Static method for construction of weakly bound nuclei for complete and incomplete fusion reactions in multi-body 3S-CMD approach

Vipul B. Katariya, Isha B. Desai, Subodh S. Godre*
Department of Physics, Veer Narmad South Gujarat University, Surat - 395007, INDIA
** email: ssgodre@yahoo.com*

Introduction

Breakup of weakly bound nuclei is an important process in their collision with other nuclei [1-3].

For reaction involving stable weakly bound nuclei multi-body 3-Stage Classical Molecular Dynamics (Multi-body 3S-CMD) model is developed [4] which is an extension of the 3-Stage Classical Molecular Dynamics (3S-CMD) model. The dynamical collision simulation in this model is carried out in three stages, (1) Rutherford trajectory calculation (2) Classical Rigid Body Dynamics (CRBD) calculation [5] and (3) Classical Molecular Dynamics (CMD) [6] calculations.

Reactions like ^{6}Li+^{209}Bi and ^{7}Li+^{209}Bi involving weakly bound nuclei are studied in detail using multi-body 3S-CMD model [4]. In these studies weakly bound ^{6}Li and ^{7}Li are constructed as a cluster of tightly bound nuclei using a "dynamic-cooling" method by carrying out rigid-body dynamic evolution like procedure [5] and setting the cluster velocities and their angular moment zero after every time-step and thus obtaining the equilibrium orientation and position of centre of mass of these constituent nuclei. The distance between centre of mass is then adjusted in such a manner that the typical ion-ion potential between them is equal to the experimental break up energy of nucleus [4].

The method described above, being dynamical, however, is time consuming and involves immense calculations. Therefore, another alternative static approach based on non-dynamical or static approach can be adopted for construction of weakly bound nuclei. This method which is based on the microscopic Static Barrier Penetration model (SBPM) [7] is discussed in this paper.

Model Details

^{6}Li can be considered as a cluster of ^{2}H and ^{4}He. Two tightly bound nuclei ^{2}H and ^{4}He, constituents of weakly bound nucleus ^{6}Li are constructed using STATIC [6] method.

A purely phenomenological soft core Gaussian Potential is used which is given by,

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

where, V_0, C, and r_0 are respectively, the depth parameter, repulsive-core radius and range parameter.

The potential parameter set V_0 = 710.0 MeV, C = 1.88 fm and r_0 = 1.15 fm is used to produce ground state properties of ^{2}H and ^{4}He. Ground state properties of ^{2}H and ^{4}He are given in Table 1. The nucleons of constituent nuclei of nucleus are not allowed to have any motion within the respective nuclei.

Table 1: Ground state properties of ^{2}H and ^{4}He

Nucleus	Calculated		Experimental	
	B.E. (MeV)	**R (fm)**	**B.E. (MeV)** [8]	**R (fm)** [9]
^{2}H (d)	2.07	1.00	2.23	2.10
^{4}He (α)	14.48	1.32	28.30	1.69

These tightly bound nuclei are placed at some initial centre-of-mass separation distance with random initial orientation.

The ion-ion potential between these two nuclei is obtained as a function of centre of mass separation in sudden-approximation [7]. The minimum potential energy between these two clusters is obtained from the ion-ion potential. This process is repeated for the same initial

separation distance but with a large number of random initial orientations. The ion-ion potential for an orientation which gives the deepest pocket with respect to maximum barrier height is chosen. The bottom of this pocket corresponds to the equilibrium configuration between ^{4}He and ^{2}H nuclei. The distance between centre of mass is then adjusted in such a manner that the typical ion-ion potential between them is equal to the experimental break up energy of the nucleus which is similar to the dynamic method described in ref. [4]. The two nuclei in this final configuration are held rigidly with respect to each other and represent the weakly-bound ^{6}Li nucleus. In the multi-body 3S-CMD model simulation the rigid-body constraint on the bond between the two constituent nuclei is relaxed at distances very close to the barrier.

Result and discussions

For construction of weakly bound ^{6}Li (α+d) nucleus, ^{2}H and ^{4}He are initially separated by 20 fm and typical ion-ion potential is calculated for large number (1000) of random orientation.

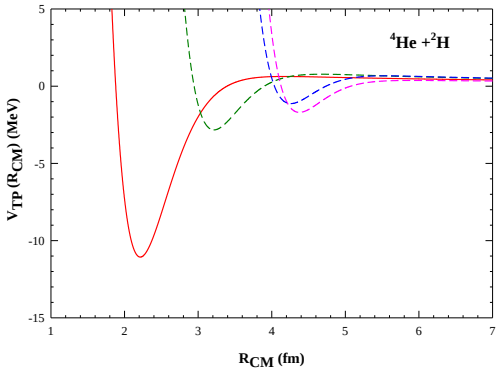

Fig. 1: Ion-Ion potential as a function of R_{cm} for ^{2}H+^{4}He

Fig. 1 shows ion-ion potential for some of the random orientations. The solid red line represents the orientation which gives deepest pockets with respect to maximum barrier height. Dashed lines are for some of the random orientation for comparison with the deepest pocket case.

For equilibrium configuration for deepest pocket orientation is obtained. The ion-ion potential at equilibrium position for deepest pocket in the present calculation is found to be -11.069 MeV. Now the distance between the centre of mass of constituent nuclei for this orientation of the two nuclei can be adjusted to produce the ion-ion potential value equal to the experimental breakup energy -1.475 MeV [3] of ^{6}Li into ^{4}He and ^{2}H .

The ground state properties of weakly bound nucleus generated in the dynamic calculation [4] are not in very good agreement with the experimental values. However, the model calculations in ref [4] still demonstrated the essential features of the reaction dynamics and complete and incomplete fusion cross sections in multi body 3S-CMD model.

Similarly, the present static method of construction of weakly bound can also demonstrate essential features of reaction dynamics and fusion cross section by incorporating it in the multi-body 3S-CMD model which is simpler than the dynamic method and will take comparatively less computational time.

References

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