Role of transfer channels in near-barrier fusion dynamics of ^{28}Si+^{140,142}Ce

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Heavy ion-induced fusion reactions [1] near the Coulomb barrier provide an excellent opportunity to explore the influence of nuclear structure and nucleon transfer channels on fusion. Numerous experimental and theoretical studies have shown that static deformation and inelastic excitation of the collision partners influence fusion reactions, often enhancing sub-barrier fusion cross sections ($\sigma_{\rm fus}$) compared to the results obtained from no-coupling calculations. However, the impact of transfer channels on fusion dynamics remains ambiguous. While some systems exhibit significant enhancement in fusion cross sections due to positive Q-value neutron transfer (PQNT) channels [2, 3], this is not universally observed across all systems [4]. To explore the effect of transfer channels on fusion dynamics further, we measured fusion excitation functions for ^{28}Si+^{140,142}Ce near the Coulomb barrier. There are two PQNT channels ($2n$ and $4n$ pickup) in ^{28}Si+^{140}Ce. In contrast, six PQNT channels ($1n$ to $6n$ pickup) exist in ^{28}Si+^{142}Ce.

The measurement was carried out using the Heavy Ion Reaction Analyzer (HIRA) [5] at IUAC. Energy of the projectile ($E_{\rm lab}$) ranged from 103.5 –136 MeV. The evaporation residues (ERs) were detected at the focal plane of the HIRA by a multi-wire proportional counter (MWPC). Unambiguous identification of the ERs were accomplished by measuring their energy loss and time-of-flight.

It is generally observed that the effect of transfer channels in reactions involving deformed reaction partners is not significant as

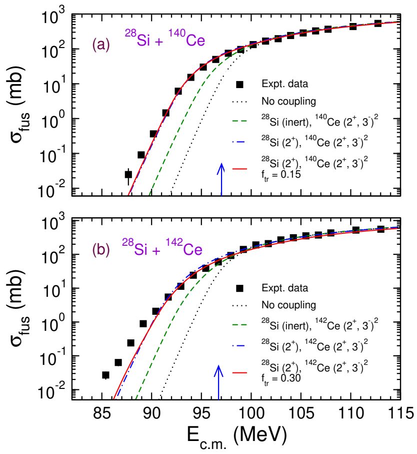

FIG. 1: Fusion excitation functions for (a) ^{28}Si+^{140}Ce and (b) ^{28}Si+^{142}Ce. Results of coupled-channels calculations are also shown.

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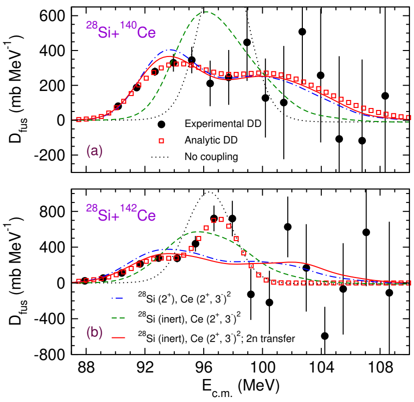

FIG. 2: Fusion barrier distributions for (a) ^{28}Si+^{140}Ce and (b) ^{28}Si+^{142}Ce. Results of coupled-channels calculations are also shown.

compared to reactions involving spherical nuclei. In such cases, the barrier distribution ($\mathcal{D}$) serves as an excellent probe for detecting the fingerprints of inelastic and transfer channels on fusion dynamics. $\mathcal{D}$ has conventionally been extracted from measured fusion cross sections ($\sigma_{\rm fus}$) by the "double-differentiation" (DD) method proposed by Rowley *et al.* [6]. A recent study [7] showed that an analytic method based on multi-Gaussian barrier height distribution could be an excellent recipe to obtain the experimental $\mathcal{D}$s. Moreover, this method is independent of energy step size and here the results remain quite robust against large uncertainties in measured $\sigma_{\rm fus}$, unlike in case of the DD method. In the present work, we derived the experimental $\mathcal{D}$ using both methods.

Measured excitation functions and the corresponding $\mathcal{D}$s, along with results of the coupled-channels (CC) calculations [8], are presented in Fig. 1 and Fig. 2, respectively. When both collision partners were treated as inert, the calculations significantly underpredicted the measured $\sigma_{\rm fus}$ at sub-barrier energies for both systems, as shown in Fig. 1(a) and 1(b). Next, we treated ^{28}Si as inert while considering two-phonon mutual excitations for both quadrupole (2^+) and octupole (3^-) modes in ^{140,142}Ce. Inclusion of this coupling enhanced the theoretical cross sections in the sub-barrier region (dashed line in Fig. 1(a) and 1(b)), improving the predictions somewhat, but still underestimated the experimental $\sigma_{\rm fus}$ for both systems. We further included the first 2^+ excited state of ^{28}Si with rotational nature, alongside the two-phonon quadrupole and octupole modes of ^{140,142}Ce. In the case of ^{28}Si+^{140}Ce, the experimental excitation function was well reproduced. However, measured excitation function remained underestimated by the calculation in the case of ^{28}Si+^{142}Ce. The corresponding $\mathcal{D}$ for ^{28}Si+^{140}Ce suggested probable role of additional weak channels due to the lower weight of the lower energy peak. On the other hand, the large underprediction of the fusion excitation function for ^{28}Si+^{142}Ce by the theory pointed to the significant influence of transfer channels in this system. For ^{28}Si+^{140}Ce, we found that a transfer strength ($f_{\rm tr}$) of 0.15 for the $2n$ pick up channel produced a somewhat better fit of the experimental $\mathcal{D}$, while a larger value distorted its shape, thereby constraining the transfer strength. In contrast, the excitation function remained underpredicted even after inclusion of $2n$-transfer coupling in the case of ^{28}Si+^{142}Ce. Also, shape of the $\mathcal{D}$, in this case, was markedly different from the experimental data. This indicated a much stronger influence of neutron transfer channels in ^{28}Si+^{142}Ce compared to ^{28}Si+^{140}Ce.

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