Coupled channels calculation of fusion cross sections and barrier distribution for ^{24}Mg+^{208}Pb collision

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Introduction

It is well known that 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. 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 [2].

Various classical and quantum mechanical calculations with macroscopic or microscopic approaches have been used to understand the reaction dynamics.

Quantum mechanical calculations such as TDHF [3, 4] have been used which are microscopic in nature but are very compute intensive. On the other hand, quantum mechanical coupled channels calculations [1, 5] have been widely used to understand the reaction mechanisms close to the fusion barrier.

Within classical approximations, effect of Coulomb reorientation on heavy-ion reactions involving light-deformed and heavy-spherical nuclei, ^{24}Mg + ^{208}Pb, has been studied by comparing fusion cross sections calculated in a microscopic *Static Barrier Penetration model* (SBPM) [6] with a *Classical Rigid-Body Dynamics model* (CRBD-model) [7, 8].

In the present work, we have investigated the effects of coupling of low lying vibrational and rotational states in the ^{24}Mg + ^{208}Pb system using the CCFULL code [5].

Calculational Details

We have investigated the effects of coupling of low lying 2^+ rotational state of the projectile (^{24}Mg) and 3^- vibrational state of the target (^{208}Pb) in ^{24}Mg + ^{208}Pb system. The main ingredients needed in the coupled channel calculations are the deformation parameter ($ß_\lambda$) and the energy (E_λ) of the vibrational and rotational states. The value of these parameters ($ß_\lambda$, E_λ) for ^{24}Mg: $\lambda = 2^+$ multipolarity are (0.4, 1.36 MeV) & ^{208}Pb: $\lambda = 3^-$ multipolarity are (0.106, 2.61 MeV) [9]. We have chosen parameters of the Woods-Saxon form of the nuclear potential (potential-1: V_0 = 290 MeV, r_0 = 0.95 fm, a_0 = 0.7 fm) in such a way that the calculated cross sections match well with the experimental data at the highest-energies.

Result and Discussion

Figure 1 shows fusion excitation functions of ^{24}Mg+^{208}Pb system calculated by the CCFULL code, with and without couplings, and are compared with the experimental data [10]. This figure clearly shows the effect of the couplings which enhances the cross sections as compared to the uncoupled case. However the calculated cross sections are underestimated at lower energies.

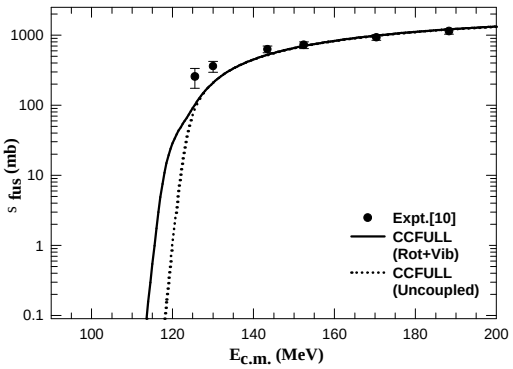

Fig.1 CCFULL calculation of fusion cross section for ^{24}Mg+^{208}Pb reaction with potential-1.

The calculated barrier distributions (BD) are shown in fig.2. The BD without couplings

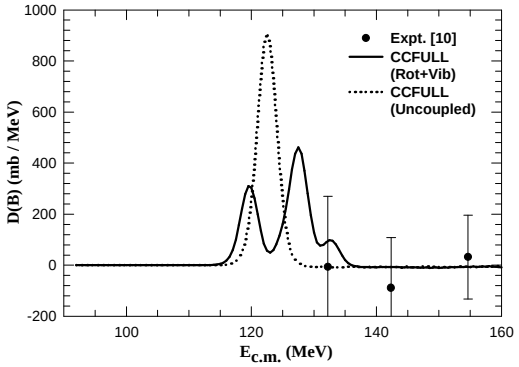

Fig.2 CCFULL calculation of barrier distribution for ^{24}Mg+^{208}Pb reaction with potential-1.

show a single peak at E_{cm}= 122.5 MeV whereas, the coupled calculation shows splitting of the peaks at 119.5 MeV and 127.5 MeV with a small but distinct feature arising at 133.0 MeV due to the vibrational coupling. Not enough experimental data is available to show any meaningful structure in BD.

The average barrier produced by the potential-1 seems to be overestimated. Therefore, we have re-adjusted the potential (potential-2: V_0 = 200 MeV, r_0 = 1.0 fm, a_0 = 0.75 fm) so that a better fit with the expt. is obtained for the lowest-energy expt. data points. Fusion excitation function of ^{24}Mg+^{208}Pb system calculated by CCFULL, with and without couplings, but with this potential-2 is shown in fig. 3. The calculated BDs are shown in fig. 4. The BDs are similar to those in fig.2 but are shifted to lower energies. Figures 3 and 4 also show the corresponding SBPM and CRBD calculations.

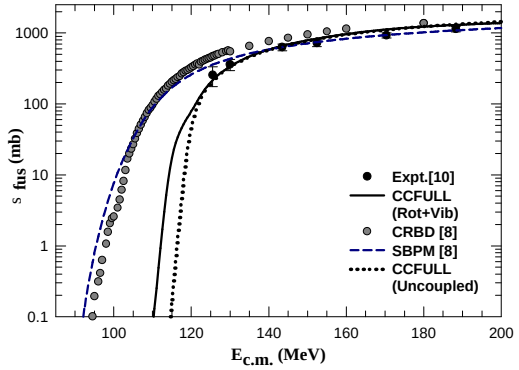

Fig.3 CCFULL calculation of fusion cross section for ^{24}Mg+^{208}Pb reaction with potential-2.

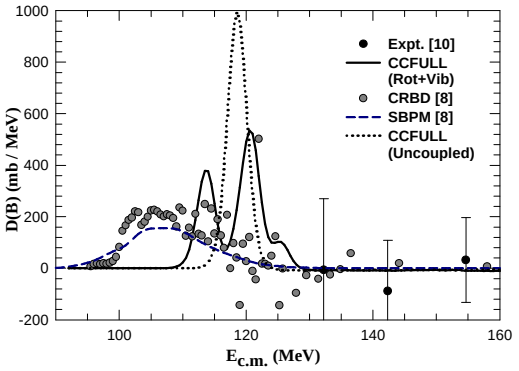

Fig.4 CCFULL calculation of barrier distribution for ^{24}Mg+^{208}Pb reaction with potential-2.

Although, there is better agreement of SBPM and CRBD calculation with the CCFULL calculations with potential-2 then with potential-1, there is still large disagreement between CRBD calculations, and the CCFULL calculations. Since the only experimental data available are of ref [10] at higher energies, there is a need for fusion data at energies near and below the barrier for ^{24}Mg + ^{208}Pb system.

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