Fusion cross sections for ^{24}Mg+^{208}Pb reaction in Classical Molecular Dynamics model

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Introduction

Heavy-ion collisions at energies near the Coulomb barrier are strongly affected by the internal structure of the colliding nuclei [1]. The coupling of the relative motion to the intrinsic degrees of freedom results in a single barrier being replaced by a distribution of barriers. Within the classical approximation, various models have been developed to study heavy-ion collisions near the barrier [2-6]. For nuclei with significant static deformation the reorientation of the deformed nucleus under the influence of the Coulomb force plays a key role in the sub-barrier collisions [3-9].

Effect of Coulomb reorientation on heavy-ion reactions involving light deformed and heavy spherical nuclei has been studied by comparing fusion cross sections calculated in a microscopic *Static Barrier Penetration model* (SBPM) [2] with a *Classical Rigid-Body Dynamics model* (CRBD-model) [3-5]. While in CRBD-model, rigid body constraints are imposed on the colliding nuclei and only rotational excitation of the nuclei is allowed; in the case of SBPM all dynamical effects are explicitly neglected.

On the other hand in the *Classical Molecular Dynamics model* (CMD-model) [6], all the degrees of freedom are in-built in the many-body solutions. In CMD-model since all modes of excitation of the nuclei are allowed, within the classical approximation, it can closely simulate the actual experimental conditions as compared to CRBD-model calculations. The effect of additional modes of excitation on fusion cross-section can be studied if fusion cross-sections calculated by CRBD-model and CMD-model are compared with each other.

In CMD-model calculation one can gain deeper insight into the various mechanism of energy transfer from the relative motion to internal excitations. The comparative contribution of rotational and other excitations can be inferred. Fusion cross section for ^{24}Mg+^{208}Pb reaction calculated in CMD-model are presented here and compared to the CRBD-model calculations.

Calculational Details

In the present CMD-model calculation, the nuclei generated by the "STATIC" method [6] with the phenomenological soft-core Gaussian form of the NN potential [6], with potential parameter set P4 (V_0 = 1155 MeV, C = 2.07 fm and r_0 = 1.2 fm) [2, 5] are chosen and placed at a large initial separation of R_{in} = 2500 fm in the reaction plane on the Rutherford trajectories. Trajectories of all the nucleons are then obtained by numerically integrating coupled Newton's equations of motion,

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

as the two nuclei approach each other. When the two nuclei come in contact, energy from the relative motion is rapidly transferred to internal excitations. Since no constraints are imposed in the CMD-model, the nuclei are not only allowed to rotate about their individual centre of mass but individual nucleons are also allowed to move about their mean positions. Therefore, in CMD-model, nuclei may have additional modes of internal excitations as compared to those in the CRBD-model with rigid-body constraints.

Since the dissipation mechanism is in-built in the microscopic many-body dynamics, the trajectories of the two nuclei do show bound states leading to fusion. Hence, fusion cross-sections can be calculated from determination of the critical impact parameter (b_{cr}) for fusion and the formula given below

$$\sigma_{fus} = \pi b_{cr}^2$$

However, for the sake of comparison with the CRBD-model calculation, fusion cross-sections are calculated in a similar manner as in the case of CRBD calculations from the ion-ion potentials obtained dynamically for central collisions (b=0) only. For a given initial relative orientation between the colliding nuclei and for a given collision energy E_{CM}, barrier parameters (V_B, R_B, ω_0) are noted. Fusion cross-section is calculated from the Wong's formula [10],

$$s\left(E_{CM}\right)=\left[\frac{R_B^2\hbar w_0}{2E_{CM}}\right]\ln\left\{1+\exp\left(2p\frac{E_{CM}-V_B}{\hbar w_0}\right)\right\}$$

using these barrier parameters at the given collision energy. About 200 initial random orientations are considered at every collision energies for the orientation-averaged fusion cross-section calculations.

Results and Discussion

Fusion cross-sections calculated in CMD-model for ^{24}Mg+^{208}Pb system, in which the light partner is prolate with β_2 = +0.40 and the heavy partner is spherical, are shown in fig. 1 and are compared to the corresponding CRBD-model and SBPM calculations.

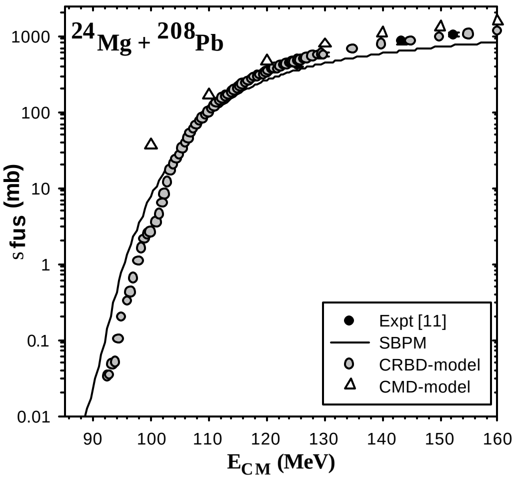

Fig.1: Fusion cross-sections for ^{24}Mg+^{208}Pb reaction calculated in CMD-, CRBD- & SBPM-models.

It is seen that fusion cross-section calculated in CMD-model at higher energies do not show appreciable differences with the CRBD-model calculations. It implies, therefore, that at higher energies the effect of excitations other than rotational excitations is small. However, at lower energies CMD-model calculations show enhancement over CRBD-model calculations.

In CMD-model, the energy of the relative motion gets transferred into rotational as well as other internal excitations of the colliding nuclei while in the CRBD-model, it can be transferred only into the rotational excitation of the nuclei. Thus in CMD-model greater amount of energy from the relative motion is transferred to internal excitations or internal degrees of freedom as compared to that in the CRBD-model.

For lower energies close to the barrier these additional modes of energy dissipation helps 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, resulting in some enhancement of fusion cross sections at lower energies.

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