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STUDY OF THE (t, p) REACTION ON O^{16}, O^{17} AND O^{18} USING 5.55 MeV TRITONS

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Abstract: The (t, p) reaction on O^{16}, O^{17} and O^{18} was studied at a triton bombarding energy of 5.55 MeV, with special attention to the reaction O^{17}(t, p)O^{19}. The position of several energy levels in O^{19} was established. Good agreement was obtained in some cases between the measured proton angular distributions and the predictions of the plane wave double stripping theory. In other cases the contribution of other reaction modes seems to be appreciable.

The spin and parity of the ground and 3.153 MeV levels in O^{19} obtained by the O^{17}(t, p) reaction were determined unambiguously to be $\frac{5}{2}^+$ arising from the $d^3_{\frac{5}{2}}$ and $d_{\frac{5}{2}}s^2_{\frac{1}{2}}$ configurations respectively. The 0.093 and 2.775 MeV levels could be identified with the $\frac{3}{2}^+$ and $\frac{9}{2}^+$ levels respectively of the $d^3_{\frac{5}{2}}$ configuration.

The results for the O^{16}(t, p)O^{18} reaction agreed with those of Jaffe *et al.* who used tritons of 5.50 MeV. In the O^{18}(t, p)O^{20} reaction the spin and parity assignments for the ground and first three excited levels of O^{20} were in essential agreement with those of Middleton *et al.* who bombarded with tritons of 10 MeV.

E | NUCLEAR REACTIONS ^{16,17,18}O (t, p), E = 5.55 MeV; measured σ (θ, E_p). ^{18,19,20}O deduced levels, J, π. Enriched targets.

1. Introduction

The study of double stripping reactions such as (t, p), (He^3, p), (α, d) and (He^3, n) has aroused increasing interest in recent years. Theoretical treatments of the double-nucleon stripping process using both the plane wave and distorted wave Born approximation have been published by several authors [1-4]).

The earlier experiments [5]) were carried out at bombarding energies of around 4 MeV and centred mainly on (He^3, p) reactions. The reaction mechanism here was found to be complex and often a mixture of compound and direct processes. Other experiments, using the (t, p) reaction, were performed by Jaffe *et al.* [6]) at 5.5 MeV and later by Middleton and Pullen [7]) using 10 MeV. These investigators found that at such energies the direct reaction mode dominates and they demonstrated in many cases the feasibility of employing these reactions to obtain useful spectroscopic information on nuclear levels.

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In this paper the O^{18}, O^{19} and O^{20} energy levels are studied using the O^{16}(t, p), O^{17}(t, p) and O^{18}(t, p) reactions at a bombarding energy of 5.55 MeV.

Recently a number of shell model calculations have been carried out for the low-lying states in O^{18}, O^{19} and O^{20} (see Talmi and Unna [8]), Shah [9]) and Pandya [10]) and Cohen *et al.* [11])). In particular, even parity levels involving the excitation of two neutrons in O^{19} were predicted. These levels were assumed to arise from the coupling of neutrons in the $s_{\frac{1}{2}}$ and $d_{\frac{5}{2}}$ orbits outside an inert O^{16} core. The contribution of the $d_{\frac{3}{2}}$ orbit was generally neglected owing to the fact that the $d_{\frac{3}{2}}$ level in O^{17} is about 5 MeV above the $d_{\frac{5}{2}}$ ground state. In O^{19}, nine even parity states can be formed with the configurations $d^3_{\frac{5}{2}}(J = \frac{5}{2}, \frac{3}{2}, \frac{9}{2})$, $d^2_{\frac{5}{2}}(4)s_{\frac{1}{2}}(J = \frac{7}{2}, \frac{9}{2})$, $d^2_{\frac{5}{2}}(2)s_{\frac{1}{2}}(J = \frac{5}{2}, \frac{3}{2})$, $d^2_{\frac{5}{2}}(0)s_{\frac{1}{2}}$ $(J = \frac{1}{2})$ and $d_{\frac{5}{2}}s^2_{\frac{1}{2}}(J = \frac{5}{2})$. Negative parity states are expected to arise from the excitation of the O^{16} core but no theoretical estimates regarding the position of such levels have yet been made.

The O^{17}(t, p)O^{19} reaction is best suited for the investigation of the predicted levels. The O^{17} ground state is $d_{\frac{5}{2}}$, and therefore by adding two neutrons to the $d_{\frac{5}{2}}$ and $s_{\frac{1}{2}}$ orbits, via the (t, p) reaction, it is possible to form each of the predicted levels. Another advantage of this reaction over others such as O^{18}(d, p) and F^{19}(n, p) is the relatively high spin of the O^{17} target nucleus which makes it a favourable choice for reaching the high spins of some of the levels.

The O^{19} energy levels were studied previously by the O^{18}(d, p)O^{19} reaction and by measuring the O^{18} neutron total cross section. In the excitation region between the ground state and 4.5 MeV, which is the region covered by the present investigation, the level structure has been studied by Armstrong and Quisenberry [12]), Sjogren *et al.* [13]), Yagi *et al.* [14]) and El Bedewi *et al.* [15]), using the O^{18}(d, p) reaction. The positions of many of the O^{19} levels were located, and, by measuring the angular distributions of the proton groups, the ground and 1.468 MeV levels were found to be single particle states of the $d^3_{\frac{5}{2}}(J = \frac{5}{2})$ and $d^2_{\frac{5}{2}}(2)s_{\frac{1}{2}}(J = \frac{1}{2})$ configurations respectively. The weak transition to the 0.093 MeV state and the measurement of its lifetime (see Zimmerman [16])) suggested that this level is the $\frac{3}{2}$ state of the $d^3_{\frac{5}{2}}$ configuration. Later experiments [17]) confirmed the spin and parity assignments for this level. The proton angular distributions corresponding to the 3.153, 3.946 and 4.107 MeV levels were also measured but no definite angular momentum assignment for the transferred neutron was obtained. The O^{19} energy levels in the excitation region between 4.5 and 7.5 MeV were studied by measuring the O^{18} neutron total cross section (see Schellenberg *et al.* [18]) and Donaghue *et al.* [19])). The positions of several levels were located and spin and parity assignments made.

A short report on part of the present work was published earlier [20]).

2. Experimental Method

Tritons were accelerated to 5.55 MeV in the Manchester University Van de Graaff accelerator. To minimize the loss of tritium throughout the experiment, the gas was mixed with helium-4 as described in ref. [6]). The dimensions of the collimated beam on the target were about 0.5 mm high and 2 mm wide. Self-supporting nickel oxide targets of 110 ± 20 μg/cm^2 were used. These were prepared [21]) by the direct oxidation of nickel foils by heating them in an atmosphere of enriched oxygen (containing 13.5 % O^{17} and 44.5 % O^{18}).

The reaction products were analysed with a broad range magnetic spectrograph using nuclear emulsion plates as detectors. The spectrograph [22]) was calibrated immediately before the experiment using Po^{210} α particles (5.3048 ± 0.0006 MeV).

3. Results

Proton spectra were measured at 12 angles between 10° and 110°. A typical spectrum obtained at a laboratory angle of 20° is shown in fig. 1. The background is seen to be generally high and is apparently due to (t, p) reactions on the nickel isotopes; these reactions have Q values around 11 MeV, and lead to highly excited states where the level density is very large.

The proton groups were identified by the characteristic rate of energy variation with angle. The groups are labelled with the symbols of the residual nuclei, the subscripts indicating the order of the energy level. The target contained all three stable oxygen isotopes in appreciable amounts, and thus the proton groups corresponds to the ground and excited states of O^{18}, O^{19} and O^{20}. The group labelled O^{19}_{10}, which corresponds to a new O^{19} level at 4.328 MeV excitation, is uncertain as it was very weak at all angles at which it was observed.

TABLE 1

Energy levels in O^{19} below 4.5 MeV excitation

Level No.	Present work (MeV)	Sjogren *et al.* (MeV)	Yagi *et al.* (MeV)
0	0	0	0
1	0.093 ± 0.01	0.098 ± 0.006	
2	1.468 ± 0.01	1.469 ± 0.03	1.468 ± 0.015
3	2.367 ± 0.01	2.353 ± 0.029	
			(2.612 ± 0.015) [a])
4	2.775 ± 0.01	2.765 ± 0.03	
5	3.061 ± 0.01	3.047 ± 0.03	
6	3.153 ± 0.01	3.144 ± 0.029	3.171 ± 0.015
7	3.223 ± 0.015		
8	3.946 ± 0.015	3.942 ± 0.03	3.942 ± 0.015
9	4.107 ± 0.015	4.109 ± 0.03	4.111 ± 0.015
10	(4.328 ± 0.02)		
11	4.396 ± 0.015		

[a]) This level was also reported by El Bedwi *et al.* [15]). They also reported the existence of another level at 0.348 MeV excitation, which was not observed in the present work.

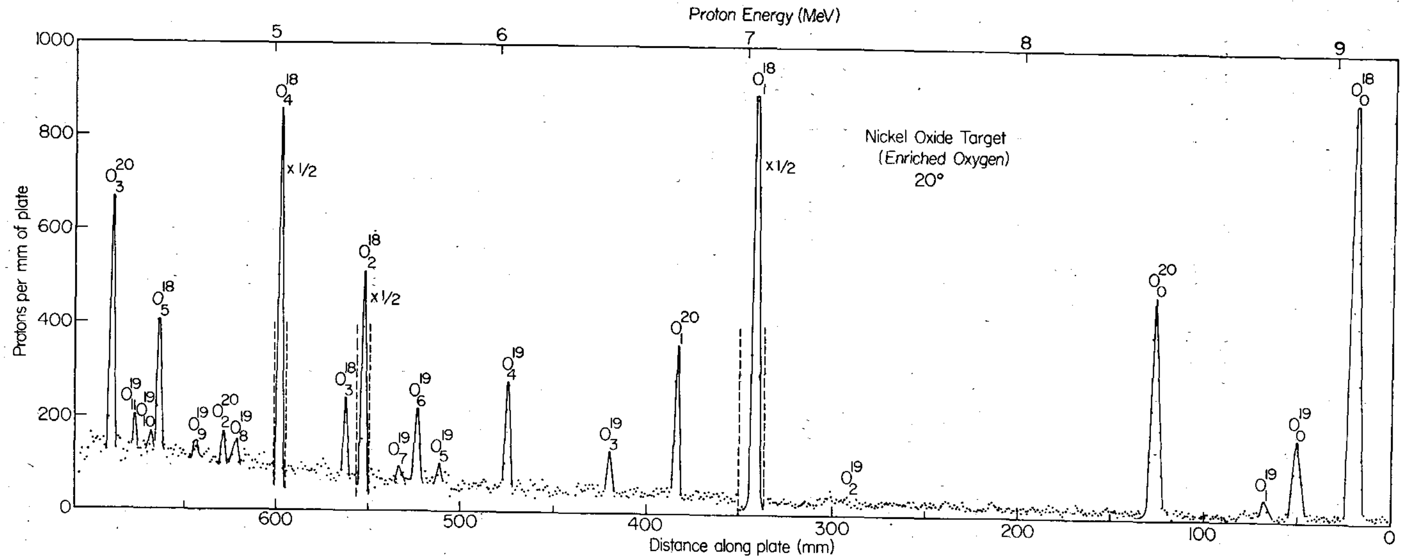

Fig. 1. Energy spectrum of the protons from the (t, p) reaction on a NiO target containing enriched oxygen (13.5 % O^{17}, 43.5 % O^{18}) at σ(lab.) = 20°. The incident triton energy is 5.55 MeV. The high background is due to the (t, p) reaction on nickel isotopes.

The energy of the incident triton beam was determined individually for each angle in terms of the known Q values of the O^{16}(t, p)O^{18} and O^{18}(t, p)O^{20} reactions leading to the ground states. These Q values were taken from ref. [23]) as 3.706±0.005 and

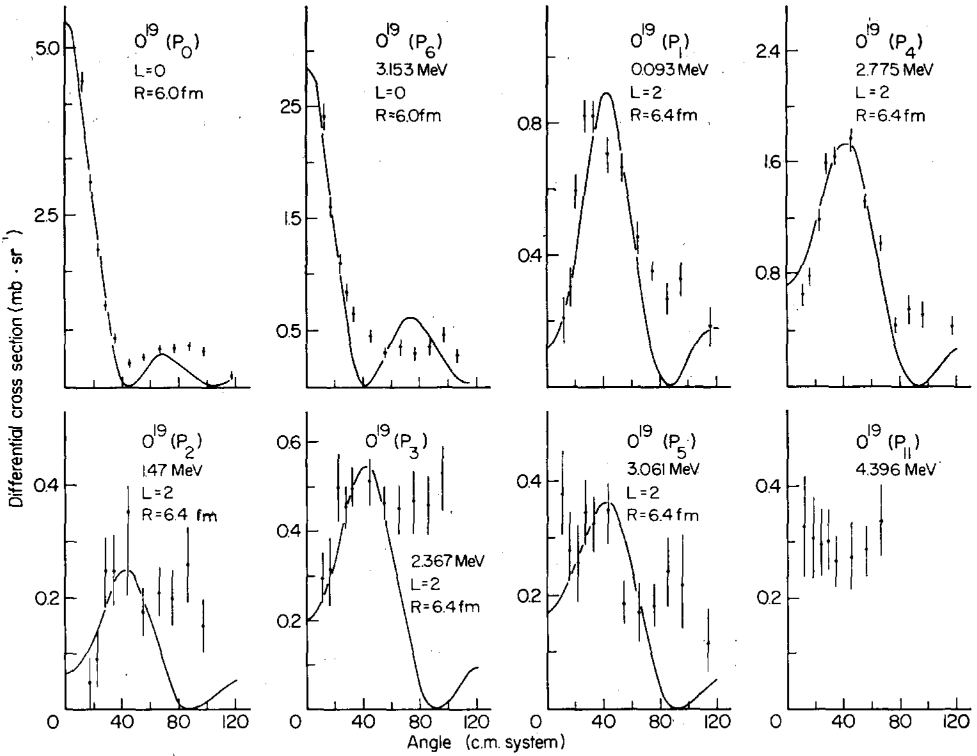

Fig. 2. Angular distributions of protons from the O^{17}(t, p)O^{19} reaction for the ground and seven excited states, measured at an incident energy of 5.55 MeV. The full curves are the calculated values of $j^2_L(kR)$. The errors shown are relative and the uncertainty in absolute cross sections is 40 %.

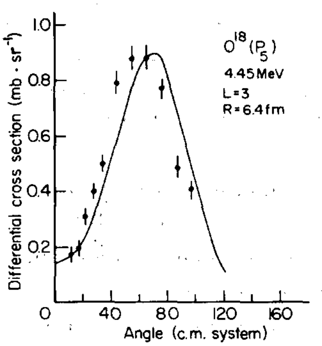

Fig. 3. Angular distribution of protons from the O^{16}(t, p)O^{18} reaction leading to the 4.45 MeV state, measured at an incident energy of 5.55 MeV. See caption to fig. 2.

3.076±0.010 MeV respectively. Using the triton energy thus obtained, twelve separate determinations were made of the O^{17}(t, p)O^{19} reaction Q value; the mean was found to be 3.524±0.007 MeV which agrees well with the value calculated from the mass values [24]) (Q_m = 3.521±0.005 MeV).

Column 1 of table 1 gives the excitation energies of eleven excited states of O^{19} as determined in the present work. Most of the values are the means of at least nine determinations, except for the weak groups. For comparison purposes columns 2 and 3 list the excitation energies reported by Sjögren *et al.* and Yagi *et al.* The agreement is good and the values are within the experimental error.

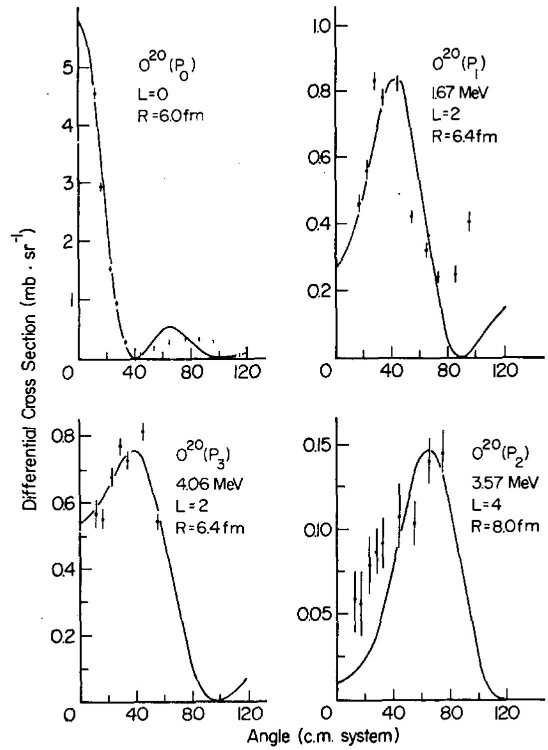

Fig. 4. Angular distribution of proton from the O^{18}(t, p)O^{20} reaction for the ground and the first three excited states, measured at an incident energy of 5.55 MeV. See caption to fig. 2.

Angular distributions of the outgoing protons were measured at 12 angles between 10° and 110°. Fig. 2 shows the results for transitions leading to some of the O^{19} energy levels, plotted in the centre-of-mass system. The full line curves were calculated from an approximate form of Newns' plane wave double stripping theory (see sect. 4). The differential cross section of the remaining proton groups was generally low and the corresponding error high; consequently only the maximum cross section is given (see table 2).

TABLE 2
Maximum cross sections of weak proton groups leading to various levels in O^{19}

Proton group	Maximum cross section (mb/sr)
O^{19}_{7}	0.3
O^{19}_{8}	0.4
O^{19}_{9}	0.45
O^{19}_{10}	0.2

The relative error in each case is around 30 %.

The angular distributions of proton groups from the O^{16}(t, p) reaction leading to the ground and first five excited states in O^{18} were also measured. The results were close to those reported by Jaffe *et al.* who studied this reaction at a bombarding energy of 5.50 MeV, that is, at 50 keV lower than in the present work. Fig. 3 shows the distribution corresponding to the fifth excited state, 4.45 MeV in O^{18}, for which the measurement of Jaffe *et al.* contained large uncertainties.

The angular distributions of the proton groups from the O^{18}(t, p) reaction leading to the ground and first three excited states in O^{20} are shown in fig. 4.

It was impossible to measure the distribution of the O^{20}_{2} and O^{20}_{3} groups at large angles. In the case of O^{20}_{2} this was due to the interference from the O^{19}_{8} group whose separation from the O^{20}_{2} group at angles above 70° was less than 15 keV. The calculated position of O^{20}_{3} was outside the photographic plate for angles above 50° and therefore no measurements in this region were obtained.

4. Discussion

The essential information obtained from the measurement of the angular distribution is the total angular momentum L transferred to the target nucleus by the captured pair of nucleons. An approximate form of the theoretical angular distribution is given by Newns [1])

$$\sigma(\theta) \approx G^2(K) \sum_L \alpha_L j_L^2(kR),$$

where $G^2(K)$ arises from the internal motion of the triton; the variation of $G^2(K)$ with angle is small for the targets and angular range studied in the present work, and it was therefore assumed to be constant. The experimental distributions were thus fitted with curves of the form $\sum_L \alpha_L j_L^2(kR)$. In all the cases considered, only one value of L was assumed to contribute.

In (t, p) reactions the selection rule regarding L is $\boldsymbol{J}_f = \boldsymbol{J}_i + \boldsymbol{L} + \boldsymbol{S}$, where $\boldsymbol{L} = \boldsymbol{l}_1 + \boldsymbol{l}_2$ and S is the total spin of the captured nucleons, which is related to their total spin in the ground state of the triton. Accordingly, $S = 0$ because all three nucleons in the ground state of the triton are predominantly in an s state. The parity of the final state is dependent on L. It is the same as or opposite to that of the initial state according to whether L is odd or even. This dependence is due to the fact that the two neutrons are in their lowest s state in the triton and thus have no internal angular momentum (see discussion in ref. [2]).

It should be noted however that a transition involving $S = 1$ in (t, p) reactions is possible, since the probability of finding the two neutrons in the ground state of the triton, coupled with their spins parallel, is of the order of a few percent [26]. The relative angular momentum of the pair should be odd so that the total wave function of the neutrons is antisymmetric. This also implies that the neutrons could only be captured into different orbits. In an $S = 1$ transition, provided that there is no spin flip of one of the neutrons, the parity is in general not dependent upon L but on l_1 and l_2.

Since all the levels considered in the present work are formed by an $S = 0$ transition, the discussion will be confined to this case only.

4.1. THE O^{19} LEVELS

The experimental proton angular distributions of the O^{17}(t, p)O^{19} reaction leading to the ground and six excited states of O^{19} were found to have a best fit with theoretical curves having either $L = 0$ or $L = 2$ and radii of 6.0 and 6.4 fm, respectively. Fig. 2 shows the sort of agreement obtained.

Since the O^{17} ground state is $\frac{5}{2}^+$, the parity selection rules fix the parity of the ground and the above six excited states of O^{19} to be even. The spin of all the levels with $L = 2$ is not determined uniquely by the spin selection rules and any half-integral value up to $\frac{9}{2}$ is permitted. The spin of the levels with $L = 0$, namely the ground and the 3.153 MeV states, is determined unambiguously to be $\frac{5}{2}$.

4.1.1. *Levels of the* $d_{\frac{5}{2}}^3$ *and* $d_{\frac{5}{2}}s_{\frac{1}{2}}^2$ *configurations*

From fig. 2 it is clear that only four of the proton groups, namely those leading to levels at 0, 0.093, 2.775 and 3.153 MeV excitation, have strong intensities and show well defined stripping patterns. These features strongly suggest that these four levels are formed from an O^{17} nucleus in its ground state, by the capture of two neutrons entering the same orbit. Since the ground state of O^{17} is a single-particle $d_{\frac{5}{2}}$ level, then using pure *j-j* coupling only four theoretical shell model states can be formed by the addition of two neutrons. These have the configurations $d_{\frac{5}{2}}^3(J = \frac{5}{2}, \frac{3}{2}, \frac{9}{2})$ and $d_{\frac{5}{2}}s_{\frac{1}{2}}^2(J = \frac{5}{2})$. Other states containing $1d_{\frac{3}{2}}$, $1f_{\frac{7}{2}}$ and higher orbits are not included because of the higher excitation energies involved. An identification of the four experimental levels with the theoretical ones suggests itself. Accordingly, the ground and the 3.153 MeV states belong to the $d_{\frac{5}{2}}^3(J = \frac{5}{2})$ and $d_{\frac{5}{2}}s_{\frac{1}{2}}^2(J = \frac{5}{2})$ configurations respectively. This follows from the energy difference between a $2s_{\frac{1}{2}}$ and $1d_{\frac{5}{2}}$ neutron. The 0.093 level, known to be $\frac{3}{2}$ from previous work [16,17] corresponds to the $d_{\frac{5}{2}}^3$ configuration, and the remaining 2.775 MeV level is then the $\frac{9}{2}$ level of the same configuration. Other configurations such as $d_{\frac{5}{2}}^2s_{\frac{1}{2}}$ may well contribute to the formation of each state, but here the discussion is confined to the major components. The results for the O^{18}(d, p) reaction, obtained by other investigators, support the above assignments.

The O^{19} ground and the 3.153 MeV states, which are two-particle states, as found in the present work, can be viewed as single-particle levels formed in the O^{18}(d, p) reaction from the $(d_{\frac{5}{2}})^2$ and $(s_{\frac{1}{2}})^2$ components respectively of the O^{18} ground state [12]) by adding one neutron to the $d_{\frac{5}{2}}$ orbit. Therefore both levels should be formed in relatively high yields and should proceed with $l = 2$ in the (d, p) single stripping process. A recent study [15]) of the O^{18}(d, p) reaction carried out at 10 MeV incident energy confirms these expectations †.

4.1.2. *Levels of the* $d_{\frac{5}{2}}^2 s_{\frac{1}{2}}$ *configuration.*

The 1.47 MeV level, known from the (d, p) reaction to be $\frac{1}{2}^+$ arising from the $d_{\frac{5}{2}}^2(0)s_{\frac{1}{2}}$ configuration, is one member of this group of levels. A weak transition was observed to this state in the (t, p) reaction. However the angular distribution could be fitted only poorly with $L = 2$. It can be seen from fig. 2 that the angular peaking is much less pronounced than that of any of the transitions discussed above. These features are probably caused on the one hand by the small statistical factor of the $\frac{1}{2}$ spin, and on the other hand by the fact that this level is formed from two neutrons entering different orbits. The shape of the angular distribution can also be partly attributed to a larger contribution of other reaction modes in this case. The transitions to the levels at 2.367 and 3.061 MeV excitation, while having stronger intensities than that of the $\frac{1}{2}$ state, reveal a similar behaviour as regards the angular distribution. These levels may have also been formed from two neutrons entering different orbits. Comparison with recent shell model calculations suggest that these two states may be identical with two of the $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$ levels arising from the $d_{\frac{5}{2}}^2 s_{\frac{1}{2}}$ configuration.

No spectroscopic information was obtained in the present work regarding the remaining levels, namely 3.223, 3.946, 4.107, 4.328 and 4.396 MeV. It is therefore impossible either to confirm or reject any of the various l assignments for the 3.946 and 4.107 MeV levels made by different investigators [12-15]) who used the O^{18}(d, p)O^{19} reaction. The 4.396 MeV level was appreciably populated by the (t, p) reaction but no stripping peak was observed in the angular distribution. The results for the O^{19} energy levels are summarized in table 3.

In fig. 5, the above results for some of the O^{19} energy levels are compared with theoretical predictions. Column 1 shows the experimental situation together with the assignments made in the present work. Columns 2, 3, 4 and 5 show the predictions made by Talmi and Unna, Pandya, Shah and Cohen *et al.*, respectively. It can be seen that while there is good agreement between all the calculations and the results of the present experiment for the $\frac{5}{2}$, $\frac{3}{2}$ and $\frac{9}{2}$ levels arising from the $d_{\frac{5}{2}}^3$ configuration, the agreement is not good for the levels of the $d_{\frac{5}{2}}^2 s_{\frac{1}{2}}$ configuration. In particular the

† It is not clear however, why the (d, p) transition to the 3.153 MeV state measured at 15 MeV bombarding energy [12,14]) could not be fitted with an $l = 2$ Butler curve having a reasonable radius.

TABLE 3

L values, spins, parities and corresponding configurations for O^{19} and O^{20} levels from the $O^{17}(t, p)O^{19}$ and $O^{18}(t, p)O^{20}$ reactions

Level No.	Excitation energy (MeV)	L value (a)	L value (b)	Configuration (most probable)	J^π (most probable)
O^{19}					
0	0	0		$d^3_{\frac{5}{2}}$	$\frac{5}{2}^+$
1	0.093	2		$d^3_{\frac{5}{2}}$	$\frac{3}{2}^+$
2	1.468	(2)		$d^2_{\frac{5}{2}}s_{\frac{1}{2}}$	$\frac{1}{2}^+$
3	2.367	(2)		$(d^2_{\frac{5}{2}}s_{\frac{1}{2}})$	$(\frac{3}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+)$
4	2.775	2		$d^3_{\frac{5}{2}}$	$\frac{9}{2}^+$
5	3.061	(2)		$(d^2_{\frac{5}{2}}s_{\frac{1}{2}})$	$(\frac{3}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+)$
6	3.153	0		$d_{\frac{5}{2}}s^2_{\frac{1}{2}}$	$\frac{5}{2}^+$
O^{20}					
0	0	0	0	$d^4_{\frac{5}{2}}$	0^+
1	1.67	2	2	$d^4_{\frac{5}{2}}$	2^+
2	3.57		4	$d^4_{\frac{5}{2}}$	4^+
3	4.06	2	2	$d^3_{\frac{5}{2}}s_{\frac{1}{2}}$	2^+

a) Present work

b) Middleton *et al.* [7])

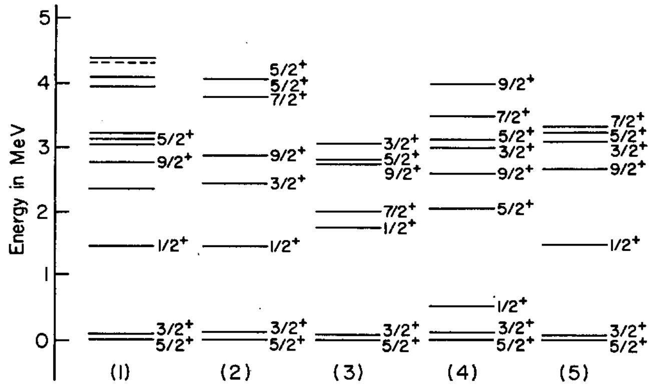

Fig. 5. Energy levels of O^{19}. (1) experimental levels, (present work), (2) calculated by Talmi and Unna, (3) calculated by Pandya, (4) calculated by Shah, (5) calculated by Cohen *et al.*

calculations of Talmi and Unna predict the $\frac{5}{2}$ state of the $d_{\frac{5}{2}}s^2_{\frac{1}{2}}$ configuration to be at a much higher excitation than was found experimentally. This is probably due to a strong configuration interaction with $d^2_{\frac{5}{2}}(2)s_{\frac{1}{2}}$, $J = \frac{5}{2}$ (ref. [8])). In fact, the calculations of Pandya and Cohen *et al.*, who included configuration mixing in their approach, yielded better agreement for this level. However, there is no agreement whatever between the various calculations for a level lying nearest to the 2.367 MeV state, believed to belong to the $d^2_{\frac{5}{2}}s_{\frac{1}{2}}$ configuration. The direct measurement of the spin of this level is clearly of great interest, as is the further verification of some of the tentative assignments made in the present work.

It should be remarked in this connection that it may be possible to obtain a better description of the O^{19} energy levels by assuming excitation of the O^{16} core. This approach would be analogous to that used by Brown [28]) and Federman and Talmi [29]), who recently calculated the O^{18} energy levels assuming two protons together with two neutrons to move in deformed orbits around an inert C^{14} core. The results showed good agreement with experiment and indicated that the actual O^{18} states are admixtures of shell model states and deformed states. It may turn out that the amount of deformed state components present is appreciable in the O^{19} energy levels as well.

4.2. THE O^{20} AND O^{18} ENERGY LEVELS

The L values of the angular distributions obtained for the O^{18}(t, p) reaction determine the spin and the parity of the O^{20} levels unambiguously. The results are summarized in table 3 and are compared with the values obtained by Middleton *et al.* [7]). In the angular range measured, the experimental distribution corresponding to the 3.57 MeV state in O^{20} did not show any peaking which could be fitted satisfactorily with theory; nevertheless the curve with $L = 4$ and $R = 8.0$ fm is shown for comparison purposes.

It is interesting to compare the O^{16}(t, p) reaction with the O^{18}(t, p) reaction, specifically the transitions to the ground and the first two excited states in both cases. In the pure *j-j* coupling these states form a 0^+, 2^+, 4^+ sequence arising from the two-particle $d_{\frac{5}{2}}^2$ configuration in O^{18}, and the two-hole $d_{\frac{5}{2}}^{-2}$ configuration in O^{20}. This analogy between initial and final states is reflected in the angular distributions proceeding to these states, as can be seen by comparing fig. 4 with the data of Jaffe *et al.* for the O^{16}(t, p) reaction.

In particular, it is noted that the transitions to the second excited states [4]) in O^{18} and O^{20} show similar behaviour. The absence of a stripping peak in the angular distributions to both states may be due to the distortion caused by the high centrifugal barrier ($L = 4$) which the two neutrons encounter on their way to the target nucleus. This view is supported by the fact that pronounced angular peaking was found [7]) at the higher bombarding energy of 10 MeV.

The transition to the 4.45 MeV level in O^{18} was found to proceed by $L = 3$. However, the assignment of a spin and parity of 3^- to this level should be rejected in view of contradictory evidence from other experiments. In particular, the measurement of the branching ratios of gamma rays [25]) from this level favours a 1^- assignment. Also, the transition to this level obtained at 10 MeV bombarding energy [7]) was very weak and did not show any stripping-like features. These observations suggest that the 4.45 MeV level is the excited 1^- state arising from the $1p^{-1}(2s, 1d)^3$ configuration predicted by Harvey [27]). It seems that the angular peaking of the transition to this level obtained in the present work is not due to a stripping process but rather to a more involved mechanism.

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