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34

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SPIN DEPENDENCE IN THE REACTIONS $^{16}O(p,t)^{14}O$ AND $^{16}O(p,{}^{3}He)^{14}N$*

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August 1970

Abstract

The reactions $^{16}O(p,t)^{14}O$ and $^{16}O(p,{}^{3}He)^{14}N$ have been studied at 43.7 MeV and 54.1 MeV bombarding energies. Several recent J^{π},T assignments have been confirmed, and a pair of states at 9.72 MeV in ^{14}O and 12.50 MeV in ^{14}N have been established as (2^{+}), T = 1 analogues. The relative spectroscopic strengths for the transfer reactions were compared with predictions from (1p)-shell wave functions, and the necessity for a 70% reduction of the S = 1 transition intensity relative to that for S = 0 was indicated. This effect was related to the spin- and isospin-dependence of the interaction potential.

NUCLEAR REACTIONS $^{16}O(p,t)^{14}O$ and $^{16}O(p,{}^{3}He)^{14}N$; E(p) = 43.7 and 54.1 MeV, measured $\sigma(\theta)$, assigned $J^{\pi}T$.

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1. Introduction

Two-nucleon transfer reactions have proved to be a useful method for determining the spins, parities and isospins of nuclear states, and in addition they can be a sensitive test of the accuracy of calculated nuclear wave functions. We have studied the reactions $^{16}O(p,t)^{14}O$, $^{16}O(p,^{3}He)^{14}N$ and $^{16}O(d,\alpha)^{14}N$. Recent assignments for states in ^{14}O, resulting from $(^{3}He,t)$ reaction$^{1)}$ studies, are confirmed and predictions using the (1p)-shell wave functions of Cohen and Kurath$^{2)}$ are compared with the data.

Both the (p,t) and (d,α) reactions permit the transfer of only a single value of isospin; for the former this value is T = 1 (spin S = 0) and for the latter, T = 0 (S = 1). The $(p,^{3}He)$ reaction, however, allows both T = 0 and 1 transfers with the result that it is possible to examine the relative strength of the isospin- (or spin-) dependent terms which appear in the nucleon-nucleon interaction-potential describing the reaction.

Following the distorted wave Born approximation (DWBA), the differential cross section for a two-nucleon pick-up reaction A(a,b)B can be expressed in the following form if the effects of spin-orbit coupling are included$^{3)}$:

$$\frac{d\sigma}{d\Omega} = \frac{\mu_a\mu_b}{(2\pi\hbar^2)^2} \cdot \frac{k_b}{k_a} \cdot \frac{2s_b+1}{2s_a+1} \sum_{M\sigma_a\sigma_b}^{J} \left| \sum^{NLST} b_{ST} \left(T_B T_{z_B}\, T\, T_z \middle| T_A T_{z_A}\right) D(S,T)\, G_N(LSJT)\, B^{NLSJT}_{M\,\sigma_a\sigma_b} \right|^2 . \tag{1}$$

Here, μ_a (μ_b) and $\hbar k_a$ $(\hbar k_b)$ are the reduced mass and relative momentum in the initial (final) channel. The quantum numbers L, S, J, T refer to the transferred pair of nucleons; all other quantum numbers relate to the particle indicated by their subscript. The z-components of the spins of particles a and b are denoted by σ_a and σ_b. The quantity b_{ST} is essentially a spectroscopic factor in the light particles a and b. It takes the values

$$b_{ST} = \begin{cases} -\delta_{S,0}\,\delta_{T,1} & \text{for } (p,t) \\ -\frac{1}{\sqrt{2}}(\delta_{S,0}\,\delta_{T,1} - \delta_{S,1}\,\delta_{T,0}) & \text{for } (p,{}^3\text{He}) \end{cases} \tag{2}$$

The nuclear structure information is contained in the factor $G_N(LSJT)$ which is determined by the wave functions of the initial and final nuclear states and their relative parentage coefficients. The kinematic properties of the reaction and the details of the interaction are included in B; a complete description of its properties together with an outline of the approximations used in its calculation have been given elsewhere$^{3)}$.

In the calculations presented here we will assume that the interaction has zero range$^{4)}$ but we will examine the strength of the spin- and isospin-exchange terms in the interaction potential. If the two-body interaction V_{ij} is written as

$$V_{ij} = U(r_{ij})[W + BP^{\sigma}_{ij} - HP^{\tau}_{ij} - MP^{\sigma\tau}_{ij}] \quad , \tag{3}$$

where P^{σ}_{ij} and P^{τ}_{ij} are the operators which exchange the spin and isospin coordinates of nucleons i and j, then it has been shown$^{5)}$ that D(S,T) in eq. (1) can be expressed as follows:

$$D(S,T) = 1 - (0.5 + \delta_{S,1})(B + H) \quad . \tag{4}$$

Thus, the larger the exchange terms, the more the S = 1 term in eq. (1) is reduced relative to that for which S = 0.

An examination of the $^{16}O(p,{}^{3}He)^{14}N$ reaction provides a sensitive measure of the strength of the exchange terms. Since the ^{16}O ground state has T = 0, the isospin of the final states (T = 0 or 1) determines uniquely the spin transferred by this reaction (S = 1 or 0, respectively). By comparing the relative strengths of transitions with S = 0 and 1, and making use of eq. (4) it will be possible to extract a value for (B + H). Actually the quantity which will be determined experimentally is R (see eq. (1)), where

$$R \equiv \left|\frac{D(1,0)}{D(0,1)}\right|^2 = \left|\frac{1 - 1.5(B + H)}{1 - 0.5(B + H)}\right|^2 \quad . \qquad (5)$$

Obviously, an accurate determination of R depends upon the reliability of the wave functions used for the initial and final states. Here ^{14}N is particularly advantageous since the wave functions of its ground and first two excited states have recently been examined extensively[6]) as to their efficacy in reproducing a variety of experimental data. Several sets of wave functions were studied, and certainly the best of them have a very good record of success. It was hoped that by using these calculations to analyze our data, a value of R might be extracted which was reasonably insensitive to the vagaries of untested model calculations.

Those states produced by the (p,t) reaction in ^{14}O have T = 1, and their analogues in ^{14}N will be produced by T = 1 transfer using the $(p,{}^{3}He)$ reaction. Since these are now analogous reactions, the (p,t) and $(p,{}^{3}He)$ reactions leading to T = 1 analogue states will have angular distributions with the same shape and relative magnitudes related by

$$A \equiv \frac{d\sigma/d\Omega\ (p,t)}{d\sigma/d\Omega\ (p,{}^3\mathrm{He})} = \frac{2}{2T-1}\,\frac{k_t}{k_{{}^3\mathrm{He}}} = \frac{2k_t}{k_{{}^3\mathrm{He}}} \quad . \tag{6}$$

This relationship ignores charge-dependent effects but appears to agree well with experimental data among light nuclei$^{7)}$. Four pairs of mirror levels have been observed in this experiment and the results will be compared to the predictions of eq. (6). Any significant deviation could be attributed to isopin mixing$^{8)}$.

2. Experimental Procedure and Results

Proton induced reactions on an ^{16}O gas target were carried out at 43.7 and 54.1 MeV using the external beam of the Berkeley 88" cyclotron. Reaction products were detected in two independent counter telescopes located on opposite sides of the scattering chamber. Energy signals from the counters in each system were fed to a Goulding-Landis particle identifier which produced an output signal characteristic of the particle type; this was used to route the total-energy signal into 1024-channel groups of a 4096-channel analyzer. The spectra recorded for each telescope corresponded to α particles, ^{3}He particles, tritons, and those particles slightly less ionizing than the selected triton group. The first and last groups were taken primarily to ensure that no ^{3}He or triton counts were lost. The experimental apparatus has been given a more detailed description previously[9,10]).

Figures 1 and 2 present energy spectra taken at 54.1 MeV for the $^{16}O(p,t)^{14}O$ and $^{16}O(p,{}^{3}He)^{14}N$ reactions, respectively; both were recorded simultaneously at $\theta_{lab} = 16°$. The excitation energies of observed levels in ^{14}O were determined using the known levels at (6.586 ± 0.012) and (7.780 ± 0.030) MeV as calibration. The results are listed in Table I where they are compared and averaged with previous results[1,11]). The levels observed in ^{14}N, together with their corresponding integrated cross sections, are given in Table II[12-15]). The ^{14}N excitation energies are well known and the values listed in the table are taken entirely from refs. 11 and 12. For comparison, the α-spectrum from the reaction $^{16}O(d,\alpha)^{14}N$ is shown in fig. 3; it was obtained using a 40 MeV deuteron beam.

Angular distributions of triton groups observed at 54.1 MeV bombarding energy are shown in fig. 4 where they have been grouped according to the L-value characterizing the transitions. The curves correspond to DWBA calculations using the program DWUCK16) with optical model parameters derived from elastic scattering data; these parameters are listed in Table III. Set I triton parameters were used for the curves shown, but both sets gave similar results. The L = 0, 1 and 2 fits are reasonably good although the 5.19 MeV and 5.91 MeV levels were only observed for a restricted angular range. It is interesting to notice the increasing strength of the second maximum in the L = 2 angular distributions as a function of excitation energy, and that this is not reproduced by the calculations. In fact, the discrepancy is sufficiently large for the 9.72 MeV level that only a tentative L = 2 assignment could be made. The angular distribution corresponding to the 6.29 MeV level is not particularly well fitted by L = 2 or L = 3 calculated distributions. Its second maximum is relatively much larger than that for the L = 2 distributions near the same excitation energy but its maxima and minima are displaced from the calculations for L = 3. From these data it is impossible to make even a tentative assignment for the L-transfer involved.

Because the transferred spin S is 0 for the (p,t) reaction, the spin-parities of the final states in this reaction are uniquely determined by the L-value, i.e., $J_f = L$ and $\pi_f = (-)^{J_f}$. The values of J^π corresponding to the L-value assignments made from fig. 4 appear in Table I where they are compared with previous assignments. There are no inconsistencies.

The L = 0 and 2 triton angular distributions are shown again on the left-hand side of fig. 5. On the right-hand side of the same figure are shown the (p,^{3}He) angular distributions to their known or suspected T = 1 analogues in

^{14}N; the latter have been multiplied by $(2k_t/k_{^3He})$ to facilitate the comparison suggested by eq. (6). In this case, the dashed curves are not the results of calculations; their shapes were determined as providing the best fit to the triton data. The same curves, but renormalized, were then drawn through the corresponding (p,^{3}He) angular distributions. For two states which are analogues, the dashed curve should fit the (p,^{3}He) data, and the magnitudes of the distributions as they appear in the figure should be the same. These conditions are satisfied for the four pairs of states shown in the figure, thus confirming them as analogues. For the 9.72 MeV state in ^{14}O and 12.50 MeV state in ^{14}N this is the first such indication, and for the latter state the deduced J^π and T are given in Table II. All our T = 1 assignments to states in ^{14}N are confirmed by the absence of these states in the (d,α) spectrum of fig. 3.

A quantitative comparison of the cross sections for the observed analogue states appears in Table IV. Agreement with the predictions of eq. (6) is similar to that obtained for other light nuclei$^{7)}$. No significant deviations are evident.

Figure 6 gives the measured angular distributions at both bombarding energies for the first four strong states produced in the (p,^{3}He) reaction. The curves are again the result of DWBA calculations using the optical-model parameters listed in Table III, and again ^{3}He parameter-sets I and II gave similar distribution shapes. In a detailed analysis of the first three transitions we have used six different sets of wave functions to calculate spectroscopic amplitudes from which the factors G_N(LSJT) of eq. (1) are derived. The wave functions range from the jj-coupling limit to effective-interaction calculations, and are taken from a recent survey article$^{6)}$ on ^{14}N. The G_N(LSJT) factors and their specific sources are listed in Table V. These factors indicate that for all wave functions the ground-state transition predominantly carries an angular momentum L = 2 while the state at 3.95 MeV strongly prefers L = 0 except in the jj-limit; the 2.31 MeV state is obviously restricted to L = 0. Thus, the shapes of the calculated angular distributions for the ground and 2.31 MeV states, shown as solid curves in the figure, are unaffected by the choice of wave functions (as is the L = 2 distribution to the 7.03 MeV state). For the 3.95 MeV state, calculations using Set I wave functions result in the solid curve, while those from the other sets result in the dashed curve.

The relative magnitudes of these angular distributions are affected not only by the details of the wave functions but also by the form of the interaction potential, or specifically by D(S,T). Since each transition is characterized by a unique value of S, then $[D(S,T)]^2$ appears as a simple multiplicative factor in the expression for the cross section, and the ratio R [see eq. (5)] can be determined directly by comparison with the data. The results appear in Table VI where they are tabulated as a function of wave function, optical-model parameters and bombarding energy. Except for wave-function sets I and II, which were deemed generally less successful[6]) in fitting experimental data, the range of R values is not large, although R is systematically lower for the higher bombarding energy. A best value of R would be ~ 0.28. The resultant $B + H \approx 0.4$ is not significantly different from the force mixtures frequently used in shell-model calculations.

Using the value of R just determined and the wave functions of Cohen and Kurath[2]) (Set VI) relative magnitudes were calculated for prominent peaks observed in the $^{16}O(p,{}^3He)^{14}N$ reaction at both bombarding energies. The results are compared with experiment in Table VII. The agreement with the first four states is within expectations for two-nucleon transfer reactions$^{3)}$ and is particularly good at the lower bombarding energy. It is noteworthy that the 7.03 MeV level, which was not used to determine R, shows such good agreement at both energies.

States above 8 MeV in ^{14}N are known to involve significant contributions from (2s,1d)-shell configurations, so the inadequacy of the (1p)-shell calculations for these states should not be surprising. Certainly for negative parity states, the lowest of which occurs at ∿ 5 MeV, (2s,1d)-shell excitation must be involved. Dominant configurations in the predicted wave functions are shown in the last column of Table II. The (1p)-shell calculations predict only one 2^+, T = 1 level at ∿ 10 MeV in ^{14}N whereas two states, at 9.172 MeV and 10.432 MeV, are observed. It has been suggested$^{14)}$ that these two states involve about equal mixtures of $(1p)^{10}$ and $(1p)^8$ $(2s,1d)^2$ configurations which would require approximately equal population for both states in the (p,^{3}He) reaction (and the same, of course, for their analogues in ^{14}O). Our results are consistent with this expectation.

The angular distribution of the (p,^{3}He) reaction leading to the 11.05 MeV state in ^{14}N is shown in fig. 7. Two states have been observed at about this excitation previously$^{11)}$; one has been assigned 1^+ but the spin of the other is unknown. The calculations reproduced in Table II show that a 3^+ level involving two holes in the $(1p_{3/2})$-shell is expected at about this excitation energy and curves are shown in the figure for DWBA calculations which assume both $J^\pi \equiv 1^+$ and 3^+. The shape of the angular distribution is better reproduced with the 3^+ assignment and better agreement with its relative magnitude is also obtained (see Table VII). Thus, it seems likely that we are observing a 3^+ level at 11.05 MeV more strongly than the 1^+ state which has previously been recorded at 11.04 MeV. A 2^+ state formed from the same $(1p_{3/2})^{-2}$ configuration is predicted at ∿ 15 MeV and there is some possibility that we are observing such a state at 12.503 MeV. However, (2s,1d)-shell components which are already significant in the 2^+ states at 10 MeV will certainly distort these simple predictions and this precludes meaningful comparison with the experimental results.

3. Discussion

Spin dependence in the interaction potential of a transfer reaction is required by the nature of the nucleon-nucleon force$^{5)}$. Its precise relationship to that force, though, is clouded by the many approximations which must be made in deriving the expression for a measurable cross section. Further, as we have pointed out, it is necessary to have reliable wave functions and a proven independence of the selection of optical model parameters. Our choice in examining the $^{16}O(p,{}^3He)^{14}N$ reaction resulted from the availability of such wave functions, and we have also demonstrated that our conclusions are insensitive to experimental parameters.

Certainly there are shortcomings since we must neglect the anticipated (2s,1d)-shell components in the first few states in ^{14}N [see ref. 13)] as well as in the ground state of ^{16}O [see ref. 17)]. However, to the extent that the states in ^{14}N can be regarded as (1p)-shell holes in the ^{16}O ground state, the effects of higher shells will be minimized. In a previous study of the reaction$^{18)}$ $^{12}C({}^3He,p)^{14}N$ the value of R extracted from experiment showed wide variation with bombarding energy and in all cases was higher than our result. It is possible that their inconsistencies can be attributed to the inadequacy of the assumed reaction mechanism at energies $\leqslant$ 20 MeV, but the apparent higher value of R may well be caused by neglecting (2s,1d)-shell configuration mixing, to which such a stripping reaction would be more sensitive.

It is certainly encouraging that the measured spin dependence is in reasonable agreement with the expected force mixture$^{5)}$, but it is still necessary to extend such measurements to a large number of nuclei over a wide region of masses.

4. Acknowledgments

We should like to thank Dr. Dieter Kurath for sending us the results of his calculations of spectroscopic amplitudes prior to their publication.

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Table I. Energy Levels of ^{14}O.

This work Excitation Energy (MeV ± keV)	J^π	Previous work[a] Excitation Energy (MeV ± keV)	J^π	Average Excitation Energy (MeV ± keV)
g.s.	0^+	g.s.	0^+	
5.21 ± 40	(1^-)	5.17 ± 40	(1^-)	5.19 ± 28
5.92 ± 60	(0^+)	5.905 ± 12	0^+	5.906 ± 12
6.28 ± 50		6.29 ± 25	(3^-)	6.29 ± 22
6.59[b]	2^+	6.586 ± 12	2^+	
7.78[b]	2^+	7.78 ± 30	2^+	
8.69 ± 60		8.74 ± 60		8.72 ± 42
9.65 ± 60	(2^+)	9.74 ± 30		9.72 ± 27

[a] Only states corresponding to transitions observed in these experiments are listed. The data are taken from ref. 11); spin-parity assignments are due to Ball and Cerny 1) and Adelberger and McDonald (Nucl. Phys. A145 (1970) 497).

[b] These values were used to determine the energy scale.

Table II. Energy Levels of ^{14}N Produced in the Reaction $^{16}O(p,{}^{3}He)^{14}N$.

Levels of $^{14}N^{a}$			Shell Model Calculations[c]	
Energy (MeV)	J^{π},T	Experimental σ^{b} at E_p = 54.1 MeV (μb)	Energy (MeV)	Dominant configurations
g.s.	1^{+}, 0	195	g.s.	$-0.208(p_{1/2}p_{3/2})^{-1} + 0.975(p_{1/2})^{-2}$
2.313	0^{+}, 1	185	2.69	$-0.405(p_{3/2})^{-2} + 0.914(p_{1/2})^{-2}$
3.945	1^{+}, 0	295	3.62	$-0.318(p_{3/2})^{-2} + 0.932(p_{1/2}p_{3/2})^{-1}$
5.106	2^{-}, 0	75	4.83	$0.983(p_{1/2})^{-3}(d_{5/2}) + 0.184(p_{1/2})^{-3}(d_{3/2})$
5.834	3^{-}, 0	60	5.60	$1.000(p_{1/2})^{-3}(d_{5/2})$
7.028	2^{+}, 0	205	6.99	$1.000(p_{1/2}p_{3/2})^{-1}$
7.966	(2^{-}),0	40	7.89	$0.184(p_{1/2})^{-3}(d_{5/2}) - 0.983(p_{1/2})^{-3}(d_{3/2})$
8.489	4^{-}, 0	100		
9.172	2^{+}, 1^{d}	145	9.14	$0.214(p_{3/2})^{-2} + 0.977(p_{1/2}p_{3/2})^{-1}$
10.432	2^{+}, 1^{d}	160		
11.053	1^{+}, 0	130	15.24	$0.945(p_{3/2})^{-2} - 0.297(p_{1/2}p_{3/2})^{-1}$
	$(3^{+}$, 0)		10.14	$1.000(p_{3/2})^{-2}$
12.503	(2^{+}),1^{e}	60	15.19	$0.977(p_{3/2})^{-2} - 0.214(p_{1/2}p_{3/2})^{-1}$

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a) Only states corresponding to transitions observed in these experiments are listed. The data are taken from refs. 11) and 12).

b) Cross section integrated from 13° to 65°.

c) Calculations for positive parity levels considered only p-shell configurations 2). For negative parity levels, ref. 13) was used in which the $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$, and $1d_{3/2}$ shells were all considered active.

d) The two experimental (2^{+}, 1) states apparently have mixed configurations, involving about equal (1p)- and (2s,1d)-shell components 14,15).

e) The J^{π},T assignment is the result of this work.

Table III. Optical Model Parameters[a] used in DWBA Calculations.

Particle	Energy[b] (MeV)	V_0 (MeV)	W_0 (MeV)	W_1 (MeV)	V_S (MeV)	r_0 (fm)	r'_0 (fm)	r_s (fm)	r_c (fm)	a (fm)	a' (fm)	a_s (fm)	Ref.
proton (54.1 MeV)	52.5	38.38	21.49	3.81	5.75	1.141	1.26	1.066	1.3	0.715	0.64	0.674	c
proton (43.7 MeV)	43.1	44.53	17.51	6.51	6.20	1.141	1.26	1.066	1.3	0.715	0.64	0.674	c
triton, ^{3}He (1)	29.0	169.0	32.1	--	--	1.14	1.82	--	1.4	0.675	0.566	--	d
triton, ^{3}He (2)	30.0	220.0	23.8	--	--	1.22	1.80	--	1.3	0.530	0.990	--	e

[a] The potential used has the form

$$V(r) = V_c(r) - V_0\left(\frac{1}{e^x+1}\right) - i\,W_0\left(\frac{1}{e^{x'}+1}\right) - i\,W_1\,e^{-x'^2} - \left(\frac{\hbar}{M_\pi c}\right)^2 V_S\,\frac{1}{r}\,\frac{d}{dr}\left(\frac{1}{e^{x_s}+1}\right)\underline{\sigma}\cdot\underline{\ell}\quad,$$

where $V_c(r)$ is the Coulomb potential for a uniformly charged sphere of radius $r_cA^{1/3}$ fm, $x = (r - r_0A^{1/3})/a$, $x' = (r - r'_0\,A^{1/3})/a'$, and $x_s = (r - r_s\,A^{1/3})/a_s$.

[b] Particle energy for which optical model parameters were determined.

[c] Determined from proton elastic scattering on ^{16}O : W. T. H. Van Oers and J. M. Cameron, Phys. Rev. 184 (1969) 1061, and private communication. In order to improve the details of the fits to our angular distributions we have increased W_0 in these parameters. This is not uncommon in such light nuclei (see, for example, L. A. Kull and E. Kashy, Phys. Rev. 167 (1968) 963) and has little effect on the predicted relative magnitudes.

(continued)

Table III. Continued

[d] Determined from ^{3}He elastic scattering on ^{14}N: J. C. Hiebert, E. Newman, and R. H. Bassel, Phys. Rev. 154 (1967) 898.

[e] Determined from ^{3}He elastic scattering on ^{12}C: N. F. Mangelson, private communication quoted in ref. [9]).

Table IV. Experimental and Calculated Cross-Section Ratios for T = 1 Analogue States in ^{14}O and ^{14}N at E_p = 54.1 MeV

Excitation Energy (MeV) in			Experimental	Calculated
^{14}O	^{14}N	J^{π}	A^a	A^a
g.s.	2.311	0^+	2.10 ± 0.20	1.91
6.59	9.170	2^+	1.67 ± 0.20	1.90
7.78	10.431	2^+	2.02 ± 0.25	1.90
9.65	12.50	(2^+)	1.83 ± 0.25	1.90

[a] A is defined in the text as $\frac{d\sigma}{d\Omega}(p,t)/\frac{d\sigma}{d\Omega}(p,{}^3He)$. The experimental value is the relative normalization factor required to produce the fits to the $(p,{}^3He)$ data in fig. 5.

Table V. The Factors $G_N(LSJT)$ Corresponding to Various Sets of p-Shell Wave Functions for the Ground and First Two Excited States of ^{14}N Produced in the Reaction $^{16}O(p,{}^3He)^{14}N$.

Calculation[a]		Ground State $(J^\pi,T)=(1^+,0)$		2.31 MeV Level $(J^\pi,T)=(0^+,1)$	3.95 MeV Level $(J^\pi,T)=(1^+,0)$	
Set	Source	$G_1(0110)$[b]	$G_0(2110)$	$G_1(0001)$[b]	$G_1(0110)$[b]	$G_0(2110)$
I	jj-limit	+0.233	-1.044	+0.700	-0.934	-0.522
II	Soper[c]	+0.247	-1.105	+0.774	-1.100	-0.381
III	Elliott[d]	-0.093	-1.190	+0.976	-1.189	+0.061
IV	Visscher & Ferrell[e]	-0.210	-1.116	+0.927	-0.986	-0.089
V	Cohen & Kurath[f]	-0.107	-1.167	+1.049	-1.168	+0.017
VI	Cohen & Kurath[g]	-0.165	-1.167	+1.067	-1.166	+0.085

[a] The wave functions used here were obtained by H. J. Rose *et al.* and are quoted in Table III of ref. [6].

[b] The corresponding G factor for which N = 0 is given by the following:

$$\frac{G_0(0110)}{G_1(0110)} = \frac{G_0(0001)}{G_1(0001)} = 0.139$$

[c] J. M. Soper (private communication to H. J. Rose, cited in ref. [6]).

[d] J. P. Elliott, Phil. Mag. 1 (1956) 503.

[e] W. M. Visscher and R. A. Ferrell, Phys. Rev. 107 (1957) 781.

[f] S. Cohen and D. Kurath, Nucl. Phys. 73 (1965) 1, (8-16)2BME, ε = 5.67 MeV.

[g] S. Cohen and D. Kurath, *ibid*, ε = 5.15 MeV.

Table VI. Values for the Ratio $[D(1,0)/D(0,1)]^2$ Determined from Experiments at Two Different Bombarding Energies, Assuming Various Sets of Wave Functions and Optical-Model Parameters.

Wave Function Set[a]	$[D(1,0)/D(0,1)]^2$				
	E_p = 43.7 MeV		E_p = 54.1 MeV		Average
	1[b]	2[b]	1[b]	2[b]	
I	0.19	0.19	0.14	0.15	0.17
II	0.19	0.19	0.15	0.15	0.17
III	0.26	0.27	0.21	0.22	0.24
IV	0.30	0.31	0.25	0.26	0.28
V	0.33	0.32	0.25	0.26	0.29
VI	0.33	0.33	0.26	0.27	0.30

[a] The references for these wave functions appear in Table V.

[b] These numbers refer to the ^{3}He optical-model parameters given in Table III. The appropriate proton parameters were used for both bombarding energies.

Table VII. Comparison of Experimental and Theoretical Relative Peak Cross Sections for the Reaction $^{16}O(p,{}^3He)^{14}N$ Leading to Positive-Parity Final States.

Levels of ^{14}N		Relative Peak Cross Section			
		E_p = 43.7 MeV		E_p = 54.1 MeV	
Energy (MeV)	J^π,T	Experiment[a]	Theory[b]	Experiment[a]	Theory[b]
g.s.	1^+, 0	1.00	1.00	1.00	1.00
2.311	0^+, 1	1.25	1.33	0.88	0.47
3.945	1^+, 0	1.40	1.30	1.09	0.50
7.029	2^+, 0	0.95	0.88	0.91	0.85
9.170	2^+, 1			0.54	--
10.431	2^+, 1			0.53	--
11.05	1^+, 0			0.36	0.06
	3^+, 0			0.36	0.68
12.50	(2^+),1			0.15	--

a) The differential cross-section at the first observed peak in the angular distribution is quoted relative to that for the ground state.

b) The wave functions used are those given in Table II; they correspond to set VI in Table V. The ^{3}He optical model parameters 1 from Table III were used. The value of R was taken to be 0.28.

Figure Captions

Fig. 1. Energy spectrum of the $^{16}O(p,t)^{14}O$ reaction.

Fig. 2. Energy spectrum of the $^{16}O(p,^{3}He)^{14}N$ reaction.

Fig. 3. Energy spectrum of the $^{16}O(d,\alpha)^{14}N$ reaction.

Fig. 4. Angular distributions of triton groups observed from the reaction $^{16}O(p,t)^{14}O$ at 54.1 MeV. The curves are from DWBA calculations for the indicated L-values using the parameters in Table III.

Fig. 5. Angular distributions for the reactions $^{16}O(p,t)^{14}O$ and $^{16}O(p,^{3}He)^{14}N$ at 54.1 MeV leading to analogue T = 1 states. The ^{3}He points have been multiplied by $(2k_t/k_{^{3}He})$. The dashed curves have no theoretical significance but are fitted to the (p,t) data; the same curves, simply renormalized, are drawn through the corresponding $(p,^{3}He)$ data.

Fig. 6. Angular distributions of ^{3}He particles from the reaction $^{16}O(p,^{3}He)^{14}N$ at two different bombarding energies. Both solid and dashed curves are the results of DWBA calculations which are described in the text.

Fig. 7. Angular distribution of ^{3}He particles from the reaction $^{16}O(p,^{3}He)^{14}N$ leading to the 11.05 MeV state in ^{14}N. The bombarding energy was 54.1 MeV. The curves are from DWBA calculations for the indicated L-values.

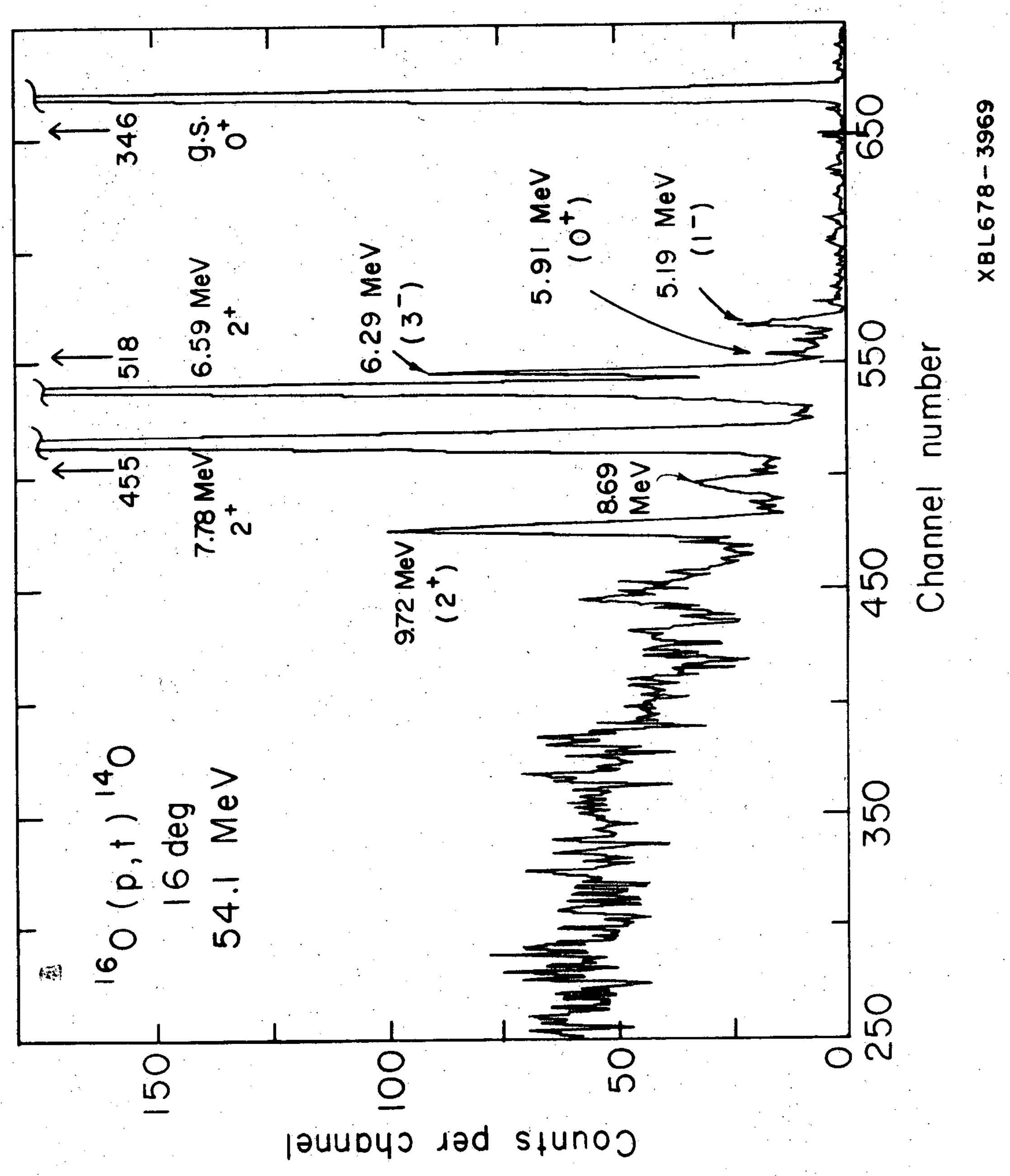

^{16}O (p,t) ^{14}O
16 deg
54.1 MeV
346
g.s.
0^+
518
6.59 MeV
2^+
6.29 MeV
(3^-)
5.91 MeV
(0^+)
5.19 MeV
(1^-)
455
7.78 MeV
2^+
8.69 MeV
9.72 MeV
(2^+)
Channel number
250
350
450
550
650
Counts per channel
0
50
100
150
XBL678-3969

Fig. 1

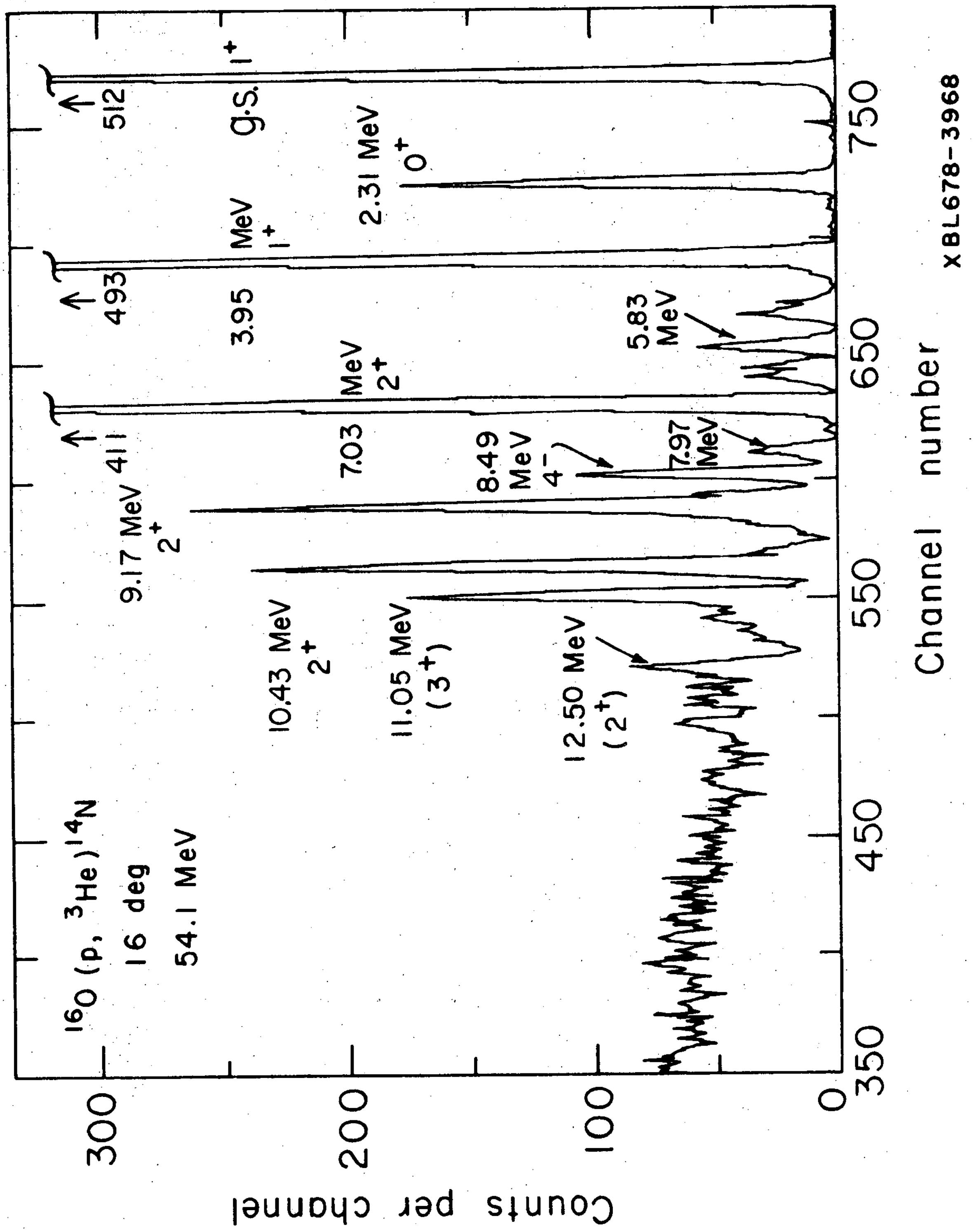

$^{16}O(p, {}^3He)^{14}N$
16 deg
54.1 MeV
512
g.s. 1^+
2.31 MeV 0^+
493
3.95 MeV 1^+
5.83 MeV
411
7.03 MeV 2^+
7.97 MeV
8.49 MeV 4^-
9.17 MeV 2^+
10.43 MeV 2^+
11.05 MeV (3^+)
12.50 MeV (2^+)
Counts per channel
0
100
200
300
Channel number
350
450
550
650
750
XBL678-3968

Fig. 2

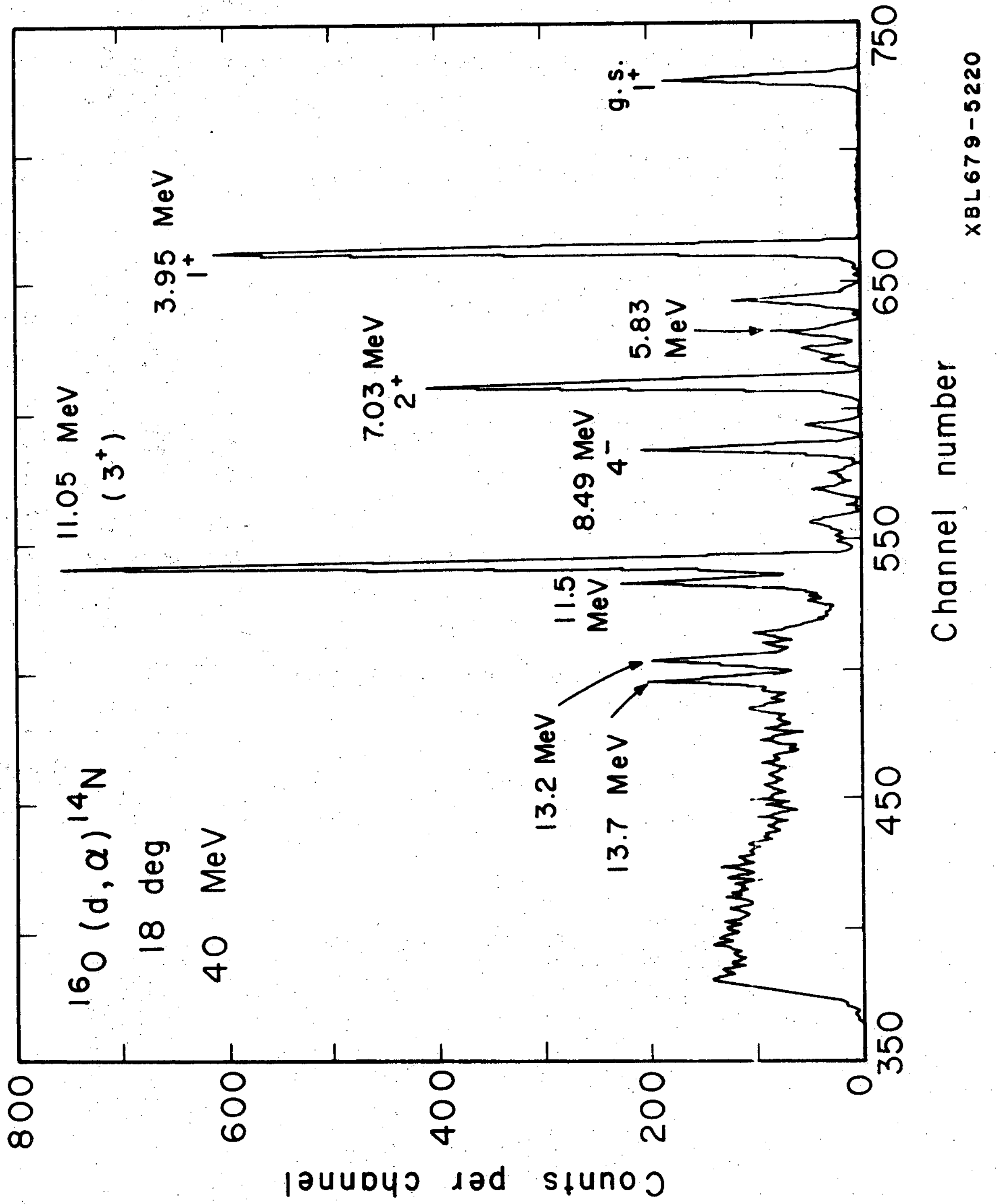
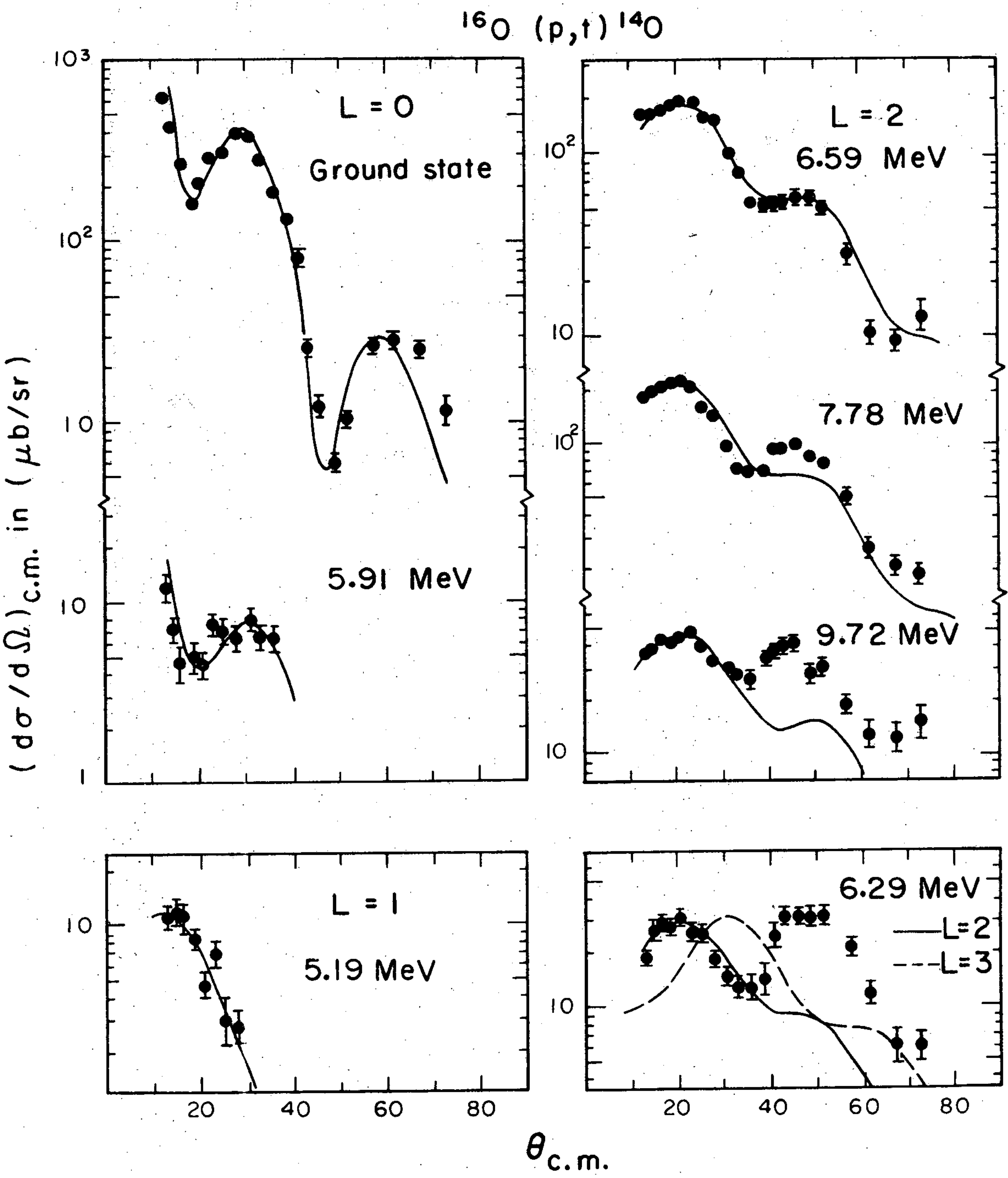
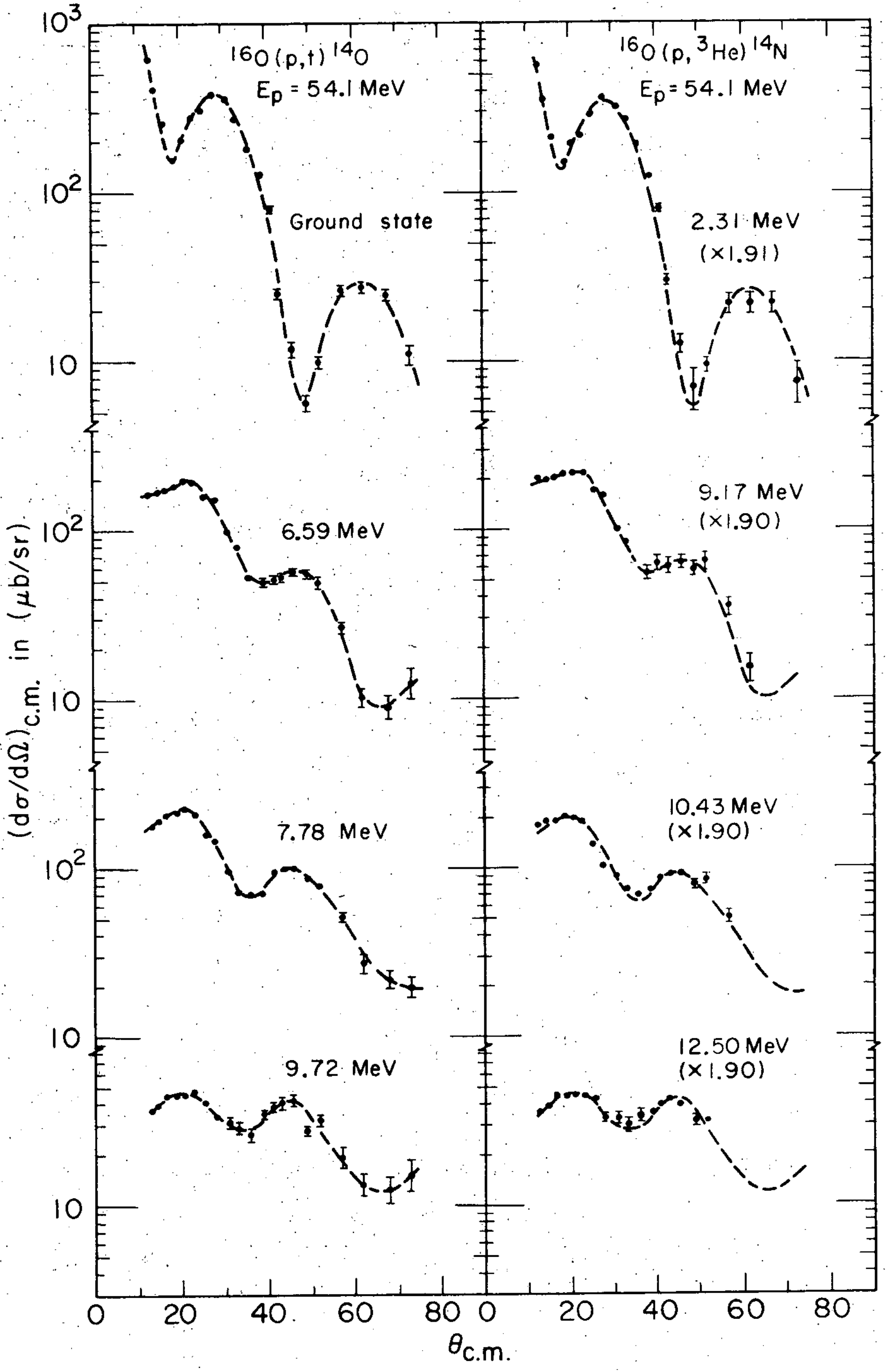

16O (d, α) 14N
18 deg
40 MeV
11.05 MeV
(3+)
3.95 MeV
1+
7.03 MeV
2+
8.49 MeV
4−
5.83 MeV
g.s.
1+
11.5 MeV
13.2 MeV
13.7 MeV
Channel number
Counts per channel
350
450
550
650
750
0
200
400
600
800
XBL679-5220

Fig. 3



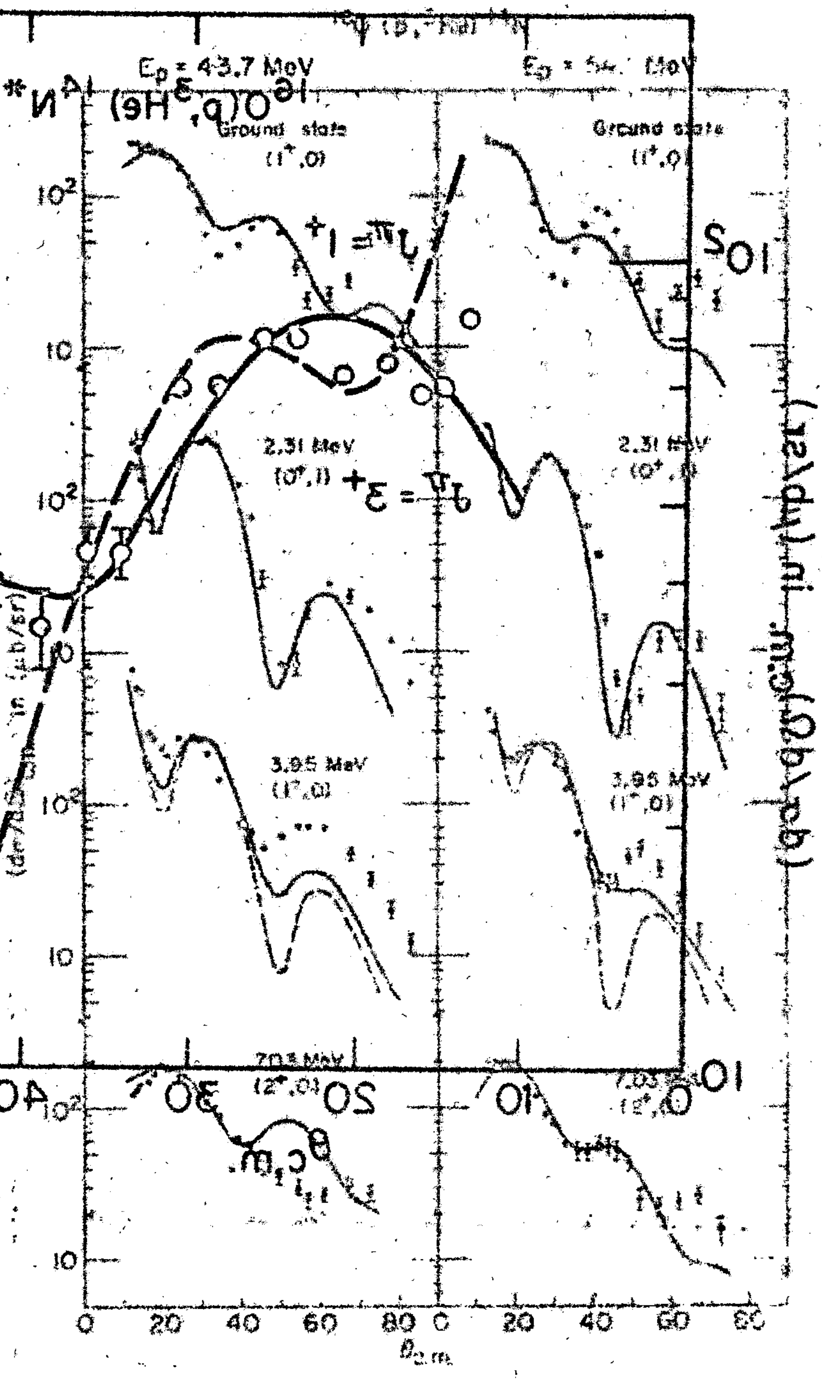
XBL704-2689

Fig. 4



XBL 708-3776

Fig. 5


Ep = 43.7 MeV
Ep = 54.1 MeV
Ground state
(1+,0)
2.31 MeV
(0+,1)
3.95 MeV
(1+,0)
7.03 MeV
(2+,0)
(dσ/dΩ)c.m. in (μb/sr)
10²
10
0
20
40
60
80
θc.m.

XBL [illegible]

Fig. 6

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