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MAXIMUM TENSOR ANALYZING POWER $A_{yy} = 1$ IN THE $^3He(\vec{d},p)\,^4He$ REACTION

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MAXIMUM TENSOR ANALYZING POWER $A_{yy} = 1$ IN THE $^3He(\vec{d},p)^4He$ REACTION*

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Polarization measurements on the $^3He(\vec{d},p)^4He$ reaction show that the efficiency A_{yy} reaches unity near $E_d = 9$ MeV and $\Theta_{CM} = 27^o$. The use of extreme values in the calibration of polarizations and the analysis of reactions is discussed.

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Maximum possible values of the analyzing power have been found in the elastic scattering of both spin-1/2 and spin-1 particles from spin-0 nuclei. Reaching an extreme value imposes conditions on the transition matrix M, which connects the spin wave functions of the incoming and outgoing channels. Experimental values for the transition matrix elements, supplied by a phase-shift analysis, can be used to determine the energy E_o and the angle Θ_o for which the conditions are met. This procedure was used by Plattner and Bacher [1] to show analytically that values $A_y = \pm 1$ occur at several energies in nucleon-^4He and ^3He-^4He elastic scattering. A similar procedure was proposed by Ohlsen _et al_. [2] for the large tensor analyzing power A_{yy} in the elastic scattering of deuterons from ^4He. On the basis of a phase-shift analysis, Grüebler _et al_. have identified 3 points (E_o,Θ_o) below 12 MeV where A_{yy} is unity [3]. It has thus been demonstrated that extreme values of polarization

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efficiencies do occur in elastic scattering with the spin configurations $1/2 + 0 \rightarrow 1/2 + 0$ and $1 + 0 \rightarrow 1 + 0$. It is the purpose of this letter to point out that they also occur in nuclear reactions.

An inspection of the $^3He(\vec{d},p)^4He$ data obtained by Grüebler et al. [4] between 2.8 and 11.5 MeV shows sizeable values for the vector efficiencies $iT_{11}(\Theta)$ and the three tensor efficiencies $T_{2q}(\Theta)$. Except for $T_{20}(0^\circ)$ near 6 MeV, no values close to the physical limits are found. Nevertheless the total polarization state is close to maximum near 10 MeV. Lakin [5] has defined a degree of polarization and described a cone which contains all physically possible states of polarization. These criteria show that states of maximum polarization are indeed attained in the $^3He(\vec{d},p)^4He$ reaction. The Cartesian efficiency

$$A_{yy}(\Theta) = -1/2\sqrt{2}\,[T_{20}(\Theta) + \sqrt{6}\,T_{22}(\Theta)] \qquad (1)$$

shows large positive values near 10 MeV for both forward and backward angles (fig. 1). Near 30 degrees some data points clearly reach the upper limit $A_{yy} = 1$. Due to possible systematic errors in the determination of the beam polarization, it is not possible to state that the efficiency indeed attains a value of unity. The data available show that the largest value of $A_{yy}(E,\Theta)$ should be found near $E_d = 9$ MeV and $\Theta_{CM} = 27^\circ$. At backward angles A_{yy} is large and rising with increasing energy. It is possible that another maximum $A_{yy} = 1$ is reached near $\Theta_{CM} = 120^\circ$ for energies above 11.5 MeV, where no data are available. More measurements are needed in both regions of interest.

In order to prove that A_{yy} must reach unity, an analysis of the reaction is needed. The data base necessary for an M-matrix analysis includes both first and second order polarization experiments at the same energy and angle. First order experiments involve the measurement of one particle polarization, while second order experiments involve the determination of two polarizations. At present not enough second order data are available to perform an M-matrix analysis in the region of interest. The occurrence of resonances makes an analysis in terms of (ℓ,s,J) reaction matrix elements possible. Considerable progress has been made in obtaining starting values for the matrix elements [6] and in performing an R-matrix fit [7] to the data. Once a good fit is available, the conditions for $A_{yy} = 1$

$$\begin{aligned} M_{1,1/2;1/2} &= - M_{-1,1/2;1/2} \\ M_{1,-1/2;1/2} &= - M_{-1,-1/2;1/2} \end{aligned} \tag{2}$$

can be discussed [1,2,3]. In eqs. (2) the M-matrix is written in the uncoupled representation. The indices denote the magnetic quantum numbers of the deuteron, ^{3}He and proton spin respectively.

The identification of points of extreme analyzing power is also possible by a method which does not involve an analysis of the reaction. Gammel et al. [8] and Ohlsen [9] have given the formulae for all first and second order polarization observables in terms of the parametrization

$$M = 1/2\sqrt{2} \begin{pmatrix} -iA-D & \sqrt{2}\,F & -iA+D & -B-C & \sqrt{2}\,E & -B+C \\ B-C & \sqrt{2}\,E & B+C & -iA+D & -\sqrt{2}\,F & -iA-D \end{pmatrix} \tag{3}$$

The equations (2) then result in the statement A = B = 0, which leads to conditions for some of the observables. At the critical energy and angle all second order coefficients given in table 1 must vanish. The quantities K_i^k and K_{ij}^k are polarization transfer coefficients, while the parameters $C_{i,k}$ and $C_{ij,k}$ are the efficiency correlation coefficients of the reaction. In addition the relations

$$P^{y'} = -A_{o,y} = K^{y'}_{yy} = -C_{yy,y}, \quad (4)$$

$$K^{y'}_{xx} = -C_{xx,y} \quad (5)$$

$$K^{y'}_{zz} = -C_{zz,y} \quad (6)$$

must be fulfilled. Here $P^{y'}$ denotes the proton polarization for unpolarized beam and target, and $A_{o,y}$ is the efficiency for target polarization. The conditions of table 1 are particularly important since the vanishing of second order coefficients does not depend on the calibration of any particle polarizations. On the other hand relations such as eqs. (4) to (6) involve the calibration of several polarizations and are thus less reliable indicators. Data from both sets are important in establishing the validity of eqs. (2), because each observable involves a different quadratic form in the parameters A through F. It is thus possible to verify eqs. (2) by a selected set of polarization experiments, which are clearly within present capabilities.

Experimental data on the $^3He(\vec{d},p)^4He$ reaction are available for all first order experiments near 9 MeV [4,10]. In addition Hardekopf et al. [11] have measured partial angular distributions of several polarization transfer coefficients at 8 MeV. Although this is somewhat below the required energy and no data are available between 25 and 30 degrees, the parameters $K^{x'}_{x}$ and $K^{x'}_{z}$, connected by a curve based on the R-matrix fit by Dodder and Hale [7], pass through zero in that region. The parameter $K^{y'}_{y}$ also vanishes, although not as a direct consequence of eq. (2). At 8 and 10 MeV parts of condition (4) can be tested, since data for the first three quantities are available (table 2). Allowing for the fact that the measurements were not taken at the critical energy and angle, the agreement is quite satisfactory. It is thus highly probable that the appropriate measurements near 9 MeV and between 25 and 30 degrees will confirm the validity of both eq. (4) and the conditions of table 1.

Once measurements of the tensor efficiencies and a few second order observables near 9 MeV and 27 degrees become available, an absolute calibration of the tensor polarization of deuterons in that energy range is possible. The $^{3}He(\vec{d},p)^{4}He$ reaction is an attractive analyzer, due to its high Q-value and relatively large cross-section. It is also well suited to calibrate other reactions because of the large energy width of the maxima.

The occurrence of maximum possible values of the analyzing power is clearly linked to resonances in the process considered. Most reactions between light nuclei exhibit relatively broad, overlapping resonances, and conditions similar to eqs. (2) may hold at some point, due to strong variations with energy induced in the transition amplitudes. Extreme values of some components of the analyzing power should therefore be a common occurrence. Indeed an inspection of the data on the $^{6}Li(\vec{d},\alpha)^{4}He$ reaction [4] yields two points near 6 and 8 MeV, for which A_{yy} is probably unity [12].

Using the procedure outlined here it is possible to identify an extreme point (E_o,Θ_o) without knowledge of the transition amplitudes of a reaction. In addition to providing an absolute calibration of polarizations, the importance of an extreme point (E_o,Θ_o) is that it offers an alternate approach to an analysis of the reaction. In terms of amplitudes the observables of a reaction form a system of bilinear equations. A solution can be obtained once an appropriate set of independent observables is available at many angles. At the point (E_o,Θ_o) additional conditions apply which are <u>linear</u> in the amplitudes.

The resulting constraints are important in view of the difficulties encountered in an analysis of nuclear reactions. It may well be worth the experimental effort to identify all extreme points (E_i, Θ_i) of a reaction, and to obtain an additional set of angular distributions at each energy E_i. In analyzing these data the linear relation is imposed directly, considerably restricting the solution space. The analysis may even be possible with a less extensive set of experimental data than otherwise required. In addition the information from the experimentally more demanding second order experiments is used to greatest advantage.

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REFERENCES

1. G. R. Plattner and A. D. Bacher, Phys. Lett. 36B (1971) 211.

2. G. G. Ohlsen, P. A. Lovoi, G. C. Salzmann, U. Meyer-Berkhout, C. K. Mitchell and W. Grüebler, Phys. Rev. C8 (1973) 1262.

3. W. Grüebler, P. A. Schmelzbach, V. König, R. Risler, B. Jenny and D. Boerma, to be published.

4. W. Grüebler, V. König and P. A. Schmelzbach, Results of measurements and analyses of nuclear reactions induced by polarized and unpolarized deuterons, Eidgenössische Technische Hochschule Zürich, internal report, May 1973.

5. W. Lakin, Phys Rev. 98 (1955) 139.

6. F. Seiler, Nucl. Phys. A187 (1972) 379, and Nucl. Phys. in print.

7. D. C. Dodder and G. M. Hale, private communication.

8. J. L. Gammel, P. W. Keaton and G. G. Ohlsen, Los Alamos Scientific Laboratory, Report No. LA-4492-MS, July 1970.

9. G. G. Ohlsen, Rep. Prog. Phys. 35 (1972) 717.

10. R. I. Brown and W. Haeberli, Phys. Rev. 130 (1963) 1163.

11. R. A. Hardekopf, D. D. Armstrong, W. Grüebler, P. W. Keaton and U. Meyer-Berkhout, Phys. Rev. C8 (1973) 1629

12. F. Seiler and F. N. Rad, to be published.

Table I. Second order polarization observables*) required to vanish for $A_{yy}=1$.

Polarization transfer coefficients	vector to vector tensor to vector	$K_{x}^{x'}$ $K_{z}^{x'}$ $K_{x}^{z'}$ $K_{z}^{z'}$ $K_{xy}^{x'}$ $K_{yz}^{x'}$ $K_{xy}^{z'}$ $K_{yz}^{z'}$
Efficiency correlation coefficients	vector and vector tensor and vector	$C_{x,x}$ $C_{z,x}$ $C_{x,z}$ $C_{z,z}$ $C_{xy,x}$ $C_{yz,x}$ $C_{xy,z}$ $C_{yz,z}$

*)Footnote: The transition matrix M in eq. (3) is given in the coordinate system defined by the incident particles [8]. The rotation to the system of the outgoing particles, denoted by primes, does not change the conditions in table 1.

Table 2. Experimental data for the parameters in eq. (4).

Parameter	E_d = 8 MeV Θ_{CM} = 35.5°	E_d = 10 MeV Θ_{CM} = 35.90	Ref.
$P^{y'}$	0.588 ± 0.014		[11]
$P^{y'}$	0.676 ± 0.022	0.757 ± 0.028	[10]
$-A_{o,y}$	0.650 ± 0.031	0.715 ± 0.031	[4]
$K_{yy}^{y'}$	0.817 ± 0.047		[11]

FIGURE CAPTIONS

Fig. 1. Values of the tensor efficiency A_{yy} for the $^3He(\vec{d},p)^4He$ reaction between 6 and 11.5 MeV [4].

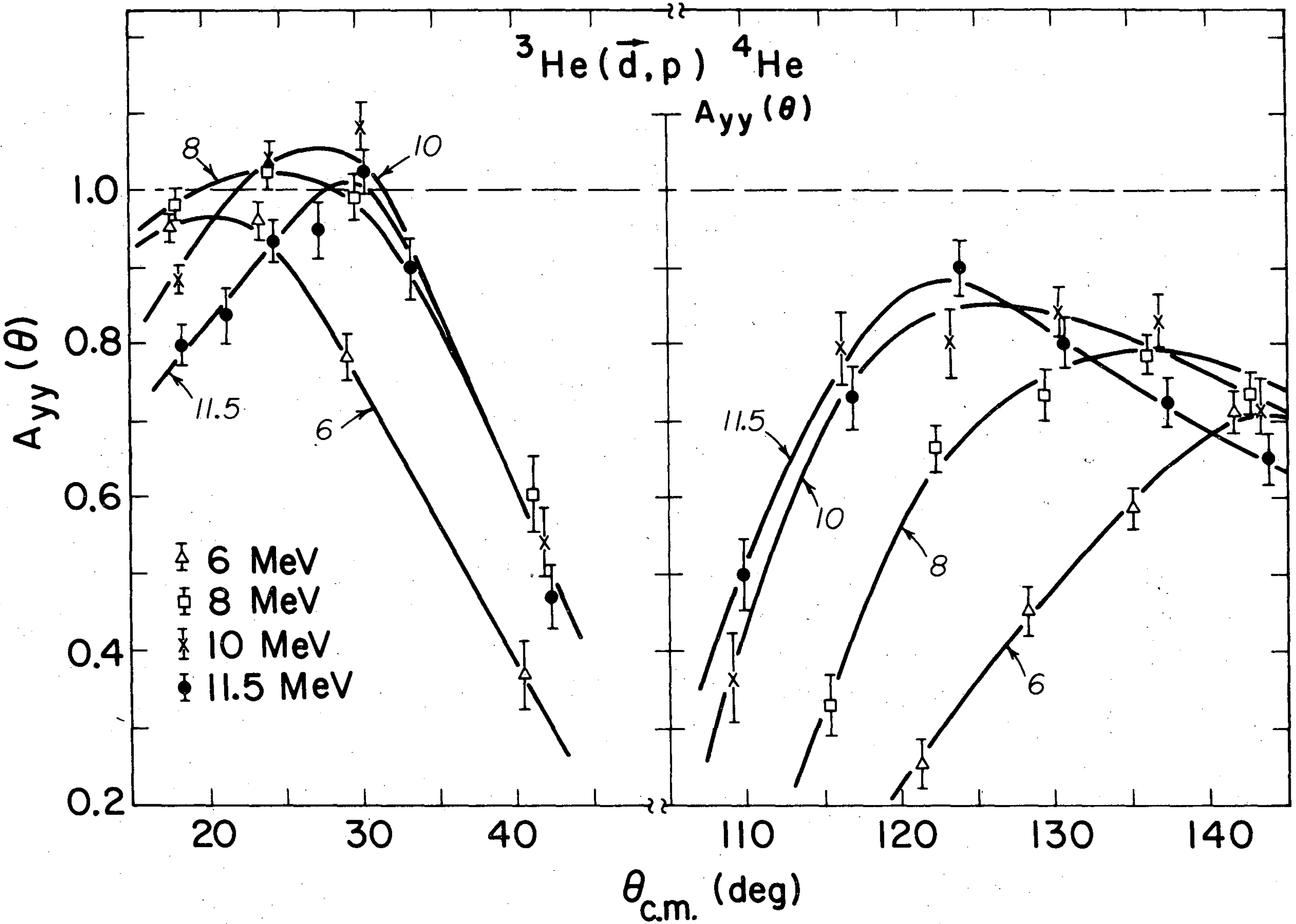

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Fig. 1

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