微視的模型を用いた原子核散乱反応におけるエネルギー依存性

Takenori Furumoto
(Yukawa Institute for Theoretical Physics)

Collaborators
Y. Sakuragi (Osaka City University)
Y. Yamamoto (RIKEN)
Introduction

• Optical model potential (OMP)
  - is complex potential
  - has the imaginary part that represents the loss of flux in elastic scattering

\[ U_{opt}(r) = V(r) + iW(r) \]
Double-Folding Model (DFM)

\[ U_{\text{opt}} (R) = \int \rho_1 (r_1) \rho_2 (r_2) \nu_{\text{NN}} (s; \rho, E) \, dr_1 \, dr_2 \]

- **nucleon density**
- **effective NN interaction**
Double-Folding Model (DFM)  
with complex G-matrix interaction

Folding model potential

\[ U(R) = V_{DFM}(R) + iW_{DFM}(R) \]

= \int \rho_1(r_1) \rho_2(r_2) v_{NN}(s; \rho, E) dr_1 dr_2

Interation  
CEG07 (complex G-matrix interaction)

CEG07b (with TBF)  
CEG07a (w/o TBF)

T. Furumoto, Y. Sakuragi and Y. Yamamoto,  
Heavy-ion elastic scattering

Important effect of three-body force

T. Furumoto, Y. Sakuragi and Y. Yamamoto,
$^{12}\text{C} + ^{12}\text{C}$ elastic scattering at various energies

$^{12}\text{C} + ^{12}\text{C}$ elastic scattering

- $E/A = 100$ MeV
- $200$ MeV ($\times 10^{-2}$)
- $300$ MeV ($\times 10^{-4}$)
- $400$ MeV ($\times 10^{-8}$)

CEG07a
CEG07b

becomes large
becomes repulsive

prediction of repulsive potential

About repulsive potential

In general, nuclear interaction is attractive.

By several reasons, nuclear interaction becomes repulsive

- medium effect (Pauli principle, three-body force)
- energy dependence

The repulsive potential is obtained in the high-energy region.

Examples
- Dirac phenomenology (p-A, d-A)
- microscopic approach (p-A)
- phenomenological optical model analysis (α-A)
About repulsive pot

In general, nuclear interaction is attractive. By several reasons, nuclear interaction becomes repulsive:

- medium effect (Pauli principle, three-body force)
- energy dependence

The repulsive potential is obtained in the high-energy region.

Examples:
- Dirac phenomenology (p-A, d-A)
- microscopic approach (p-A)
- phenomenological optical model analysis (α-A)


Fig. 2. The central potential from the reaction based analysis (Refs. 7, 8 omitted).

Fig. 8. Real central potential for d+^{16}O (solid line), cal (d-A).
$^{12}$C + $^{12}$C elastic scattering at various energies

The prediction of repulsive potential becomes large as the energy increases. The potential becomes repulsive at certain energies. The calculations are based on the work of T. Furumoto, Y. Sakuragi, and Y. Yamamoto, Phys. Rev. C82, 044612 (2010).
(a) Attractive potential ($V < 0$)

The cross section by semi-classical schematic representation

(b) Repulsive potential ($V > 0$)

The cross section by semi-classical schematic representation

Potential

Scattering wave

Classical trajectory

Nearsise

Farside

$\log \sigma(\theta)$

$\theta$

$\sigma$

$F$

$N$

$T.$

Nearside and farside (N/F) decomposition

repulsive potential (E/A = 400 MeV)

$^{12}\text{C} + ^{12}\text{C}$ folding potential

attractive potential (E/A = 100 MeV)

$^{12}\text{C} + ^{12}\text{C}$ elastic scattering

The strong interference of N/F components appears.

Next step

- Inelastic cross section

Today

- Dynamical coupling effect to elastic cross section

JPS meeting (19pSF-4)
Microscopic Coupled Channel (MCC) with CEG07

Coupled Channel equation

\[
\left[ T_R + V_{\alpha\alpha}(R) - E_{\alpha} \right] \chi_{\alpha}(R) = -\sum_{\beta \neq \alpha}^{N} V_{\alpha\beta}(R) \chi_{\beta}(R)
\]

The diagonal and coupling potentials are derived from microscopic view point.

\[
V_{\alpha\beta}(R) = \int \rho_{\alpha\beta}^{(P)}(r_1) \rho_{\alpha\beta}^{(T)}(r_2) v_{NN}(s; \rho, E) dr_1 dr_2
\]

transition density

CEG07

Transition density

\[
\rho_{ik}(\vec{r}) = \langle \phi_i(\xi) | \sum_i \delta(\vec{r}_i - \vec{r}) | \phi_k(\xi) \rangle
\]

Projectile

Target
$^{12}\text{C} + ^{12}\text{C}$ elastic and inelastic scatterings at various energies

Elastic

$^{12}\text{C} + ^{12}\text{C}$ elastic scattering

$E/A = 100$ MeV

$E/A = 200$ MeV

$E/A = 300$ MeV

$E/A = 400$ MeV

Inelastic

$^{12}\text{C} + ^{12}\text{C}$ inelastic scattering

$E_x = 7.65$ MeV ($^0_2^+$)

$E/A = 100$ MeV

$E/A = 200$ MeV

$E/A = 300$ MeV

$E/A = 400$ MeV
$^{12}\text{C} + ^{12}\text{C}$ inelastic scatterings at various energies

$2_{1}^{+}$

$E_{x} = 4.44$ MeV

$E/A = 100$ MeV

$E/A = 200$ MeV

$E/A = 300$ MeV

$E/A = 400$ MeV

$3_{1}^{-}$

$E_{x} = 9.64$ MeV

$E/A = 100$ MeV

$E/A = 200$ MeV

$E/A = 300$ MeV

$E/A = 400$ MeV
CEG07 folding model predicts the repulsive nuclear potential at high energy region \((E/A = 300 - 400 \text{ MeV})\).

It is first survey that the repulsive potential for heavy-ion system is derived from the microscopic viewpoint.

**Property of nuclear repulsive potential**

- The nearside becomes large and the farside becomes small around backward angles by **not Coulomb potential but nuclear potential**.

- **The strong interference** appears at a certain energy by repulsive shift of nuclear potential in energy evolution.