Fusion cross section for $^{16}O+^{28}Si$ reaction in 3-stage classical dynamical model

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Introduction

Heavy-ion fusion reactions have been of interest for many years [1, 2]. In classical microscopic approaches for heavy-ion collisions such as Classical Molecular Dynamics (CMD) [3] or three-stage Classical Molecular Dynamics (3S-CMD) models [4-7] the initial conditions dictate requirement of positions of all the nucleons within the particular collision partners. These ground-state configurations of colliding nuclei are obtained by the variational potential energy minimization procedure "STATIC" code [3].

In classical approximations heavy-ion fusion cross sections have been calculated with a soft-core Gaussian form of NN-potential

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

Fusion cross sections for several reaction have been calculated with a potential parameter set P4 (V_0 =1155 MeV, C = 2.07 fm, r_0 = 1.2 fm) which gives reasonable agreement with the expt. data [4-7]. In the present contribution we calculate fusion cross sections for $^{16}O+^{28}Si$ reaction in the 3S-CMD approach.

Calculation Details

Nucleon distribution in each tightly bound nucleus is obtained by the *STATIC* code with a soft-core Gaussian form of NN-potential along with the usual Coulomb interaction. The ground state properties of the nuclei generated with potential P4 in the present calculations are given in table-1.

The dynamical collision simulation is carried out in the 3S-CMD model [4, 7] which proceeds in the following 3-stages:
(1) Rutherford trajectory calculation up to R_{cm}= 2500 fm for given E_{cm} and *b*; (2) thereafter, assuming the two nuclei as rigid bodies, using CRBD model calculation; (3) the rigid-body constraints at about R_{cm}=13 fm are relaxed and the trajectories of all the nucleons are computed as in CMD model calculation.

Table1: Ground state properties of the ^{16}O and ^{28}Si nuclei using the potential Parameter P4: (V_0 = 1155 MeV, C = 2.07 fm and r_0 = 1.2 fm)

		BE(MeV)	R(fm)	β_2
^{16}O	Cal.	-120.34	2.44	-0.05
	Expt.	-127.62	2.73	-0.01
^{28}Si	Cal.	-236.63	3.11	-0.38
	Expt.	-236.54	3.12	-0.36

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 [8] given below:

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

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

We also calculate classical fusion cross section using the value of b_{cr} in the sharp cut off approximation, given by [3],

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

Result and Discussions

Calculated fusion cross sections for $^{16}O+^{28}Si$ reaction using potential P4 in 3S-CMD approach with the Wong's formula (eq.2) for $b=0$ as well as $b=b_{cr}$ collisions are shown in fig-1 as function of the collision Energy E_{cm}. Figure-1 also shows experimental [9, 10] measurements of the fusion cross sections for this reaction.

Calculation with eq (3) is in good agreement with experimental data of ref [9] at higher energies. Although, the rms radius of ^{28}Si produced with the potential parameter set P4 matches well with the expt. value, but the rms radius of ^{16}O produced with this potential P4 (see Table) is smaller by about 11%. The smaller size of ^{16}O results in slight underestimation compared to the expt. cross sections.

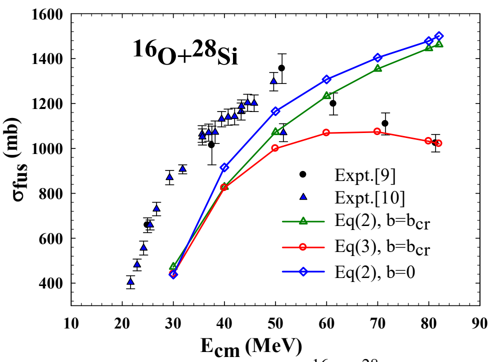

Fig. 1: Fusion cross section for $^{16}O+^{28}Si$ reaction as function of E_{cm}.

The calculated fusion cross sections with the use of Wong's formula eq.(2) with $b=b_{cr}$ match fairly well with the experiments at middle energies but are highly underestimated compared to the experimental data at lower energies. Fusion cross sections calculated for head-on collisions (b=0) with eq. (2) are overestimated compared to those with eq (2) and $b=b_{cr}$.

In the low energy approximation of the Wong's formula, experimental fusion cross section follow a linear dependence on Ecm^{-1}. Therefore, we show the calculated and experimental fusion cross sections as also a function of the reciprocal of collision energy, ie., Ecm^{-1} in fig-2.

Experimental data also show a turnaround at mid energy region and decreasing cross sections as collision energy is increased further. This behavior 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 of decreasing fusion cross sections at higher collision energies but it also shows reasonable agreement with the experimental data of ref [9] within the expt. uncertainties.

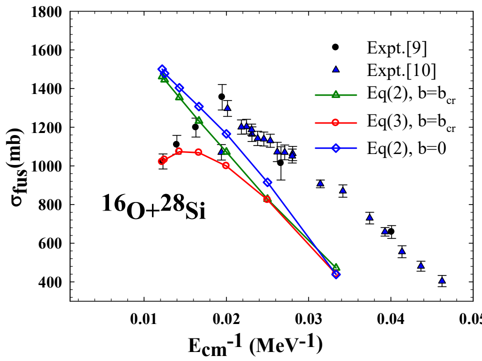

Fig. 2: Fusion cross section for $^{16}O+^{28}Si$ reaction as function $1/E_{cm}$

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