Fusion cross sections for $^{16}O+^{120}Sn$ and $^{16}O+^{208}Pb$ reactions in three-stage classical molecular dynamics model

Jignasha H. Patel, Subodh S. Godre*
Department of Physics, Veer Narmad South Gujarat University, Surat – 395007, India
** email: ssgodre@yahoo.com*

Introduction

Fusion cross sections for heavy-ion reactions have been calculated in various classical and semi-classical models. In the classical approach fusion cross sections have been calculated using different model such as **C**lassical **M**olecular **D**ynamics (CMD) [1], **C**lassical **R**igid-**B**ody **D**ynamics (CRBD) [2], a **3-S**tage **C**lassical **M**olecular **D**ynamics (3S-CMD) [3] model and a microscopic **S**tatic **B**arrier-**P**enetration **M**odel (SBPM) [4]. In the present work 3S-CMD model is used to calculate fusion cross section. This model combines the advantages of both CMD and CRBD models. This model uses ion-ion potential obtained from dynamically evolving classical microscopic configurations of nuclei with a suitable NN-potential.

The 3S-CMD model calculation [3] proceeds in the following three stages: (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 by numerically solving Coupled Newton's equations of motion for all the point nucleons.

In the present work we calculate fusion cross sections for $^{16}O+^{120}Sn$ and $^{16}O+^{208}Pb$ systems in 3S-CMD model. Fusion cross sections are calculated using classical and semi-classical approximations and compared with the experiments.

Fusion cross sections for $^{16}O+^{16}O$ and $^{16}O+^{208}Pb$ has been calculated using the 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) [1] in ref. [5]. Using this potential, the fusion cross sections calculated for $^{16}O+^{16}O$ reaction in ref. [5] shows good agreement with the expt. data but in the case of $^{16}O+^{208}Pb$ reaction it is overestimated below the barrier energies. The reason for this overestimation is the larger rms radius of the ^{208}Pb which is produced in the calculation in ref. [5] with P4.

In the present work we have used a new potential parameter set (called as NP) from ref. [6], where it is used to reproduce the correct ground-state properties of the heavy-mass nucleus ^{209}Bi. The use of this potential parameter set might give better agreement in the case of 3S-CMD calculation of classical fusion cross sections for $^{16}O+^{208}Pb$ reaction and to some extent for $^{16}O+^{120}Sn$ reaction also. We have also used another set of potential parameters named NP1 for $^{16}O+^{120}Sn$ reaction, which correctly reproduces the ground-state properties of ^{120}Sn.

Calculation Details

The nuclei are generated using the variational potential energy minimization code *STATIC* [1] and are further "cooled" using *DYNAMIC* [1] method. The ground state properties of the nuclei are calculated using the parameter set NP (V_0 = 710 MeV, C = 1.88 fm, r_0 = 1.15 fm) [6]; and NP1 (V_0 = 550 MeV, C = 1.88 fm, r_0 = 1.2 fm) which closely reproduces the ground state properties of ^{120}Sn. The calculated ground state properties of the nuclei used in the present calculations are given below:

			BE(MeV)	R(fm)	β_2
^{16}O	Cal.	NP	-107.98	2.23	-0.05
		NP1	-111.49	2.33	-0.11
	Exp.		**127.62**	**2.73**	**0.00**
^{120}Sn	Cal.	NP	-965.61	4.56	0.03
		NP1	-1014.53	4.68	-0.08
	Exp.		**1020.55**	**4.65**	**0.00**
^{208}Pb	Cal.	NP	-1604.44	5.51	0.14
	Exp.		**1636.46**	**5.50**	**0.00**

Fusion cross sections are calculated using the classical formula [1],

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

Where, b_{cr} is the maximum (critical) impact parameter for which the two nuclei fuse. In the semi-classical approximation, the fusion cross sections are calculated using the Wong's formula [3],

$$\sigma_{fus} = \left[\frac{\hbar\omega_B}{2E_{cm}}\right] R_B^2 \ln\left[1+\exp\left(2\pi\frac{E_{cm}-V_B}{\hbar\omega_B}\right)\right] \quad (3)$$

where, V_B, R_B and ω are barrier parameters for a trajectory near the critical impact parameter (b_{cr}).

Result and Discussions

^{16}O+^{208}Pb Reaction : Fusion cross sections for ^{16}O+^{208}Pb reaction calculated using NP and using eq.(2&3) are shown in fig.1 and are compared with the experimental data of ref. [7,8]. This fig. also shows the result of ref. [5] for potential P4. The dynamical simulation is carried out in 3S-CMD model.

The potential parameter set NP gives the good agreement with expt. for ^{6}Li+^{209}Bi in ref. [6], however, for ^{16}O+^{208}Pb reaction the calculated fusion cross sections with this potential NP are underestimated compared to the experimental data. However, it shows the usual experimental trend of falling cross sections at very high energies although there is no experimental data available in this energy region for comparisons for this reaction.

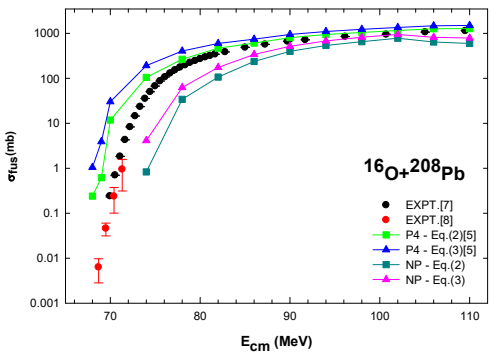

Fig. 1: Fusion cross section for ^{16}O+^{208}Pb reaction

^{16}O+^{120}Sn Reaction: Fusion cross sections for ^{16}O+^{120}Sn reaction are calculated in 3S-CMD simulation with potential NP and NP1 and using eq.(2&3) are shown in fig.2 and compared with the expt. data [9]. The fusion cross sections calculated using potential NP and using eq.(3) are underestimated with all of the expt. data. The ground state properties of the generated nuclei for ^{120}Sn using potential NP in table above are not in close agreement with the experimental values.

The fusion cross sections calculated using the potential NP1 which shows close agreement for the ground state properties of ^{120}Sn are also shown in fig.2. The fusion cross sections calculated using the Wong's formula eq.(3) with potential NP1 shows overall good agreement with most of the experimental data at higher energies. At lower energies it is overestimated while the fusion cross sections calculated using the classical formula for fusion cross sections eq. (2) match with the experimental data below the barrier energies while at higher energies it is underestimated.

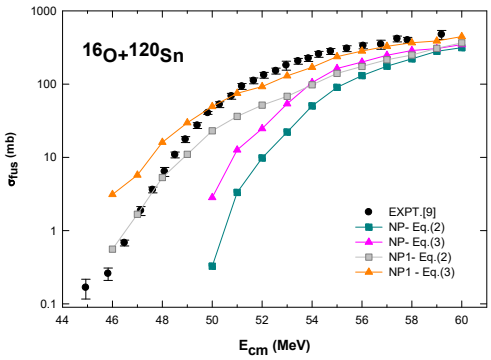

Fig. 2: Fusion cross section for ^{16}O+^{120}Sn reaction

References

[1] S. S. Godre, Y. R. Waghmare, Phys. Rev. C **36**, 1632(1987).
[2] S. S. Godre, Pranama-J. Phys., **82**, 879(2014).
[3] S. S. Godre, EPJ Web of Conf. **86**, 00012(2015).
[4] S. S. Godre, Nucl. Phys. A **734**, E17(2004).
[5] Jignasha H. Patel, Mitul R. Morker, S. S. Godre, Proc. Symp on Nucl. Phys, **61**, 454(2016).
[6] M. R. Morker and S. S. Godre, EPJ Web of Conf. **86**, 00028(2015).
[7] C. R. Morton *et al*, Phys. Rev. C **60**, 044608(1999).
[8] M. Dasgupta *et al*, Phy. Rev. Lett. **99**, 192701(2007).
[9] Lagy T. Baby *et al*, Phys. Rev. C **62**, 014603(2000).