Fusion cross sections for ^{16}O+^{27}Al reaction in 3-stage classical molecular dynamics model

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Introduction

Within the frame work of classical approximations, heavy-ion fusion cross sections have been calculated in a Classical Molecular Dynamics (CMD) approach [1]. The ^{16}O+^{16}O reaction has been studied in this approach with a soft-core Gaussian form of NN-potential,

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

with the parameter set P3 (V_0 = 3360 MeV, C = 2.35 fm, r_0 = 1.2 fm) [1] which gave reasonable agreement with the experimental data. However, fusion cross sections for ^{40}Ca+^{40}Ca reaction calculated with this potential P3 overestimated the experimental data. Use of another parameter set P4 (V_0 = 1155 MeV, C = 2.07 fm, r_0 = 1.2 fm), however, resulted in a closer agreement with the experimental data for ^{40}Ca+^{40}Ca reaction [1].

It has been shown using a Classical Rigid-Body Dynamics (CRBD) calculation [2] that in the case of deformed nuclei their re-orientation resulting from their long range torque results in modified reaction dynamics and cross sections.

Therefore, a three-stage classical molecular dynamics (3S-CMD) model [3, 4] has been developed in which the reaction dynamics proceeds in 3-stages, viz: (1) Rutherford trajectory calculation at very large separations, followed by (2) CRBD calculation with rigid-body constraint on both the nuclei up to distances close to the barrier, followed by (3) finding the trajectories of all the nucleons from the coupled Newton's equations of motion in a full CMD calculation for further evolution.

Using the potential parameters P4, fusion cross sections for spherical and symmetrical systems, ^{16}O+^{16}O [5] and ^{40}Ca+^{40}Ca [6] reactions were recently re-calculated using this 3S-CMD model. Calculated results agree much more closely with the experiments. Fusion cross sections for spherical but asymmetrical systems ^{16}O+^{40}Ca [6] and ^{16}O+^{208}Pb [5] and light-deformed + heavy-spherical system ^{24}Mg+^{208}Pb [4] were also calculated which showed good agreements with the experiments.

In this contribution we calculate fusion cross sections for light-spherical + light-deformed system, ^{16}O+^{27}Al making use of the parameter set P4 and the 3S-CMD approach. Fusion cross sections are calculated using classical and semi-classical approximations and calculated results are 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 potential energy minimization code *STATIC* [1] are given in the Table below:

	Calculated			Experiment [7-9]]		
	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
^{27}Al	-222.83	3.03	0.25	-224.95	3.06	0.25

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 $R_{cm} \leq$ 13 fm for ^{16}O+^{27}Al reaction.

Barrier parameters V_B, R_B, ω are calculated from the dynamically evolved ion-ion potential for a trajectory with *b*=0 (head-on collision) or even near *b*=b_{cr} (critical impact parameter for which the two nuclei fuse). These parameters are used in the Wong's formula (eq.2) [10];

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

to calculate fusion cross-section in the semi-classical approximation for a given initially random orientation of the two nuclei for a collision energy E_{cm} as in ref [4].

For 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.

We also calculate classical fusion cross section [1], using the value of b_{cr} in the sharp-cutoff approximation, given by

$$\sigma_{fusion} = \pi b_{cr}^2 \qquad (3)$$

Results and Discussions

Calculated fusion cross sections for $^{16}O+^{27}Al$ reaction using potential P4 in 3S-CMD approach with the Wong's formula (eq.1) for $b=0$ as well as $b=b_{cr}$ collisions are separately shown in figure-1 as function of the collision energy E_{cm}. The two calculations almost match with each other at lower energies and there are small differences between them at higher energies. Figure-1 also shows experimental [11-14] measurements of the fusion cross sections for this reaction. These experimental measurements span different regions of collision energy and use different techniques for fusion cross section determination. The calculated fusion cross sections with the use of Wong's formula match fairly well with the experiments at lower energies but are highly overestimated at medium and higher energies.
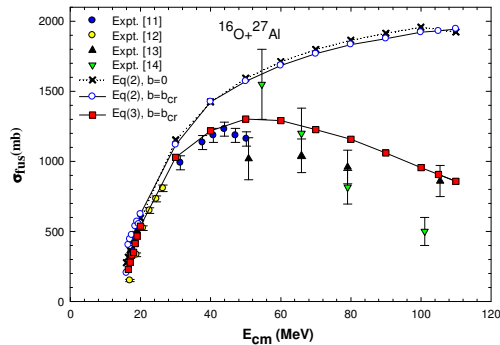

Fig. 1: Fusion cross section for $^{16}O+^{27}Al$ reaction.

Fusion cross sections for $^{16}O+^{27}Al$ reaction calculated in 3S-CMD simulation with potential P4 and eq.(3) are also shown in figure-1, which are in overall good agreement with most of the experimental data.

In the low energy approximation of the Wong's formula, experimental fusion cross section follow a linear dependence on E_{cm}^{-1}. Therefore, we also show the calculated and experimental fusion cross sections as a function of the reciprocal of collision energy, E_{cm}^{-1} in figure-2. Experimental data also show a turnaround at mid energy region and decreasing cross sections as collision energy is increased further. This behav-

ior can be attributed to the onset of deep-inelastic processes [11] which take away the flux from the fusion events at higher energies. While the fusion cross sections calculated with Wong's formula shows almost a linear rising behavior even at higher energies, fusion cross sections calculated with the classical formula (eq-3) not only show the correct experimental trend but it also shows reasonable agreement with the experimental data within the expt. uncertainties.
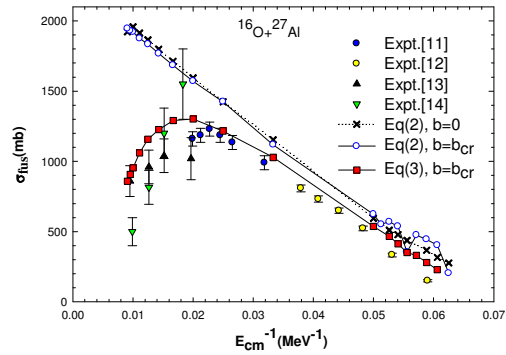

Fig. 2: Fusion cross section for $^{16}O+^{27}Al$ reaction.

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