Coupled channels calculations of fusion cross section and barrier distribution for deformed-spherical ^{28}Si + ^{120}Sn system

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Introduction

The heavy-ion fusion process has been extensively studied over the last decade [1], and a large amount of data has already been obtained for a wide variety of systems. Even so, many questions in this field are not completely solved yet. It is well known that fusion cross section data for heavy-ion systems show large enhancements at sub-barrier energies in comparison with theoretical predictions from the one-dimensional barrier penetration model (BPM).

In many works, the enhancements have been explained for several particular systems by considering the internal structure of the participating nuclei through coupled-channel (CC) calculations. The coupling between the relative motion and the internal degrees of freedom such as static deformation, vibration of nuclear surface, zero point motion, rotations of nuclei during collision, etc. results in the splitting of the uncoupled Coulomb barrier into distribution of barriers of varying heights.

The role of complex quadrupole and octupole surface vibrations and static rotations are of particular interest [2] and the calculations within the coupled channels model may become challenging in most nuclei.

In order to study the role of important degrees of freedom of spherical nuclei in the fusion mechanism, we have calculated fusion cross section and barrier distribution (BD) for ^{28}Si + ^{120}Sn system which is a deformed-spherical system using the code CCFULL [3].

Calculational details

In the present work, the effects of coupling of low lying vibrational states of target nuclei and their mutual excitation for ^{28}Si + ^{120}Sn systems is investigated. In particular, the effects of couplings of low lying 2^+ and 3^- vibrational states of ^{120}Sn, target nucleus, and their mutual excitations and low-lying 2^+ and 4^+ rotational states of ^{28}Si, projectile nucleus, are studied. The values of the parameters such as deformation parameter β_λ, and excitation energy E_λ were taken from the literature [4, 5] and are given in Table I. The experimental data for ^{28}Si + ^{120}Sn is taken from the ref. [5].

Table: I. The deformation parameters, excitation energies, and the multipolarities of the states of different nuclei used in the coupled-channel calculations.

Nuclei	J^π	E_x (MeV)	β
^{28}Si	2^+	1.78	-0.407
	4^+	4.67	
^{120}Sn	2^+	1.17	0.107
	3^-	2.40	0.15

The parameters of the Woods-Saxon form of the nuclear potential for ^{28}Si + ^{120}Sn, (V_0 = 250.0 MeV, r_0 = 1.07 fm, a_0 = 0.667 fm) are taken from the ref. [5] which are chosen in such a way that the calculated cross sections fit well with the experimental data at the highest energies.

Results and Discussion

Figs. (1) and (2) show the calculated and the experimental fusion cross section and fusion barrier distribution (BD) for ^{28}Si + ^{120}Sn system, respectively. First we assume the deformed projectile (^{28}Si) and the spherical target (^{120}Sn) to be inert, i.e., no excitation level, which gives a single peaked structure which is not shown in the figures. Then we introduce the result of coupled channel calculations taking into account the coupling to two rotational states (2^+, 4^+) of ^{28}Si and two single phonon states (2^+, 3^-) of ^{120}Sn, taking $\beta_2^C = \beta_2^N = 0.107$, which is denoted by

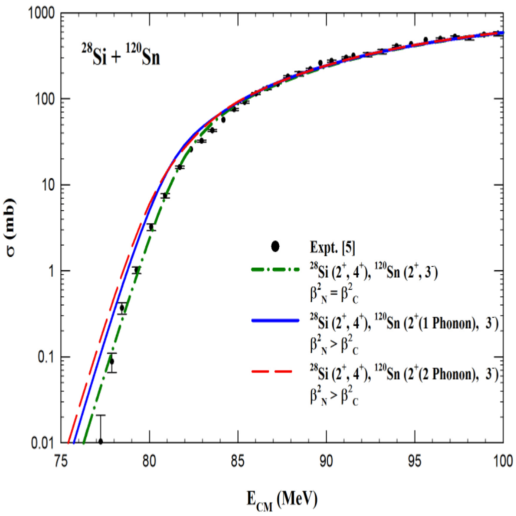

Fig. 1. Comparison of CCFULL calculations with expt. data for the fusion cross section for ^{28}Si + ^{120}Sn system.

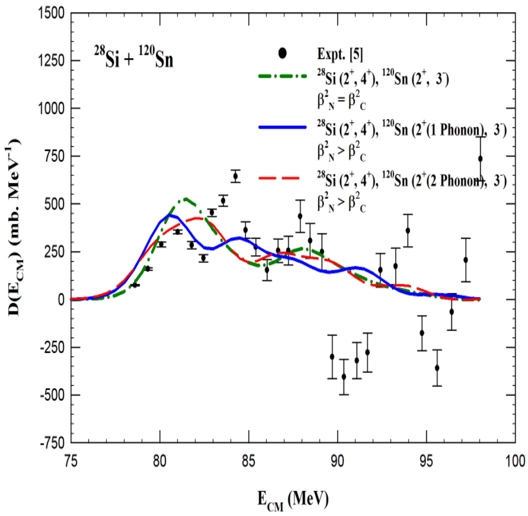

Fig. 2. Comparison of CCFULL calculations with expt. data for barrier distribution for ^{28}Si + ^{120}Sn system.

dot-dashed line. This result matches well with the experimental cross section.

However, as seen in Fig.(2), the experimental barrier distribution is a multiple peaked structure and the above calculation fails to reproduce the barrier distribution correctly. Therefore, we repeat this calculation by varying the value of nuclear deformation parameter β_2^N as in ref. [6] in order to achieve the best fit to the experimental data. The agreement between the calculations and the experimental data are improved in this way and we find the optimum value of $\beta_2^N = 0.165$ which is the same value as found in our earlier study of ^{16}O + ^{120}Sn collision [6]. This calculation is denoted by solid line which well reproduces the experimental fusion data. Then we also introduce the double phonon states of 2^+ state of ^{120}Sn with $\beta_2^N > \beta_2^C$ which is denoted by dashed line. This calculation gives the correct multiple barrier distribution structure. In ref. [5] also this coupled channel calculation with the couplings as chosen for the results in fig. 2 shown with the dashed line but with $\beta_2^C = \beta_2^N = 0.107$ is carried out; but this calculation does not reproduce the barrier like structure around E_{CM} = 83 MeV to 86 MeV.

Therefore, it is evident that the coupling to the quadrupole and octupole phonon states in the spherical nucleus requires $\beta_2^N > \beta_2^C$ to explain the experimental fusion data of ^{28}Si + ^{120}Sn reaction.

Conclusion

From the present calculations, we concluded that the nuclear deformation parameter β_2^N plays an important role in fusion reaction near the Coulomb barrier and it may have values greater than that for the Coulomb deformation parameter β_2^C.

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