Role of potential depth in phenomenological Nuclear Potential

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Introduction

Many-body systems in nuclear collisions of complex nature are reduced to one body problem for easiness. The one-body complex potential which describes nuclear collision is known as *optical potential.* Ginocchio potential is a versatile potential with few important parameters. We construct a phenomenological optical potential in the light of Ginocchio potential by choosing its proper parameter values related to depth and flatness in order to reproduce and explain angular distributions of experimental scattering and fusion cross-sections in wide angular ranges. The present paper discusses the effect of potential depth of the nuclear potential at the radial distance.

Theoretical Formulation

A phenomenological nuclear potential is framed using versatile Ginocchio potential [1] by developing algorithm in *FORTRAN* to study heavy-ion elastic collisions. The effective potential $V_{eff}(r)$ represented by Eq.1 contains nuclear potential $V_N(r)$, Coulomb potential $V_C(r)$ and centrifugal part V_{CF}. The complex nuclear potential $V_N(r)$ is described by Eq.2 whose real part $V_n(r)$ is given [2-8] by Eq.3. The potential has two regions, namely, volume region ($r < R_0$) and surface region ($r \geq R_0$).

$$V_{eff}(r) = V_N(r) + V_C(r) + V_{CF} \quad \ldots (1)$$

$$V_N(r) = V_n(r) + i\,W_n(r) \quad \ldots (2)$$

$$\mathbf{V_n(r)} = \begin{cases} -\frac{V_B}{B_1}\left[B_0 + \frac{(B_1 - B_0)}{\cosh^2\rho_1}\right], & \text{if } 0 < r < R_0 \\ -\frac{V_B}{B_2}\left[\frac{B_2}{\cosh^2\rho_2}\right], & \text{if } r \geq R_0 \end{cases} \quad (3)$$

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The two parameters ρ_1 and ρ_2 are given by $\rho_1 = (r - R_0)\, b_1$ and $\rho_2 = (r - R_0)\, b_2$. Here R_0 is the radial distance in surface region; b_n is slope parameter, $b_n = \frac{\sqrt{2mV_B}}{\hbar^2 B_n}$, μ is reduced mass and V_B is barrier height in MeV at $r = R_0$. Parameter B_0 controls potential depth at the origin $r = 0$, whereas, parameter V_B is related to the potential depth at R_0 position. V_B controls parameter b_n as well. The other parameter B_n decides the range of the potential. The slope parameter (b_n) is also affected by range parameter (B_n) on either side of R_0. Imaginary part $W_n(r)$ of the potential has similar expression as that of real part, but the imaginary part is weaker in strength.

Interacting nuclei, namely, projectile (P) and target (T) behave as a uniformly charged sphere. Radius (R_C) of the sphere is known as *reduced radius*, $R_C = r_C\,(A_P^{1/3} + A_T^{1/3})$. The Coulomb potential $V_C(r)$ arises due to these two interacting nuclei involved in the scattering system. The potential can be given by

$$V_C(r) = \begin{cases} \frac{Z_P Z_T e^2}{2 R_C^3}\left(3R_C^2 - r^2\right), & \text{if } r < R_C \\ \frac{Z_P Z_T e^2}{r}, & \text{if } r \geq R_C \end{cases} \quad (4)$$

Z_P and Z_T represent atomic numbers of the projectile and target. In the expression of reduced radius, r_C is the Coulomb radius parameter, A_P is the mass number of projectile nucleus and A_T is the mass number of target nucleus. The Coulomb radius parameter (r_C) is taken within the range from 1.2 fm to 1.4 fm while analyzing different collision systems.

The centrifugal potential V_{CF} be represented as $l(l+1)\hbar^2/2\mu r^2$ with reduced mass μ expressed as $\mu = \frac{m_T m_P}{m_T + m_P}$, where m_P and m_T are masses of projectile and target. This term may be neglected for $l = 0$.

Results and Discussions

The study of potential parameters helps us reproduce and explain scattering and fusion cross-sections of heavy-ion collisions [4, 6]. The nuclear potential has a non-trivial feature resulting in *neck-formation* [4] at radial distance R_0. The effective potential in Fig.1 has has an attractive potential-well with depth B_0, whereas, the depth of neck-formation is given by parameter V_B. We discuss the effect of potential depth V_B at radial distance on the shape of nuclear potential. The three different curves in Fig.2 explain the effect of V_B. The curves are compared for different parameter values, i.e., $V_B = 4$, $V_B = 6$ and $V_B = 8$. The depth for the highest V_B , i.e., $V_B = 8$ is found maximum, which is represented by a dash-curve. The curve with V_B= 4 (lowest) is found to have the minimum depth. The curve for intermediate value $V_B = 6$ is found in between those two curves.

The depth of attractive potential-well can be increased by increasing the B_0 value. Similarly, the depth of neck from the zero-line can be altered with the variation of V_B. Greater the magnitude of V_B, the bigger will be the depth of neck-structure from the zero-line. The location of the neck-structure is dependent upon R_0 value. The position of the neck-structure is shifted towards right when the value of R_0 increases, and shifted towards left when R_0 decreases. All these parameters simultaneously help us theoretically reproduce different experimental results in different energy ranges.

Conclusion

All the parameters of real part and imaginary part are theoretically significant to reproduce different experimental results in different energy ranges. They explain angular distribution in scattering cross-sections and fusion cross-sections of different systems. The proper choice of V_B value helps us explain experimental results of different scattering and fusion systems.

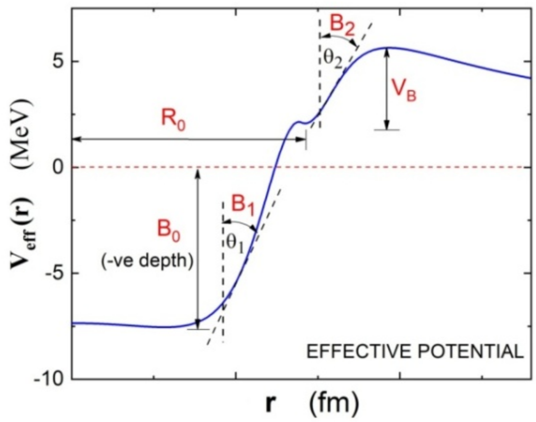

Fig.1 : *Representation of the effective potential*

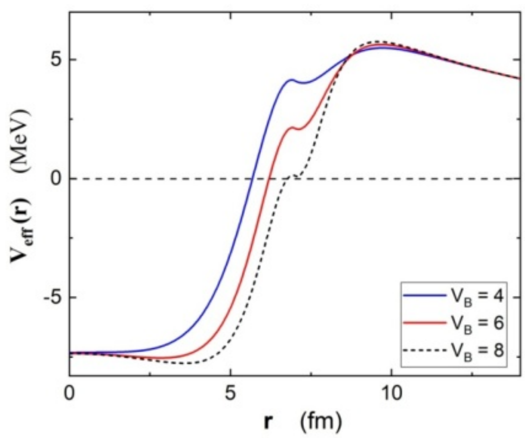

Fig.2 : *Effect of V_B on the effective potential*

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