Heavy-ion Fusion reactions of ^{32}S on ^{90,96}Zr targets

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1. Introduction

Heavy-ion fusion reactions in low energy range at, above and below the Coulomb barrier have been an area of extensive investigations for many years [1, 2]. In the present work, the fusion excitation functions and barrier distributions for the fusion of well deformed ^{32}S on nearly spherical ^{90,96}Zr have been calculated using one-dimensional barrier penetration model, taking scattering potential as the sum of Coulomb and proximity potential [3] and the calculated values are compared with experimental data [4].

2. Theory

In nuclear reactions, the interaction barrier for two colliding nuclei is given as:

$$V = \frac{Z_1 Z_2 e^2}{r} + V_P(z) + \frac{\hbar^2 \ell(\ell+1)}{2\mu r^2} \quad (1)$$

Where $V_P(z)$ is the proximity potential given as:

$$V_P(z) = 4\pi\gamma b \frac{C_1 C_2}{C_1 + C_2} \phi(\frac{z}{b}) \quad (2)$$

with the nuclear surface tension coefficient,

$$\gamma = 0.9517[1 - 1.7826(N-Z)^2 / A^2] \quad (3)$$

Here ϕ is the universal proximity potential.

During the last three decades several attempts have been made to improve the proximity potential. In these works an improved version of nuclear surface tension co-efficient is presented by Reisdorf as:

$$\gamma = 1.2496[1 - 2.3(N-Z)^2 / A^2] \quad (4)$$

For energy E_ℓ, using the probability for the absorption of ℓ^{th} partial wave given by Hill-Wheeler formula, Wong arrived at the total cross section for the fusion of two nuclei by quantum mechanical penetration of simple one-dimensional potential barrier as:

$$\sigma = \frac{\pi}{k^2} \sum_\ell \frac{2\ell+1}{1+\exp[2\pi(E_\ell - E)/\hbar\omega_\ell]} \quad (5)$$

where $k = \sqrt{\frac{2\mu E}{\hbar^2}}$. Here $\hbar\omega_\ell$ is the curvature of the inverted parabola.

Below the barrier, the tunneling through the barrier has to occur in order to allow the fusion of the two nuclei and in terms of partial wave; the fusion cross section is given as:

$$\sigma = \frac{\pi}{k^2} \sum_{\ell=0}^{\ell=\ell_C} (2\ell+1)P \quad (6)$$

where $\ell_C = R_a \sqrt{2\mu(E_{CM} - V_{(R_a,\eta_{in},\ell=0)})} / \hbar$, R_a is the first turning point and η_{in} is the entrance channel asymmetry. Here, P is the WKB penetration probability given as:

$$P = \exp\left\{ -\frac{2}{\hbar} \int_a^b \sqrt{2\mu(V-E)} dz \right\} \quad (7)$$

where a and b are the inner and outer turning points defined as $V(a) = V(b) = E$.

In the case of deformed nuclei the penetration probability is different in different directions. The averaging of penetrability over different directions is done using the expression

$$P = \frac{1}{2} \int_0^\pi P(E,\theta,\ell) Sin(\theta) d\theta \quad (8)$$

The Coulomb interaction between the two deformed and oriented nuclei with higher multipole deformation included is given as,

$$V_C = \frac{Z_1 Z_2 e^2}{r} + 3 Z_1 Z_2 e^2 \sum_{\lambda,i=1,2} \frac{1}{2\lambda+1} \frac{R_i^\lambda}{r^{\lambda+1}} Y_\lambda^{(0)}(\alpha_i) \left[\beta_{\lambda i} + \frac{4}{7} \beta_{\lambda i}^2 Y_\lambda^{(0)}(\alpha_i) \delta_{\lambda,2} \right] \quad (9)$$

The concept of barrier distribution directly extracted from a measured fusion cross section σ, by taking the second derivative of the product $E\sigma$ with respect to center-of-mass energy E is given as:

$$\frac{d^2(E\sigma)}{dE^2} = 2\left[\frac{(E\sigma)_3 - (E\sigma)_2}{E_3 - E_2} - \frac{(E\sigma)_2 - (E\sigma)_1}{E_2 - E_1} \right] \frac{1}{(E_3 - E_1)} \quad (10)$$

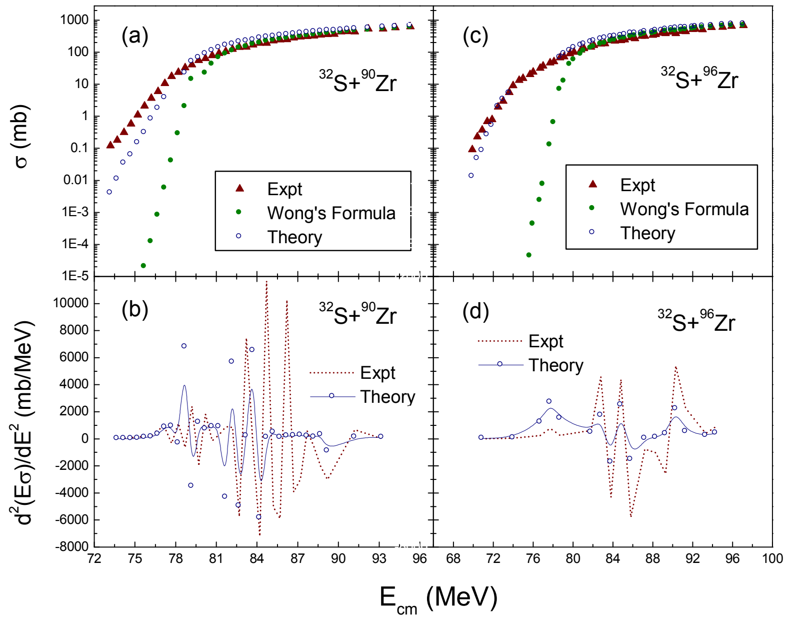

Fig.1. Fusion cross section and barrier distribution for $^{32}S+^{90}Zr$ and $^{32}S+^{96}Zr$ reactions.

3. Results and discussion

In Figs. 1(a) and (c), in the reactions of ^{32}S + ^{90}Zr and ^{32}S + ^{96}Zr**,** at and above the barrier, the fusion cross-sections (diamonds) computed using Wong's formula given by Eq. (5) and nuclear surface tension co-efficient given by Eq. (3) fit very well with the experimental data (solid up triangles), whereas below the barrier show some disagreement. Below the barrier, we have considered the fusion process as a tunneling process and the cross sections (open circles) calculated using Eqs. (3), (7) and (10) show relatively good agreement with the experimental data. In Fig. 1(c), in the reaction of ^{32}S + ^{96}Zr, for getting a better result we have changed the value of nuclear surface coefficient given by Eq. (3) by Eq. (4).

In Figs. 1(b) and 1(d), the calculated barrier distributions for the reactions ^{32}S + ^{90}Zr and ^{32}S + ^{96}Zr with Eqs. (5), (6) and (11) agree with overall location, width and shape of the measured lobe.

4. Conclusions

At and above the barrier, the simple one dimension barrier penetration model developed by Wong explains the fusion reactions of heavy ions very well, while using the scattering potential as the sum of Coulomb and proximity potentials. Below the barrier the fusion process can be considered as a tunneling process and in the quantum mechanical tunneling of one dimension barrier penetration model the inclusion of nuclear deformation parameters in Coulomb and proximity potential model explains the nuclear fusion cross sections comparatively well.

References

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