Coupled channel calculations for fusion of ^{28}Si projectile with ^{124}Sn target

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In the current nuclear research, the role of nuclear intrinsic degrees of freedom in fusion dynamics has been the motivation of many experimental studies [1]. The intrinsic degrees of freedom such as inelastic excitation, neutron transfer, static or dynamic deformation affect the fusion dynamics due to their coupling to the relative motion of the interacting nuclei. The comparison of the experimental results with coupled channels predictions gives the experimental signatures of these coupling via fusion cross-section enhancement and structure in fusion barrier distribution [2]. Hence the coupled channels calculations have well established the role of various couplings in heavy ion fusion mechanism.

In one of such studies, the fusion barrier distribution derived from quasi-elastic backscattering has been investigated for the ^{28,30}Si + ^{124}Sn system [3]. It is observed that the coupled channels calculations performed using the CCFULL program [4] explain the experimental barrier distribution for the ^{30}Si + ^{124}Sn system after including the target and projectile inelastic channels and the positive Q-value 2n-transfer channel couplings. However, the CCFULL calculations with similar inelastic couplings and only the highest positive Q-value 4n-transfer channel couplings fail to reproduce the experimental fusion barrier distribution for the ^{28}Si + ^{124}Sn system, because it has positive Q values for 2n to 6n transfer channels. The major difference between the two studied systems is the role of multi-neutron transfer channels. However according to the earlier studies, the transfer channels only smoothen the barrier distribution and do not generate any structure. Hence the exclusion of transfer channels gives the tentative fit to the barrier distribution and their presence improves the fit. Here we perform the CCFULL calculations for ^{28}Si + ^{124}Sn system without including the transfer channels to check the fit to the experimental data.

Moreover the β_4 value of ^{28}Si used for the CCFULL calculations in the ref. [3] is 0.10. However, in our earlier work we have noticed that despite the well-established rotational nature of ^{28}Si (having both quadrupole and hexadecapole deformations), a coupled-channel calculation with vibrational coupling to its first 2^+ state reproduces the barrier distribution structure rather well. Later we observed that the resolution of this anomaly lies in the hexadecapole deformation of ^{28}Si. An almost identical result is found with two coupling schemes if one considers the large positive hexadecapole deformation of the projectile. A large value leads to a strong cancellation in the re-orientation term that couples the 2^+ state back to itself, hence making the rotational state look vibrational in this process. Hence it shows a sensitivity of fusion mechanism to the hexadecapole deformation of ^{28}Si.

To check the influence of hexadecapole deformation of ^{28}Si on the fusion of ^{28}Si + ^{124}Sn system, we have performed the coupled channels calculations with different coupling schemes. In ref. [3], they have observed that treating the 2^+ state in ^{28}Si as a prolate rotor with β_4=0.10 give poor representations of the data. For the better fit to the experimental data they have reported that there is need to include the transfer channels and for this they perform the semiempirical coupled-channel calculations using the NRV code [5].

However, in the NRV code [5], either rotational or vibrational channel coupling has to be considered simultaneously for both target and projectile in a reaction along with transfer channel coupling. Because of this limita-

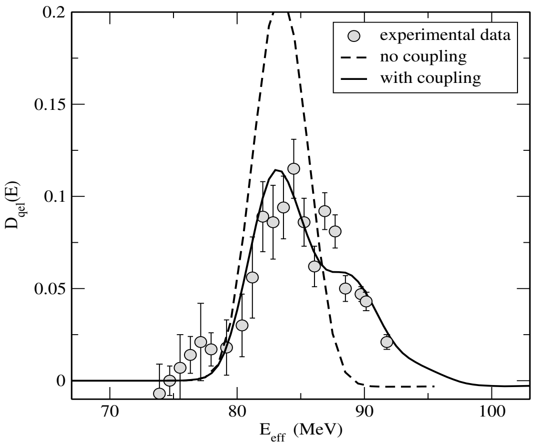

FIG. 1: Results of coupled channels calculations for the fusion barrier distribution of ^{28}Si + ^{124}Sn system without (dashed line) and with couplings scheme (solid line). Filled circles represent the experimental data.

tion, they considered rotational coupling for both target and projectile in the NRV calculations. Whereas in the CCFULL code, rotational or vibrational channel coupling can be considered independently for the target and the projectile. In the present CCFULL calculations, the rotational coupling for the projectile ^{28}Si and the vibrational coupling for the target ^{124}Sn have been considered.

Apart from this the β_2 and β_3 values of ^{124}Sn target used in the ref. [3], are different from the those quoted in the RAMAN table [6]. In the present work, we have used the deformation and excitation energy values from the RAMAN table.

Fig. 1 shows the barrier distribution obtained from the coupled channels calculations without and with the coupling scheme. The coupling scheme includes the rotational excitation of the projectile and the vibrational excitation of the target. Interestingly we noticed that a good fit to the experimental barrier distribution is found for ^{28}Si + ^{124}Sn system also with the rotational and vibrational coupling scheme if one considers the large positive hexadecapole deformation of the projectile. The only qualitative difference between the rotational and vibrational coupling schemes is the absence of a re-orientation term when the 2^+ state is treated as a phonon. That is, there is no $2_1^+ \rightarrow 2_1^+$ coupling. In the rotational scheme this coupling is present and it is important here to note that the 2^+ state may be coupled to itself by both quadrupole and hexadecapole deformations. The coupling strength will, therefore, depend on the value of β_4 that one uses. There is a range of positive values of this parameter in the literature for ^{28}Si. The best theoretical value is probably that due to Möller and Nix [7], $\beta_4 = 0.25$.

Hence similar observation is appeared here as observed for the ^{28}Si + ^{154}Sm system, showing a sensitivity of fusion process to the ^{28}Si hexadecapole deformation [8]. Thus, we conclude that the rotational excitation of the ^{28}Si projectile with its large β_4 value plays a significant role in the fusion mechanism of ^{28}Si + ^{124}Sn system. Although the inclusion of transfer channels will improve the fit, the inelastic excitation of the projectile and the target alone seems to give a nice explanation to the experimental data.

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