Fusion cross-sections for $^{40,48}Ca +^{48} Ca$ reactions using Classical Molecular Dynamics Model

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Introduction

Various classical microscopic and macroscopic approaches have been used for studying heavy-ion reaction [1-3] because of validity of classical approximations due to the small de Broglie wavelength of heavy ions even at lower energies. Within the classical approximation, it is possible to include all the degrees of freedom in a completely un-constrained microscopic calculation such as Classical Molecular Dynamics model(CMD-model).

Recetly, a particular experimental attention has been given to fusion reactions involving Ca isotopes [4,5]. Ca isotopes have been also studied theoretically by TDHF approach [6,7]. In the present work, the simulation of heavy ion collision for mass asymmetric reaction: $^{40}Ca +^{48} Ca$ and mass symmetric reaction: $^{48}Ca +^{48} Ca$ is carried out at and around barrier energies using CMD-Model and the fusion cross-sections are calculated using barrier parameters which are obtained from the dynamically evolved ion-ion potential using Wong's Formula [8].

The calculated fusion cross-sections using CMD-Model are compared with experimental [4] and TDHF data [6]. To study the role of vibrational excitation, fusion cross-sections obtained using CMD-Model are compared with those calculated using Classical Rigid Body Dynamical Model (CRBD-Model) in which only rotational and translational degrees of freedom are taken into account [9] and with microscopic static barrier penetration model (SBPM-model) [10] in which all the degrees of freedom are suppressed explicitly and dynamical effects are neglected.

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Calculational Detail

In the present CMD-model calculation, the individual nuclei are first generated using Potential minimization procedure "STATIC" method [3] with the phenomenological soft-core Gaussian form of NN-potential. The potential parameter P4 (V_0 = 1155 MeV, C = 2.07 fm and r_0 = 1.2 fm) is chosen to reproduce gross properties of the nuclei in their ground state such as binding energy, the RMS radius (R_{rms}), Quadrapole deformation parameter (β_2). The ground state properties of the nuclei used in the present calculation is given in below table.

TABLE I: Ground state properties of ^{40}Ca and ^{48}Ca used in present calculation

	Present			EXP		
	BE MeV	R_{rms} fm	β_2	BE MeV	R_{rms} fm	β_2
^{40}Ca	-326.88	3.54	0.058	-342.057	3.47	0.0
^{48}Ca	-436.12	3.65	-0.049	-415.99	3.47	0.0

The collision simulation process is initiated by bringing the two nuclei along their Rutherford trajectories from far off distance to finite distance, assuming both the nuclei to be point charged particles with given collision energy, E_{CM} and impact parameter, b=0. For the present collision simulation initial separation is R_{in} = 60 fm. Trajectories of all the nucleons are computed in the centre of mass frame of colliding system by numerically integrating coupled Newton's equation of motion,

$$m\frac{d^2\vec{r}_i}{dt^2} = -\vec{\nabla}_i[\sum_{i\neq j} V_{ij}] \qquad (1)$$

To calculate fusion cross-sections, barrier parameters are dynamically determined for given initial orientations of the two nuclei and for a given collision energy E_{CM}. Using these barrier parameters in the Wong's formula [8] average fusion cross-sections are determined for that particular energy only. Similarly, fusion cross-sections are determined for other energies also.

Result and Discussion

Fusion cross-sections calculated for both the reactions $^{40,48}Ca+^{48}Ca$ in CMD-model along with experimental and TDHF data are shown in fig. 1 and fig. 2 respectively. Also, fusion cross-sections calculated in CMD-model are compared with those calculated with CRBD and SBPM-model.

From both the figures it can be seen that fusion cross-sections calculated in CMD-model at lower energies over estimated the experimental [4] and TDHF data [6]. At higher energy side fusion cross-sections are better reproduced and match well with experimental and TDHF data.

Fusion cross-sections calculated with CMD-model shows enhancement compared with CRBD-model and SBPM-model calcualtions at lower energies. In CMD-model at lower energies greater amount of energy from the relative motion is transferred to internal excitations or internal degrees of freedom as compared to that in CRBD-model. For lower energies close to the barrier additional modes of energy dissipation help the two interacting nuclei to get trapped in the pocket in the ion-ion potential after they cross over the Coulomb barrier. Therefore, at lower energies not only rotational excitation but other internal excitations of the colliding nuclei also play an important role in fusion. For these reactions, it can be concluded that effect of vibrational excitation on fusion cross-sections is small at higher energies and becomes significant at lower collision energies close to the barrier.The effect of vibrational excitation is seen more in reaction $^{40}Ca +^{48} Ca$ as compared to $^{48}Ca +^{48} Ca$

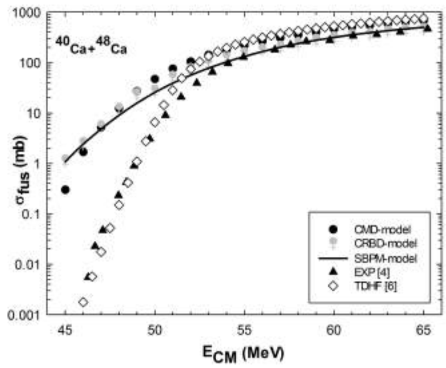

FIG. 1: Fusion cross-sections for $^{40}Ca +^{48} Ca$ in CMD, CRBD and SBPM-models.

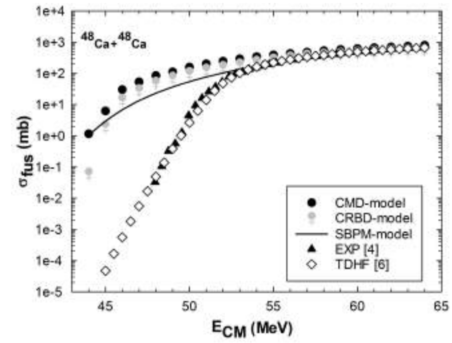

FIG. 2: Fusion cross-sections for $^{48}Ca +^{48} Ca$ in CMD, CRBD and SBPM-models.

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