-bound projectile ^{6}Li is constructed making use of the stable ^{2}H and ^{4}He as discussed earlier with the potential energy between the fragments equal to -1.467 MeV. The collision calculation are carried out with different collision energies and impact parameter b=0 for a large number of initially random orientations of the projectile and target nuclei at far-off distances. Collision calculations with different assumptions are carried out as detailed below and in each case fusion cross sections are calculated using the Wong's formula from the calculated barrier-parameters.

Results and discussion

Initially we have calculated fusion cross sections for the above reactions in the SBPM-model treating ^{6}Li and ^{209}Bi as rigid bodies and finding the barrier parameters from the ion-ion potential calculated in the frozen-density approximation. This result is shown in fig.1 as *dotted line* which does not agree with the expt. data in all the energy ranges.

Next removing the frozen-density approximation we calculate fusion cross sections in the CRBD-model as described earlier. The calculated cross sections are shown connected by *dashed line* in fig. 1. These values are underestimating the expt. data at lower energies.

We carry out 3S-CMD model [6] calculation in the following three stages:

(1) Rutherford Trajectory Calculation in which the two nuclei, assumed as charged point particles, are brought up to R_{cm} = 2500 fm at given E_{cm} and b=0;

(2) CRBD model Calculation in which two nuclei, assumed as rigid bodies, are then allowed to evolve by solving translational and rotational equations of motion [4];

(3) CMD Calculation in which rigid-body constraints are relaxed at about R_{cm}= 13 fm near the fusion barrier and trajectories of all the nucleons are computed using the coupled Newton's equations of motion [5, 6].

This calculated result is shown connected by *solid line* in fig.1 which matches well with the expt. data.

Finally we have also carried out a 3S-CMD* model calculation where even after R_{cm}= 13 fm, ^{6}Li is still treated as a rigid-body but the rigid-body constraint for ^{209}Bi is relaxed as in the CMD calculation. This result is shown connected by a *dot-dashed line* in fig.1. This calculation also underestimates the expt. data in fig.1.

Conclusion

Complete fusion cross section calculations for ^{6}Li+^{209}Bi reactions involving a weakly-bound projectile constructed from different fragments, and under varying degrees of assumptions are presented. It is seen that proper dissipations of the energy from the relative motion to the internal excitations for all the three-bodies involved in the collision simulation is necessary to get correct description of the fusion process involving weakly-bound projectiles.

In some of the cases with b ≠ 0 we observe incomplete fusion involving capture of only one of the projectile fragment. Taking into account of this process can give incomplete fusion cross sections for this reaction. The calculations for the same are underway and will be presented.

M. R. Morker acknowledges receiving a fellowship under a DAE-BRNS project no. 2009/37/20/BRNS.

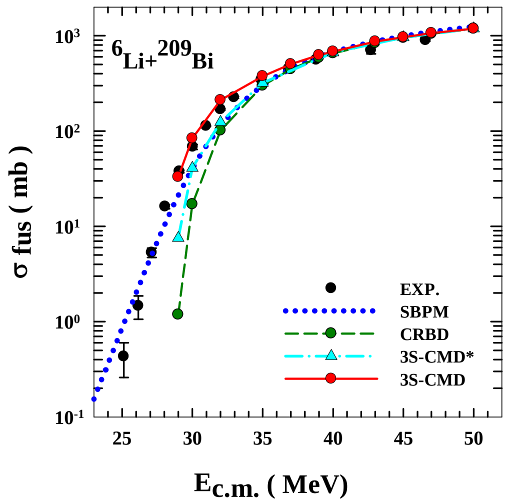

Fig.1: Complete fusion cross sections for ^{6}Li+^{209}Bi reaction. Experimental data is from ref. [1].

References

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