Fusion cross sections for $^{16}O+^{92}Zr$ reaction in three-stage classical molecular dynamics model

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Introduction

Fusion reactions at energies near the Coulomb barrier have been of interest [1] for the understanding of the nuclear structure effect and, the study is also useful in the formation of super heavy elements (SHE). Various classical microscopic and macroscopic approaches have been used for studying heavy-ion reaction because of validity of classical approximations due to the small de Broglie wavelength of heavy ions even at lower energies [2]. Within the classical approximation, 3S-CMD [3] model is developed comprising of (1) Rutherford trajectory stage, (2) Classical rigid-body dynamics stage (CRBD) and, (3) CMD stage [4]. This model explicitly takes into account not only the long-range reorientation effect at large separations but internal excitations at close separations as well, seamlessly in the same simulation code.

In the present work we calculate fusion cross sections for $^{16}O+^{92}Zr$ system in 3S-CMD model. Fusion cross sections are calculated using classical approximations and compared with the experiments. Fusion cross sections for many reactions have been calculated using a soft-core Gaussian form of NN-potential (eq.(1)), with the parameter set P4 [4]. However, the calculated fusion cross sections do not match with the experimental data for many reactions at different energies [5].

In CCFULL calculation, the Wood-Saxon potential is used whose parameters are usually adjusted in such a way that the calculated fusion cross section fit well with the experimental fusion cross section at the highest energies [1,6]. Similarly, in present work we choose a new set of parameters of NN-potential so that the calculated fusion cross sections in 3S-CMD model match well with the experimental fusion cross sections at higher energy and then study how well it reproduces fusion cross sections for $^{16}O+^{92}Zr$ reaction at near and below barrier energies.

Calculation Details

The soft-core Gaussian form of NN-potential is given by,

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

where V_0, C and r_0 are the depth parameter, repulsive core-radius and range parameter respectively. In the present 3S-CMD calculation, the individual nuclei are first generated using the variational potential energy minimization code *STATIC* [2] and are further "cooled" using *DYNAMIC* [2] method. The nuclei are generated using the parameter set P4(V_0 = 1155 MeV, C = 2.07 fm, r_0 = 1.2 fm)[2] which reproduces the ground state properties close to the experimental values(see Table 1).

Table 1: Ground state properties of **^{16}O** and **^{92}Zr** nuclei used in present calculation.

			BE(MeV)	R(fm)	β_2
^{16}O	Cal.	P4	-122.28	2.43	-0.05
		NP	-140.40	2.43	0.16
	Exp.		**-127.62**	**2.73**	**0.00**
^{92}Zr	Cal.	P4	-827.33	4.59	-0.14
		NP	-1067.33	4.32	-0.10
	Exp.		**-799.73**	**4.30**	**0.00**

Fusion cross sections are calculated using the classical formula [2],

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

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

Result and Discussions

$^{16}O+^{92}Zr$Reaction:

Fusion cross-sections calculated using potentialP4 and eq.(2) in 3S-CMD model are shown in fig. 1 and fig. 2 which are highly overestimated compared to the experimental data [7] at all energy ranges.

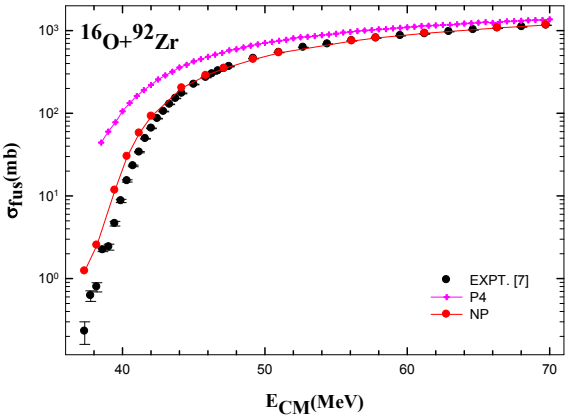

Fig. 1: Fusion cross section for $^{16}O+^{92}Z$rreaction (log scale)

We then determine a new potential parameter set called NP (V_0 = 900 MeV, C = 1.95fm, r_0 = 1.2 fm)such that it closely reproduces the calculated fusion cross sections for $^{16}O+^{92}Zr$ reaction at the highest energy E_{CM} = 69.76 MeV, as is also done in the CCFULL calculation, is shown in Table 2.

Table 2: Fusion cross sections for $^{16}O+^{92}Zr$ at higher energy.

POTENTIAL	E_{CM} (MeV)	σ_{fus} (mb)
Expt. [7]	69.76	1159.0
NP	69.76	1168.6
P4	69.50	1348.0

Fusion cross section calculated using potential parameter set NP and eq.(2) in 3S-CMD model are shown in fig. 1 & 2 which matches well with the experimental data above the barrier energies. While at below the barrier energies it is only slightly overestimated.

However, it may be noted that even though the calculated fusion cross sections show good agreement with the experimental data, the ground state properties of the nuclei generated using this potential (NP)are not close to the experiment values(Table 1).

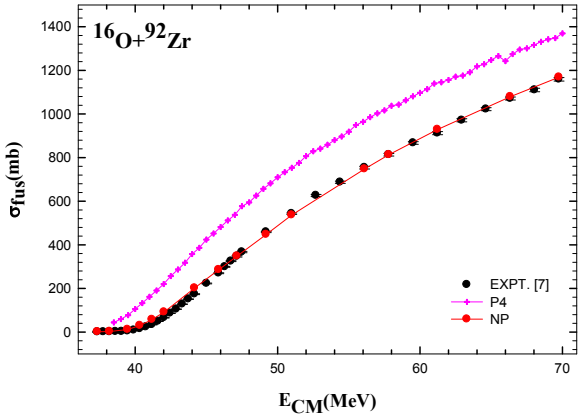

Fig.2: Fusion cross section for $^{16}O+^{92}Z$rreaction (linear scale).

References

[1] M. Dasgupta *et al*, Ann. Rev. Nucl. Part. Sci. **48**, 401 (1998).
[2] S. S. Godre, Y. R. Waghmare, Phys. Rev. C **36**, 1632(1987).
[3] S. S. Godre, EPJ Web of Conf. **86**, 00012(2015).
[4] S. S. Godre, Pranama-J. Phys., **82**, 879(2014).
[5] Jignasha H. Patel, Mitul R. Morker, S. S. Godre, Proc.Symp on Nucl. Phys, **61**, 454(2016).
[6] K. Hagino, N. Takigawa, Prog. Theo. Phys., **128**, 1061 (2012).
[7] J. O. Newton *et al*,Phys. Rev. C **64**, 064608(2001).