Coupled channel calculations of ^{40}Ca+^{40,48}Ca reactions

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Introduction

Heavy-ion fusion at energies close to the Coulomb barrier is affected by the target and projectile deformations, surface vibrations, and nucleon transfers. Coupled channel calculations such as CCFULL [1] has been very helpful in finding the important couplings in various heavy-ion reactions. The reactions involving closed shell nuclei such as ^{16}O+^{208}Pb, ^{40}Ca+^{40,48}Ca and ^{48}Ca+^{48}Ca have been of special interest owing to their magic numbers. Detailed effects of the octupole phonons of both calcium isotopes were suggested by Rowley in [2].

We investigate the effects of coupling of vibrational excitations of projectile and target and their mutual excitation for ^{40}Ca+^{40,48}Ca system using the code CCFULL. In particular, the effects of couplings of 3^- and 2^+ vibrational states of ^{48}Ca and their mutual excitations and low-lying 3^-, 2^+ and 5^- vibrational states of ^{40}Ca are presented here.

Calculational details

The values of the deformation parameter β_λ, and excitation energy E_λ used in the present calculation are given in Table I.

Table: I. Deformation parameters, excitation energies, and multi-polarities of the states of different nuclei used in the coupled-channel calculations. [3]

Nuclei	aπ	E_{x^a} (MeV)	β_λ
^{40}Ca	3^-	3.737	0.41
	2^+	3.905	0.123
	5^-	4.497	0.25
^{48}Ca	3^-	4.507	0.23
	2^+	3.832	0.106

The parameters of the Wood-Saxon form of the nuclear potential for ^{40}Ca+^{40}Ca reaction (V_0 = 196 MeV, r_0 = 0.999 fm, a_0 = 0.709 fm) and for ^{40}Ca+^{48}Ca (V_0 = 65 MeV, r_0 = 1.18 fm, a_0 = 0.5 fm) are chosen in such a way that the calculated cross sections fit well with the experimental data at the highest energies. For both the reactions, the fusion barrier distribution (BD) has been extracted with the usual three-point formula and an energy step of 1.5 MeV and are normalized to ®R_b^2 where R_b is the barrier radius resulting from the Wood-Saxon parameterization of Akyüz-Winther potential.

Results and Discussion

Calculated fusion cross sections (σ_{fus}) and BD for ^{40}Ca+^{40}Ca system and the expt. data are shown in Fig. 1(a) and (b), respectively. Result of keeping the projectile inert and the inclusion of 2^+ and 5^- vibrational excitation for the target, as well as the uncoupled calculation are highly underestimated. However, inclusion of 3^- state in the projectile vibration enhances σ_{fus}, which matches with the higher energy data but are underestimated at lower energies.

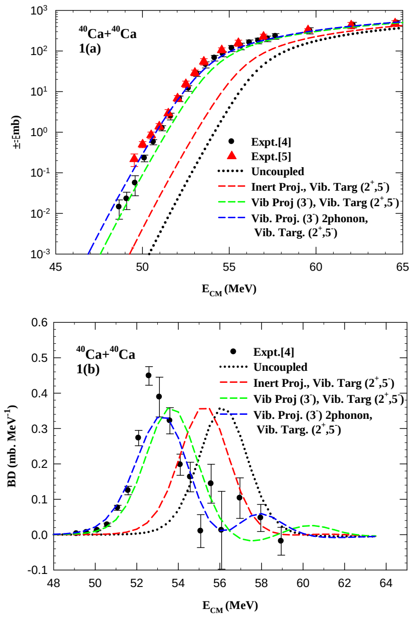

Fig. 1. CCFULL calculations **(a)** the fusion cross section and **(b)** barrier distribution for ^{40}Ca+^{40}Ca system.

Calculation with 2-phonon vibrations of the projectile with 3^- state gives good agreement with the expts [4, 5] at all energies except the lowest ones. At lower energies calculated values are overestimated compared to expt data of ref.[4] and underestimated compared to expt data of ref.[5]. The corresponding BD also matches well with the BD derived from the expt [4] data indicating that the double octupole phonon vibration in case of ^{40}Ca nucleus is strongly coupled.

In case of ^{40}Ca+^{48}Ca system we include the coupling to two single vib. phonon states (2^+, 3^-) of ^{48}Ca and their mutual excitation and 2^+ or 3^- state for ^{40}Ca. The calculated σ_{fus} shown in Fig. 2 once again demonstrate the importance of the double phonon octupole vib. excitation in ^{40}Ca for this reaction also. The calculated results with 2^+ state of ^{40}Ca as well as single phonon octupole state of ^{40}Ca are underestimating the expt data [6] shown in Fig. 2. The result with the 2-phonon octupole state of ^{40}Ca gives significant enhancements; however, it is still underestimated at and below the barrier energies compared to the expt data. The results of uncoupled calculations, as well as the result of keeping the projectile inert, are also shown in Fig. 2 for comparison.

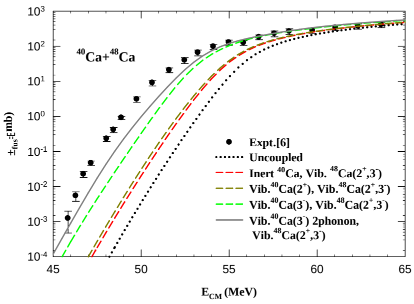

Fig. 2. CCFULL calculations of fusion cross section for ^{40}Ca+^{48}Ca system.

We repeat the last calculation by including transfer channels also. We take the 2n, 4n pick-up channel and also 1p and 2p stripping transfer channel with positive Q values [5]. We ignore the neutron stripping and proton pick-up transfer channels because these channels have very large and negative Q values. These calculations are shown in Fig. 3. These transfer channels produce very small changes in the calculated σ_{fus} in Fig. 3 but show some improvements in the agreements with the height of the main peak in expt BD.

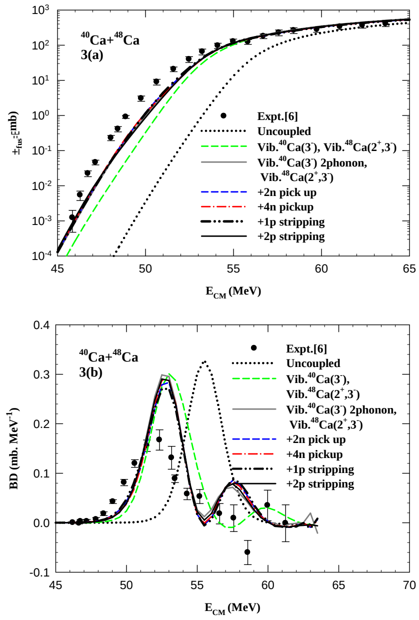

Fig. 3. CCFULL calculations **(a)** the fusion cross section and **(b)** barrier distribution for ^{40}Ca+^{48}Ca system.

Conclusion

From the present calculations it can be concluded that the ^{40}Ca octupole phonon state is much stronger than the quadrupole phonon state and double phonon excitations for ^{40}Ca in ^{40}Ca+^{40,48}Ca system shows enhancement in the sub-barrier σ_{fus} as well as BD compared to other couplings. Further the investigated transfer couplings give better agreement with the main peak in the BD and a shift of ~ 2.5 MeV in the smaller peak at higher energy for ^{40}Ca+^{48}Ca system.

References

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