Systematic study of the effect of coupling strength and channel coupling parameter on barrier distribution

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Introduction :

Nuclear fusion is an important probe for the measurements of barrier distributions. The fusion barrier distribution data of a particular system provide a vital ingredient for unveiling the issues related to the associated nuclear reaction dynamics . Nuclear potential also plays a major role in controlling fusion cross sections as well as barrier distributions. Barrier structure is highly sensitive to the depth (V_0), range (r_0), and diffuseness (a_0) parameters. The coupling of different intrinsic channels very often lead to the alternation of the shape of the fusion excitation function plot (specially at the sub-barrier region) as well as the associated barrier distribution profile. This effect of channel coupling can be visualized from the values of channel coupling parameter, λ [1] . In the present work, the necessary calculations for various systems have been carried out in order to extract the values of channel coupling parameter λ and their possible correlations, if any, with the associated coupling strength, $Z_pZ_t\beta$ [2].

Methodology :

In the present work , we have extracted the channel coupling parameter λ by introducing the concept of Symmetric-Asymmetric Gaussian Barrier Distribution (SAGBD*)* [1] model. We have used the required potential parameters as per Akyüz-Winther Systematics (AWS) available in the Nuclear Reaction Video (NRV) project [3]. We have modified the value of r_0 parameter so that the predicted result from the CCFULL code [4] provides the best fit to the experimentally observed fusion excitation data at the above barrier region. The uncoupled barrier height (V_{CB}) has been determined by adding the Nuclear (V_N) and Coulomb (V_C) potential. The barrier distribution obtained from the CCFULL predicted cross-section data has been used to obtain the mean barrier height, V_{B0} and standard deviation, Δ. In this connection, the weighted mean of experimental barrier height has been estimated by considering the range of Gaussian distribution [5] as obtained from CCFULL calculation. The methodology prescribed in Ref. [1] has been used for carrying out further estimation related to SAGBD model calculations using modified Wongs formula. Further adjustments in V_{B0} and Δ values are made in order to reproduce the experimental fusion excitation function data over the entire energy range. This adjusted value has been categorized under the term, V_{eff} and defined as follows :

$$\lambda = V_{CB} - V_{eff}\ .$$

The experimental barrier width (ΔB_{exp}) has been extracted using the following relation :

$$\Delta B_{exp} = 2.355 * \Delta$$

The experimental data are taken from the publications (Refs. [6], [7], and [8]), as shown in the table below.

TABLE I **:** Extracted parameters for a set of target-projectile systems .

System	λ	$Z_pZ_t\beta$	Δ	ΔB_{exp}
$^{32}S+^{90}Zr$ [6]	1.32	129.88	1.6	3.77
$^{32}S+^{94}Zr$ [7]	0.92	128.64	2.7	6.36
$^{32}S+^{96}Zr$ [6]	0.53	119.68	2.9	6.83
$^{16}O+^{144}Sm$ [8]	0.31	109.39	1.0	0.73
$^{16}O+^{148}Sm$ [8]	0.37	122.76	1.9	0.87
$^{16}O+^{154}Sm$ [8]	0.85	171.61	2.8	2.00

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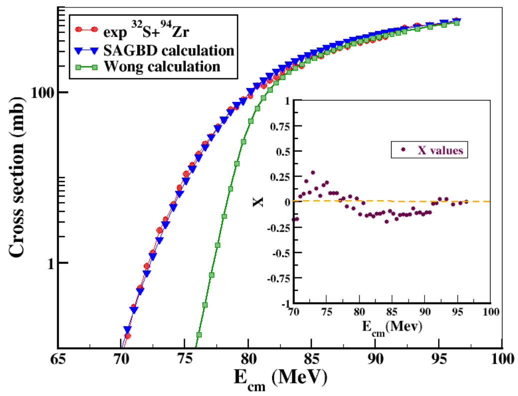

Fig.1 **:** Excitaion function plot for $^{16}O+^{94}Zr$ system. Red: experimental data; Blue: result following SAGBD model; Green: result using Wong's formula. Here , X = [(Experimental cross section – Theoretical cross section) /Theoretical cross section]. A scatter plot of X vs E_{cm} is shown in the inset.

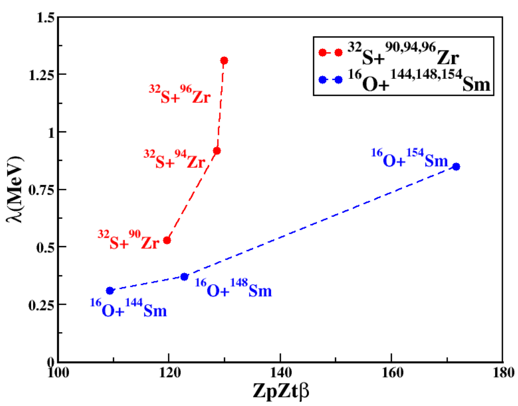

Fig.2 **:** λ vs $Z_pZ_t\beta$ plot. Red :$^{32}S+^{92,94,96}Zr$; Blue : $^{16}O+^{144,148,154}Sm$. Here, Z_p, Z_t denotes respectively the charges of the concerned projectile and target nucleus; wheres, β is their average deformation.

Results and discussions :

For the sake of demonstration, the fusion excitation function plots for the system, $^{32}S+^{94}Zr$ is shown in Fig.1. It can be seen from the figure that the predicted plot following Wong's formula significantly deviates from the experimental plot specially in the sub-barrier region. A good agreement between the experimental results and the theoretical results based on SAGBD model calculation is obtained. The goodness of fit between the experimental and SAGBD model calculation results is shown in the inset scatter plot of Fig.1. The scatter plot indicates that the good agreement sustain for the entire range of the projectile energy (E_{cm}) values .

It is to be pointed out here that a positive value for λ indicates a movement in the barrier location to a lower value. This serves as an evidence for the presence of different coupling channels during the fusion process. The barrier width also somewhat spreads out because of the channel couplings. This is evident from the values of the coupling strength parameter ($Z_pZ_t\beta$) and the channel coupling parameter (λ) as presented in Table 1. Likewise, when the target mass number increases, the value of Δ also increases. Thus, all these parameters seem to have direct correlations, and the same can be visualized from the varying profile of the data points shown in Fig.2. The calculations inco-rporating larger number of systems are in progress. The detail findings related to the correlated behavior of the concerned parameters and the underlying physics issues will be presented in the symposium.

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