FUSION DYNAMICS OF ^{48}TI + ^{60}NI REACTION

Abstract

The fusion dynamics of ^{48}Ti + ^{60}Ni reaction is studied through simple Wong formula and Symmetric Asymmetric Gaussian Barrier Distribution (SAGBD) model. Fusion excitation function estimated by using Wong formula is significantly deviated from experiment data at sub-barrier energies, which demonstrates significance of intrinsic channels associated with participants in fusion process. Simple Wong formula falls short of explaining data particularly at energies below the barrier but the SAGBD model explained data qualitatively as well as quantitatively for above reaction. The impacts of dominant channels on fusion process for their action ^{48}Ti + ^{60}Ni is examined in terms of channel coupling parameter λ and V_{CBRED}.The percentage reduction in height of effective barrier(V_{CBRED}) relative to Coulomb barrier is due to involvement of nuclear structure effect. The non-vanishing values of these parameters indicates significant impacts of nuclear structural properties of fusing pair on the fusion process.

Keywords-Sub-barrier fusion; Fusion excitation function; Woods-Saxon potential; SAGBD model; channel coupling effect.

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I. INTRODUCTION

Heavy-ion fusion reactions have been carefully explored in an effort to identify the cause of the fusion enhancement in the below-barrier domain from last 40 years. Whenever internal channels of the projectile target pair are not taken into account then explanation based on the simple barrier penetration model (BPM) give no fusion enhancement. So, we can say that the enhancement is an outcome from the coupling to additional degree of freedom besides the relative motion of participants and this is called sub-barrier fusion enhancement[1-3].Sub-barrier fusion is quite intriguing due to the complex connection between the reaction's kinetics and the internal channels of the participating nuclei and has been analyzed by many authors[3-6].The simply one concentrates on the issue of knowing the process leading to increase in sub-barrier fusion cross sections relative to the one-dimensional. The most challenging in heavy-ion processes is fusion reaction dynamics since so many aspects of these reactions are yet unknown. Vinod kumar *et al.*[5] carried out an experiment and extracted fusion data for the reaction^{48}Ti + ^{60}Ni at Nuclear Science Centre (NSC), New Delhi, India by using a 15UD Pelletron accerlator in energy range126-168 MeV. In present case, the fusion analysis for the reaction ^{48}Ti + ^{60}Ni has been carried out theoretically using simple Wong Formula[4] and SAGBD model[7-9]. The results from Wong formula are not able to address the fusion cross-section data usually at energies lower than the nominal barrier. However, for the above barrier area; Wong based calculations approximately explained fusion data asthe effects of channel coupling are not significant. Within SAGBD model, a single Gaussian-function is weighted to simple Wong formula to account for the effects of inclusion of intrinsic degree of freedom of the colliding pairs[10], as simple Wong formula doesn't account for the above mentioned channel. In SAGBD approach; the effect of channel coupling for the reaction, which is accountable for enhancement of fusion excitation function; is defined in terms of 'λ' and the percentage decrease of effective fusion barrier 'V_{CBRED}' with relative to Coulomb Barrier 'V_{CB}'.

II. THEORETICAL APPROACH

The simple Wong formula [4] for the fusion cross section is given below:

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

where, V_{CB},$\hbar\omega_B$ and R_B arebarrier heights, barrier curvature and barrier positionof nominal barrier respectively.$E_{c.m.}$ is the center of mass energy. In this work, we have taken the Woods-Saxon potential form of nuclear potential is taken which is given by:

$$V_N(r) = \frac{-V_0}{\left[1+\exp\left(\frac{R-R_0}{a_0}\right)\right]}, \tag{2}$$

where V_0 is the depth, a_0 is the diffuseness and R_0 is the radius parameter of the nuclear potential. Here, the radius parameter is definedas:

$$R_0 = r_0\left(A_P^{1/3} + A_T^{1/3}\right), \tag{3}$$

Here, the range for Woods-Saxon potential is denoted by $r_0.A_P$ (A_T) are the mass of projectile (target). Total fusion cross-section can be evaluated in the SAGBD model[7-9] by weighting the Wong formula with single Gaussian function[11].The total weighted fusion cross-section is defined below by the expression:

$$\sigma^{SAGBD}(E_{c.m.}, V_{CB}) = \int_0^\infty D_f(V_{CB})\sigma^{Wong}(E_{c.m.}, V_{CB})dV_{CB}, \tag{4}$$

and $$\int D_f V_{CB} dV_{CB} = 1,$$

where, $D_f(V_{CB})$ represents the effective barrier distribution, which is given by following relation

$$D_f(V_{CB}) = \frac{1}{N}\exp\left[-\frac{(V_{CB}-V_{B0})^2}{2\Delta^2}\right], \tag{5}$$

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

here, Δ &V_{B0} are the standard deviation and mean barrier height of barrier distribution of selected system.In this work, the effects of inherent channels linked with the fusing nuclei are determined by evaluating$\lambda$and V_{CBRED}. Mathematically, the value of λ is given as:

$$\lambda = V_{CB} - V_{eff}, \tag{6}$$

where, $V_{eff}$is effective fusion barrier andV_{CBRED} mathematically evaluates using following eqn.

$$V_{CBRED} = \frac{V_{CB}-V_{eff}}{V_{CB}} \times 100\% \tag{7}$$

For more details of SAGBD formalism, readers can read the Refs.[7-9].

III. RESULT AND DISCUSSION

For the exploration of the system ^{48}Ti+^{60}Ni theoretically, we have used the Woods-Saxon potential and potential depth, diffuseness and range are taken as $110\ MeV$,$0.87\ fm$ and $1.00\ fm$ respectively. The potential barrier between fusing nuclei using SAGBD model are shown in figure 1(a).Fusion cross-section obtained with the help of Wong formula and SAGBD model are also shown in figure1. Figure 1 (a) shows the Coulomb barrier for the selected system, which is under study. The Coulomb barrier (V_{CB}), barrier curvature ($\hbar\omega$) and barrier position (R_B) are also calculated using Woods-Saxon potential. These barrier characteristics as$V_{CB} = 82.89\ MeV$, $\hbar\omega = 3.33\ MeV$ and $R_B = 9.65\ fm$ are used in theoretical calculations. Figure 1 (b) shows the fusion excitation function for reaction ^{48}Ti + ^{60}Ni. The symbol indicates the experimental fusion cross section data; the dash line shows the Wong calculations and the solid line gives result of calculations due to SAGBD approach. The fusion cross-section data were experimentally measured by the author of Ref. [5]. Theoretical calculations using Wong formula are considerably lower than the data at specific energies due to absence of the multidimensional behavior in one dimensional Wong formula. Vinod kumar *et al.* [5], explained fusion data by considering coupled channel calculations by using the code CCMOD [12]. By including the effects of lowest 2^+ and 3^- vibrational states of fusing nuclei. In current work, Wong based calculations are incapable to retrieve the data at below realm. Although, SAGBD model calculations replicate the fusion excitation function at all range of incident energies. In SAGBD model, the effects of intrinsic channels related to the reaction partners are explained in the forms ofλ and V_{CBRED}.The value of $\lambda$and V_{CBRED}respectively for the reaction ^{48}Ti + ^{60}Ni is 4.59 and 5.54% of V_{CB}. The decrease in effective barrier is due to participation of nuclear structural effect of the colliding nuclei and this involvement further enhances the fusion cross section relative to simple Wong formula specially at below barrier energies as seen in the SAGBD prediction.

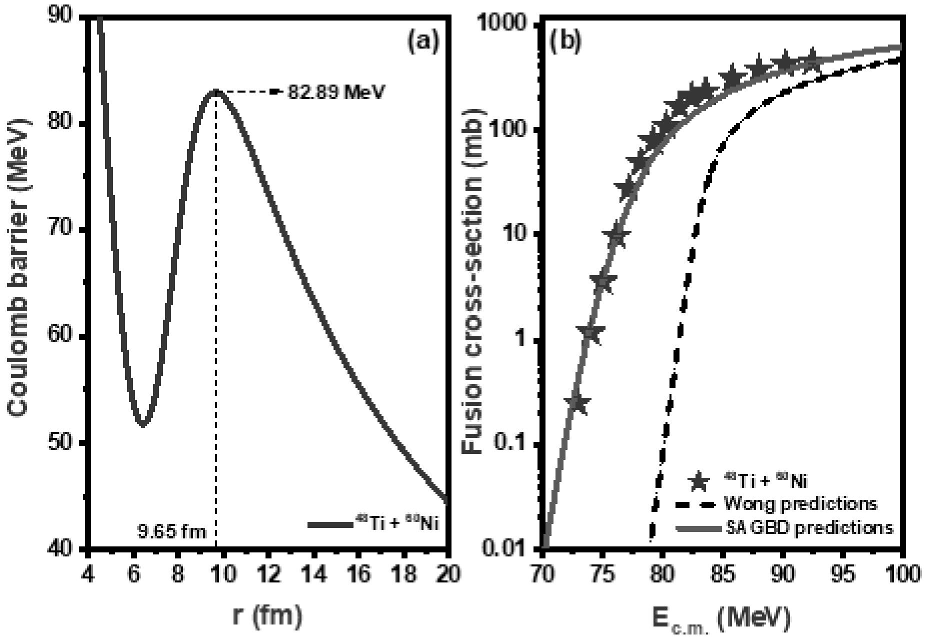

Figure 1:(a)Radial dependence of the fusion barrierfor ^{48}Ti+^{60}Ni reaction and(b) Fusion excitation function for the system ^{48}Ti + ^{60}Niobtained by using SAGBD model as a function of $E_{c.m.}$.The calculations are contrasted with Wong formula based calculations and the theoretical predictions compared with experimental results obtained from Ref. [5].

IV. CONCLUSION

The excitation function for the fusion reaction ^{48}Ti + ^{60}Ni is explored at sub energies using simple Wong formula and SAGBD model. The fusion cross-section estimated using simple Wong formula remain significantly deviated with reference to the experimental outcomes in below barrier area. Although, SAGBD approach reproduces fusion excitation function for the system ^{48}Ti + ^{60}Ni.The parameters $\lambda$and V_{CBRED}determines quantitative involvement of the channel coupling effects in the fusion process. The larger value of both the parameters suggests the participation of nuclear structure of colliding nuclei in fusion is significant.

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