Fusion barrier distribution described by pocket resonances

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Introduction

In a nucleus-nucleus collision, resonances depicted by larger values of reaction cross section (σ_R) at specific energies are generated by the combined Coulomb-nuclear potential by virtue of well-developed pocket or well in it.The generation of such resonance is ascertained by peak value of phase-shift time at the resonance energy.

In this work, within the framework of optical potential scattering in three dimension, we shall calculate the values of fusion cross section (σ_F) from σ_R at different incident energies by adopting a nuclear potential which in combination with electrostatic and centrifugal potentials generate significant resonances in the reaction. Due to the existance of such resonances we present barrier distribution function as D(E)=($d^2(E\sigma_F)/dE^2$);the second energy derivative of the product of σ_F and energy E. In principle the variation of the quantity D(E) as a function of energy shows two peaks and a negative deep in between them around each resonance energy. There can be several resonances in a given angular momentum trajectory denoted by partial wave l. Hence each l would carry a number of peaks and deeps for the result of D(E) over a range of energy. These results of D(E) from large number of ls involved in a heavy ion collision shall be added together and after some mutual cancellation and addition the final result of D(E) will show an oscillatory structure in the higher energy region above the coulomb barrier.

Formulation

Coming to the analysis of the nucleus-nucleus collision with full optical potential, a new potential for the nuclear part has been constructed by us recently [1]. This is expressed as

$$V_N^R(r) = V_0 f_{\rho_0}(r) + V_1\ r\ f'_{\rho_1}(r), \qquad (1)$$

with the form factors

$$f_{\rho_0}(r) = \begin{cases} -e^{\frac{r^2}{r^2-\rho_0^2}}, & \text{if } r < \rho_0, \\ 0 \quad , & \text{if } r \geq \rho_0, \end{cases} \qquad (2)$$

$$f'_{\rho_1}(r) = \begin{cases} \frac{2r\rho_1^2}{(r^2-\rho_1^2)^2} e^{\frac{a_s r^2}{r^2-\rho_1^2}}, & \text{if } r < \rho_1, \\ 0 \quad , & \text{if } r \geq \rho_1. \end{cases} \qquad (3)$$

The factor $f'_{\rho_1}(r)$ is the first derivative of the direct one $f_{\rho_0}(r)$ with inclusion of an unit-less diffuseness parameter a_s in the exponential term in (3). The strength of the direct term $V_0 > 0$ and derivative term $V_1 < 0$ and they are in MeV unit. The two radii ρ_0 and ρ_1 are expressed as $\rho_0 = r_0(A_1^{1/3} + A_2^{1/3})$ and $\rho_1 = r_1(A_1^{1/3} + A_2^{1/3})$ in terms of distance parameters r_0 and r_1 in fm units, and mass numbers A_1 and A_2 of the partner nuclei. Always $\rho_1 < \rho_0$. Thus, the nuclear potential given by (1) is a five-parameter coordinate dependent expression with the adjustable parameters V_0, V_1, r_0, r_1 and a_s. Along with the Coulomb and centrifugal potentials, this potential (1) generates a repulsive barrier in the outer region with a prominent pocket in the inner side in each partial wave trajectory specified by $l = 0,\ 1,\ 2,\ 3$...... This barier along with pocket found in a given l gradually vanishes with the increase of l.

The Schrödinger equation with the total complex potential $V(r) = V_N^R(r) + V_c(r) + V_l(r) - iW_0 f_{\rho_0}(r)$ specified by altogether seven parameters V_0, V_1, r_0, r_1, a_s, r_c and $W_0(> 0)$ is solved by using a simple approximation method described in [1] and analytical expressions for S-matrix and region-wise absorption are obtained to compute the value of fusion cross section σ_F for different partial waves as a function of bombarding energy. From the results of σ_F calculated at very close energy interval we extract the final expression of fusion distribution function as a function of energy E by using point difference formula [5] given by

$$D_F(E) = \sum_\ell (2\ell + 1) D_{F\ell}. \qquad (4)$$

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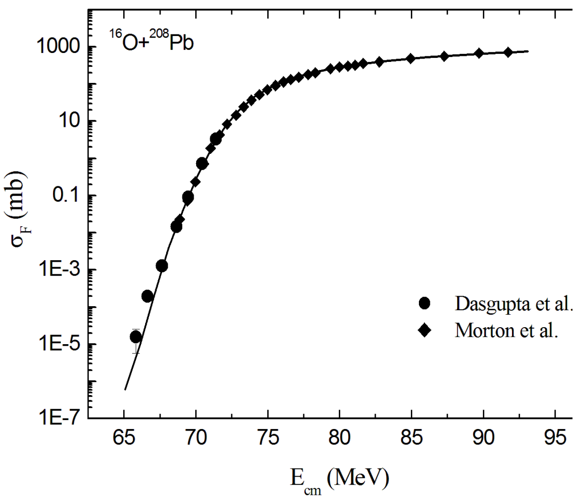

FIG. 1: Variation of fusion cross section as function of center-of-mass energy for ^{16}O+^{208}Pb system. The solid curve represents the results of present optical model (S-matrix) calculation. The experimental data shown by solid circles and diamonds are obtained from Refs. [3] and [4], respectively.

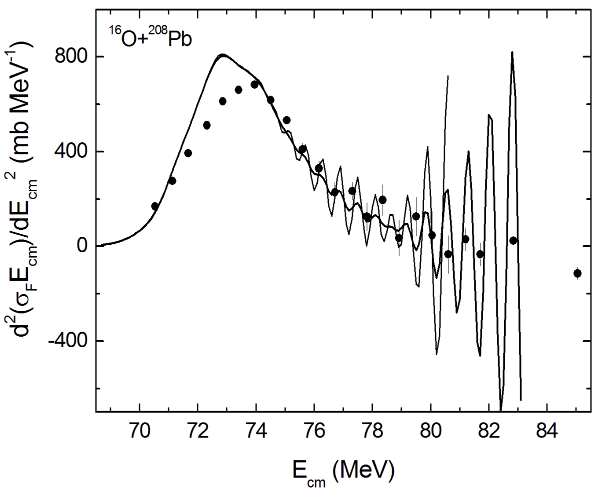

FIG. 2: Variation of $D(E_{cm}) = d^2(E_{cm}\sigma_F)/dE_{cm}^2$ as a function of energy E_{cm} corresponding to results of σ_F in Fig. 1 for the ^{16}O+^{208}Pb system. The solid curves represent the results of present calculation where thin and thick curves are obtained by using energy step ΔE= 0.1 MeV and 0.4 MeV, respectively. The experimental data shown by solid dots are obtained from Ref. [4].

In the application of the above formulation we take ^{16}O+^{208}Pb system and the seven potential parameters are V_0=74 MeV, V_1=0.56 MeV, r_0=1.655 fm, r_1=1.53 fm, a_s=0.45, r_C=1.1 fm and W_0=2.0 MeV. Using the analytical expression (22) given in Ref. [1] to extract a part of the reaction cross section by considering the amount of absorption over a spatial region from origin r=0 to r= R_F =9.2 fm. These calculated results of σ_F and hence D(E_{cm}) as a function of E_{cm} are shown in Fig. 1 and Fig. 2 respectively.

Conclusion

In the framework of three-dimentional potential scattering process the weakly absorbtive potential for the nucleus-nucleus collision in different angular momentum trajectories is found to generate resonances which are menifested as peaks in the value of σ_R at specific energies of resonances. In a natural consideration, a part of σ_R is taken as σ_F. Hence the results of σ_F contains all important resonance character found in the results of σ_R. The results of σ_F when presented in the form D(E_{cm})= $\frac{d^2(E_{cm}\sigma_F)}{dE_{cm}^2}$ exhibits oscillatory structure with peeks and deeps in its variation with E_{cm}. This theoretical results are in good aggrement with the corresponding experimental data [3, 4]. With this we come to conclusion that the developement of pocket resonances in heavy ion collision is the doorway to the generation of oscillatory structure in the results of distribution function.

This work is supported by BRNS, DAE, Mumbai, India, via Research Grant No. 2011/37P/28/BRNS/1781 and SERB, DST, Govt. of India, vi-de Grant No-SR/FTP/PS-106/2013.

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