Elastic $^3$He-transfer Reaction of $^6$He on the $^9$Be Target at 25 MeV/nucleon

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Extraction of the SFs: sources of uncertainties

For the transfer reaction \( A(a,b)B \) where \( a = b + x \), \( B = A + x \) and \( x \) is the transferred particle, the SFs are determined by

\[
\frac{d\sigma}{d\Omega} = S_{Ax} S_{bx} \sigma_{DW} \Rightarrow S_{Ax} = \frac{\frac{d\sigma}{d\Omega}}{S_{bx} \sigma_{DW}}
\]

and the DWBA cross sections are calculated by

\[
\sigma_{DW} = \left| \langle \chi_f^{(-)} \phi_b \phi_B | \Delta V | \phi_a \phi_A \chi_i^{(+)} \rangle \right|^2
\]

with

\[
\Delta V = \begin{cases} 
V_{bx} + V_{bA} - U_{bB} & \text{(post form)} \\
V_{bA} + V_{xA} - U_{aA} & \text{(prior form)}
\end{cases}
\]

A transfer reaction involves two SFs, one is of the donator \( (S_{bx}) \) and one of the acceptor \( (S_{Ax}) \).
Elastic transfer: elastic scattering + transfer reaction

\[ A + a = A(a + x) + a \rightarrow \begin{cases} 
A(a + x) + a & \text{elastic scattering}, \\
A + A(a + x) & \text{transfer of } x.
\end{cases} \]

elastic transfer is an unique tool for extracting spectroscopic factors

- For elastic transfer process, the donator and the acceptor is the same, i.e., only one SF involved. **The transfer cross section is proportional to \( S^2 \).**
- There is only one set of optical potentials.
- The interference between the elastic scattering and the transfer provides additional constraints to the optical potentials, which further helps to determine the SF.

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Introduction to the experiment

This experiment was performed with RIPS @ RIKEN.

The detector system. (Y.L. Ye et al. PRC, 71(2005)014604)
Particle identification of the telescopes

$\Delta E - E @ \text{Tel4}$

$\Delta E - \Delta E @ \text{Tel4}: \text{Be isotopes}$

D.Y. Pang (Peking University)
The energy spectrum of $^9$Be

Be isotopes

Energy spectrum of $^9$Be @ Tel4

D.Y. Pang (Peking University)  elastic-transfer between $^6$He and $^9$Be  Shanghai 2006
Angular Distribution of the elastic-transfer cross section

elastic transfer reaction of $^6$He on the $^9$Be target at 25 MeV/nucleon

outgoing $^6$He particles

inclusive $^9$Be, converted to the CM angle of $^6$He includes three mechanisms
three mechanisms: elastic, transfer, and breakup

potential scattering

$^9\text{Be}$  $^6\text{He}$  $^4\text{He}$  $^3\text{He}$  n

$^3\text{He}$-cluster *elastic-transfer* ($^6\text{He}$)

$^3\text{He}$-cluster transfer with $^6\text{He}$ breakup ($^4\text{He}$)
three mechanisms: elastic, transfer, and breakup

breakup at forward and backward angles: a mirror process

potential scattering and breakup at the forward angles

potential scattering and breakup at the backward angles
Elastic scattering and breakup cross sections at the forward angles

Subtraction of the breakup cross sections at the backward angles

elastic transfer reaction of $^6$He on the $^9$Be target at 25 MeV/nucleon

- $\sigma$ vs. $\theta$ (deg)
Calculation of the elastic transfer cross sections:

Coherent sum of elastic scattering and transfer cross sections

The amplitude of the elastic-transfer ($f_{et}(\theta)$) is the coherent sum of the amplitudes of the elastic scattering ($f_{el}(\theta)$) and the transfer ($f_{tr}(\pi - \theta)$):

$$|f_{et}(\theta)|^2 = |f_{el}(\theta) + (-)^A f_{tr}(\pi - \theta)|^2$$


We use FRESCO to do the calculations.

The entrance- and exit-channel optical potential were obtained by fitting the elastic scattering at the forward angles.

Assuming the $^3$He cluster has the quantum numbers $2N + L = 3$ and $2N + L = 4$ in the ground and the first excited state of $^9$Be, respectively, bound by a Woods-Saxon potential with $r_0 = 1.25$ fm and $a = 0.65$ fm.
A large SA is needed for our experimental data

Theoretically, the spectroscopic amplitude (SA, SF=SA\(^2\)) of \(^3\)He in the ground state of \(^9\)Be is 0.29, (D. Kurath and D.J. Millener, Nucl. Phys. A238 (1975) 269)

Our experiment requires a SA as large as 1.4.
A large SA is needed for our experimental data to look more closely...

The first excited state of $^9$Be mainly contributes to the last two points.
1 Elastic-transfer is an very effective tool of extracting the spectroscopic factors.

2 The large cross section at the backward angles in the elastic channel can be described by the $^3$He transfer.

3 The spectroscopic amplitude of the $^3$He cluster in the ground state of $^9$Be is $\sim 1.4$, which is much larger than its theoretical value.

4 Further experimental and theoretical efforts are needed for the $^3$He-cluster spectroscopic amplitude/factor.

5 Theoretically explicit treatment of the coupling effect of the breakup channel would be interesting.
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Thank you!