Study of heavy-ion reactions $^{16}O+^{208}Pb$ & $^{16}O+^{238}U$ in Classical Molecular Dynamics Model

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Introduction

Due to the short de Broglie wavelength of heavy-ions even at low energies compared to the size of the ions, various classical microscopic and macroscopic approaches have been used for studying heavy-ion reactions such as fusion and deep-inelastic collision [1-5].Within the classical approximation, it is possible to include all the degrees of freedom (vibrational, rotational, translational) in a completely un-constrained microscopic calculation such as Classical Molecular Dynamics (CMD-model).

To bring out vibrational excitations in nuclei participating in fusion reaction, Fusion cross-sections obtained using Classical Molecular Dynamics are compared with Classical Rigid Body Dynamics Model (CRBD-model) which takes into account all the translational and rotational degrees of freedom [1] and with microscopic Static Barrier Penetration Model (SBPM-model), in which all the degrees of freedom are suppressed explicitly and dynamical effects are neglected.

In CMD-model calculation one can gain deeper insight into the various mechanism of energy transfer from relative motion to internal excitations [6]. In the present work, simulations of heavy-ion collision for $^{16}O+^{208}Pb$ and $^{16}O+^{238}U$ are carried out at and around barrier energies using CMD-model and fusion cross-sections obtained using CMD-model are compared with CRBD-model and SBPM-model.

Calculational Details

In the present CMD-model calculation, the individual nuclei are first generated using Potential minimization procedure "STATIC" with the phenomenological soft-core Gaussian form of NN-potential given by

$$V_N(r_{ij}) = -V_0(1-\frac{C}{r_{ij}})\exp(-\frac{r_{ij}^2}{r_0^2})$$

Where V_0, C and r_0 are respectively the depth parameter, repulsive core-radius and range parameter. Here r_{ij} is the distance between i^{th} and j^{th} particle. The Coulomb potential between protons has the usual form given by

$$V_c(r_{ij}) = \frac{1.44}{r_{ij}}\ (\text{MeV})$$

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. 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

$$m\frac{d^2r_i}{dt^2} = -\nabla_i\left[\sum_{j\neq i} V_{ij}\right]$$

Here, Fusion cross-sections are calculated from the ion-ion potentials obtained dynamically from central collision (b=0) only. The barrier parameters viz. the height of barrier **(V_B)**, the barrier radius **(R_B)** and oscillator frequency **(ω_B)** for a given initial orientation of the two nuclei and for a given collision energy E_{cm} are noted. Fusion cross-sections are calculated from dynamically determined barrier parameters using the Wong's formula [7].

$$\sigma(E) = \left(\frac{R_B^2\hbar\omega_0}{2E_{CM}}\right)\ln\left\{1+\exp\left[\frac{2\pi(E_{CM}-V_B)}{\hbar\omega_0}\right]\right\}$$

Results and Discussion

$^{16}O+^{208}Pb$ System

Fusion cross- sections calculated in CMD- model for $^{16}O+^{208}Pb$ system, in which

both lighter and heavy nuclei are spherical, are shown in fig.1which are compared to the corresponding CRBD-model and SBPM calculations.

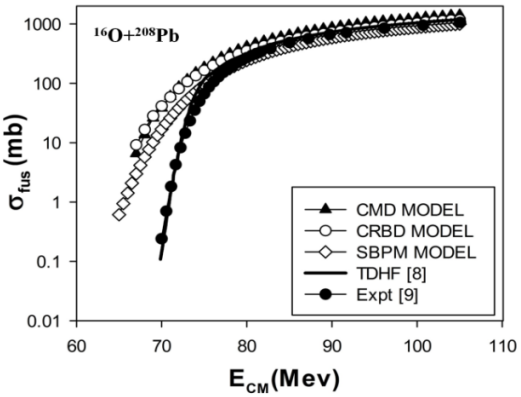

Fig.1 Fusion cross-sections for ^{16}O+^{208}Pb reaction calculated in CMD-,CRBD-, and SBPM- models.

It is seen that fusion cross-sections calculated in CMD-model at higher energies are better reproduced and do not show appreciable difference with CRBD-model and match well with experimental fusion cross-sections [9]. It indicates that at higher energies the effect of vibrational excitations is small compared to rotational excitations. However, at lower energies CMD-model calculations shows enhancement over CRBD-model and experimental data. 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 and overestimated the experimental value.

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.

^{16}O+^{238}U System

Fusion cross-sections for light-spherical and heavy-deformed ^{16}O+^{238}U system are also calculated in CMD-model and shown in fig.2

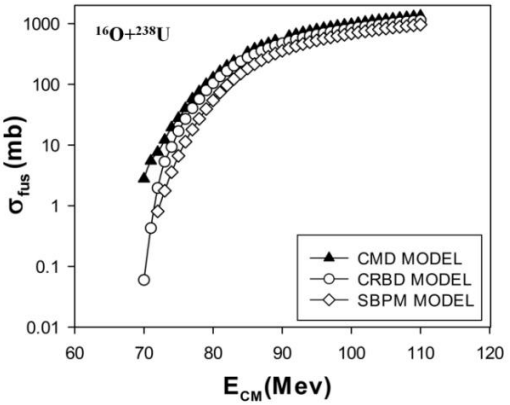

Fig.2 Fusion cross-sections for ^{16}O+^{238}U reaction calculated in CMD-,CRBD-, and SBPM- models.

Comparison of CMD calculations with CRBD-model and SBPM calculations for this reaction shows that reorientation of the deformed nucleus does have small effect on fusion cross-sections. CMD calculations show enhancement in fusion cross-sections as compared to CRBD and SBPM calculations. The enhancement at lower energies is small since the deformed nucleus ^{238}U is heavy in ^{16}O+^{238}U reaction.

References

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