Fusion dynamics of ^{37}Cl + ^{93}Nb reaction

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Introduction

Fusion reactions play a significant role in extension of nuclear chart and synthesizing the heavy and super heavy elements [1]. Throughout the fusion process, it has been well acknowledged that the kinetic energy associated with the kinematics of fusing pairs can be moderately absorbed by the internal structure degrees of freedom of the fusing nuclei. Therefore, various kinds of static and dynamical effects due to participants are appearing during quantum mechanical tunneling across the interaction barrier between fusing pairs [2-3]. The effect of permanent shape deformation of interacting nuclei, zero point oscillation of nuclear shape, neck formation; nucleon transfer reactions have been considered by various authors in past to explain the behavior of fusion cross-sections correctly. Current work analyzes the fusion dynamics of ^{37}Cl + ^{93}Nb reaction in sub-barrier domain by using simple Wong formula [4] and SAGBD approach [5-10]. The simple Wong formula based predictions fail to reconstruct the fusion data in sub-barrier domain because simple Wong formula does not include the intrinsic channels in the theoretical estimations, whereas the above barrier data are explained by using such model. The calculations based on SAGBD approach are able to identify the quantitative influences of dominant channels which are significant in fusion dynamics of ^{37}Cl +^{93}Nb reaction and resonantly explained the observed fusion dynamics of studied reaction. The SAGBD model considers the impacts of intrinsic channels in the theoretical estimations via Gaussian function type of weight function and retrieves the sub-barrier fusion data. In SAGBD model, the contributions of intrinsic channel linked with the collision partners are analyzed in terms of the model parameters λ^{SAGBD} and V_{CBRED}. The λ^{SAGBD} is channel coupling parameter and its value is related to the dominant channel coupling effects that are responsible for sub-barrier fusion enhancement.

The V_{CBRED} describes the percentage reduction in the fusion barrier relative to the uncoupled Coulomb barrier. The non-zero and large positive values of λ^{SAGBD} and V_{CBRED} unambiguously reflect the involvement of nuclear structure degrees of freedom of the collision partners during fusion process.

SAGBD model

The simple Wong formula which is used in the present calculations is given as

$$\sigma^{Wong}(E_{c.m.},V_{CB}) = \frac{\hbar\omega_B R_B^2}{2E_{c.m.}} ln\left[1 + exp\left(\frac{2\Pi}{\hbar\omega_B}\left(E_{c.m.} - V_{CB}\right)\right)\right] \quad (1)$$

In above equation, $\hbar\omega_B$ is barrier curvature, R_B is barrier position & V_{CB} is barrier height. In SAGBD method, the role of internal channels are entertained by weighting simple Wong formula by a Gaussian function type of weight function and the total fusion cross- sections are estimated by using following expression

$$\sigma_{Fus}^{SAGBD}(E_{c.m.},V_{CB}) = \int_0^\infty D_f\,(V_{CB})\sigma^{Wong}(E_{c.m.},V_{CB})\,dV_{CB} \quad (2)$$

here, the normalized, continuous & symmetric function '$D_f\,(V_{CB})$' is termed as effective barrier distribution, which is expressed by Eq. (3).

$$D_f\,(V_{CB}) = \frac{1}{N} exp\left[-\frac{(V_{CB}-V_{Bx})^2}{2\Delta^2}\right] \quad (3)$$

where in $N = \Delta\sqrt{2\pi}$

In Eq. (3), Δ is standard deviation that corresponds to the half width of effective fusion barrier at 60% of full height and V_{Bx} is mean barrier height. The model parameter λ^{SAGBD} is defined by the following relation:

$$\lambda^{SAGBD} = V_{CB} - V_{eff} \quad (4)$$

V_{CBRED} calculates the percentage reduction in the effective fusion barrier (V_{eff}) relative to nominal barrier [7] and is expressed as:

$$V_{CBRED} = \frac{V_{CB}-V_{eff}}{V_{CB}} \times 100\% \quad (5)$$

For more details of SAGBD model, readers are advised to follow the references [5-10].

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Results and discussion

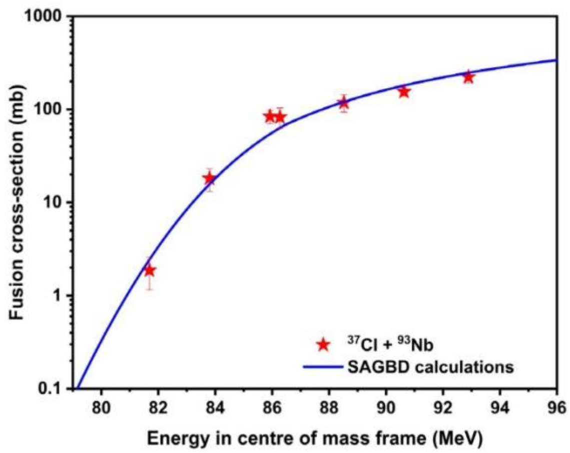

Fig. 1: Theoretical fusion excitation function obtained from SAGBD model for ^{37}Cl + ^{93}Nb reaction as a function of $E_{c.m.}$. The estimated fusion cross-sections are compared with experimental data taken from [11].

For ^{37}Cl + ^{93}Nb reaction, the value of potential depth of Woods-Saxon potential has been kept fixed $(120 MeV)$, while the other parameters diffuseness (a_0) and range (r_0) are varied in such a way that the shape of experimental data can be retrieved. For present system, the extracted values of above-mentioned parameters are $a_0 = 0.98\, fm$ & $r_0 = 0.98\, fm$. The barrier characteristics such barrier height $V_{CB} = 89.84\, MeV$, barrier curvature $\hbar\omega_B = 2.72\, MeV$ and barrier position $R_B = 3.09\, fm$ have been obtained which in turn are used in SAGBD method.

The predictions based on one-dimensional Wong formula fail to explain the fusion data in sub-barrier domain. As simple Wong formula does not entertain channel coupling effects linked with collision pairs, therefore, the fusion cross-sections remained much smaller than the experimental findings especially in sub-barrier energy regions. This suggests that channel coupling effects must be included in theoretical formalism. For this, the SAGBD model has been utilized to explore the fusion dynamics of given reaction. The SAGBD model results appropriately retrieve the shape of experimental data qualitatively as well as quantitatively as evident in Fig. 1. This clearly suggests that the influences of dominant intrinsic channels associated with nuclear structure of fusing nuclei are included into the SAGBD calculations. The influences of such couplings in adopted model are extracted quantitatively in terms of λ^{SAGBD}. The value of λ^{SAGBD} for present system is found to be 4.97 MeV. Furthermore, the parameter V_{CBRED} is also extracted from SAGBD calculations, which also highlights the role of internal structure effects associated with fusing nuclei and the value of V_{CBRED} for ^{37}Cl + ^{93}Nb reaction is 5.53% of V_{CB}. From Fig. 1, one can easily noticed that SAGBD outcomes fairly addressed the fusion excitation function for the ^{37}Cl + ^{93}Nb reaction.

Conclusion

The present work examined the fusion of ^{37}Cl + ^{93}Nb reaction using simple Wong formula and SAGBD model. The SAGBD calculations fairly reproduce the fusion excitation function data of the ^{37}Cl + ^{93}Nb system, which clearly suggests that the role of internal structure of fusion participants has been intrinsically included in adopted approach. While the calculations based on simple Wong formula remained under predicted with respect to sub-barrier fusion data. The contribution from the inherent degrees of freedom of fusion participants in SAGBD approach are mathematically obtained in terms $of\ \lambda^{SAGBD}$ & V_{CBRED}. The large positive values of aforesaid parameters suggested that internal structure of fusing pairs plays a very effective role and displayed their impression on the fusion dynamics of the studied system.

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