New form of nuclear potential for unified description of heavy-ion scattering and fusion cross sections at extreme sub-barrier energies

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As an alternative to the conventional Woods-Saxon (WS) form, we adopt a new form of phenomenological nuclear potential to undertake the task of explaining the measured results cross sections of elastic ($\sigma_{\rm el}$) and fusion ($\sigma_{\rm fus}$) in a unified way within the framework of optical potential (OP) model of scattering. In the OP model analysis of scattering of two nuclei of mass number A_1 and A_2 and proton number Z_1 and Z_2, the OP in the entrance channel is described by the sum $V(r) = V_N(r)+V_C(r)+V_\ell(r)$ of complex nuclear term (V_N(r)), Coulomb term (V_C(r)) and centrifugal term (V_ℓ(r)) for different partial wave ℓ. The forms of second two terms are wellknown where V_C(r) is specified by a radius parameter r_c as $R_c = r_c(A_1^{1/3} + A_2^{1/3})$. The complex nuclear potential $V_N(r) = V_N^R(r)+iV_N^I(r)$ consists of a real part $V_N^R(r)$ and imaginary part $V_N^I(r)$. The real part is taken as

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

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 is in MeV unit whereas the strength of the derivative term $V_1 < 0$ and is in MeV fm 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 always $\rho_1 < \rho_0$. The imaginary part of $V_N(r)$ is taken in the simple form (2) such that $V_N^I(r) = W_0 f_{\rho_0}(r)$ with the strength $W_0 > 0$ in MeV unit. We get this form from [1].

In the analysis of elastic and fusion cross section data of the heavy-ion system ^{28}Si+^{64}Ni, the values of the potential parameters describing the optical potential (1) are given by V_0=57 MeV, V_1=12 MeV fm, r_0=1.68 fm, r_1=1.615 fm, a_s=0.55 fm, r_c=1.22 fm and W_0=4 fm. The values of the height V_B^0=51.1 MeV and radius R_B^0=10.9 fm are for the s-wave barrier. Using this potential, the results of S-matrix are obtained using the method given in [2] to give the values of differential scattering cross section as a function of center-of-mass angle at several incident energies. These results are presented in figure 1 as solid curves and are compared with the respective measured data shown by solid dots in the same figure. It is clearly seen that the fitting of the data is quite good. Using the same potential without any modification, the results of $\sigma_{\rm fus}$ as a function of bombarding energy are obtained by using the analytical expression given in [2] with a fusion radius R_{fus}=8.0 fm. These calculated results are shown as a solid curve in figure 2 and

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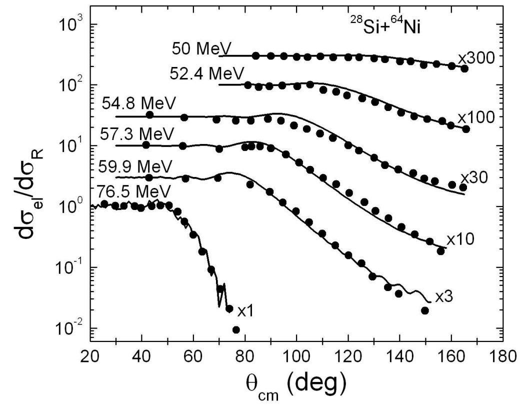

FIG. 1: Angular distribution of elastic scattering cross sections (ratios to Rutherford) of ^{28}Si+^{64}Ni system at center-of-mass energies 50, 52.4, 54.8, 57.3, 59.9 and 76.5 MeV. The full drawn curves are theoretical results of present optical model calculation. The filled in circles are experimental cross sections from [3].

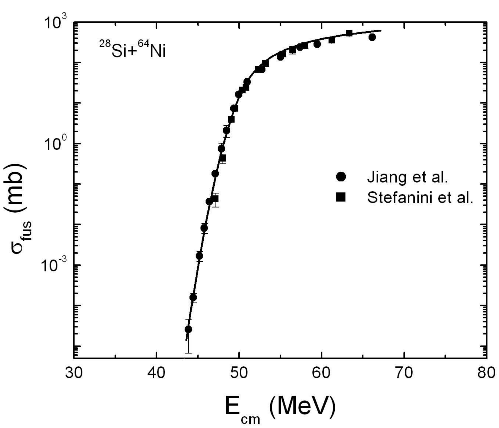

FIG. 2: Variation of fusion cross section as function of center-of-mass energy for ^{28}Si+^{64}Ni system. The solid curve represents the results of present optical model (S-matrix) calculation. The experimental data shown by solid circles and squares are obtained from [4] and [5], respectively.

they are found to explain the corresponding experimental data shown by solid dots with remarkable success. In particular, the description of the sharply falling small values of measured data in the deep sub-barrier region is outstanding. The results of $\sigma_{\rm fus}$ calculated

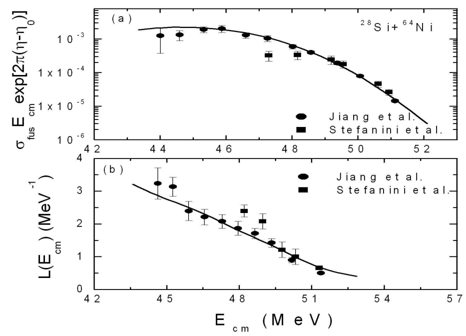

FIG. 3: (a) Comparison of calculated S factor (solid curve) with the experimental results shown by solid circles [4] and solid squares [5] for the ^{28}Si+^{64}Ni system. Here η_0=41.07. (b) Comparison of calculated L factor (solid curve) with the experimental results shown by solid circles [4] and solid squares [5] for the ^{28}Si+^{64}Ni system.

above at different energies are presented in the form of S ($=\sigma_{\rm fus}{\rm E}_{cm}\exp[2\pi(\eta-\eta_0)]$) factor, η being the Sommerfeld parameter, and L ($={\rm dln(E}\sigma_{\rm fus})/{\rm dE}$) factor. in figure 3 as solid curves and they are compared with the corresponding experimental data. While reproducing the measured data, it is clearly seen that the special features of a maximum in S factor and steep rise in L factor are closely accounted for by our calculated results.

References

[1] P Salamon and T Vertse *Phys. Rev.* C **77** 037302 (2008).

[2] Basudeb Sahu, G S Mallick, B B Sahu, S K Agarwalla and C S Shastry *Phys. Rev.* C **77** 024604 (2008).

[3] Y Sugiyama *et al Phys. Rev. Lett.* **62** 1727 (1989).

[4] C L Jiang *et al Phys. Lett.* B **640** 18 (2006).

[5] A M Stefanini *et al* 1986 *Nucl. Phys.* **456** 509 (1986)
A M Stefanini *et al Phys. Rev.* C **30** 2088 (1984).