To Extract Optical Potentials of Exotic-Nucleus Systems by Transfer Reactions


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I. Introduction -- Why?

II. Principle -- How to?

III. Some examples

\[ {^{208}\text{Pb}}({^{7}\text{Li},^{6}\text{He}})^{209}\text{Bi}} \]

\[ {^{11}\text{B}}({^{7}\text{Li},^{6}\text{He}})^{12}\text{C}} \]

\[ {^{209}\text{Bi}}({^{16}\text{O},^{17}\text{F}})^{208}\text{Pb}} \]

IV. Conclusion
I. Introduction

i) Meanings:

♠ Nucleus-nucleus interaction potentials (optical potentials) is the basic elements in studying of nuclear reactions.

♠ Optical potentials of weakly-bound systems are quite different to those of the tightly-bound systems.

♠ Limited by the intensities and qualities of radioactive beams, it is difficult to extract optical potentials, even from elastic scatterings.

♠ Advantages of extracting potentials from transfer reactions
  a) use of stable beams – high intensities and good qualities
  b) separate the different nuclear states

$^{17}\text{F}$: G.S. (1d$_{5/2}$, no halo) v.s. Ex1 (2s$_{1/2}$, halo)
ii) Current status of optical potentials for exotic nucleus systems

$^6\text{He} + ^{209}\text{Bi}$

$\Delta E = 1.2 \text{ MeV}, \Delta \theta = 9 - 11^\circ$

$\Delta E = 1.5 \text{ MeV}, \Delta \theta = 6^\circ$

iii) Tow empirical estimations - directly from elastic scatterings

a) Variable-diffuseness model

Real potential:

\[ V = 150 \text{ MeV}, \]
\[ R = 7.95 \text{ fm}, \]
\[ a = 0.68 \text{ fm}. \]

Imaginary potential:

\[ W = 25 \text{ MeV}, \]
\[ R_I = 9.38 \text{ fm}, \]
\[ a_I = (1.964 - 0.045E_{\text{c.m.}}) \text{ fm}. \]


b) Variable-radius model

Real potential:

Double folding potential

\(^6\text{He} \) density distributions \( \leftarrow ^6\text{Li} \)

Imaginary potential:


with \( J_0 = 127 \text{ MeV} \cdot \text{fm}^3 \) and
\[ \Delta = 12.7 \text{ MeV}, \]
\[ R_I = (5.341 + 131.7/E_{\text{c.m.}}) \text{ fm}, \]
\[ a_I = 0.60 \text{ fm}. \]

II Principle

Transfer reaction: \( A(a,b)B \)

Transition amplitude:

\[
T = J \int d^3r_b \int d^3r_a \chi^{(-)}(\vec{k}_f, \vec{r}_b)^* \langle bB|V|aA \rangle \chi^{(+)}(\vec{k}_i, \vec{r}_a),
\]

4 wave functions are needed in DWBA calculations:

- two bound states: \( b+x \) & \( A+x \) (single-particle potential model)
- two scattering states: incoming & outgoing (optical potentials)
**III Some examples**

Experiments are done at HI-13 tandem accelerator at CIAE.

- $^{208}$Pb($^7$Li,$^6$He)$^{209}$Bi $E_{\text{beam}} = 42.55, 37.55, 32.55, 28.55, 25.67$ MeV
- $^{11}$B($^7$Li,$^6$He)$^{12}$C $E_{\text{beam}} = 28.3, 18.3$ MeV
- $^{209}$Bi($^{16}$O,$^{17}$F)$^{208}$Pb $E_{\text{beam}} = 93.4$ MeV

The experimental setup includes a Q3D magnet spectrometer, a Faraday cup, and a target with a thickness of 120 µg/cm². The 7Li beam is directed towards the target at an angle of $\pm 10^\circ$, with a beam energy of -300 V H.V. to suppress electron emission.
i) $^{208}\text{Pb}(^7\text{Li}, ^6\text{He})^{209}\text{Bi}$ experimental results
$^{208}$Pb($^7$Li,$^7$Li)$^{208}$Pb $E_{lab} = 42.55$ MeV

$^{208}$Pb($^7$Li,$^6$He)$^{209}$Bi(G.S.,9/2$^-$)

$^{208}$Pb($^7$Li,$^6$He)$^{209}$Bi(0.896 MeV,7/2$^-$)

$^{208}$Pb($^7$Li,$^6$He)$^{209}$Bi(1.609 MeV,13/2$^+$)

Potentials: $V=150$ MeV, $V_t=25$ MeV

Solid lines: $r_0=r_{10}=1.05$ fm, $\alpha=\alpha_1=0.80$ fm

Dotted lines: $r_0=1.0256$ fm, $\alpha=0.68$ fm, $r_{10}=1.2101$ fm, $\alpha_1=0.39$ fm
\[ \frac{d\sigma_{el}}{d\Omega_R} \]

- \( ^7 \text{Li} + ^{208} \text{Pb} \) elas. \( E_{\text{Lab}} = 25.67 \text{ MeV} \)
- \( ^6 \text{He} + ^{209} \text{Bi} \) elas. \( E_{\text{Lab}} = 19.13 \text{ MeV} \)
- \( ^{208} \text{Pb}(^7 \text{Li},^6 \text{He})^{209} \text{Bi} \)
- \( ^{208} \text{Pb}(^7 \text{Li},^6 \text{He})^{209} \text{Bi}(0.896 \text{MeV, } 7/2^-) \)
- \( ^{208} \text{Pb}(^7 \text{Li},^6 \text{He})^{209} \text{Bi}(1.609 \text{MeV, } 13/2^+) \)

Potentials: \( V = 150 \text{MeV}, V' = 25 \text{MeV} \)
Solid lines: \( r_0 = r_{l0} = 1.10 \text{fm}, \alpha = \alpha_l = 0.80 \text{fm} \)
Dotted lines: \( r_0 = 1.0256 \text{fm}, \alpha = 0.68 \text{fm}, \)
\( r_{l0} = 1.2101 \text{fm}, \alpha_l = 1.12 \text{fm} \)
ii) $^{11}\text{B}(^7\text{Li},^6\text{He})^{12}\text{C}$

**Sensitivity test**

**Phase shift !!!**

**Radius dependence**

$^{7}\text{Li}+^{11}\text{B}$ pot. – A.A. Rudchik et al., PRC 72, 034608 (2005).

$^6\text{He}+^{12}\text{C}$ pot. – M. Milin et al., NPA 730, 285 (2004).

$^{11}\text{B}(^{7}\text{Li},^{6}\text{He})^{12}\text{C}$ $E_{\text{Lab}} = 34$ MeV


$\alpha+^{40}\text{Ca}$ elastic scatterings

iii) $^{209}\text{Bi}(^{16}\text{O},^{17}\text{F})^{208}\text{Pb}$

Deduction:
Optical potentials are strongly affected by the density distributions of valence proton.
IV. Conclusions

♦ Phase shift phenomena are relative to the halo structures.

♦ The variable-radius model is more reasonable than the variable-diffuseness model.

♦ Interaction potentials are strongly dependent on the nuclear structures, especially on the halo structures.

♦ Transfer reactions are sensitive probes to extract the optical potentials of exotic-nucleus systems.
Thank you very much.