# Examination of effects of weak transfer channels on quasi-elastic barrier distribution measurements.

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The study of channel coupling in heavy-ion collisions has been a topic of interest for several years now. The enhancement in fusion reactions at sub-barrier reactions results from this environmental channel coupling, which cannot be accounted by a single barrier potential model. The single potential barrier ($V_b$ ) splits into a distribution of barriers due to the coupling of the relative motion between the colliding nuclei to their intrinsic motions and direct reaction channels. The barrier distribution (BD) formed due to this coupling acts as a fingerprint for any reaction. Understanding the coupling schemes in any reaction is vital as it has a greater influence on the formation probability of compound nuclei. The BD can be experimentally studied by the measurement of fusion excitation function using relation

$$D_{fus} = \frac{d^2\sigma_{fus}}{dE^2}$$

as well as the quasi-elastic excitation function using

$$D_{qel} = -\frac{d}{dE}\left(\frac{\sigma_{qe}}{\sigma_R}\right)$$

Theoretically, this study can be carried out by the coupled-channel calculation scheme [1].

To gain insight into the couplings involved in the fusion enhancement at the sub-barrier energies has been the motivation behind the objectives of the present thesis work. Many experimental results have shown the effect of target excitations on the quasi-elastic barrier distribution, but lesser is known about the role of projectile excitations. This leads to the first objective of the thesis. It has been proven that fusion BD and QE-BD contain similar information. One of the systems $^{16}O+^{144}Sm$ measured by Timmers et al. [1] is a case of discrepancy in which the structure of experimental fusion BD and QE BD is different. The experimental QE-BD gets smoothened at the energy where the structure is expected from the fusion measurements as well as from the theoretical calculations performed. It was suggested that the smoothing could be the result of the residual reaction channel, such as nucleon transfer. This leads to the second objective of the thesis.

In the first part of the present thesis work, the experiment for QE measurements for the systems $^{28}Si+^{144}Sm$ at large angles was performed at the Inter-University Accelerator Center (IUAC) using GPSC facility and pelletron-accelerated beam. HYTAR [2] detection facility was employed. The targets used in the experiment were prepared using the resistive heating technique at the target lab of IUAC [3]. The barrier distribution (BD) for the same has been extracted from the experimentally obtained QE excitation function. The CC calculations were performed using CCFULL code to understand the coupling in this reaction. To locate the effect of the coupling in the experimentally observed BD, a comparison of QE excitation function and the extracted BD of $^{28}Si+1^{44}Sm$ has been made with those of $^{16}O+^{144}Sm$. It has been observed that though below the barrier, the shape of BD for both the systems is the same, the effect of the collective states of $^{28}Si$ is being reflected as the peak-like structures at higher energy.

On the theoretical front, it has been observed that the peak-like structure in BD for the $^{28}Si+^{144}Sm$ system can be reproduced using coupled channel calculation. Considering $^{28}Si$ as a pure rotor having a large value of hexadecapole deformation (in our analysis for $^{28}Si+^{144}Sm$ system, we have used the value of $\beta_4$=0.25), the best fit to the experimental barrier distribution can be obtained. Also, identical results can be obtained from the theoretical calculations with $^{28}Si$ as a pure vibrator having single phonon excitation. This is also observed in the study of $^{28}Si+^{154}Sm$ [4], where almost similar results were obtained using the rotational as well as vibrational couplings. This effect due to the hexadecapole deformation observed to be more vibrant in BD of $^{28}Si+^{144}Sm$. This is due to the spherical nature of the target $^{144}Sm$ that the BD shows more sensitivity towards the projectile excitations [5]. Apart from this, from the above comparison, it is seen that the BD for $^{28}Si+^{154}Sm$ shows the smoothing at the higher energy end as compared to $^{28}Si+^{144}Sm$. The smoothing has been explained by considering the octupole phonon excitations of $^{154}Sm$ along with its rotational nature. But $^{28}Si+^{144}Sm$ have negative Q-value transfer channels, and $^{28}Si+^{154}Sm$ has a positive neutron transfer Q-value transfer channel. It can be argued that weak coupling to transfer channels can lead to such smoothing in the $^{28}Si+^{154}Sm$ system.

In the second part of this thesis work, we have measured the quasi-elastic excitation function for the system $^{16}O+^{144}Sm$, a system that shows a case of discrepancy when compared to its corresponding fusion BD. The fusion data shows the high energy peak in the structure of BD, which gets smeared in the QE-BD. No CC calculations could define this smoothing of the high energy peak in the QE-BD. Our measurement results have also shown the smoothing at the higher end though it is somewhat lesser than the previously published results. It was suggested that this smoothing could be due to the coupling to the transfer channel as it possess positive $Q_{opt}$ value for a transfer channel. To examine the same, the transfer cross-section measurements were carried out for this system at various angles around the grazing angle for an energy corresponding to the expected peak position. For comparison, we have also measured the transfer cross-section for the system $^{16}O+^{154}Sm$ at the same energy. We have chosen the system $^{16}O+^{154}Sm$ as this system also shows the effects of weakly coupled transfer channels as observed in the fusion BD studies [6]. The transfer channel cross-section values for 1p and 2p transfer channels obtained for these measurements show almost the same transfer cross-sections for both the systems $^{16}O+^{154}Sm$ and $^{16}O+^{144}Sm$. From this observation, it can be conjectured that the weak coupling to proton transfer channels can be responsible for the smoothening of QE-BD at high energy. Further, details of the experiments and of the results will be presented.

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