Lawrence Berkeley National Laboratory
Recent Work

Title
POLARIZATION SYMMETRIES IN DIRECT REACTIONS: 3He(t,d)i*He and 2H(d,p) 3H

Permalink
https://escholarship.org/uc/item/46q316kf

Author
Conzett, H.E.

Publication Date
1975-08-01
To be presented at the 4th International Symposium on Polarization Phenomena in Nuclear Reactions, Zürich, Switzerland, August 25 - 29, 1975

POLARIZATION SYMMETRIES IN DIRECT REACTIONS: $^3\text{He}(t, d)^4\text{He}$ AND $^2\text{H}(d, p)\ ^3\text{H}$

H. E. Conzett

August 1975

Prepared for the U. S. Energy Research and Development Administration under Contract W-7405-ENG-48

For Reference

Not to be taken from this room
DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.
POLARIZATION SYMMETRIES IN DIRECT REACTIONS:

$^3$He(\(\hat{t},d\))$^4$He AND $^2$H(\(\hat{d},p\))$^3$H

H. E. Conzett

Lawrence Berkeley Laboratory, University of California
Berkeley, California, 94720

The observable consequences of particle symmetry or charge symmetry in reactions of the type \(b(a,c)c'\) are well known. Here, the final-state particles \(c\) and \(c'\) are the charge-symmetric members of an isospin doublet or are identical particles, \(c = c'\). The symmetries imposed on the angular distributions of the cross section and the analyzing powers have been given by Barsay and Temmer\(^1\) and Simonius\(^2\):

\[
\sigma(\theta) = \sigma(\pi - \theta) \quad \text{for a state of definite isospin.} \quad (1A)
\]

\[
T_{Kq}(\theta) = (-1)^q T_{Kq}(\pi - \theta) \quad (1B)
\]

These symmetries are exact for \(c = c'\), but significant deviations from (1) have been observed in the $^3$He(\(d,t\))$^3$He reaction (or its inverse) at deuteron energies ranging from threshold (21.5 MeV) to 41 MeV. Nocken et al\(^3\) have concluded that the lower energy cross-section data from the inverse reaction\(^4\) are explained in terms of the compound-nucleus reaction mechanism, and they suggest that the deviations from symmetry about \(\theta = \pi/2\) result from isospin mixing in the $^6$Li intermediate nucleus. At the higher energies \(E_d = 32\) and 41 MeV, deviations from the symmetries (1) in both the cross-section\(^5\) and in the deuteron vector analyzing power\(^6\) have, in large measure, been explained via DWBA calculations as resulting from the slightly different proton and neutron transfer amplitudes\(^5,7,8\). This explanation in terms of expected Coulomb effects thus retains the concept of basic charge-symmetry at these higher energies.

There is no symmetry condition such as (1B) imposed on the polarizations, \(T_{Kq}(\theta)\), of the outgoing particle in the \(b(a,c)c'\) reaction; so, it follows that in a reaction \(a'(\hat{a},c)d\), where the identical particles \(a' = a\) or isospin partners are in the initial state, the condition (1B) on the analyzing powers does, in general, not apply. However, in this paper it is shown that if the reaction mechanism is a purely direct transfer process, condition (1B) is imposed on the analyzing powers in the \(a'(\hat{a},c)d\) reaction. This symmetry then becomes, in this class of reactions, a clear signature of the direct transfer mechanism as contrasted with the compound-nucleus, or intermediate state, process.

Figure 1 shows the two direct transfer amplitudes which are added coherently; \(N_1\) and \(N_2\) are the transferred nucleons or nucleon clusters. As examples, in the $^4$He(\(\hat{d},p\))$^4$He reaction \(N_1 = N_2 = n\), and in the $^3$He(\(\hat{t},d\))$^3$He reaction \(N_1 = n\) and \(N_2 = p\). As is noted in fig. 1, the M-matrix amplitude $M_{d,c}^{m,m}a'a$ for the transfer of \(N_2\), producing particle \(d\) at the angle \(\pi - \theta\), is described in the coordinate system with the y-axis along $\hat{k}_1\times(-\hat{k}_f)$. Rotation of the coordinate system through an angle \(\pi\) around the z-axis, so that the y-axis is along $\hat{k}_1\times\hat{k}_f$, gives\(^9\)

\[
(-1)^m M_{d,c}^{m,m}a'a \quad (\pi - \theta) \quad (2A)
\]

and \(m, m_a', m_c, m_d\) are the spin magnetic substates of particles \(a, a', c, d\).
and d. The complete M-matrix amplitude is then
\[ M_{m_m,m_d}^{(k)}(\theta) = M_{m_m,m_d}^{(1)}(\theta) + (-1)^m M_{m_m,m_d}^{(2)}(\pi-\theta) \]

In terms of two indices \( \nu = m_a + m_d \) and \( \mu = m_c + m_d \) it becomes
\[ M_{\nu \mu}(\theta) = M_{\nu \mu}^{(1)}(\theta) + (-1)^{\nu-\mu} M_{\nu \mu}^{(2)}(\pi-\theta). \] (2)

In terms of the transition matrix \( M \), the analyzing powers are given by the expression
\[ X_{\kappa \nu \nu'}(\theta) \equiv \sigma(\theta) T_{\kappa \nu \nu'} = \text{Tr}M(\theta) \tau_{\kappa \nu \nu'}^\dagger M(\theta), \] (3)
where the \( \tau_{\kappa \nu \nu'} \) are spherical tensor operators\(^9,10\) with elements
\[ \left[ \tau_{\kappa \nu \nu'} \right]_{\nu \nu'} = (2S_a + 1)/2 (-1)^{S_a-\nu'} \left< S_a, \nu \right| \left< S_a, \nu' \right| \kappa \rangle. \]
The vector addition coefficient provides that
\[ \left[ \tau_{\kappa \nu \nu'} \right]_{\nu \nu'} \neq 0 \text{ if } \kappa = \nu - \nu'. \] (4)

In terms of the elements of \( M, T_{\kappa \nu \nu'} \), and \( \tau_{\kappa \nu \nu'}^\dagger \) (3) becomes
\[ X_{\kappa \nu \nu'}(\theta) = \sum_{\mu \nu \nu'} M_{\nu \mu}(\theta) \left[ \tau_{\kappa \nu \nu'}^\dagger \right]_{\nu \nu'}^{\mu \nu}, (\theta), \] (5)

where \( \nu \) and \( \mu \) span the \((2S_a + 1)(2S_a' + 1)\) and \((2S_c + 1)(2S_d + 1)\) dimensions of the \( M \) matrix, and \( \tau_{\kappa \nu \nu'}^\dagger = \tau_{\kappa \nu \nu'} \times 1 \) is the direct product of \( \tau_{\kappa \nu \nu'} \) and the unit matrix of dimension \((2S_a' + 1)\). Using (4), eq. (5) becomes
\[ X_{\kappa \nu \nu'}(\theta) = \sum_{\mu \nu} M_{\nu \mu}(\theta) \left[ \tau_{\kappa \nu \nu'}^\dagger \right]_{\nu \nu'}^{\mu \nu} M_{\mu \nu,q}(\theta), \] (6)
and with eq. (2)

$$x_{kq}(\theta) = \sum_{\mu \nu} [ M_{\mu \nu}^{(1)}(\theta) + (-1)^{\nu-q} M_{\mu \nu}^{(2)}(\pi-\theta)] [\tau_{kq}^{(1)}(\theta) + (-1)^{\nu-q} M_{\mu \nu}^{(2)}(\pi-\theta)].$$

(7)

The particle identity or charge symmetry provides that

$$M_{\mu \nu}^{(1)}(\theta) = M_{\mu \nu}^{(2)}(\theta), \text{ or}$$

$$M_{\mu \nu}^{(1)}(\theta) = M_{\mu \nu}^{(2)}(\theta) \text{ for } a' = a.$$  

(8)

Here and in the following, wherever an equality is written for \(a' = a\) it is an approximate equality for \(a' \neq a\). Using (8) in eq. (7),

$$x_{kq}(\theta) = \sum_{\mu \nu} [ M_{\mu \nu}^{(2)}(\theta) + (-1)^{\nu-q} M_{\mu \nu}^{(1)}(\pi-\theta)] [\tau_{kq}^{(1)}(\theta) + (-1)^{\nu-q} M_{\mu \nu}^{(2)}(\pi-\theta)].$$

so that

$$x_{kq}(\theta) = (-1)^q x_{kq}(\pi-\theta) \text{ for } a' = a.$$  

(9)

It follows \((T_{00} = 1)\) that

$$T_{kq}(\theta) = (-1)^q T_{kq}(\pi-\theta) \text{ for } a' = a.$$  

(10)

The symmetry (10) thus provides clear indication of a purely direct transfer process. Of course, if the reaction should proceed through a single \(J^P\) state or states of the same parity in the compound nucleus, this symmetry condition could also result. However, an examination of the energy dependence of \(T_{kq}(\theta)\) should resolve any ambiguity. Also, the excitation energies of the intermediate nuclei which are accessible in this class of reactions with polarized beams would, almost certainly, be in regions of overlapping levels.

As a clear example of these considerations, fig. 2 shows angular distributions of the vector analyzing power \(A_{2y}(\theta) = (2/\sqrt{3})iT_{11}(\theta)\) in the \(^2\text{H}(d,p)^3\text{H}\) reaction at energies from 11.5 to 30 MeV. The 11.5 MeV data are from Zürich\(^{11}\), and the other data are from Berkeley\(^{12}\). The corresponding range of excitation energies in \(^4\text{He}\) is 29.6 to 38.8 MeV, and one sees the obvious transition from a complete lack of symmetry in the angular distribution to one of near antisymmetry with respect to \(\theta = \pi/2\), as given by eq. (10). The Zürich data range down to \(^4\text{He}\) excitation energies of 24.2 MeV, and all the analyzing power components \(T_{kq}(\theta)\) are consistent in that no such symmetry exists. Hence, analysis of these data in terms of \(^4\text{He}\) intermediate states is required at the lower deuteron energies, whereas analysis in terms of the direct nucleon-transfer process is appropriate above 30 MeV. It should be noted from the data of fig 2. that evidence persists for some contribution from
the compound-nucleus process at energies above that of the highest suggested excited state of \(^4\)He, \(^4\)He\(^*\) (32 MeV) corresponding to \(E_d = 16.5\) MeV\(^{13}\).

Another case of interest is the \(^3\)He(\(t\),d)\(^4\)He (or \(^3\)H(\(^3\)He,d)\(^4\)He) reaction. As was noted before, it has been reported\(^3\) that the lower energy cross section data suggest isospin mixing in the compound nucleus \(^6\)Li. Support for this conclusion could be provided by measurements at those energies of an analyzing power component \(T_{KQ}(\theta)\) in the \(^3\)He(\(t\),d)\(^4\)He reaction. The lack of symmetry of the form (10) would be confirming evidence for the compound-nucleus reaction mechanism. With respect to the higher energies, fig. 3 shows a DWBA calculation of the analyzing power \(A_y(\theta)\) in the \(^3\)He(\(t\),d)\(^4\)He reaction at an energy equivalent to \(E_d = 32\) MeV\(^{17}\) in the inverse reaction. The parameter values were those used by Dahme, Buttle et al\(^8\) in their fits to \(\sigma(\theta)\) and \(iT_{11}(\theta)\) in that inverse reaction \(^3\)He(\(d\),t)\(^3\)He. The near antisymmetry of \(A_y(\theta)\) about \(\theta = \pi/2\) is distinct.
Considering the presently available polarized beams, we list in Table 1 examples of reactions in which measurements of $T_{Kq}(\theta)$ may provide unambiguous information on the reaction mechanism.

\begin{table}
\begin{align*}
\text{\textsuperscript{2}H}(d,p)\text{\textsuperscript{3}H} & \quad \text{\textsuperscript{6}Li}(\text{\textsuperscript{6}Li},p)\text{\textsuperscript{11}B} \\
\text{\textsuperscript{3}He}(t,d)\text{\textsuperscript{4}He} & \quad \text{\textsuperscript{6}Li}(\text{\textsuperscript{6}Li},d)\text{\textsuperscript{10}B} \\
\text{\textsuperscript{3}He}(t,p)\text{\textsuperscript{5}He} & \quad \text{\textsuperscript{6}Li}(\text{\textsuperscript{6}Li},\text{\textsuperscript{3}He})\text{\textsuperscript{9}Be} \\
\text{\textsuperscript{3}He}(\text{\textsuperscript{3}He},p)\text{\textsuperscript{5}Li} & \quad \text{\textsuperscript{6}Li}(\text{\textsuperscript{6}Li},\alpha)\text{\textsuperscript{8}Be} \\
\end{align*}
\end{table}

The $^{6}\text{Li} + ^{6}\text{Li}$ reactions, for example, could be particularly interesting, since deviations from the symmetry (10) would provide qualitative information about states in $^{12}\text{C}$ which have some overlap with the appropriate cluster configurations.
In summary, we find that the analyzing powers, in reactions with identical or charge-symmetric particles in the initial state, can provide definite identification of the reaction mechanism, whereas no such information is available from cross-section data alone.

References

4) G. J. Wagner et al., Few Particle Problems in the Nuclear Interaction, eds. I. Slaus et al. (North Holland, Amsterdam, 1972) p. 747.
8) W. Dahme et al., Fourth Polarization Symp.
10) W. Lakin, Phys. Rev. 98 (1955) 139.
LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.