Effect of the target structure on the quasi-elastic barrier distribution

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Study of the heavy-ion fusion reactions has played a crucial role in nuclear physics research due to their applicability in producing the exotic nuclei even away from the stability line. The detailed information about the nuclear structure (static ground state deformations of atomic nuclei such as quadrupole (β_2), octopole (β_3), and hexadecapole (β_4), etc.) is of fundamental importance, not only to understand the microscopic interactions controlling the structure of the nuclei, but also for their role in the heavy-ion reaction mechanism [1, 2]. It has been observed that the heavy-ion collisions at energies around the Coulomb barrier are strongly affected by the internal structure of the colliding nuclei [3–8]. The coupling between relative motion and internal degrees of freedom results in a number of distributed barriers in place of a single potential barrier. The fusion barrier distribution (BD) can be extracted, experimentally, from the fusion excitation function σ_{fus}(E) by taking the second derivative of the product Eσ_{fus}(E) with respect to the center-of-mass energy E, that is, $d^2(E\sigma_{fus})/dE^2$, where it is much easier to see the precise effects of coupling than that of the fusion excitation functions [3]. Further, Timmers et al.[5] has suggested that the channel couplings can also affect the scattering process and the nuclear structure information can also be obtained from the quasi-elastic (QE) scattering cross sections at large backward angles using the prescription D_{qel} =-$d[\sigma_{qel}(E)/\sigma_{Ruth}(E)]/dE$, which gives an alternative representation of the fusion BD [4]. The term quasi-elastic reaction, which contains inelastic scattering and few-nucleon transfer reactions populating low-lying states. One of the important point is that for heavy systems, where other reaction processes like deep inelastic processes become important, then in that case Zagrebaev suggested that the QE barrier distribution represents the total reaction threshold distribution which is different than that of the fusion barrier [6].

Several studies have shown that the structural properties obtained from BD studies are in agreement with the spectroscopic studies [1, 2]. Although the value of β_4 is difficult to extract experimentally, though the differences in experimentally measured fusion BDs of ^{16}O+^{186}W and ^{16}O+^{154}Sm systems has suggested that the fusion reactions are very sensitive not only to β_2 but also to β_4 of the target nucleus [4]. Even though the information obtained will be a model-dependent estimation, this methodology may be of significant importance to study the radioactive nuclei where spectroscopic study is difficult. In the present work, the QE-excitation function mea-

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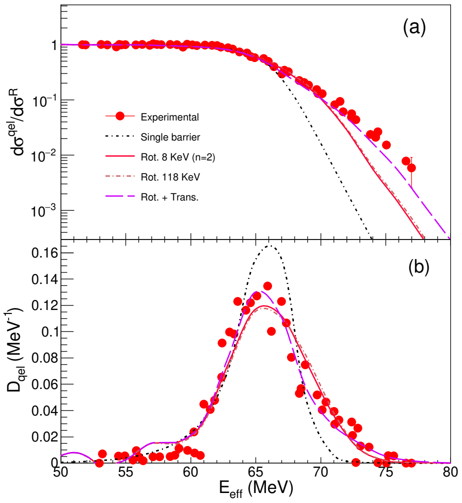

FIG. 1: Experimentally measured QE excitation function and the derived BD along with calculations for different coupling schemes.

surements have been performed for the system ^{16}O+^{169}Tm, which have been translated to BD, also.

The experiments have been performed at the Inter-University Accelerator Centre (IUAC), New Delhi using the HYTAR detecting set-up in the GPSC [9]. The isotopically pure ^{169}Tm target ($\beta_2 \sim 0.287$ $\beta_4 \sim -0.024$) of areal density ≈ 600 μg/cm^2 were prepared using the rolling technique. The energy of ^{16}O beam were varied in steps of 3 MeV ranging from 17% below barrier to 16% above the fusion barrier. The bombarding energies were corrected for energy loss in half of the target thickness. The QE-measurements were performed employing HYTAR's hybrid telescope detectors comprising of ΔE and E detectors, where four telescope detectors each at an angle of 173° have been arranged in a symmetrical cone geometry to measure the back-scattered quasi-elastic events and nine telescopes, six at angles from +60° to +160° with angular separation of 20° and other three telescopes at angles -110°, -122° and -134° were, also, placed. Two monitor detectors have been placed at ±10° for beam normalization purpose.

The QE-events have been identified by E-ΔE, 2D spectra. The standard formulation has been used to obtain the QE cross-section. As each scattering angle corresponds to scattering at a certain angular momentum, hence the cross section is scaled in energy by taking into account the centrifugal correction using $E_{eff}=2E_{CM}/(1+\mathrm{cosec}(\theta_{CM}/2))$, and the QE-excitation function as a function of E_{eff} is shown in Fig.1(a). From experimentally measured QE-excitation function, the experimental BD has been derived by combining the data from all the detectors, the QE-excitation function with energy step of less than 1 MeV is obtained, and shown in Fig.1(b). The coupled channel calculations were performed using CCFULL-SC code [7], and the Woods-Saxon form and Akyuz-Winther potential parameterisation was used. Different coupling schemes have been used to understand the experimentally observed BD. Further, details of the analysis and interpretation of the results will be presented.

The authors thank to the HOD, Department of Physics, Jamia Millia Islamia, New Delhi and the Director, IUAC, New Delhi, India, for providing all the necessary facilities to carry out this work. A.Y. also thanks to the DST for providing support through INSPIRE Faculty scheme ref: IFA18-PH209.

References

[1] R.S. Mackintosh, Rep. Prog. Phys. **40**, 731 (1977).
[2] Y. K. Gupta *et* al., Phys. Letts. B **806**, 135473 (2020).
[3] N. Rowley *et* al., Phys. Lett. **B254**, 25 (1991).
[4] M. Dasgupta *et* al., Annu. Rev. Nucl. Part. Sci. **48**, 401 (1998).
[5] H. Timmers *et* al., Nucl. Phys. A **584**, 190 (1995).
[6] V. Zagrebaev, PRC **78**, 047602 (2008)
[7] K. Hagino, *et* al., Comp. Phys. Comm. **123**, 143 (1999).
[8] Md. Moin Shaikh *et* al., Phys. Rev. C **91**, 034615 (2015).
[9] Akhil Jhingan *et* al., Nuc. Inst. & Methods in Phy. **903**, 326 (2018).