Sub-barrier fusion analysis of $^{17}O + ^{144}Sm$ reaction

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Heavy ion fusion process plays a crucial role in the formation of superheavy nuclei as well as in the nucleosynthesis & nuclear stellar evaluations and is of astrophysical interest [1]. In literature [1-2] it was found out that various degrees of freedom such as collective vibrational states, nucleon transfer, static & higher order deformations, neck formation associated with colliding nuclei affects the fusion process in the close vicinity of Coulomb barrier [1-2]. In addition, other factors like nucleus-nucleus potential and related parameters were also highlighted to play a significant role in predictions of fusion cross-sections for various heavy-ion systems [3]. The nucleus-nucleus potential is the sum of Coulomb, nuclear and centrifugal potential terms. In the literature, the various forms of nuclear potentials such as proximity potentials, double folding potential, M3Y repulsive potential, Woods-Saxon potential were used [4-5]. With an optimum choice of potential parameters, one can address the fusion cross-sections data adequately. The simplest formula used for estimation of fusion cross-sections for various heavy-ion systems was given by C Y Wong [6]. This formula was based on the assumption that total interaction potential between heavy-ions can be replace by an inverted parabola. According to one dimensional barrier penetration model (BPM), the projectile and target systems are considered as inert and other degrees of freedom of fusing nuclei are ignored except relative separation co-ordinate. For $^{17}O + ^{144}Sm$ system, the evaporation residues has been measured by Leigh et al. [7] within energy range $E_{lab} = 50-110 MeV$. Using code CCMOD, the authors emphasized that couplings to low-lying 2^+ and 3^- vibrational states of target nuclei (^{144}Sm) as well as one neutron transfer channel with positive Q-value were found to be essential for retrieving of the fusion data.

Theoretical formalism

In the literature, authors [8] focuses on use of Gaussian function type of weight function to Wong formula and by using such approach, authors had effectively explored the sub-barrier fusion enhancement of various reactions. Keeping this in view, SAGBD model [9-11] is applied to address the fusion dynamics of $^{17}O + ^{144}Sm$ reaction. In SAGBD model, several intrinsic degrees of freedom are included into calculations by weighting a Gaussian type function to Wong formula. Therefore, the total fusion cross-sections in SAGBD model is given as :

$$\sigma_F = \int_0^\infty D_f(V_{CB})\sigma^{Wong}(E_{c.m.}, V_{CB})\, dV_{CB} \qquad (1)$$

where, $\sigma^{Wong}(E_{c.m.}, V_{CB})$ and $D_f(V_{CB})$ respectively are Wong formula [6] and effective fusion barrier distribution. $D_f(V_{CB})$ is normalised, continuous and symmetric and defined by the expression:

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

with $N = \Delta\sqrt{2\pi}$

where Δ and V_{Bx} respectively defines standard deviation and mean barrier height of the effective barrier distribution. The impacts of involvement of intrinsic channels of fusing nuclei on fusion process is defined in terms of channel coupling parameter λ^{SAGBD} which is defined as:

$$\lambda^{SAGBD} = V_{CB} - V_{eff} \qquad (3)$$

and $$V_{CBRED} = \frac{V_{CB} - V_{eff}}{V_{CB}} \times 100 \qquad (4)$$

where, V_{eff} is the effective fusion barrier.

Results and discussions

In this work, the fusion cross-sections for $^{17}O + ^{144}Sm$ reaction has been theoretically analyzed by using Wong formula and SAGBD model with Akyüz-Winther [12] and an optimum diffuseness parameterizations. The potential parameters used in SAGBD model are $V_0 = 150 MeV$, $r_0 = 0.997 fm$. The Akyüz-Winther diffuseness is defined as

$$a_{\text{Akyüz-Winther}} = \frac{1}{1.16\left[1 + 0.48(A_P^{-1/3} + A_T^{-1/3})\right]}$$

For $^{17}O + ^{144}Sm$ system, the barrier characteristics obtained using Akyüz-Winther diffuseness $(a_0 = 0.67 fm)$ are

$V_{CB} = 66.10 MeV$, $R_B = 10.06 fm$ and $\hbar\omega = 5.37 MeV$ & the barrier characteristics obtained using an optimum diffuseness ($a_0 = 0.780 fm$) are $V_{CB} = 63.58 MeV$, $R_B = 10.35 fm$ and $\hbar\omega = 4.20 MeV$.

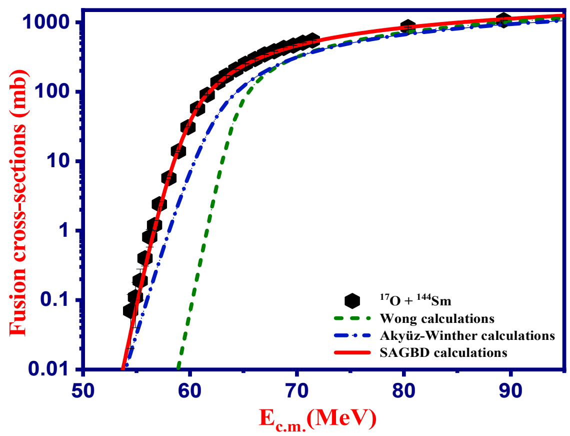

Fig. 1 Fusion cross-sections estimated by using Wong formula and SAGBD model.

For ^{17}O + ^{144}Sm reaction in the above barrier energy regions, the outputs of fusion cross-sections are obtained by using Wong formula (that considers the relative separation co-ordinate between projectile and target as the only degree of freedom) addresses the above barrier fusion data but the same calculations are found to be underpredicted at energies lying below the Coulomb barrier (see Fig. 1). This suggests the inclusion of more degrees of freedom of colliding nuclei to address the fusion data in the below the barrier energy regions. To explore the fusion dynamics of ^{17}O + ^{144}Sm reaction, the various degrees of freedom of fusing nuclei are incorporated in SAGBD model by weighting a Gaussian type function to Wong formula. Using Akyüz-Winther diffuseness in SAGBD model, the estimated fusion cross-sections are found to be enhanced relative to outcomes of Wong formula but are still underpredicted with reference to fusion data. In order to retrace the fusion data, an optimized diffuseness is used in SAGBD model. An optimum diffuseness parameter which is larger than Akyüz-Winther diffuseness results in lower fusion barrier and hence enhanced fusion cross-sections are obtained. Therefore, from Fig. 1 one can say that using an optimum diffuseness value for Woods-Saxon potential the fusion data around the barrier energy regions are readily addressed. The effects of involvement of various degrees of freedom in fusion process are estimated in terms of channel coupling parameter λ^{SAGBD}. V_{CBRED} estimate the percentage decrease in the height of the interaction barrier. The estimated value of λ^{SAGBD} and V_{CBRED} for ^{17}O + ^{144}Sm reaction is 3.46 and 5.44% of V_{CB} respectively and for such values of model parameter, SAGBD model encompass all the relevant channel coupling effects in formalism and hence fairly explained the experimental data of given reaction.

Conclusion

Fusion dynamics of ^{17}O + ^{144}Sm reaction has been investigated by employing Wong formula, Akyüz-Winther diffuseness and an optimum diffuseness within SAGBD model. Using Akyüz-Winther diffuseness, the outputs of fusion cross-sections are found to be enhanced relative to Wong calculations but the same calculations remained underpredicted with respect to fusion data. With an optimum value of diffuseness parameter in SAGBD model, the estimated fusion cross-sections adequately address the experimental data in whole range of incident energies. The non-zero and positive value of model parameters λ^{SAGBD} and V_{CBRED} unambiguously suggested that channel coupling effects played a significant role in the enhancement of sub-barrier fusion data relative to the outputs of Wong formula.

References

[1] C. L. Jiang et al., Eur. Phys. J. A **57,** 235 (2021).
[2] B. B. Back et al., Rev. Mod. Phys. **86**, 317 (2014).
[3] J. O. Newton et al., Phys. Rev. C **70**, 024605 (2004).
[4] I. I. Gontchar et al., Phys. Rev. C **69**, 024610 (2004).
[5] R. D. Woods and D. S. Saxon, Phys. Rev. **95**, 577 (1954).
[6] C. Y. Wong, Phys. Rev. Lett. **31,** 766 (1973).
[7] J. R. Leigh et al., Phys. Rev. C **52**, 3151 (1995).
[8] P. H. Stelson et al., Phys. Lett. B **205**, 190 (1988).
[9] Vijay et al., Phys. Rev. C **103**, 024607 (2021).
[10] V. Ghanghas et al., Braz. J. Phys. **52**, 84 (2022).
[11] Samiksha et al., Braz. J. Phys. **54**, 179 (2024).
[12] O. Akyüz and A. Winther, proceedings of the Enrico Fermi International School of Physics 492 (1979), edited by R. A. Broglia, C. H. Dasso and R. Ricci, North-Holland, Amsterdam (1981).