Diffraction phenomena in nucleus-nucleus elastic scattering

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Introduction

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

$$U_{opt}(r) = V(r) + iW(r)$$
1. Fresnel diffraction

1. illuminant near the wall $\Rightarrow$『low energy heavy-ion scattering』
   - strong absorption,
   - strong Coulomb repulsion

heavy ion scattering by heavy ion target at low energy
   - strong absorption
   - strong Coulomb repulsion

strength

illuminated region

shadow region

$\theta_c$
$16\text{O} + 90\text{Zr}$ elastic scattering

$\text{E}_{\text{lab}} = 100 \text{ MeV}$

$(E/A = 6.25 \text{ MeV})$
2. Fraunhofer diffraction

- illuminant from infinity to the slit

A ray of light incident (incident wave) is a plane wave

\[ \lambda_D = 2R_0 (\sin \theta_2 - \sin \theta_1) \]

\[ = 2R_0 (\theta_2 - \theta_1) \]

\[ = 2R_0 \Delta \theta \]

\[ \Delta \theta = \frac{\lambda_D}{2R_0} = \frac{\pi}{kR_0} \]

\[ = \frac{\pi}{L_{gr}} \]
$4\text{He} + 90\text{Zr}$ elastic scattering

$E_{\text{lab}} = 141.7$ MeV

$(E/A = 35.6$ MeV$)$
Near-side-Farside decomposition

Near-side

Far-side

\[ \theta \]

non–Nucl.pot, non–Coul.pot.
1. $V_{coul} = 0, \ V_{nucl} \ (\text{real}) = 0$

2. $V_{coul} \neq 0, \ V_{nucl} \ (\text{real}) = 0$

3. $V_{coul} \neq 0, \ V_{nucl} \ (\text{real}) \neq 0$
**Nearside-Farside decomposition of the scattering amplitude**

- R.C. Fuller, Phys. Rev. C12, 1561 (1975),

\[
f^{(\text{nucl.})}(\theta) = \frac{i}{2k} \sum_{\ell=0}^{\infty} (2\ell + 1)e^{2i\sigma_{\ell}} (1 - S_{\ell}) P_{\ell}(\cos\theta),
\]

\[P_{\ell}(\cos\theta) = \widetilde{Q}_{\ell}^{(+)}(\cos\theta) + \widetilde{Q}_{\ell}^{(-)}(\cos\theta)\]

\[\widetilde{Q}_{\ell}^{(\pm)}(\cos\theta) = \frac{1}{2} [P_{\ell}(\cos\theta) \mp iQ_{\ell}(\cos\theta)]\]

\[= f_N(\theta) + f_F(\theta),\ (Q_{\ell}(\cos\theta) : \text{Legendre function of second kind})\]

\[
f^{(\text{nucl.})}_N(\theta) = \frac{i}{2k} \sum_{\ell=0}^{\infty} (2\ell + 1)e^{2i\sigma_{\ell}} (1 - S_{\ell}) \widetilde{Q}_{\ell}^{(+)}(\cos\theta) : \text{Nearside amplitude}\]

\[
f^{(\text{nucl.})}_F(\theta) = \frac{i}{2k} \sum_{\ell=0}^{\infty} (2\ell + 1)e^{2i\sigma_{\ell}} (1 - S_{\ell}) \widetilde{Q}_{\ell}^{(-)}(\cos\theta) : \text{Farside amplitude}\]

\[
|f^{(\text{nucl.})}(\theta)|^2 = \left|f^{(\text{nucl.})}_N(\theta)\right|^2 + \left|f^{(\text{nucl.})}_F(\theta)\right|^2 + 2\text{Re}\left(f^{(\text{nucl.})}_N(\theta)f^{*(\text{nucl.})}_F(\theta)\right)\]
Fig. 11.17. Far-side/near-side decomposition for a case \( n = 2.15, \Lambda = 17.5, \Delta = 0.86, \alpha = 1.3 \) corresponding to \( \alpha + {^{44}}\text{Ti} \) at 42 MeV. The dashed curve is the cross section due to the near-side amplitude \( f^{(+)}(\theta) \) alone, the solid straight line is due to the far-side amplitude \( f^{(-)}(\theta) \) alone, and the oscillatory solid curve is due to their coherent sum. The two terms are equal at \( \bar{\theta} \approx 36^\circ \). (After Rowley and Marty 1976.)
**Formalism**
(microscopic approach)

Folding model potential

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

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

Interaction

**CEG07** (complex G-matrix interaction)

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

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$^{12}\text{C} + ^{12}\text{C}$ elastic scattering at various energies

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

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

becomes repulsive

prediction of repulsive potential

becomes large

imaginary part

(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.
Nearside and farside (N/F) decomposition

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

- Repulsive potential ($E/A = 400$ MeV)
- Attractive potential ($E/A = 100$ MeV)

The strong interference of N/F components appears.

**Summary**

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 nucleus-nucleus potential is derived from the microscopic view point.

**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.