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Differential cross sections for $^{16}O(d,\alpha_3)^{14}N$ and unnatural parity states of ^{18}F

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The $^{16}O(d,\alpha_3)^{14}N$ reaction involves the spin-parity system $0^+1^+ \to 0^+0^-$ and as such is important for absolute determination of deuteron vector analyzing powers. To aid in such uses I have measured $d\sigma/d\Omega$ at 17 angles for $6.7 < E_d < 12.5$ MeV. The new data identify a number of unnatural parity states in ^{18}F and usually limit their J^π assignments to one of two values.

NUCLEAR REACTIONS $^{16}O(d,\alpha_3)^{14}N$, $E_d = 6.7–12.5$ MeV; measured $\sigma(E,\theta)$ at 17 angles, $\Delta E_d = 30$ keV for $E_d < 12.0$ MeV; ^{18}F deduced levels, J, π. Calculated coherence widths.

Stephenson, Knutson, and Haeberli[1] describe the conditions under which a spin-parity system $0^+1^+ \to 0^+0^-$ accurately determines (absolutely) the vector analyzing power from relatively inaccurate measurements of the tensor analyzing powers. Based upon unpublished data of Chen[2](at this laboratory), Stephenson *et al.* chose the $^{16}O(\vec{d},\alpha_3)^{14}N$ reaction at $E_d = 6.84$ MeV and $\theta_{lab} \sim 29°$ and 34°, and they obtained good absolute $|iT_{11}|$ measurements. However, the low count rate and the strong energy dependence of the reaction made the calibration measurement difficult. Since Chen's data were only for $6 < E_d < 7$ MeV, the possibility seemed good that there might be more promising energies and angles. To explore this possibility I have made detailed measurements at 17 angles of the $^{16}O(d,\alpha_3)^{14}N$ reaction in the energy range $6.7 < E_d < 12.5$ MeV. A good calibration point requires that both the cross section be high and that $|iT_{11}|$ be large. The present measurements involve only the differential cross section survey for an unpolarized beam.

The $^{16}O(d,\alpha_3)^{14}N$ reaction is also of interest because the final spin-parities (0^+, 0^-) permit only unnatural parity states of the compound nucleus ^{18}F to contribute.

The only other study of this reaction, by Jobst,[3] involved just six angles and $E_d < 9$ MeV. He did indeed see several resonances or large fluctuations in the cross section.

Silicon surface barrier detectors in a differentially pumped gas scattering chamber[4] yielded simultaneously taken excitation curves at 17 angles ($25° \le \theta_{lab} \le 170°$). For $E_d > 12$ MeV, I added another detector at $\theta_{lab} = 20°$. Careful choice of detector thicknesses permitted separation of the α_3 from all other α, proton, and deuteron groups. Natural oxygen gas (99.995% pure) at approximately 900 Pa (7 Torr) served as the target. Target thickness varied with angle and detector slits but was always small compared to the size of the deuteron energy steps; the latter were 30 keV for $E_d < 12$ MeV and 60 keV for $E_d > 12$ MeV. The deuterons lost only 7–8 keV while traveling to the center of the chamber.

Figure 1 shows the differential cross sections versus E_d for those angles which had the largest cross sections. Error bars correspond to the errors associated with counting statistics and background subtraction. Figure 2 displays all the data in terms of a Legendre polynomial expansion

$$\frac{d\sigma}{d\Omega_{c.m.}} = \sum_{0}^{\nu_{max}} a_\nu P_\nu(\cos\theta) .$$

For $E_d < 8.48$ MeV good fits required $\nu_{max} = 8$. Above $E_d = 8.48$ MeV, $\nu_{max} = 10$ was sufficient. Numerical values of the cross sections and the Legendre coefficients are available from the American Institute of Physics depository service (PAPS).[5]

For my measurements, the excitation energy in the compound nucleus ^{18}F ranges from ~13.5 to 18.6 MeV. Jolivette[6] has discussed ^{18}F in terms of the level densities expected and the observed coherence widths. He concluded that fluctuation effects become important at $E_x > 12$ MeV ($E_d \sim 5$ MeV), but for $E_x < 12$ MeV, experimental peaks probably reflect the spacings of prominent narrow levels. However, since my reaction is forbidden for natural parity states, the chance of seeing a peak from a single strong, but narrow, unnatural parity state will perhaps extend to higher excitation energies. The structure below E_d

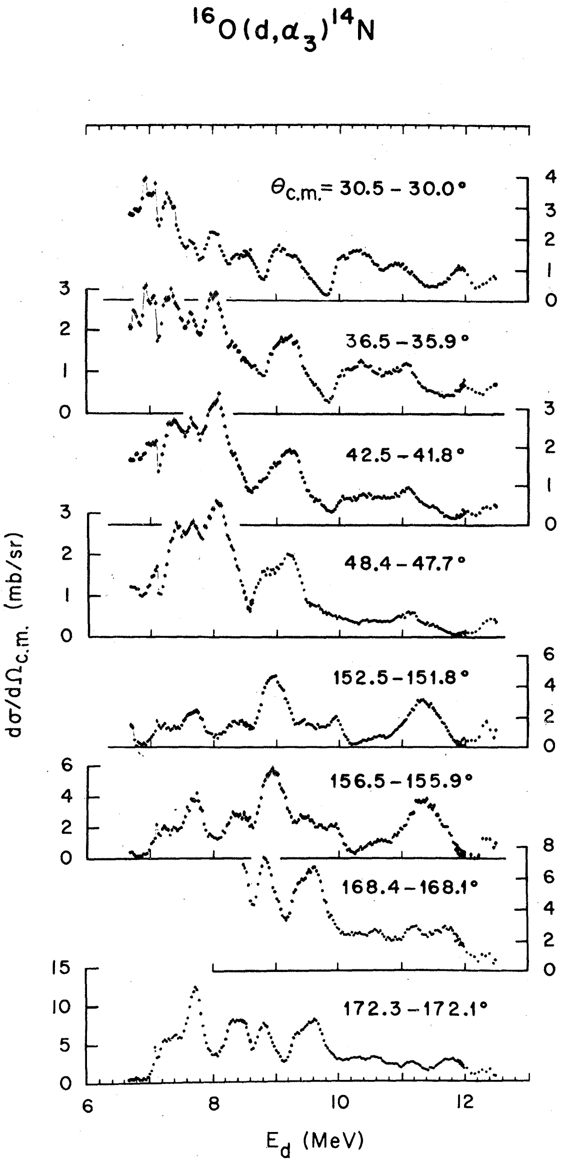

FIG. 1. Differential cross sections for the eight out of 17 laboratory angles ($\theta_{\rm lab} = 25°$, $30°$, $35°$, $40°$, $145°$, $150°$, $165°$, $170°$) which showed the largest cross sections. The abscissa is the deuteron energy at the center of the scattering chamber. Center-of-mass angles correspond to the lowest and highest E_d at $\theta_{\rm lab}$. When not shown explicitly, error bars are less than the point size.

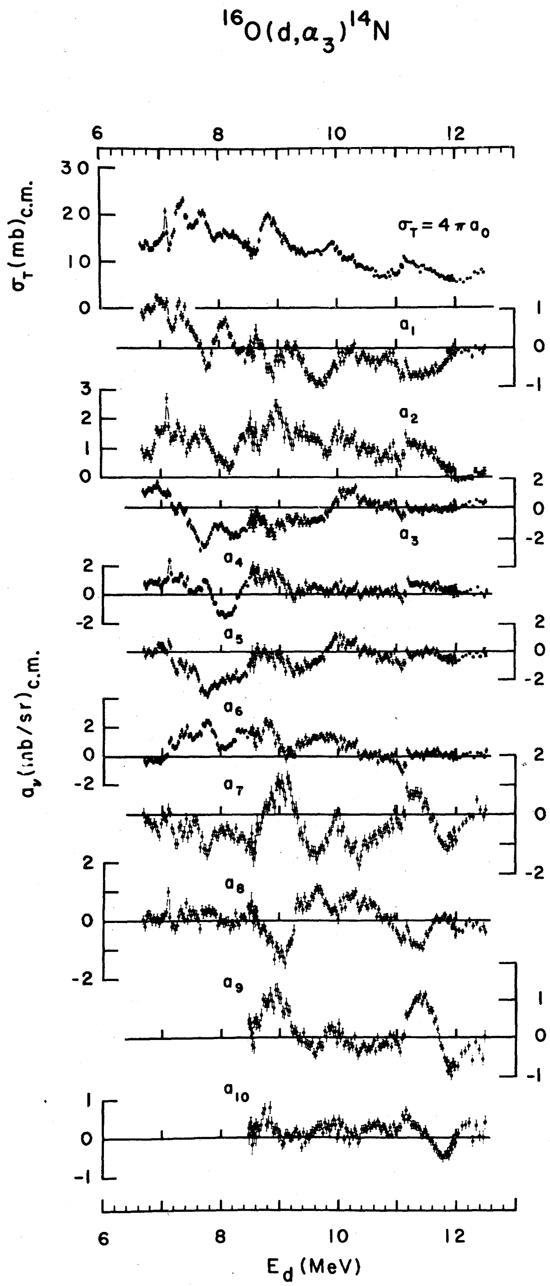

FIG. 2. Legendre coefficients for ^{16}O$(d, \alpha_3)^{14}$N.

$= 9$ MeV ($E_x = 15.5$ MeV) in the total cross section ($4\pi a_0$ in Fig. 2) seems to confirm this view. The coherence widths obtained by peak counting and the equation $\Gamma = 0.55/k$ where k is the number of peaks per MeV (Ref. 7) are listed in Table I. These coherence widths are averages over the 17 angles I studied and I saw no systematic angular dependence. The two low energy intervals have coherence widths smaller than the upper intervals by ~30%.

Table II lists the unnatural parity states in ^{18}F which I infer from Fig. 2. If a resonance appears in a_{2l}, but no higher order coefficient, then the spin system $0^+ 1^+ \rightarrow 0^+ 0^-$ ensures that the compound nucleus must have unnatural parity and $J = l$ or $l + 1$. The resonance at $E_d = 11.15$ MeV has three

TABLE I. Coherence widths.

Laboratory energy interval (MeV)	E_x (^{18}F) (MeV)	Coherence width (laboratory) (keV)
6.68-7.5	13.45-14.2	172
7.5-8.5	14.2-15.1	206
8.5-9.5	15.1-16.0	313
9.5-10.5	16.0-16.9	313
10.5-11.5	16.9-17.7	329
11.5-12.5	17.7-18.6	327

TABLE II. Unnatural parity states in ^{18}F.

E_d (MeV)	E_x (^{18}F; MeV)	Γ_{lab} (keV)	J
7.10	13.83	60	$4^-, 5^+$
7.31	14.02	60	$4^-, 5^+$
7.41	14.11	60	$4^-, 5^+$
7.74	14.40	200	$3^+, 4^-$
8.52	15.09	150	$4^-, 5^+$
8.80	15.34	200	$5^+, 6^-$
9.62	16.07	250	$4^-, 5^+$
10.35	16.72	60	$4^-, 5^+$
11.15	17.43	80	$4^-, 5^+, 6^-$

values listed for J^π since the resonance is clearly visible in a_8 ($J=4^-$, 5^+), but also it may appear in a_{10} which result implies $J=5^+$, 6^-. (The width of the a_{10} peak may imply additional states.) The uncertainty in the resonance energy is about 30 keV, and the uncertainty of the resonance width is about 20% of the listed width.

The forward angle data (Fig. 1) show no regions with cross section significantly larger than that used in Ref. 1. At backward angles there are several promising resonances or broad regions with large cross sections; for example, E_d ~7.7, 8.4, 8.8, and 9.6 MeV, but of course the vector analyzing power vanishes at $\theta=180°$.

To test the suitability of these regions for determination of vector analyzing powers requires investigation with polarized deuteron beams following the procedures described in Ref. 1. Such studies are planned at Wisconsin.[8]

My cross sections agree well with Jobst[3] in the regions of overlap. I overlap all of his angles except the one at $\theta_{c.m.} \sim 94°$. Our closest detector to this angle is at $\theta_{c.m.} \sim 87°$, but even then the agreement is good up to approximately $E_d = 8$ MeV.

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[1]K. Stephenson, L. D. Knutson, and W. Haeberli, Nucl. Phys. A277, 365 (1977).

[2]J. Chen, Ph.D. thesis, University of Wisconsin, 1977 (unpublished), available through University Microfilm, Inc., Ann Arbor, Michigan.

[3]J. E. Jobst, Phys. Rev. 168, 1156 (1968).

[4]P. B. Tollefsrud, Ph.D. thesis, University of Wisconsin, 1969 (unpublished), available through University Microfilms, Inc., Ann Arbor, Michigan; P. B. Tollefsrud and P. L. Jolivette, Phys. Rev. C 1, 398 (1970).

[5]"See AIP document No. PAPS 18-1547-40 for 40 pages of differential cross sections and Legendre coefficients. Order by PAPS number and journal reference from American Institute of Physics, Physics Auxiliary Publication Service, 335 East 45th Street, New York, N. Y. 10017. The price is $1.50 for microfiche, or $6.50 for photocopies; airmail additional. Make checks payable to the American Institute of Physics. This material also appears in *Current Physics Microform*, the monthly microfilm edition of the complete set of journals published by AIP, on the frames immediately following this journal article."

[6]P. L. Jolivette, Phys. Rev. C 8, 1230 (1973).

[7]M. G. Braga Marcazzan and L. Milazzo Colli, in *Progress in Nuclear Physics*, edited by D. M. Brink and J. H. Mulvey (Pergamon, New York, 1970), Vol. 11, p. 145.

[8]L. D. Knutson, private communication.