The Threshold Anomaly of Optical Potentials and the Dispersion Relation for Weakly-bound Nuclear Systems


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I. Introduction

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IV. Summary
Introduction: OMP

1. Optical Model Potential (OMP/OP)

♦ A basic task in nuclear reaction study is to probe the nuclear interaction potential.

♦ A successful model is the optical model, which resembles the case of light scattered by an opaque glass sphere.

Optical Model Potential:

\[ U = V(r) + iW(r) \]

♦ The potential is independent on the energy, at beginning.

Introduction: TA

2. Threshold Anomaly (TA)

\[ U(r; E) = V(r; E) + iW(r; E) \]
\[ V(r; E) = V_0(r; E) + \Delta V(r; E) \]

Dynamic polarization potential:
\[ \Delta V(r; E) = \frac{P}{\pi} \int_0^\infty \frac{W(r; E')}{E' - E} dE' \]

Dispersion relation (results from the causality)


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3. Breakup Threshold Anomaly (BTA)

For weakly-bound nuclear systems -- $^{6,7}$Li, $^9$Be and RNB induced reactions

Questions:

1) W increases with energy decreasing.
   - What is the reason?
   - Due to the breakup? [Hussein’s opinion]
   - Continue increasing?
   - Where is the threshold?

2) V behavior?

3) Dose the dispersion relation still hold for those systems?

4. Methods to probe OMPs

In general, OMPs are extracted by fitting angular distributions of elastic scattering.

\[ \Delta \theta = 6^{\circ} \pm 11^{\circ} \]
\[ \Delta E = 1.2 - 1.5 \text{ MeV} \]

★ Almost impossible to extract an effective OMP at energy below the barrier.

Introduction: methods

We proposed to extract the OMPs through **transfer reactions**.

\[
\begin{align*}
A + b^x & \rightarrow b + A^x \\
\text{Transfer reaction } A(a,b)B
\end{align*}
\]

In the **DWBA** calculation,

Transition amplitude:

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

4 wave functions are needed,

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

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

Two experiments have been done at HI-13 tandem acc. @ CIAE

Exp1: $E_{\text{beam}} = 42.55, 37.55, 32.55, 28.55, 25.67$ MeV
Exp2: $E_{\text{beam}} = 28.55, 25.67, 24.3, 21.2$ MeV
Experiment: exp1 spectrum

7Li

209Bi(Ex1)

209Bi(Ex2)

G.S.

6He

208Pb(Ex2)

208Pb(Ex1)

G.S.

6He

4.44 MeV

3.63 MeV

1.61 MeV

0.90 MeV

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Experiment: exp2 setup

Exp2 setup
Experiment: exp2 spectrum

(a) $^7$Li$+^{208}$Pb $E_{\text{beam}} = 28.55$ MeV

(b) Single-particle states
Results: elastic

1. Elastic scattering

![Graph showing elastic scattering data for different energies.]

CRC scheme

(a) \(^7\text{Li}\) 5/2-  \(\rightarrow\) 6.68

7/2-  \(\rightarrow\) 4.63

1/2-  \(\rightarrow\) 0.48

3/2-  \(\rightarrow\)

(b) \(^6\text{He} + ^{209}\text{Bi}\)  \(\rightarrow\) \(^6\text{Li} + ^{209}\text{Pb}\)

2. Transfer reactions

Results:

$^{208}\text{Pb}(^7\text{Li},^7\text{Li})^{208}\text{Pb}$ $E_{\text{lab}} = 42.55$ MeV

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

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

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

Potentials: $V=150$ MeV, $V_1=25$ MeV
Solid lines: $r_0=r_0=1.05$ fm, $a=a=0.80$ fm
Dotted lines: $r_0=1.0256$ fm, $a=0.68$ fm,
$r_1=1.2101$ fm, $a_1=0.39$ fm
Fig. Angular distributions of $^{208}\text{Pb}({}^7\text{Li},{}^6\text{He})^{209}\text{Bi}$ at $E_{\text{lab}}({}^7\text{Li})=28.55$ and 25.67 MeV.
Results: $^6\text{He}+^{209}\text{Bi}$ OMPs

- OMPs of the $^6\text{He}+^{209}\text{Bi}$ system are determined precisely for the first time;

- The decreasing trend in the imaginary part is observed, and the threshold energy is about 13.69 MeV ($\sim 0.73V_B$);

- The behavior of real part looks normal, i.e. like a bell shape around the barrier;

- The traditional dispersion relation does NOT hold in this system.
Transfer reactions are employed to extract the OMPs of exotic nuclear systems in the exiting channels.

- **Advantage:**
  1. stable beam;
  2. high-quality data;
  3. precise OPs.
  4. good for sub-barrier energy, where the absolute C.S. sections provide extra constraints on OMP.

OMP of the $^6\text{He}+^{209}\text{Bi}$ system have been determined precisely, showing:
  1. an abnormal TA behavior;
  2. the threshold energy. ($\sim 0.73 V_B$)

The traditional dispersion relation does not hold for the exotic systems. A new dispersion relation are strongly called for.
THANKS!
Supplement

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

\(-W(R_s)\) ($R_s = 13.5$ fm)

\(-V(R_s)\)

$E_{\text{c.m.}}$ (MeV)

$\theta_{\text{c.m.}}$ (deg)

$14.3 \text{ MeV} \times 10^3$

$17.3 \text{ MeV} \times 10^2$

$18.6 \text{ MeV} \times 10$

$21.4 \text{ MeV}$

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

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