Dependence of “reorientation effect” on rotational energies and ground state deformations

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Introduction

In a seminal work of C. Simenel *et al.*, [1] showed using Time Dependent Hartree-Fock (TDHF) calculations that fusion cross section around the barrier, expected to be enhanced owing to channel couplings, is suppressed due to reorientation of the deformed projectile in the field of spherical target or vice a versa. In terms of classical mechanics, orientation of axially deformed projectile is changed while approaching the strong Coulomb field of spherical heavy target. This leads to a hugging configuration of the fusing partners, thereby making large fusion barrier and reduced fusion cross section. Experimentally, this “reorientation effect” has not been demonstrated explicitly so far.

The origin of this “reorientation effect” lies in the rotational couplings, where a term corresponding to coupling of first 2^+ state to the same 2^+ state remains non-vanishing. The frozen orientations correspond to zero rotational energies. According to Ref. [1], this effect depends only on the magnitude of deformation and inertia of the deformed partner of the heavy-ion collision. It is interesting to understand its dependence “reorientation effect” on other factors. It would be also interesting to see how this effect changes from prolate (positive β_2) to oblate (negative β_2) shaped projectiles for a common spherical target nucleus. With this motivation we have investigated this effect for ^{24}Mg (Prolate, E(2^+)=1.368 MeV) and ^{28}Si (oblate, E(2^+)=1.799 MeV) projectiles with a semi-magic ^{90}Zr (spherical) target, for which FBDs have already been determined [2, 3]. Experimental FBDs are analyzed within the framework of Coupled Channel Calculations (CC) [4].

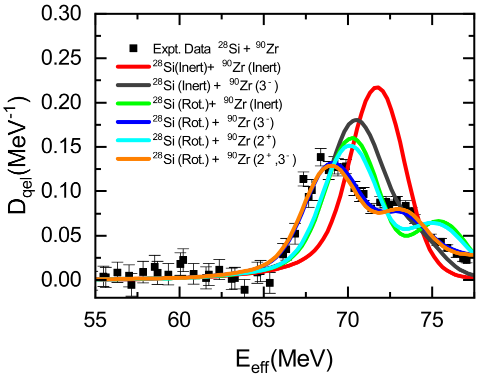

FIG. 1: Fusion barrier distribution in ^{28}Si $+^{90}$ Zr reaction. Solid lines represent CC calculations for different cases.

CC Calculations & Results

The primary indication about the presence of “reorientation effect” comes from asymmetric FBD as shown in the Fig. for ^{28}Si + ^{90}Zr reaction. It is seen that when no coupling (both inert), the shape of FBD is close to a Gaussian. By including vibrational coupling of ^{90}Zr via 3^- state at 2.75 MeV with strength of 0.211 the FBD becomes broader and the peak shifts to lower barriers. Whereas, if ^{90}Zr is treated as inert and rotational couplings of ^{28}Si (0^+, 2^+, 4^+) are included, a prominent peak at around 76 MeV is obtained. The 2^+ state of ^{90}Zr at 2.18 MeV with strength of 0.089 does not make any significant change in the FBD obtained with rotational couplings of ^{28}Si. However, the 3^- state of ^{90}Zr shift the FBD towards the lower barriers, bringing close proximity of the secondary peak to the experimental shoulder. With including both 2^+ and 3^- states of ^{90}Zr along with rotational couplings of ^{28}Si, the CC calculations reproduce the data very well as shown in the Fig. 1. These comparisons for different coupling cases of ^{90}Zr exhibit that the asymmetric FBD (shoulder) stem pri-

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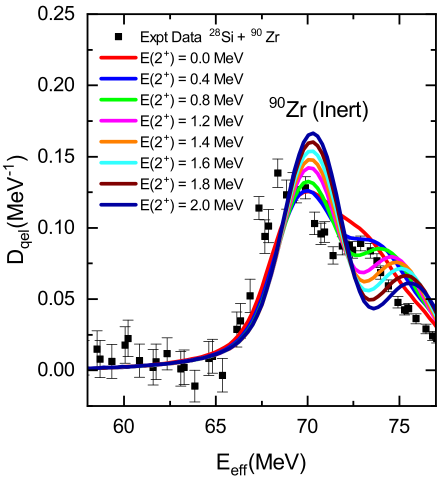

FIG. 2: CC calculations for ^{28}Si$+^{90}$Zr reaction as a function of rotational energy of ^{28}Si.

marily from rotational couplings of ^{28}Si. The above discussed calculations were also carried for ^{24}Mg + ^{90}Zr reaction. However, the rotational couplings of ^{24}Mg do not lead to as pronounced shoulder as ^{28}Si does which might be attributed to low $\mathrm{Z_P}Z_\mathrm{T}$.

In order to pin down the effect of rotational couplings in making a shoulder like structure in the FBD for ^{28}Si + ^{90}Zr reactions, CC calculations have been carried out with ^{90}Zr as an inert nucleus and varying the rotational coupling parameters. CC calculations for several rotational energies of the oblate deformed ^{28}Si are depicted in the Fig. 2. It is seen from this figure that when E(2^+) is zero which correspond to the frozen orientations (or AOF), the barrier distribution becomes flat-top (highly asymmetric) structure. With increasing values of E(2^+), the higher barriers begin separating from the flat top and form a peak like structure of reduced height at further higher barriers. It is noted from Fig. 2 that with increasing E(2^+) from 0 to 2 MeV, the primary peak at around 70 MeV remains at the same position with increasing strength, however, the secondary peak keep shifting to higher barrier with decreasing strength. It implies that while going from "frozen" to "free" orientations, the higher barriers stand up and FBD tends to be symmetrical shape.

The reorientation term in the rotational coupling matrix includes both quadrapole (β_2) and hexadecapole (β_4) deformations. Therefore, in addition to the effect of E(2^+), it is crucially important to investigate the correlated effect of β_2 and β_4 values. Fig. 3 shows CC calculations for ^{28}Si + ^{90}Zr reactions for oblate and prolate cases of ^{28}Si. For the each value of β_2, three values of β_4 have been choosen; -.05, 0.00, and +0.05. It is interesting to note that in the oblate cases, the reorientation effect is seen at higher barrier side, whereas it affects the lower barriers in the cases of prolate ground state shape.

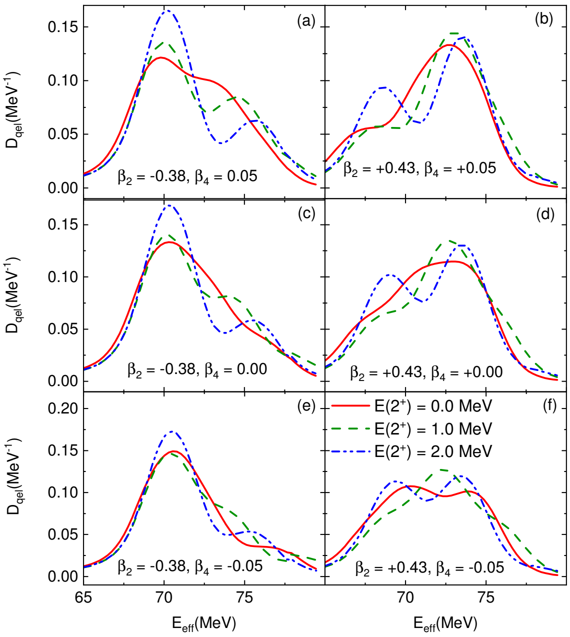

FIG. 3: CC calculations for different values of β_2 and β_4 of ^{28}Si in ^{28}Si$+^{90}$Zr reaction for three cases of rotational energies of ^{28}Si.

Conclusions

In conclusion, the reorientation effect depends on following factors: (i) $\mathrm{Z_P}Z_\mathrm{T}$ product, (ii) excitation energy of rotational states of the deformed partner, and (iii) ground state deformations. Detailed results will be presented.

References

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