Isotopic dependence of fusion probabilities for oxygen nuclei and ^{92}Zr

R. R. Swain[1], B. Sahu[2], and B. B. Sahu[1*]
[1]*Department of Physics, School of Applied Sciences, Kalinga Institute of Industrial Technology (KIIT) University, Bhubaneswar-751 024, INDIA and*
[2]*Rtd. Professor from Department of Physics, North Orissa University, Baripada-757003, INDIA*

The availability of a large number of neutron-rich/-deficient nuclear beams and the discovery of a number of isotopes of different nuclei at the extreme, the isotopic dependence of interacting potential and fusion cross sections has been studied in Ref.[1–3] . It is one of the current interesting subjects in nuclear physics. Such type of reactions not only provide a check for the validity of nuclear-structure models, it also enhances the possibility of synthesis of new and very neutron-rich nuclei. The isotopic study offusion probability has been made on the basis of N/Z ration of the compound nuclei. In all investigations, the isotopic dependence of barrier heights V_B and positions R_B as well as fusion cross sections σ_{fus} versus N/Z ratio, has been examined [1–3]. Our objective in this work is, how the fusion probability is affected by the radius parameter with addition/removal of neutrons from the projectile nucleus. The present study is carried out within the framework of optical model potential analysis.

We have developed and adopted an analytical recursive procedure called multistep potential(MP) [4] method to analyze the data of angular variations of elastic scattering cross section and expression for the absorption [5] 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, $\Sigma_{i=1}^{j-1} w_i < r \le \Sigma_{i=1}^{j} w_i$,the strength and width of the potential be denoted by U_j and w_j, respectively. The reduced Schroedinger equation in this region is

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

with the solution

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

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 $r \ge R_{max}$ 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

$$\eta_\ell = 2iC_\ell + 1, \qquad (3)$$

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

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

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

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

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

This is equal to the absorption cross section

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

*Electronic address: bbsnou@gmail.com

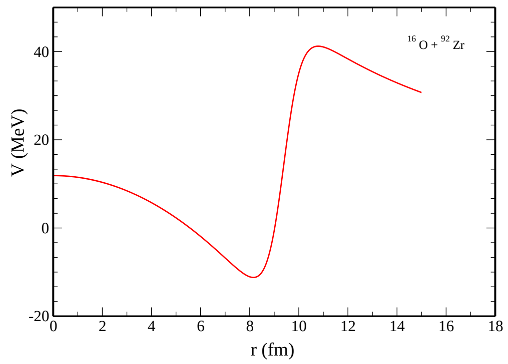

FIG. 1: Plot of real part of nuclear plus Coulomb potentials for partial wave l = 0 as a function of radial distance.

where I_j is the absorption cross section from the jth region [5].

The symbol $\star$ indicates the complex conjugate of the respective quantity. The problem of higher partial wave can be treated as scattering by effective potential $V_N(r)+V_C(r)+V_\ell(r)$ shown in Fig.1 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=1.334 fm ($r_v = r_0 \times (A_p^{1/3} + A_t^{1/3})$), 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 [6] and obtain a good explanation of the corresponding experimental data [7, 8]. Here also we have used the same single potential for the study of fusion cross sections.

So by using the same potential, the results of σ_{fus} for the systems $^{16-20}O +^{92} Zr$ are calculated and are compared with the corresponding experimental data [9] (solid dots) in Fig. 2 with remarkable success shown by full curves. We have taken R_{fus}=8.4 fm which is less than R_B=10.79 fm with the barrier height of V_B=41.216 MeV.

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 [6]. 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. iii) The radius parameter $r_v = r_0 \times (A_p^{1/3} + A_t^{1/3})$ for the respective systems $^{17-20}O$+^{92}Zr increases with the decrease of V_B and hence the fusion probability.

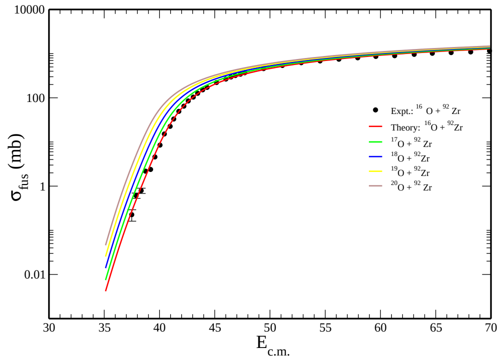

FIG. 2: Variation of σ_{fus} as function of $E_{c.m.}$ for the $^{16}O +^{92} Zr$ system. The full drawn curves represent calculated results.The experimental data shown by solid dots are obtained from [9].

In conclusion, we can say with the addition/removal of neutron the fusion cross sections follow a linear dependence for all considered isotopic systems.

This work is supported by SERB, DST, Govt. of India, vi-de Grant No-SR/FTP/PS-106/2013.

References

[1] R. K. Puri, M. K. Sharma, and R. K. Gupta, Eur. Phys. J. A 3, 277 (1998).

[2] R. K. Puri, and N. K. Dhiman, Eur. Phys. J. A 23, 429 (2005).

[3] N. K. Dhiman and R. K. Puri, Acta. Phys. Pol. B 37, 1855 (2006).

[4] Basudeb Sahu, B.B. Sahu and S.K. Agarwal, Pramana; J. Phys. **70**, 27 (2008)

[5] Basudeb Sahu et al., Phys. Rev. C **77**, 024604 (2008)

[6] R.R. Swain, R.K. Paira, B.B. Sahu, and B. Sahu, Proceedings of the DAE-BRNS Symp. on Nucl. Phys. **60**, 566 (2015).

[7] M. A. G. Alvarez, et al., Nucl. Phys. A **656**, 187 (1999).

[8] E. M. takagui et al., Nucl. Phys. A **514**, 120 (1990).

[9] J. O. Newton et al, Phys. Rev. C **64**, 064608 (2001)