Fusion Reaction Study of ^{16}O+^{92}Zr System

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We have developed and adopted an analytical recursive procedure called multistep potential(MP) [1] method to analyze the data of angular variations of elastic scattering cross section and expression for the absorption [2] from arbitrary small intervals which will lead to the explanation of the fusion cross section (σ_{fus}) data at various incident center-of-mass energies $E_{c.m.}$. This procedure here considered as a replacement of Rungee-kutta or similar numerical integration methods to solve the Schroedinger equation. A smoothly varying potential U(r) can be considered as a chain of 'n' number of rectangular potentials each one of which has arbitrarily small width 'w'. Having simulated the potential upto a maximum range $r = R_{max}$ we have $R_{max} = \Sigma_i^n w_i$ where $w_i = w$ is the width of the ith rectangle. Let in the jth region, $\Sigma_{i=1}^{j-1} w_i < r \leq \Sigma_{i=1}^{j} w_i$,the strength and width of the potential be denoted by U_j and w_j, respectively. The reduced Schroedinger equation in this region is

$$\frac{d^2\Phi(r)}{dr^2} + \frac{2m}{\hbar^2}(E - U_j)\Phi(r) = 0, \tag{1}$$

with the solution

$$\Phi_j(r) = a_j e^{ik_j r} + b_j e^{-ik_j r}, \tag{2}$$

where the wave number k_j is defined as $k_j = \sqrt{\frac{2m}{\hbar^2}(E - U_j)}$ for the jth segment of width w_j. Here E indicates incident energy and m stands for the mass of the particle. Using the exact Coulomb wave function i.e. G_l and F_l and their derivatives in the outer region $r \geq R_{max}$ and the wave function $\Phi_n(r)$ and its derivative in the left side of $r = R_{max}$, and matching them at $r = R_{max}$ we get the expression for partial wave S-matrix η_ℓ as

$$\eta_\ell = 2iC_\ell + 1, \tag{3}$$

$$C_\ell = \frac{kF'_\ell - F_\ell H}{H(G_\ell + iF_\ell) - k(G'_\ell + iF'_\ell)}, \tag{4}$$

$$H = \frac{\Phi'_n}{\Phi_n} = ik_n \frac{D^{(\ell)}\ e^{ik_n R_{max}} - e^{-ik_n R_{max}}}{D^{(\ell)}\ e^{ik_n R_{max}} + e^{-ik_n R_{max}}}, \tag{5}$$

$$D^{(\ell)} = \frac{a_n}{b_n} = q_{n,n-1,n-2,...1}$$
$$= \frac{q_{n,n-1} + q_{n-1,n-2,...1} e^{2ik_{n-1}w_{n-1}}}{1 + q_{n,n-1} \times q_{n-1,n-2,...1} e^{2ik_{n-1}w_{n-1}}}, \tag{6}$$

with q_{21}=-1.

We use the notation $q_{ji} = -q_{ij} = \frac{k_j - k_i}{k_j + k_i}$. Using the above expression (3) for η_ℓ we explain the elastic scattering of $^{16}O +^{92} Zr$ system. For the total reaction cross section one can use the formula

$$\sigma_r = \frac{\pi}{k^2}\sum_\ell (2\ell + 1)(1 - |\eta_\ell|^2) \tag{7}$$

This is equal to the absorption cross section

$$\sigma_{abs} = \frac{\pi}{k^2}\sum_\ell (2\ell + 1)(1 - \frac{|\ a_n\ |^2}{|\ b_n\ |^2})$$
$$= \frac{\pi}{k^2}\sum_\ell (2\ell + 1)(\sum_{j=1}^{n} I_j^{(\ell)}) \tag{8}$$

where I_j is the absorption cross section from the jth region [2].

The symbol $\star$ indicates the complex conjugate of the respective quantity. The problem of higher

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partial wave can be treated as scattering by effective potential $V_N(r) + V_C(r) + V_\ell(r)$ and one can adopt the MP approximation method described above for this effective potential. Using a deep potential in Woods-Saxon form for the nuclear part with parameters V_N=-70 MeV, r_v=1.337 fm, a_v=0.367 fm, Coulomb radius parameter r_c=1.2 fm and a shallow imaginary potential with strength W=-4.0 MeV, we calculate the result of differential scattering cross section at several energies in the case of $^{16}O +^{92} Zr$ system and obtain a good explanation of the corresponding experimental data [3, 4] as shown in figure 1. Here we have used a single potential for all energies.

Using the same potential, the results of σ_{fus} are calculated and the corresponding experimental data [5] (solid dots) in Fig. 2 is explained with remarkable success by our calculated results shown by full curves. we have taken R$_{fus}$=8.4 fm which is less than R$_B$=10.58 fm with the barrier height of V$_B$=42.15 MeV. To achieve thid we have slightly changed the r_v value from 1.337 fm to 1.334 fm.

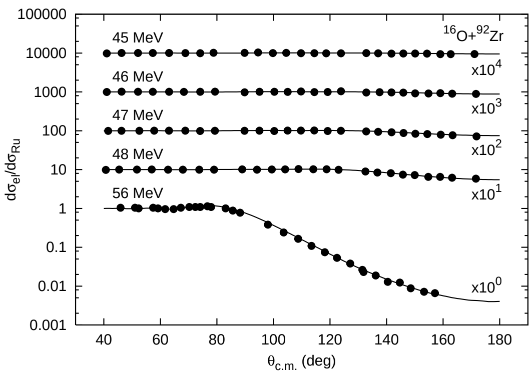

FIG. 1: Angular distribution of elastic scattering cross sections (ratio to Rutherford) of $^{16}O+^{92} Zr$ system at different laboratory energies. The full drawn curves are theoretical results of present optical model calculation. The circles are experimental cross section from [3, 4].

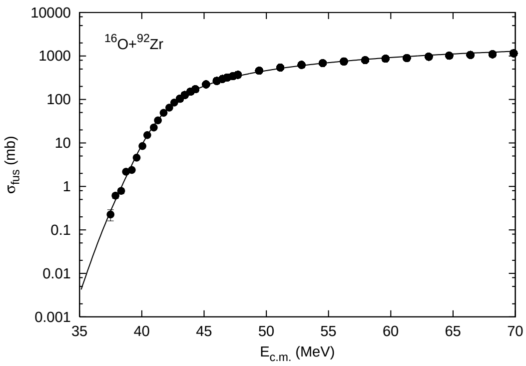

FIG. 2: Variation of σ_{fus} as function of $E_{c.m.}$ for the $^{16}O +^{92} Zr$ system. The full drawn curves represent calculated results.The experimental data shown by solid dots are obtained from [5].

The important features that emerge from this analysis can be summarized as; i) A single and energy independent nuclear potenetial in Woods-Saxon from is found to be successful in explaining the scattering data at several energies. ii) Extraction of the part of reaction cross section to account for the fusion cross section through this method is a significant feature in this calculation.

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