Alternative approach to study fusion barrier distribution

Indu Bala[1,*] and Abhishek Yadav[1]
[1]NP-Group: Inter-University Accelerator Centre, New Delhi-110 067, Delhi, India

Fusion reactions induced by heavy-ions (HIs) at around barrier energies, play an important role in nuclear physics since they enable to study the nuclei away from the valley of stability [1]. On the other hand, heavy-ion collisions, at below & near barrier energies, provide an ideal opportunity to study quantum tunneling phenomena in systems with many degrees of freedom [2]. In a simple model, a potential barrier for the relative motion between the interacting nuclei is created by the strong interplay of the repulsive Coulomb and the attractive nuclear force. It has, now, been well recognized that heavy-ion collisions at energies around the Coulomb barrier are strongly affected by the internal structure of interacting nuclei [3, 4]. The couplings of the relative motion to the intrinsic degrees of freedom (such as collective inelastic excitations of the colliding nuclei and/or transfer processes) replaced a single potential barrier to a number of distributed barriers, leading to the enhancement in heavy ion fusion cross sections at energies near and below the Coulomb barrier than those expected from single one-dimensional barrier.

Rowley *et al.* [5], has proposed a method to extract the barrier distribution experimentally from the second derivative of the function σ_{fus}.E with respect to the center-of-mass energy E, that is, $d^2\sigma_{fus}E/dE^2$. The extracted fusion barrier distributions have been found to be very sensitive to the structure of the colliding nuclei, and thus the barrier distribution method has opened up the possibility of using the heavy-ion fusion reaction as a quantum tunneling microscope in order to investigate both the static and dynamical properties of atomic nuclei. The barrier distribution is a fingerprint of the reaction characterising the important channel couplings. However, this requires fusion cross sections to be measured with high precision (due to second derivative).

Recently, Timmers *et al.* [6, 7], has used the conservation of total flux and proposed a method to extracted the barrier distribution from the quasi-elastic (QEL) scattering measured at backward angles. Here, QEL is defined as the sum of the elastic scattering and all other peripheral reaction processes [6, 7]. It was suggested that the same information can be obtained from the cross-section of quasi-elastic scattering because total flux is conserved. The channel couplings also affect the scattering process, which corresponds to the refleacted part of the incident flux. A necesssary condition for this approach is, however, that the inelastic reaction channels must follow Rutherford orbitals to avoid partial-wave mixing for different reaction types contributing to the quasi-elastic yield.

Further, efficient γ-multiplicity filters in combination with high-resolution γ-detector arrays, particle-detector array and/or recoil mass spectrometers are now available through which the information about total angular momentum distribution can be extracted. The measured multiplicity distribution and/or angular momentum distribution can be transformed into relative partial-wave cross-section distributions using relation;

$$\sigma_\ell(E) = T(E,\ell)(2\ell+1)\pi\lambda^2 \quad (1)$$

where λ is the DeBroglie wavelength of the system. The relation between the fusion cross-section and the partial wave transmission coefficient is

*Email: indu.phy@gmail.com

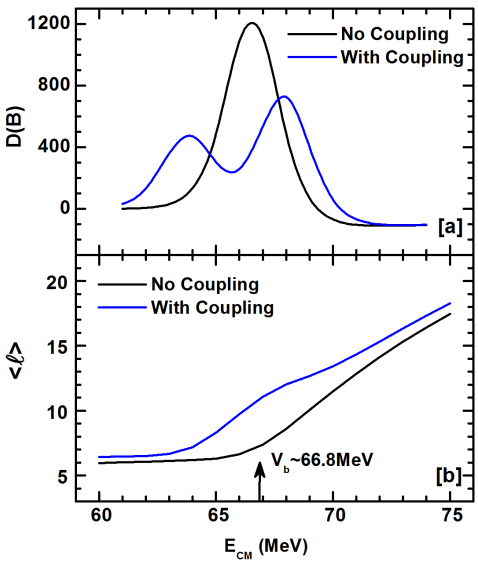

FIG. 1: (color online) (*a*) Theoretically calculated barrier distribution with and without coupling for ^{16}O+^{169}Tm system. (*b*) The effect of coupling on the average angular momentum distribution.

$$T(E,\ell) = \frac{1}{\pi R_b^2}[(E')\frac{d(E\sigma_{fus})}{dE}] + \sigma_{fus}(E') \quad (2)$$

where $E' = E - E_{rot}$

The basic assumption T(E,ℓ) = T(E-E$_{rot}$,ℓ=0), allows the transformation of the angular momentum distribution into the transmission function T(E) assigning to each angular momentum ℓ to the corresponding energy E-E$_{rot}(\ell)$ [8]. By evaluating equation (1) & (2), one can obtain the relation

$$D(B) = \frac{1}{\pi R_b^2}\frac{d^2 E\sigma_{fus}}{dE^2} = \frac{1}{(2\ell+1)\pi\lambda^2}\frac{d\sigma_\ell}{dE} \quad (3)$$

In this way the barrier distribution function D(B) can be extracted from a angular momentum distribution [9]. This method is consistent with the one proposed by Rowley *et al* [5]. As a representative case, a theoretically calculated barrier distribution and angular momemtum distribution has been shown in Fig.1 for ^{16}O+^{169}Tm system. The calculations have been done using theoretical code CCFULL [10], which take coupling to interinsic degrees of freedom of interacting nuclei into account. In these calculations the projectile ^{16}O has treated as inert and only target excitation (rotational coupling) have been considered. ^{169}Tm haivng β_2 and β_4 values 0.271 and -0.009, respectively. As can be seen from the figure that near barrier energies (V$_b \approx$ 66.8 MeV) the coupling significantly affact the angular momentum distribution (Fig.1(b)) and same is reflected in calculated barrier distribution as well, see Fig.1(a). The details of the present work will be presented during the conference.

The authors are grateful to the Director of IUAC, New Delhi, India, for providing facilities. AY thanks the Department of Science & Technology for providing financial support through Project No. SB/FTP/PS-194/2013 under the Fast Track Scheme for Young Scientists.

References

[1] S. Hofmann, *et al.*, Eur. Phys. J. A **32**, 251 (2007); 14, 147 (2002).

[2] M. Dasgupta, *et al.*, Annu. Rev. Nucl. Part. Sci. **48**, 401 (1998).

[3] K. Hagino, *et al.*, Phys. Rev. C **69**, 054610 (2004).

[4] J. R. Leigh, *et al.*, Phys. Rev. C **47**, 437 (R) (1993).

[5] N. Rowley, *et al.*, Phys. Letts. B **245**, 25 (1991).

[6] H. Timmers, *et al.*, Nucl. Phys. A **584**, 190 (1995).

[7] H. Timmers, *et al.*, J. Phys. G: Nucl. Part. Phys. **23**, 1175 (1997).

[8] C. C. Sahm, *et al.*, Nucl. Phys. A **441**, 316 (1985).

[9] D. Ackermann, *et al.*, Acta Physica Polonica B **26**, 517 (1995).

[10] K. Hagino *et al.*, Comput. Phys. Commun. **123**, 143 (1999).