Fusion cross sections for ^{16}O+^{232}Th reaction in 3-stage classical molecular dynamics model

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

Introduction

Heavy-ion reactions involve large scale transfer of energy from the relative motion to internal excitations [1]. Due to the large de-Broglie wavelengths of heavy-ions, as well as due to the case of computational efforts, classical approximations also have been used to study heavy-ion fusion reactions [2]. One such approach is Classical Molecular Dynamic approach [3] and its improved version namely 3-Stage Classical Molecular Dynamics (3S-CMD) approach [4] which also takes into account reorientation of the deformed nuclei resulting from the deformed nuclei resulting from the long range torque on it.

In the three-stage classical molecular dynamics (3S-CMD) model [3, 4] the reaction dynamics proceeds in 3-stages, viz:
(1) Rutherford trajectory calculation in which the two nuclei are bought up to R_{cm} = 2500 fm at given collision energy (E_{cm}) and impact parameter (b), followed by
(2) CRBD calculation in which the two nuclei assumed as rigid bodies are then allowed to evolve by solving translation and rotational equation of motion [2], followed by
(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 coupled Newton's equation of motion.

Many heavy-ion reaction have been studied using 3S-CMD model with a soft-core Gaussian form of NN-potential,

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

with the parameter set P4 (V_0 = 1155 MeV, C = 2.07 fm, r_0 = 1.2 fm) [2], giving reasonable agreement with the corresponding experimental data.

Fusion cross sections for a light spherical and light deformed system ^{16}O+^{27}Al reaction [5] were recently calculated using 3S-CMD model and potential parameter set P4. The calculated results match fairly well with the experiment data.

In the present contribution we calculate fusion cross sections for a light-spherical + heavy-deformed system, ^{16}O+^{232}Th making use of the same parameter set P4 and the 3S-CMD approach. Fusion cross sections are calculated using classical and semi-classical approximations and compared with the experiments.

Calculation Details

The calculated ground state properties of the nuclei used in the present calculations with potential parameter set P4 and the variational potential energy minimization code *STATIC* [1] are given in the Table below:

	Calculated			Experiment [6-8]		
	BE (MeV)	R (fm)	β_2	BE (MeV)	R (fm)	β_2
^{16}O	-127.76	2.45	0.37	-127.62	2.73	-0.01
^{232}Th	-2003.69	6.42	0.33	-1766.71	5.77	0.21

The dynamical collision simulation is carried out in the 3S-CMD model which is described in detail in [4]. In the present calculations the 3rd stage, *ie*., the CMD stage is carried out for $R_{cm} \leq$ 15 fm for ^{16}O+^{232}Th reaction..

The barrier parameters V_B, R_B, ω are calculated from the dynamically evolved ion-ion potential for a trajectory for b=0 (head-on collision) or even at near b=b_{cr} (critical impact parameter). These parameters are used in the Wong's formula (eq.2) [10] to calculate fusion cross-section in the semi-classical approximation for a given orientation of a collision energy E_{cm} is given by,

$$\sigma_{fus} = \left[\frac{\hbar\omega_B}{2E_{cm}}\right]R_B^2\ln\left[1+\exp\left(2\pi\frac{E_{cm}-V_B}{\hbar\omega_B}\right)\right] \qquad (2)$$

For a given E_{cm}, a large number of random initial orientations (about 2000 at lower energies and 500 at higher energies) are considered in the present calculation and the orientation-averaged fusion cross section is calculated.

In a classical approximation to the Wong's formula, fusion cross section is given by the following equation [9];

$$\sigma_{fusion} = \pi b_{cr}^2 \tag{3}$$

where b_{cr} is the maximum (critical) impact parameter for which the two nuclei fuse.

Result and Discussions

Calculated fusion cross sections for $^{16}O+^{232}Th$ reaction using potential P4 in 3S-CMD approach with the Wong's formula (eq.2) for b=0 (black circle) as well as $b=b_{cr}$ upper triangle) collisions are shown in fig.-1 as function of E_{cm}. Fig.-1 also shows the experimental measurement of this reaction fusion cross section [11-15]. Fusion cross section calculated with the Wong formula (b=0) fairly match with the experiment data and reproduce the observed trend at near barrier to higher energies. Fusion cross sections with the Wong formula for $b=b_{cr}$, are overestimated compared with the experiment data.

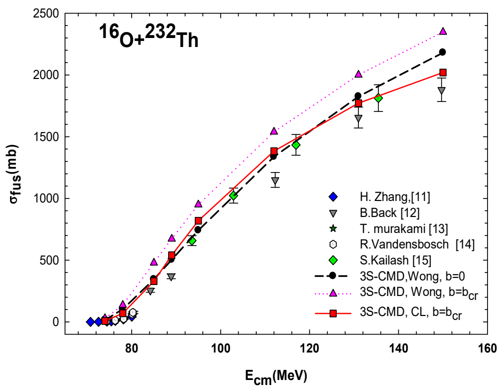

Fig.1 Fusion cross section for $^{16}O+^{232}Th$ reaction.

Fusion cross section for $^{16}O+^{232}Th$ reaction is also calculated using the classical approximation eq.(3) in 3S-CMD approach. The calculated cross sections (red square) are over all in good agreement with most of the experiment data. The calculated fusion cross sections are slightly overestimated compared with the experimental data. The reason for this overestimation lies with the larger rms radius of the ^{232}Th produced in this calculation as compared to the expt. value (see Table). Thus the smaller size of the lighter nucleus combined with the larger size of the heavier nucleus is resulting in a small overestimation of fusion cross sections for this reaction.

In the sharp cut-off classical approximation of the Wong's formula, experimental fusion cross section follow the linear dependence on E_{cm}^{-1}. Calculated fusion cross section using Wong formula shows almost linear rising behavior even at higher collision energies which gives good agreement with the experimental trend in fig.2 in which fusion cross section is shown as a function of reciprocal of the collision energy E_{cm}.

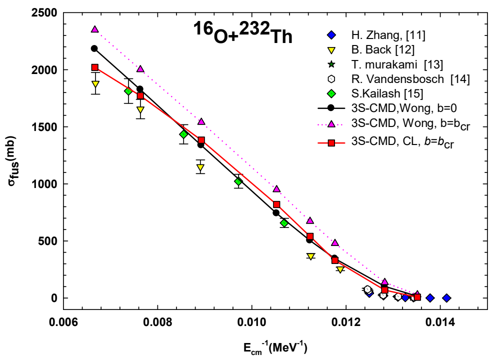

Fig.2 Fusion cross section as a function of E_{cm}^{-1}

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