Coupling effect in the ^{28}Si+^{154}Sm reaction: A study through quasi-elastic scattering

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Understanding the couplings to collective states of the interacting nuclei in fusion mechanism is important as they influence the barrier height and the formation probability of the compound nuclei, which in turn may be related to the synthesis of super heavy elements (SHEs) in heavier systems. With the motive to investigate such couplings, we obtain an experimental signature of coupling to ^{28}Si projectile and ^{154}Sm target excitation through barrier distribution (BD) study. To this end, the BDs of the ^{28}Si+^{154}Sm and ^{16}O+^{154}Sm systems have been compared using quasi-elastic (QE) scattering data prior to perform the coupled channel calculations. For the ^{28}Si+^{154}Sm system, the QE data is measured in the present work, however, for the ^{16}O projectile data is taken from the literature [1].

The experimental details of QE measurement for the ^{28}Si+^{154}Sm system can be found in Ref. [2]. A comparison of the experimental QE excitation functions and BDs is shown in Fig. 1 (a) and (b), respectively, for the two systems. Here, the ^{16}O data is scaled to remove the effect of higher Z for ^{28}Si on BD width. After scaling any remaining differences should be simply due to the couplings in ^{28}Si. Moreover, the effect of the high-energy octupole excitation in ^{16}O is removed by shifting the data. Fig. 1 (c) shows the resulting QE excitation function after these operations. It is observed that at the highest energies ($(E_{\mathrm{eff}} - V_{\mathrm{B}}) > 5$ MeV), the slope of the function appears to be different for the two systems. In other words, the QE cross-section for ^{28}Si+^{154}Sm shows an enhancement compared with that for ^{16}O+^{154}Sm system at the highest energies. To better visualize the difference, we compare the two experimental QE BDs in Fig. 1 (d) which reveals an interesting feature for the ^{28}Si+^{154}Sm system. A peak-like structure (shown by the arrow) in Fig. 1 (d) is clearly visible for this system and is absent for ^{16}O+^{154}Sm. Since all other effects are essentially eliminated, we attribute this structure to couplings to ^{28}Si excitations. The strong similarity between their BD showed that the ^{154}Sm deformation plays a dominating role in the fusion process.

From the coupled channel calculations, it is observed that the peak like structure of ^{28}Si could be reproduced using ^{28}Si as a pure vibrator despite its well established rotational nature (with hexadecapole deformation as 0.1) as shown in Fig. 2. We observe that the resolution of this anomaly lies in the hexadecapole deformation of ^{28}Si; the contributions to the re-orientation coupling ($2_1^+ \rightarrow 2_1^+$) from the quadrupole deformation is largely cancelled out by that from the hexadecapole deformation. In order to achieve this cancellation, one requires a large positive value of β_4 and we have used here the Möller-Nix value of $\beta_4 = 0.25$ [3] as shown in Fig. 2. Hence our results reveal that this nucleus does indeed possess a large positive hexadecapole moment. Recently, the hexadecapole deformation of target nuclei is estimated from QE scat-

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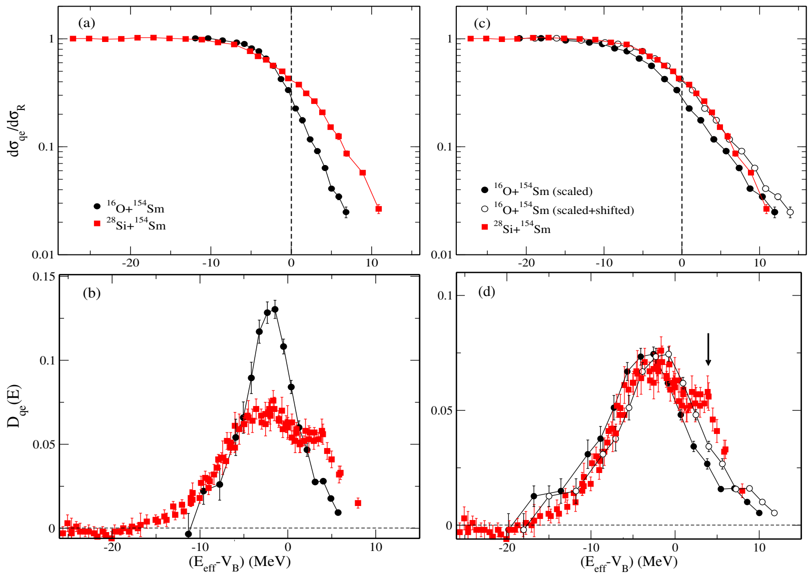

FIG. 1: Comparison of experimental QE excitation functions (upper panels) and corresponding barrier distributions (lower panels) for the systems ^{16}O+^{154}Sm and ^{28}Si+^{154}Sm. Left-hand plots (a), (b) are before scaling whereas right-hand plots (c), (d) show the comparison after scaling the ^{16}O+^{154}Sm data.

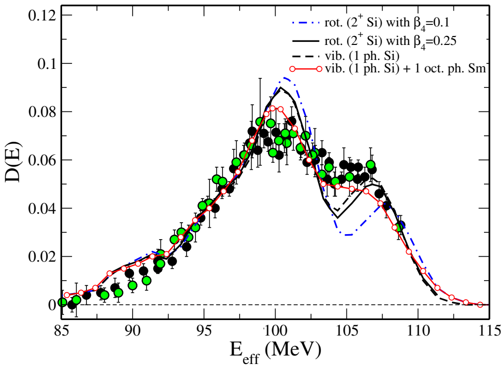

FIG. 2: Coupled-channels predictions compared with experimental QE barrier distributions for the ^{28}Si+^{154}Sm system.

tering experimental technique [4]. To the best of our knowledge, for the first time we observe the sensitivity of hexadecapole deformation of projectile from QE BD technique. Moreover, the octupole vibration of ^{154}Sm seems to play a significant role in better explanation of BD as shown in Fig. 2.

Apart from this, in our theoretical calculations we have observed that when deformation of ^{154}Sm is included alone, considering the projectile to be inert, the most probable barrier shifts by ≈ 2 MeV above the uncoupled barrier. This may have implications in the heavier systems where deformed actinide targets are utilized for the production of SHEs. Such a shift in the most probable barrier (deciding the probability of SHE formation) may occur when the deformed target interacts either with spherical projectile or if the projectile excitation is weaker relative to permanent deformation of the target.

In summary, the experimental observation as well as coupled-channels calculations of the present work suggest that the QE BD (hence fusion) is sensitive to projectile excitations even though the target considered here is permanently deformed with significantly large coupling influence on BD. It is expected that the QE reactions may offer an alternative method of identifying the coupling to excitation in other projectiles. Hence for heavier systems where compound nucleus is too fissile, one can attempt to study the coupling effects by measuring QE scattering.

References

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