Near and above barrier fusion cross sections for $^{16}O+^{16}O$ and $^{16}O+^{208}Pb$ reactions in three-stage classical dynamical model

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1. Introduction

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

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

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 expt. data. However, fusion cross sections for $^{40}Ca+^{40}Ca$ reaction calculated with this potential P3 overestimated the expt. 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 expt. data for $^{40}Ca+^{40}Ca$ reaction [1].

The CMD calculations performed in ref [1] were carried out from an initial separation of 20 fm between the target and the projectile after obtaining the initial conditions for the collision from the respective Rutherford trajectories. Only few initial orientations (about 12) were considered.

It has been shown using a Classical Rigid-Body Dynamics (CRBD) calculation [2] that in case of deformed nuclei their re-orientation resulting from their long range torque results in modified reaction dynamics and cross sections [2]. On the other hand, at distances close to the barrier, dissipation mechanisms require relaxation of the rigid-body constraint and evolution of the system as in CMD calculation. Therefore, a 3S-CMD model [3] has been developed in which the reaction dynamics proceeds in 3-stages, viz: (1) Rutherford trajectory calculation at very large separation, 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 in a full CMD calculation for further evolution.

In this contribution we calculate fusion cross sections for $^{16}O+^{16}O$ reaction making use of the parameter set P4 and the 3S-CMD approach with larger number of initial orientations. We also calculate fusion cross sections for another light-spherical + heavy-spherical reaction, i.e., $^{16}O+^{208}Pb$. Fusion cross sections are calculated using classical and semi-classical approximations and compared with the experiments.

2. 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		
	BE(MeV)	R(fm)	β_2	BE(MeV)	R(fm)	β_2
^{16}O	-129.02	2.46	0.37	-127.62	2.73	0.02
^{208}Pb	-1799.56	6.08	0.17	1636.46	5.50	0.00

The dynamical collision simulation is carried out in the 3S-CMD model which is described in detail in [2]. In the present calculations the CMD stage is carried out for $R_{cm} \leq$ 13 fm for $^{16}O+^{16}O$ reaction and $R_{cm} \leq$ 14 fm for $^{16}O+^{208}Pb$ reaction.

In the classical approximation, fusion cross section is calculated from the following classical formula [1],

$$\pm_{fusion} = \circledR b_{cr}^2 \qquad (2)$$

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

The barrier parameters V_B, R_B, ω calculated from the dynamically evolved ion-ion potential for a trajectory near the critical impact parameter (b_{cr}) are used in the Wong's formula to calculate fusion cross-section in the semi-classical approximation for a given orientation of a collision energy E_{cm} [2],

$$\pm_{fus} = \left[\frac{\hbar\mu_B}{2E_{cm}}\right] R_B^2 \ln\left[1+\exp\left(2\circledR\,\frac{E_{cm}-V_B}{\hbar\mu_B}\right)\right] \qquad (3)$$

For a given E_{cm} a large number of random initial orientations (about 1000 at lower energies and 100 at higher energies) are considered in the present calculation and the orientation-averaged fusion cross section is calculated.

3. Result and Discussions

^{16}O+^{16}O Reaction : Calculated fusion cross sections for ^{16}O+^{16}O reaction using potential P3 [1] in CMD approach with eq.(2) are reproduced in Fig.1. This result reproduces well the observed trend in expt. data over near to high above barrier energies. Moreover it is in close agreement with the expt. data [5,8,9]. However, it over estimates other available expt. data [4, 6,7,10].

Fusion cross sections for ^{16}O+^{16}O reaction calculated in 3S-CMD simulation with potential P4 and eq.(2) are shown in Fig.1, which are in much better agreement with most of the expt. data. Smaller size of ^{16}O produced with this potential P4 (see Table) results in lower fusion cross sections as compared with those with P3.

Semi-classical fusion cross sections calculated using eq.(3) with potential P4 are also shown in Fig.1. Inclusion of penetrability factor in eq.(3) results in cross sections slightly higher than those with eq.(2) at lower energies. However, cross sections with eq.(3) are highly overestimated at higher energies.

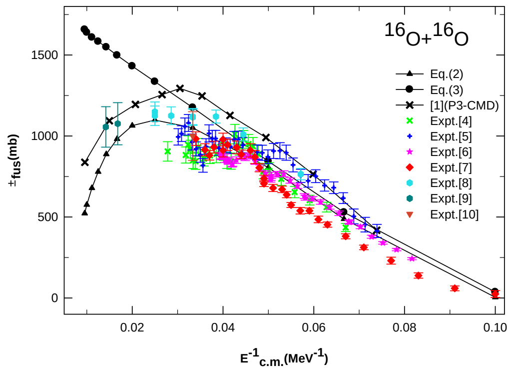

Fig. 1: Fusion cross section for ^{16}O+^{16}O reaction.

^{16}O+^{208}Pb Reaction : We use the same potential P4 and calculate fusion cross sections of ^{16}O with a heavy-spherical nucleus, viz ^{208}Pb.

Fusion cross sections for ^{16}O+^{208}Pb reaction calculated in 3S-CMD simulation with potential parameters P4 and eq.(2) are shown in Fig.2 and compared with the expt. data [11, 12]. The calculated cross sections are in over all good agreement with the expt. data except at energies below the barrier where they are overestimated. The reason for this overestimation lies with the larger rms radius of the ^{208}Pb produced in this calculation as compared to the expt. value (see Table), which is overestimated by about 10%. Thus the small 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. Semi-classical calculation of fusion cross sections with eq.(3) are only slightly over estimated at lower energies as compared to the calculations with eq.(2)

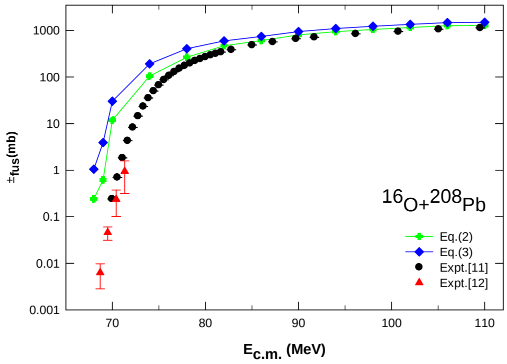

Fig 2: Fusion cross section for ^{16}O+^{208}Pb reaction.

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