PHYSICAL REVIEW C VOLUME 11, NUMBER 2 FEBRUARY 1975

Distorted-wave analysis of the $^{14}N(t,p)^{16}N$ reaction*

D. J. Crozier† and H. T. Fortune
Physics Department, University of Pennsylvania, Philadelphia, Pennsylvania 19174
(Received 3 October 1974)

Angular distributions from the $^{14}N(t,p)^{16}N$ reaction have been analyzed using distorted-wave techniques and employing two-particle-transfer amplitudes from a recent $1p_{1/2}$-$1d_{5/2}$-$2s_{1/2}$ shell-model calculation. Ten experimental levels in ^{16}N can be identified with shell-model counterparts. Restrictions are placed on the spin and parity assignments of several of the remaining states.

[NUCLEAR REACTIONS DWBA analysis of old $^{14}N(t,p)$ data, $E(t)=12.0$ MeV. Comparison of data with $p_{1/2}$-$d_{5/2}$-$s_{1/2}$ shell-model calculations. Discussion of J^π assignments.]

I. INTRODUCTION

Experimental interest in the $1p$- and $2s1d$ shells has been increasingly stimulated by improvements in shell-model calculations for nuclei in this mass region. Recent calculations[1-3] have produced good quantitative agreement for the strengths of one-[4] and two-nucleon-transfer reactions[5,6] involving nuclei in the beginning of the *sd* shell. Even though the predictions for two-nucleon transfer are extremely sensitive to the details of the wave functions, modern shell-model calculations[1,3] were able to describe the $^{17}O(t,p)^{19}O$[6] and $^{18}O(^3He,p)^{20}F$[5] reactions with surprising success.

This accomplishment encouraged further investigations. A distorted-wave (DW) analysis of earlier data[7] from the $^{14}N(t,p)^{16}N$ reaction, using shell-model wave functions, seemed a particularly attractive venture. The data for this reaction have been previously published,[7] but with only a plane-wave analysis. In that work, even the L values were ambiguous for several states.

Though a great deal of information is available concerning ^{16}N, there remain many unanswered questions for even the low-lying states. For convenience in the following discussion, an energy-level diagram of ^{16}N is presented in Fig. 1. (The spin-parity assignments include those from the literature[8] and those of the present work.)

II. ANALYSIS

Kurath[9] has performed a shell-model calculation for ^{16}N and for the ground state of ^{14}N, using interaction II of Zuker, Buck, and McGrory[10] (ZBM). A closed $1p_{3/2}$ core was assumed and particles were allowed to occupy the $1p_{1/2}$, $1d_{5/2}$, and $2s_{1/2}$ orbitals.

Two-particle-transfer amplitudes from this shell-model calculation are presented in Table I. Theoretical levels are identified in the first two columns of the table by their J^π values and their predicted excitation energies. The remaining columns identify the transferred orbital angular momentum, L [which for a (t,p) reaction is equal to the total transferred angular momentum J], and the transfer amplitudes for the various possible configurations. Because of the truncation assumed in the shell-model calculations the possible configurations that can contribute to a given transition are greatly reduced. In fact, in the present $p_{1/2}$-$d_{5/2}$-$s_{1/2}$ basis, all transfers except $L=0$ and 2 contain only one configuration. For example $L=1$ transfer can involve only the configuration $p_{1/2}s_{1/2}$ for the transferred pair, since $p_{1/2}d_{5/2}$ cannot couple to $L=1$, $J=1$. Similarly, $L=3$ transfer involves only $p_{1/2}d_{5/2}$. Also, since $(p_{1/2})^2$ and $(s_{1/2})^2$ can couple at most to $J=1$, then $L=4$ transfer involves only the configuration $(d_{5/2})^2$ and $L=2$ transfer only $(d_{5/2})^2$ and $s_{1/2}d_{5/2}$. If the present $1p_{1/2}$-$1d_{5/2}$-$2s_{1/2}$ basis is too restrictive, this fact will manifest itself in the presence of L values not allowed in the present calculation. This point will be reexamined below in connection with specific final states.

The DW calculations were performed using the two-particle-transfer option of the code DWUCK.[11] Optical-model parameters[12] used in the present analysis are shown in Table II. These parameters have previously been used to analyze angular distributions and polarization data from the $^{12}C(t,p)$-^{14}C reaction. Angular distributions for states with reasonably certain shell-model counterparts are shown in Fig. 2. Solid lines represent the theoretical calculations, which have been independently normalized for each state. The relative ratios of experimental to theoretical cross sections, $N=\sigma_{exp}/\sigma_{th}$, are given in Table III for these states.

Here, the experimental levels are identified by their measured excitation energies while the shell-model states are denoted by spin and parity and predicted excitation energy. Since only relative cross sections were measured,[7] the absolute magnitude of σ_{exp}/σ_{th} is not obtainable. The normalization in Table III has been chosen so that the average of the ratios for the ground state and first three excited states is equal to one.

A number of states could not be adequately identified with corresponding shell-model levels. Angular distributions for these are shown in Figs. 3–6 where they have been fitted with independently normalized DW angular distributions corresponding to the possible L values. Whenever mixtures of two L values have been used, the components are denoted by broken lines, their sums by solid lines. The results are discussed below for the various states that were populated in the $^{14}N(t,p)^{16}N$ reaction.

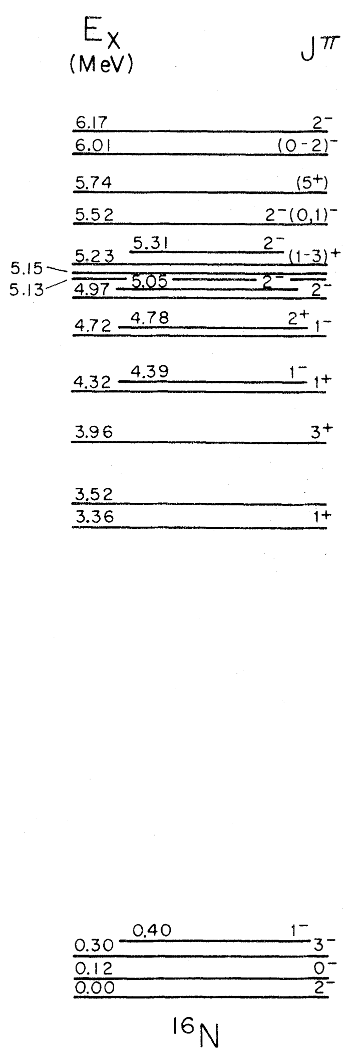

FIG. 1. Energy-level diagram of ^{16}N. Spin-parity assignments are from the literature (Ref. 8) and the present work.

III. DISCUSSION

A. States at 0.00, 0.12, 0.30, and 0.40 MeV

The spins and parities of the four lowest levels of ^{16}N have been known, for some time, to be 2^- (g.s.), 0^-(0.12 MeV), 3^-(0.30 MeV), and 1^-(0.40 MeV). These four states are easily identified with the four lowest levels predicted by the shell model. The dominant configuration of these states is a

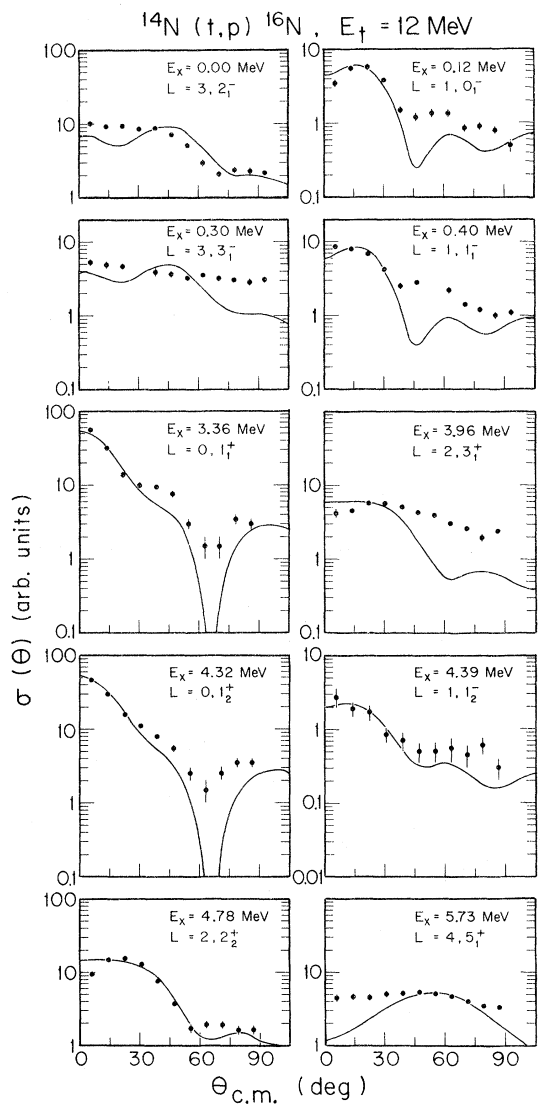

FIG. 2. Angular distributions of the $^{14}N(t, p)^{16}N$ reaction for states with reasonably certain shell-model counterparts. Curves are results of DWBA calculations, as described in text. Data are from Ref. 7.

TABLE I. Results of the shell-model calculations (Ref. 9).

J^π	E_x (MeV)	L	Spectroscopic amplitudes $p_{1/2}, d_{5/2}$	$p_{1/2}, s_{1/2}$	$(p_{1/2})^2$	$(d_{5/2})^2$	$d_{5/2}, s_{1/2}$	$(s_{1/2})^2$
0_1^-	0.01	1		0.437 068				
0_2^-	2.97	1		−0.109 962				
1_1^-	0.00	1		0.352 855				
1_2^-	3.32	1		0.091 924				
1_3^-	5.91	1		−0.011 965				
2_1^-	0.00	1		0.000 426				
		3	−0.392 073					
2_2^-	4.44	1		0.000 098				
		3	0.049 759					
2_3^-	5.57	1		−0.004 036				
		3	−0.057 897					
3_1^-	0.29	3	0.293 256					
3_2^-	4.39	3	0.056 367					
4_1^-	6.71	3	0.000 322					
1_1^+	2.24	0			0.005 614	−0.168 245		−0.149 365
		2				0.058 221	0.012 343	
1_2^+	3.80	0			−0.001 782	−0.299 640		−0.153 604
		2				−0.081 132	−0.026 432	
2_1^+	3.02	2				0.143 244	0.119 094	
2_2^+	4.13	2				−0.056 105	−0.192 421	
3_1^+	3.35	2				0.182 262	0.172 080	
		4				−0.037 497		
4_1^+	3.98	4				−0.178 918		
5_1^+	4.40	4				0.141 727		

$1d_{5/2}$ or $2s_{1/2}$ neutron coupled to the ^{15}N ground state (g.s.). Evidence for this structure is provided by the large spectroscopic factors measured in the ^{15}N$(d,p)^{16}$N reaction[13,14] for these four states. The ^{14}N$(t,p)^{16}$N angular distributions for these four levels are displayed at the top of Fig. 2, together with DW predictions.

The ground state has $J^\pi = 2^-$. Macroscopic selection rules for a (t,p) reaction from a 1^+ target to a 2^- state allow both $L=1$ and $L=3$. However, the dominant configuration of the model ground state is a $p_{1/2}d_{5/2}$ pair coupled to the ^{14}N g.s., so little $L=1$ is predicted. The underprediction of the cross section at forward angles may be an indication of a need for more $L=1$. In Fig. 3, these same data are fitted with an arbitrary mixture of $L=1$ and $L=3$. An increase in the magnitude of the $L=1$ component improves the

TABLE II. Optical-model parameters used in the distorted-wave calculations (Ref. 12).

Particle	V	W	$W'=4W_D$	V_{so}	$r_0=r_{so}$	$a=a_{so}$	r_0'	a'
Triton	130	18.9	0	0	1.29	0.58	1.37	0.96
Proton	60	0	34.2	5.5	1.13	0.57	1.13	0.50
Bound state	···	···	···	$\lambda=25$	1.26	0.60	···	···

fit somewhat and also reduces the relative normalization needed for the $L=3$ component by about 30% below the value given in Table III. This new normalization would be in much better agreement with the values obtained for other states. Thus, the apparent need for more $L=1$ in the g.s. angular distribution may indicate the presence of other components not accounted for in the present calculations, such as, e.g. $p_{3/2}d_{5/2}$ or $p_{1/2}d_{3/2}$. However, the evidence is not compelling. The fit at extreme forward angles is almost as bad for the 0.30-MeV, 3^- state. In this case, the fit cannot be improved by adding an $L=1$ component, since $L=1$ violates the selection rules for a $1^+ \rightarrow 3^-$ (t,p) transition.

The 0^- and 1^- states at 0.12 and 0.40 MeV, respectively, can be populated in a direct (t,p) reaction only via $L=1$, which within the present shell-model calculation, involves only $p_{1/2}s_{1/2}$ transfer. The resulting fits to the data are reasonably good, especially at forward angles where the cross section is largest. The ratio of experimental to theoretical cross section for both states is in reasonably good agreement with those for other states, although somewhat low for the 1^- state.

B. States at 3.36, 3.96, 4.32, 4.39, 4.78, and 5.73 MeV

In addition to the ground-state quadruplet, six other states are associated with probable shell-model counterparts in Fig. 2. These are discussed in the present subsection.

The angular distribution for the 3.36-MeV level exhibits a large $L=0$ component; thus this must be a 1^+ state. Neutron scattering also yields a

TABLE III. Relative normalizations of experimental to theoretical cross sections.

Experimental state E_x (MeV)	Theoretical state E_x (MeV)	J^π	$N=\sigma_{exp}/\sigma_{th}$ (relative units)
0.00	0.00	2_1^-	1.56
0.12	0.01	0_1^-	0.84
0.30	0.29	3_1^-	1.02
0.40	0.00	1_1^-	0.58
3.36	2.24	1_1^+	0.56
3.96	3.35	3_1^+	1.02
4.32	3.80	1_2^+	0.33
4.39	3.32	1_2^-	1.80
4.78	4.13	2_2^+	1.18
5.73	4.40	5_1^+	5.96

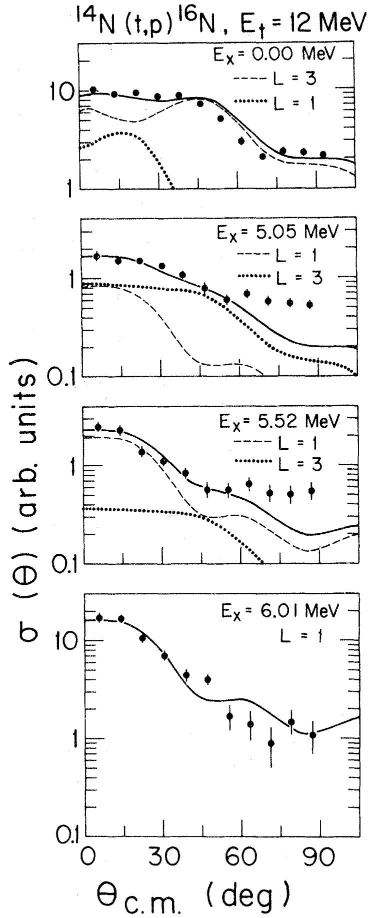

FIG. 3. Angular distributions of $^{14}N(t,p)^{16}N$ for negative-parity states of ^{16}N. The data of Ref. 7 have been fitted with arbitrarily normalized mixtures of $L=1$ and 3 DWBA calculations.

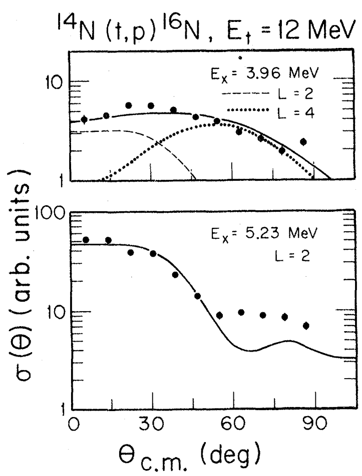

FIG. 4. Angular distributions of $^{14}N(t,p)^{16}N$. The data of Ref. 7 have been fitted with arbitrarily normalized mixtures of $L=2$ and 4 DWBA calculations.

1^+ assignment.[15-17] The $L=0$ transition observed for this state in the $^{14}C(^3He,p)^{16}N$ reaction[18] is also consistent with a 1^+ assignment. The lowest positive-parity state predicted by the shell-model calculations is a 1^+ state. We thus identify the 3.36-MeV state with the 1_1^+ model state. The resulting DW angular distribution gives a good fit to the data, with an acceptable ratio of σ_{exp}/σ_{th}.

The state at 3.96 MeV was populated with $l_n=3$ in the $^{15}N(d,p)^{16}N$ reaction,[19] thus implying $J^\pi=2^+$, 3^+, or 4^+. The $L=2$ transition observed in $^{14}C(^3He,p)^{16}N$ [18] requires $J^\pi=(1,2,3)^+$. The absence of $L=0$ there argues against a 1^+ assignment. However, neutron resonance studies[16,17] have suggested a $J=1$ resonance in this vicinity. It has been suggested[18] that the 3.96-MeV state has $J^\pi=3^+$ and that it is largely a 2p-2h state. The shell model predicts a 2^+ and a 3^+ state in this region, both with dominantly $L=2$ angular distributions in the $^{14}N(t,p)^{16}N$ reaction. In Fig. 2, the 3.96-MeV level has been fitted with the 3_1^+ theoretical distribution. The resulting ratio, σ_{exp}/σ_{th}, is quite acceptable. This level could, of course, correspond to the 2_1^+ shell-model state but the relative normalization would then be four times as large. In either case, one shell-model state (3_1^+ or 2_1^+) appears to lack a counterpart in the experimental level scheme. The fit obtained for the shape of the angular distribution of the 3.96-MeV state, shown in Fig. 2, is not totally adequate; a larger $L=4$ contribution appears to be required. Therefore, in Fig. 4, the experimental angular distribution is fitted with an arbitrary mixture of $L=2$ and $L=4$ components, improving the fit considerably. The necessity for an $L=4$ component suggests that 3^+ is the correct assignment.

The 4.32-MeV level has a firm 1^+ assignment. It is populated with $l_n=1$ in the $^{15}N(d,p)^{16}N$ reaction,[19] and with $L=0+2$ in the $^{14}C(^3He,p)^{16}N$ reaction.[18] Neutron scattering also yields a 1^+ assignment.[16,17,20] The dominant $L=0$ component observed in the $^{14}N(t,p)^{16}N$ angular distribution for this state is consistent only with $J^\pi=1^+$. Therefore, this level is identified with the 1_2^+ shell-model state. The predicted shape is in good agreement with the data but the magnitude is somewhat low.

The weak state at 4.39 MeV has an apparent $L=1$ angular distribution. If this state is identified with the 1_2^- model state, the fit to the shape of the angular distribution is satisfactory, but the relative normalization in Table III is somewhat high. Since the level is predicted to be weak, a small admixture of some other configuration could account for the large normalization. The only other low-lying experimental candidate for the 1_2^- model state is the state at 3.52 MeV, which is discussed further in Sec. III F. However, its cross section is about 20 times stronger than that predicted for the 1_2^- state. The $^{15}N(d,p)^{16}N$ reaction gives $l_n=0$ for the 4.39-MeV level[19] and neutron scattering indicates $J^\pi=1^-$.[16,17,20] This state is also identified in $^{14}C(^3He,p)^{16}N$.[21]

The 4.78-MeV level has an angular distribution characteristic of $L=2$. Neutron scattering indicates a 2^+ assignment for this state,[17,20] which is also populated in $^{14}C(^3He,p)^{16}N$.[21] If this state is identified with the 2_2^+ model state, the resulting ratio, σ_{exp}/σ_{th}, is in good agreement with that

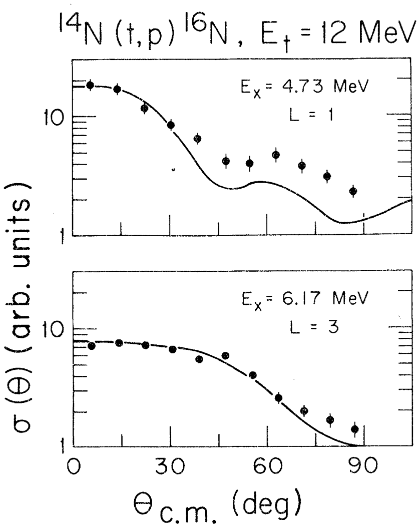

FIG. 5. Angular distributions of $^{14}N(t,p)^{16}N$ for negative-parity states. The data are from Ref. 7. The distribution of the 4.73-MeV level has been fitted with an arbitrarily normalized $L=1$ DW fit, and that of the 6.17-MeV state with $L=3$.

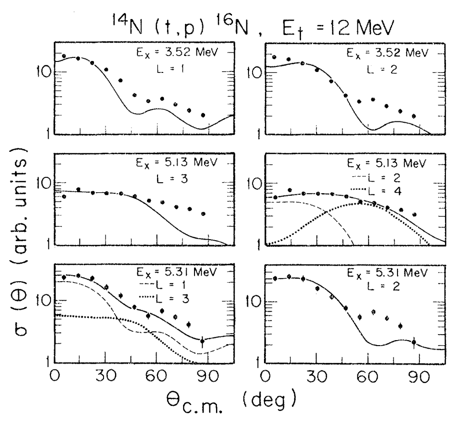

FIG. 6. Angular distributions of $^{14}N(t,p)^{16}N$ for states of uncertain parity. The data of Ref. 7 are fitted with arbitrarily normalized DW calculations. The fits on the left are for the negative-parity assumption; those on the right for positive parity.

for other states. It is disturbing, however, that the experimental counterpart for the state 2_1^+ cannot be identified. This point is discussed further below.

A level at 5.73 MeV has been assigned $J^\pi = 5^+$ on the basis of an apparent $L = 4$ angular distribution in the $^{14}C(^3He,p)^{16}N$ reaction[18] and from results of the $^{14}C(\alpha,d)^{16}N$ reaction.[22] The $^{14}N(t,p)^{16}N$ angular distribution is not well fitted with $L = 4$. Also, the cross section for this state is more than 5 times as strong as that predicted for the first 5^+ model state. There is, furthermore, some conflicting evidence: in $^{15}N(d,p)^{16}N$ [19] this state is populated by an $l_n = 2$ transition, thus indicating negative parity; and neutron scattering[17] suggests a $J^\pi = 1^+$ resonance near this energy. If this state is not 5^+, there is no other candidate below 6 MeV for the first 5^+ state.

C. States at 5.05, 5.52, and 6.01 MeV excitation

Angular distributions for the 5.05-, 5.52-, and 6.01-MeV states are displayed in Fig. 3. These states all appear to have negative parity but cannot be identified with shell-model counterparts. The measured distributions are fitted with independently normalized $L = 1$ and $L = 3$ DW calculations.

The angular distribution of the 5.05-MeV state is fitted with an arbitrary mixture of $L = 1$ and $L = 3$. The need for the $L = 3$ component indicates that this is a 2^- state. This assignment is consistent with an observed $l_n = 2$ transition in $^{15}N(d,p)^{16}N$,[19] and with a $(1,2)^-$ assignment from neutron scattering.[20] This level has also been identified in the $^{14}C(^3He,p)^{16}N$ reaction.[21]

The angular distribution of the 5.52-MeV state is dominated by $L = 1$, with a hint of a small $L = 3$ component. The presence of an $L = 3$ component would indicate that the level is 2^- but this component is not well established. Other evidence conflicts with a negative-parity assignment: Fuchs, *et al.*[19] report an $l_n = 3$ angular distribution in the $^{15}N(d,p)^{16}N$ reaction but it appears that $l_n = 2$ might also fit; an $L = 2$ angular distribution has been reported for a 5.512-MeV state in the $^{14}C(^3He,p)^{16}N$ reaction.[18]

The angular distribution of the 6.01-MeV level is characteristic of $L = 1$. This L value is consistent with a 1^- assignment based upon neutron scattering data.[17]

D. States at 4.73 and 6.17 MeV

From their angular distributions, shown in Fig. 5, the states at 4.73 and 6.17 MeV appear to have negative parity.

The angular distribution of the 4.73-MeV level is adequately described by an $L = 1$ DW calculation. This L value agrees with a (1^-) assignment from neutron scattering.[17] On the other hand, Fuchs, *et al.*[19] report an $l_n = 1$ transition in $^{15}N(d,p)^{16}N$, but this is based upon only three points and might equally well be fitted with $l_n = 2$. (These authors presumably misread Ref. 17.) The 4.73-MeV level presumably[7] has the dominant configuration $d_{3/2}(p_{1/2})^{-1}$ and hence, is not contained in the present shell-model calculation.

The angular distribution of the 6.17-MeV level is satisfactorily fitted by an $L = 3$ DW calculation—indicating spin and parity $(2-4)^-$. This state has also been identified in the $^{15}N(d,p)^{16}N$ reaction.[19]

E. State at 5.23 MeV

An $L = 2$ DW calculation gives a good account of the measured angular distribution for the 5.23-MeV level displayed in Fig. 4. Thus, the spin and parity of this state are $(1-3)^+$. The $^{15}N(d,p)^{16}N$

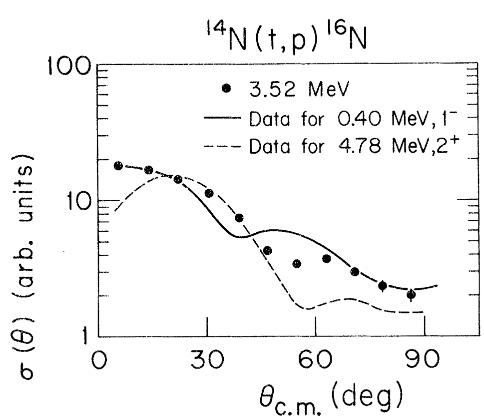

FIG. 7. Comparison of the angular distribution of the 3.52-MeV state with smooth lines drawn through experimental angular distributions of known 1^- and 2^+ states.

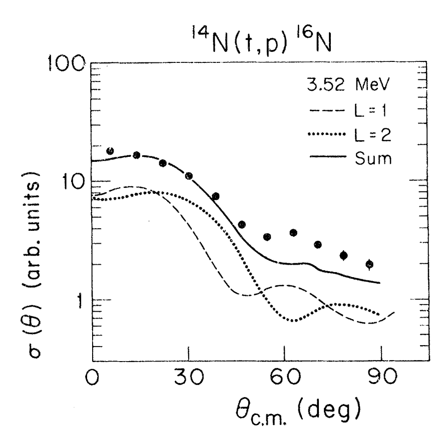

FIG. 8. Experimental angular distribution of the 3.52-MeV state with a mixture of $L = 1$ and $L = 2$ DWBA curves.

reaction populates this level with $l_n = 3$ [19] and $L = 2$ is observed in the $^{14}C(^3He,p)^{16}N$ reaction.[18] These results favor $J^\pi = (2, 3)^+$. This level is also observed in neutron scattering.[17] No shell-model counterpart can be identified with certainty.

F. States at 3.52, 5.13, and 5.31 MeV

Angular distributions for the 3.52-, 5.13-, and 5.31-MeV states are displayed in Fig. 6. The present results alone do not yield an unambiguous parity assignment for these states. The angular distribution for the state at 5.31 MeV can be equally well fitted by either $L = 2$ or $L = 1 + 3$. A state at 5.31-MeV has been suggested[7] to have $J^\pi = 2^-$ and to be of the dominant configuration $1d_{3/2}(1p_{1/2})^{-1}$. However, neutron scattering suggests $(2^+, 3^+)$[20] or 1^+.[17] If the state has negative parity, the present $L = 1 + 3$ fit is consistent only with 2^-. Such a state is also not contained in the shell-model calculations, because of the neglect of the $d_{3/2}$ orbital.

In Fig. 6, the angular distribution for the level at $E_x = 3.52$ MeV is fitted on the left with an $L = 1$ DW calculation and on the right with $L = 2$. Both calculations give marginally acceptable agreement

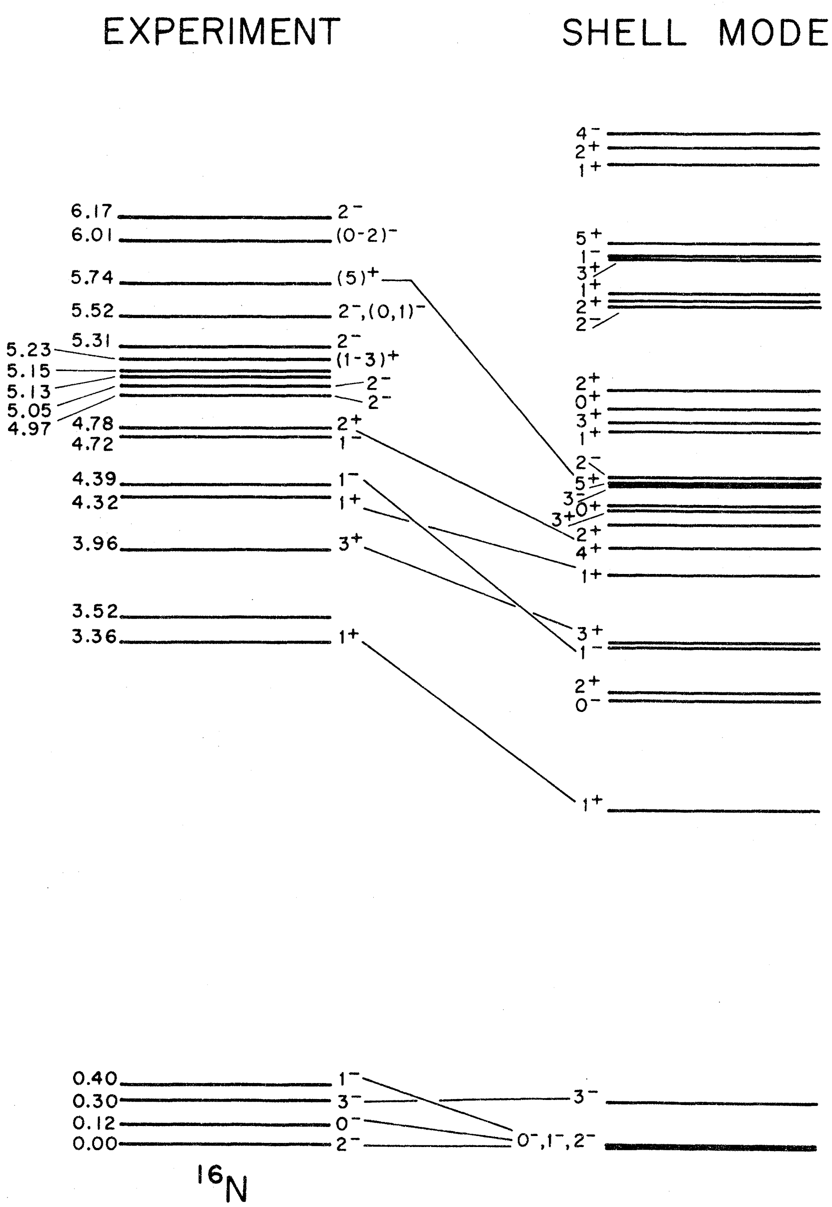

FIG. 9. Comparison of experimental level scheme of ^{16}N with results of a shell-model calculation.

with the data. In Fig. 7, the experimental angular distribution is compared with smooth lines drawn through experimental angular distributions of known 1^- and 2^+ states. Neither gives perfect agreement with the data. Positive parity would be consistent with the $L=2$ transition observed in $^{14}C(^3He,p)^{16}N$ [18] but not with the $l_n=2$ transition reported for the $^{15}N(d,p)^{16}N$ reaction.[19] (However, it is possible that the latter could be fitted with a mixture of $l_n=1$ and $l_n=3$, which would imply a 2^+ assignment.) Neutron scattering[17] indicates a $J=1$ resonance in this region of excitation. In the present analysis, if this state is identified with either the 0_2^-, 1_2^-, 2_2^-, 1_2^+, or 2_1^+ model states, the resulting ratio, σ_{exp}/σ_{th}, is unusually large. One possibility consistent with all the evidence is that the 3.52-MeV level may actually be a doublet—one member having positive parity and the other negative parity. In fact, a sum of $L=1$ and 2 gives an excellent account of the data, as shown in Fig. 8. If $L=1+2$ is correct then the negative-parity state must have $J^\pi=(0,1,2)^-$ and the positive-parity state $J^\pi=(1,2,3)^+$. If the $J=1$ assignment from neutron scattering[17] is correct, then one of the states must have $J=1$, further restricting the possibilities (e.g. a 0^-, 2^+ doublet would not be allowed by the neutron results).

In Fig. 6, the angular distribution of the 5.13-MeV state has been fitted with an $L=3$ distribution on the left and a mixture of $L=2$ and $L=4$ on the right. The positive-parity assumption produces a better fit but not significantly enough to make a definite assignment. Neutron scattering suggests a (3^-) assignment.[17] The $^{15}N(d,p)^{16}N$ [19] and $^{14}C(^3He,p)^{16}N$ [21] reactions also populate this state, but only weakly.

IV. CONCLUSION

Figure 9 compares the experimentally determined level scheme of ^{16}N with that predicted by the shell model. The correspondence between the lowest four states in each is apparent. We have identified the 3.36-MeV level with the 1_1^+ shell-model state, the 4.32-MeV level with 1_2^+, the 4.39-MeV state with 1_2^-, and the 4.78-MeV state with 2_2^+. The 5.74-MeV state has been previously assigned 5^+ and therefore we associate it with the 5_1^+ shell-model level, although the relative normalization is several times too large. The 3.96-MeV state most likely corresponds to 3_1^+, but 2_1^+ is also possible if the large relative normalization obtained is accepted. Although there are a number of theoretical levels for which no experimental counterpart can be identified, the levels 0_2^-, 2_1^+, and 4_1^+ are perhaps the most disturbing examples. There are, however, a number of experimental states which are possible counterparts. Clearly further experimental investigations of ^{16}N are needed in order to clarify the situation.

We are grateful to D. Kurath for providing us with the two-particle-transfer amplitudes.

---

*Work supported by the National Science Foundation.
†Present address: Kansas State University, Manhattan, Kansas 66506.
[1] E. C. Halbert, J. B. McGrory, B. H. Wildenthal, and S. P. Pandya, in *Advances in Nuclear Physics*, edited by M. Baranger and E. Vogt (Plenum, New York, 1971), Vol. IV.
[2] J. B. McGrory, private communication.
[3] B. H. Wildenthal, private communication.
[4] H. T. Fortune, G. C. Morrison, R. C. Bearse, J. L. Yntema, and B. H. Wildenthal, Phys. Rev. C 6, 21 (1972).
[5] D. J. Crozier and H. T. Fortune, Phys. Rev. C 10, 1697 (1974).
[6] D. J. Crozier, H. T. Fortune, R. Middleton, J. L. Wiza, and B. H. Wildenthal, Phys. Lett. 41B, 291 (1972).
[7] P. B. Hewka, C. H. Holbrow, and R. Middleton, Nucl. Phys. 88, 561 (1966).
[8] F. Ajzenberg-Selove, Nucl. Phys. A166, 1 (1971).
[9] D. Kurath, private communication.
[10] A. P. Zuker, B. Buck, and J. B. McGrory, Phys. Rev. Lett. 21, 39 (1968).
[11] P. D. Kunz, private communication.
[12] P. W. Keaton *et al.*, Nucl. Phys. A179, 561 (1972).
[13] E. K. Warburton and J. N. McGruer, Phys. Rev. 105, 639 (1957).
[14] W. Bohne, J. Bommer, H. Fuchs, K. Grabisch, H. Kluge, and G. Roschert, Nucl. Phys. A196, 41 (1972).
[15] T. R. Donoghue, A. F. Behof, and S. E. Darden, Nucl. Phys. 54, 49 (1964).
[16] D. B. Fossan, R. A. Chalmers, L. F. Chase, and S. R. Salisbury, Phys. Rev. 135, B1347 (1964).
[17] B. Zeitnitz, H. Dubenkropp, R. Putzki, G. J. Kuonac, S. Cierjacks, J. Nebe, and C. B. Dover, Nucl. Phys. A166, 443 (1971).
[18] H. Freiesleben and R. Weibezahn, Nucl. Phys. A184, 273 (1972).
[19] H. Fuchs, H. Homeyer, H. Oeschler, R. Lipperheide, and K. Mohring, Nucl. Phys. A196, 286 (1972).
[20] C. P. Sikkema, Nucl. Phys. 32, 470 (1962).
[21] A. Gallman, P. Fintz, J. B. Nelson, and D. E. Alburger, Phys. Rev. 147, 753 (1966).
[22] C. C. Lu, M. S. Zisman, and B. G. Harvey, Phys. Rev. 186, 1086 (1969).