Energy dissipation in heavy-ion collision in the 3S-CMD model

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Introduction

Heavy-ion reactions involve large scale transfer of energy from the relative motion to internal excitations [1]. Due to the large de Broglie wavelengths of the heavy-ions, as well as due to the ease of computational efforts, classical approximations also have been used to study heavy-ion fusion reactions [2]. One such approach is Classical Molecular Dynamics (CMD) approach [3] and its improved version namely 3-Stage Classical Molecular Dynamics (3S-CMD) approach [4] which also takes in to account reorientation of the deformed nuclei resulting from the long rage torque on it.

The light-deformed + heavy-spherical system ^{24}Mg+^{208}Pb has been studied in the Classical Rigid Body Dynamics (CRBD) approach which clearly established the importance of the inclusion of reorientation of the nuclei on collision dynamics [5]. This reaction has also been studied in 3S-CMD approach [4, 6] which established a smooth transition from the CRBD stage of the calculation to CMD stage at distances close to the barrier.

In the present contribution we study the interplay of the energy in the relative motion to the dynamical excitations and rotations of the two nuclei in ^{24}Mg+^{208}Pb reaction in order to understand the energy transfer/dissipation mechanisms in heavy-ion fusion.

Calculation Details

Heavy-ion collision simulations in the present study are a carried out in the 3-stages in 3S-CMD model consisting of (1) Rutherford trajectory calculation followed by (2) CRBD stage and finally (3) CMD stage at R_{cm}=50 fm near the barrier. Calculation details are given in ref [4, 6].

A soft-core Gaussian form of NN-potential with the potential parameter set P4 and the ground-state configurations of nucleons of the "cooled" nuclei, ^{24}Mg and ^{208}Pb, used in ref [6] are used in the present calculation also.

We calculate the total energy in relative motion T_{rel} = T_{cm} + V_{12}, where T_{cm} is the total energy of the centre of masses and V_{12} is the ion-ion potential between the two nuclei.

We also calculate the total energy of the internal excitation T_{int} = T_{rot} + T_{vib} + ΔBE, where T_{rot} is the total rotational energy, T_{vib} is the total internal vibrational excitation energy and ΔBE is the total change in the potential energy (binding energy) of both the nuclei.

Results & Discussions

The time evolution of T_{rel} and T_{int} for ^{24}Mg+^{208}Pb reaction at E_{cm}= 120 MeV (just above the fusion barrier energy) is shown in Fig.1. This figure shows calculated values at three impact parameters corresponding to (a) scattering event at *b* = 3 fm; (b) fusion event at critical impact parameter b_{cr} = 2 fm; (c) fusion event at *b* = 0 fm. All the above cases correspond to the same but arbitrary initial orientation of the two nuclei. As *b* decreases, more and more energy from the relative motion (T_{rel}) is transferred to internal excitations (T_{int}).

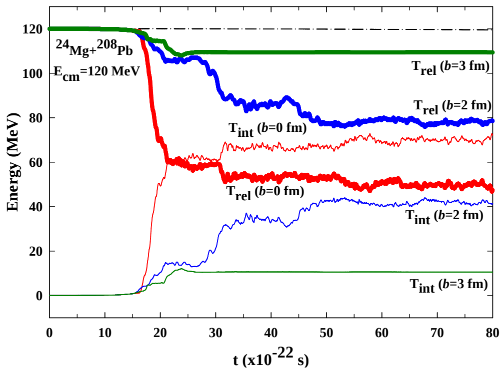

Fig. 1 Energy in the relative motion (T_{rel}) and the internal motion (T_{int}) for *b* = 0, 2, and 3 fm.

Similar calculations at higher collision energy, E_{cm}= 200 MeV, show even larger transfer of energy from the relative motion to T_{int}.

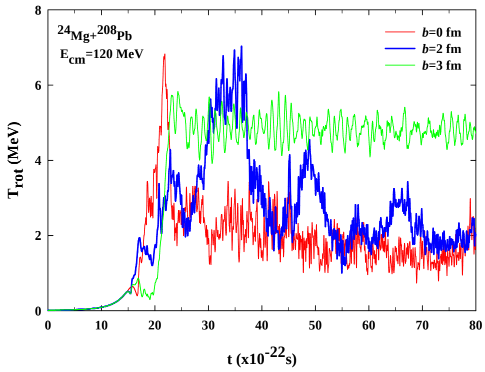

Fig. 2 T_{rot} of the system at b = 0, 2, 3 fm resp.

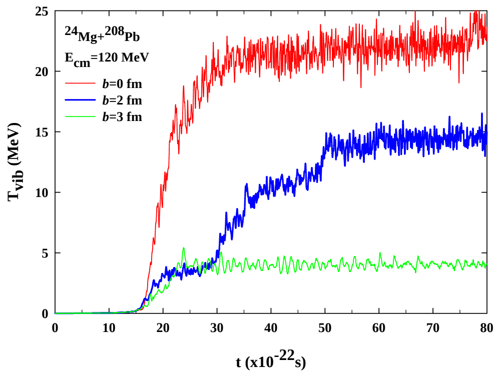

Fig. 3 T_{vib} of the system at b = 0, 2, 3 fm resp.

T_{rot} and T_{vib} components in T_{int} for the three impact parameters are shown in Figs. 2 and 3 respectively. For b = 0 fm the two nuclei acquire small T_{rot} but large T_{vib} resulting from the maximum change in the internal potential energy (BE) of the individual nuclei.

For b_{cr} = 2 fm, the angular collision initially results in higher rotational energy on contact, but soon dissipates as the system moves towards fusion. Along with this decrease in rotational energy there is a corresponding rise in the T_{vib} energy. T_{vib} for b_{cr} is at a reduced level as compared to that for b = 0 fm case.

For collision at b = 3 fm resulting in scattering, the system has more rotational energy as compared to that for b = 0 and 2 fm cases but, it does not dissipate and remains constant with some fluctuations about a mean. This situation corresponds to the two nuclei leaving in the outgoing channel with rotational excitations, along with only small T_{vib} which is almost of the same magnitude as T_{rot} value in this case.

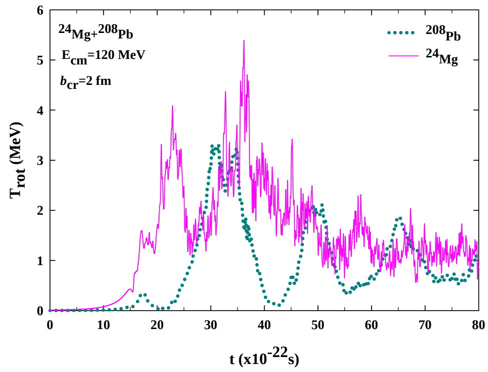

Fig. 4 T_{rot} of the individual nuclei at b_{cr} = 2 fm.

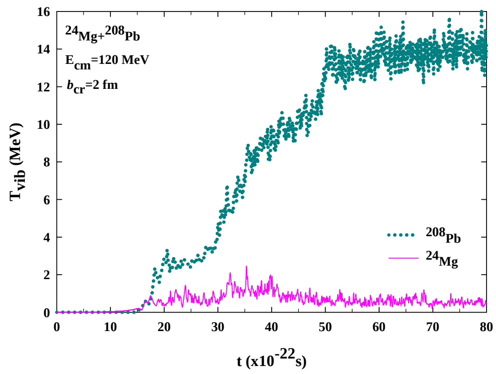

Fig. 5 T_{vib} of the individual nuclei at b_{cr} = 2 fm.

The rotational (T_{rot}) and vibrational kinetic energies (T_{vib}) of the individual nuclei are shown in Figs. 4 and 5 respectively. Fig. 4 shows that the light-deformed nucleus ^{24}Mg has the maximum rotational energy which is derived from the relative motion while ^{208}Pb which is heavy-spherical nucleus takes comparatively small T_{rot} but maximum T_{vib}.

References

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