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Positions and Widths of O^{17} Levels from 4- to 6-Mev Excitation*

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The $O^{16}(d,p)O^{17}$ reaction was used to measure the positions and widths of O^{17} levels from 4- to 6-Mev excitation. Proton spectra were obtained at high resolution with a broad-range spectrograph. This instrument accurately measured the widths and shapes of the energy distributions of the proton groups arising from the wider levels. Disagreements among other experiments concerning the O^{17} levels are explained in terms of the large difference in level widths. A comparison of these directly measured widths is made with those obtained from neutron scattering experiments. The observed shape of the energy distribution is that predicted by resonance theory. The 0.87-Mev level is found to be single rather than double as recently suggested. Excitation energies obtained (in Mev) are 0.871 ± 0.004, 3.055 ± 0.004, 3.846 ± 0.005, 4.553 ± 0.006, 5.083 ± 0.010, 5.215 ± 0.005, 5.378 ± 0.007, 5.695 ± 0.005, 5.731 ± 0.005, 5.866 ± 0.005, 5.94 ± 0.015. Widths of levels 4, 5, 7, and 11 are (in kev) 40 ± 5, 95 ± 5, 28 ± 7, and 23 ± 10, respectively. The other levels have widths less than 8 kev.

I. INTRODUCTION

THIS work was undertaken to resolve disagreements among previous experiments concerning the positions and widths of the nuclear levels of O^{17} above 4-Mev excitation energy. The levels lying below 4-Mev are well known; the best excitation values come from results of an experiment using the $O^{16}(d,p)O^{17}$ reaction.[1] Information about levels above 4-Mev comes from three different reactions. These are, the $F^{19}(d,\alpha)O^{17}$ reaction, the $O^{16}(d,p)O^{17}$ reaction and the O^{16} total cross section for neutron scattering.

By use of photoplate techniques and a deuteron energy of 7.86 Mev, the energies of α particles and protons, respectively, from the first two reactions have been measured.[2] The results from the two reactions agreed fairly well within the rather large (20 to 60 kev) uncertainties. A magnetic spectrograph was used[3] to analyze the α particles from the first reaction to obtain more accurate values for the excitation energies and a measure of the level widths. In this experiment three new levels were seen but one previously observed level was not reported. The neutron scattering data[4] measure positions and widths precisely but disagree with the second experiment as to most of the widths and fail to show one of the levels. These data will be discussed and compared with the present results in a later section.

The MIT broad-range magnetic spectrograph[5] proved to be an ideal instrument for studying the proton spectrum from the $O^{16}(d,p)O^{17}$ reaction because it could record all proton groups leading to the O^{17} levels in question simultaneously and with high dispersion and negligible instrumental aberration. It became apparent in the course of the work that much of the disagreement in previous experiments arose from large differences in widths of the various nuclear energy levels. The broad-range spectrograph permitted both the widths and the positions of the levels to be measured accurately.

II. PROCEDURE

The procedures involved in taking data with the broad-range spectrograph and obtaining from the data the energies of the observed particles have been discussed previously.[5] In this experiment thin targets of solid oxide on Formvar backings were used. Either metallic lithium or iron was evaporated and then allowed to oxidize, or SiO_2 was evaporated directly. The slit settings on the beam-analyzing magnet determined an energy spread in the deuteron beam of 0.1% and defined a target spot $\frac{1}{2}$ millimeter wide in the energy-dependent direction. This spot served as the object for the spectrograph. Bombarding energies ranged from 6.5 to 7.5 Mev; angles of observation were 30°, 60°, 70°, and 90° with respect to the incoming beam. For observation at 30° the target was so set that particles collected had passed through the target whereas at the other observation angles particles from the front face of the target entered the spectrograph.

Identification of the observed particle groups with the proper nuclear reaction is based on the observed change in energy of the emitted particles with a change in bombarding energy or observation angle and a comparison of the spectra from the different target materials.

In calculating the energy of an observed particle group that comes from a nuclear level with an appreciable natural width, a procedure must be used that is somewhat different than that used for a group from an exceedingly narrow level. In the latter case the shape of the observed peak is determined by target and instrumental effects only, and the point on the peak

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† Most of the data analysis and calculations appearing in this paper were carried out at the author's present address, the University of Notre Dame, Notre Dame, Indiana.

[1] Sperduto, Buechner, Bockelman, and Browne, Phys. Rev. **96**, 1316 (1954).

[2] Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **209**, 478 (1951).

[3] H. A. Watson and W. W. Buechner, Phys. Rev. **88**, 1324 (1952).

[4] C. K. Bockelman, Phys. Rev. **80**, 1011 (1950); Bockelman, Miller, Adair and Barschall, Phys. Rev. **84**, 69 (1951).

[5] C. P. Browne and W. W. Buechner, Rev. Sci. Instr. **27**, 899 (1956).

whose position is least sensitive to these effects, namely the point at one-third maximum, is chosen to represent the peak position on the plate-distance scale. This point is obviously unsuitable for the present case, where the observed width arises mainly from natural level width. The procedure used was to determine the position of the center of the peak and add to this the distance from the center to the one-third height point for the polonium alpha-particle peaks used to calibrate the spectrograph. As the energy equivalent of the half width of the calibration peaks is about 2 kev, the error involved in this transformation of calibration from one-third height position to peak center position should be no more than a fraction of a kev.

In order to obtain the natural level width from the width of the group of emitted particles on the nuclear track plate, the various factors contributing to this observed width must be known. These include energy spread of the incoming beam, energy loss in the target, finite size of the target spot that forms the object for the spectrograph, spread in angle of observation, fluctuations in the magnetic fields of the beam-analyzing magnet and the spectrograph, and aberration in the spectrograph focus. The relative effect of each of these depends, among other things, on the dispersion and magnification of the spectrograph. The magnitude of each of these effects has been measured or an upper limit set for the conditions under which these data were taken.

Under the conditions existing for this experiment the only significant contributions to the line width were the spread in incoming beam energy, the target spot size, and the energy loss in the target.

In the runs made to determine widths, the targets were thin enough for the loss in energy in the target to be negligible. This was shown (1) by the fact that the energy spread of relatively low-energy proton groups from some of the more highly excited levels was no more than that of relatively high-energy proton groups from the lower levels, and (2) by the fact that widths measured at 30 degrees, where all particles passed through the target, agreed with widths measured at other angles, where the spectrograph took particles from the front face of the target.

Four of the O^{17} levels were found to have widths greater than the lower observable limit. In the case of two of these levels the natural width was so much larger than the instrumental width that the latter became negligible. The instrumental widths contributed a significant amount to the observed width in the other two cases but even here it was a small fraction of the total.

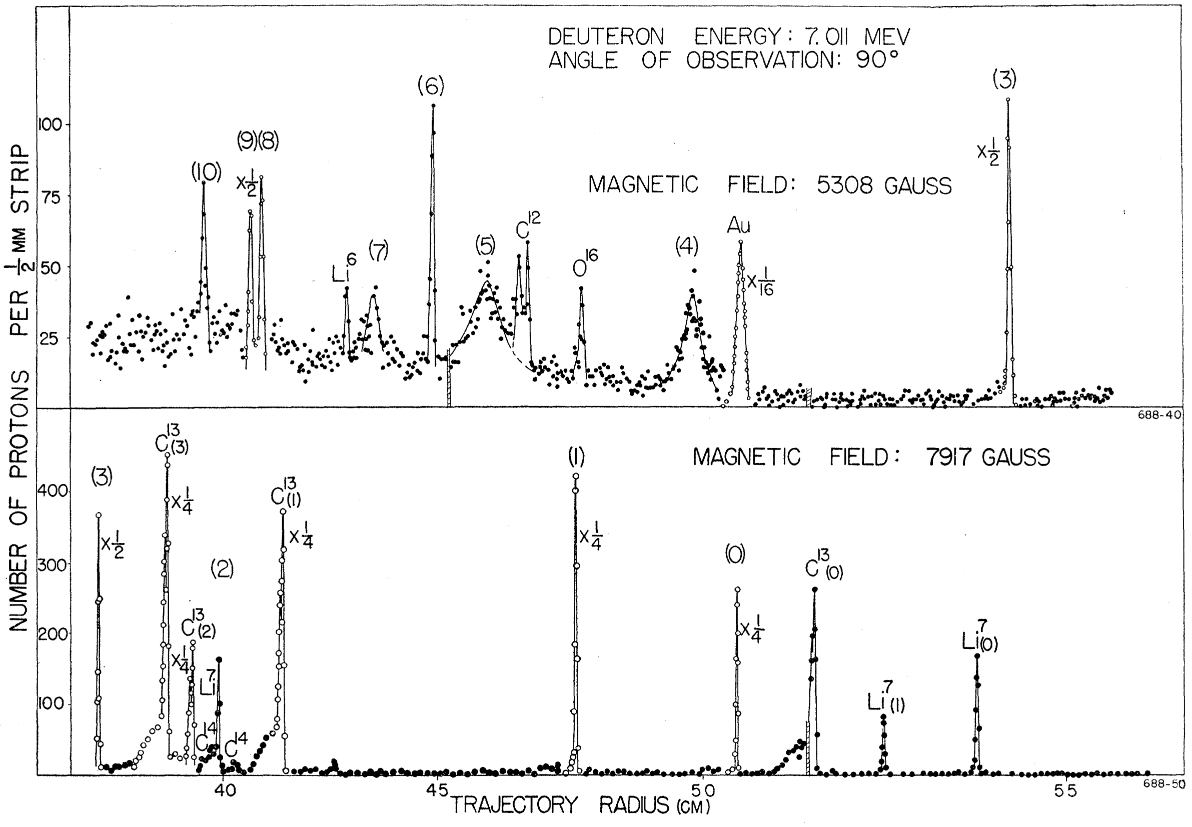

FIG. 1. Spectra of protons emitted at 90° from a LiOH on Formvar target bombarded with 7.01-Mev deuterons. The magnetic field settings for the two plots were such as to cover different ranges of proton energies.

For the purpose of subtracting the small instrumental width, a Gaussian curve may be used as a good approximation to the true resonance curve. The observed width is then taken to be the square root of the sum of the squares of the natural and instrumental energy spreads.

The two important factors in the so-called instrumental width are the object size and the energy spread of the incoming beam. The object size alone gives a rectangular distribution to the particles in the image. This known distribution is taken out of the observed approximately Gaussian distribution by use of curves obtained by numerical integration of the combination of rectangular and Gaussian distributions. The remaining distribution is ascribed to the various energy spreads. The instrumental energy spread found from the ground state group and groups from other sharp levels is then subtracted as a Gaussian from the total energy spread to leave the natural energy distribution.

III. RESULTS

A. Level Positions

Typical plots of the proton spectra obtained appear in Figs. 1 and 2. Figure 1 shows the results of two exposures made at a 90 degree angle with 7.0-Mev bombarding energy on a LiOH target. The lower plot covers the region of excitation in O^{17} from the ground state to 3.85 Mev and the upper plot covers the range from 3.8 to 6.2 Mev. The region of particular interest in this experiment is that covered by the upper plot. The data in the lower plot were taken for comparison with previous results[1] and to obtain the instrumental widths for the ground state and first three excited state groups.

In both plots the groups leading to O^{17} levels are identified in order of increasing excitation energy by numbers beginning with zero for the ground state. Other proton groups appearing on the lower plot arise from the $C^{12}(d,p)C^{13}$ reaction, the $C^{13}(d,p)C^{14}$ reaction, and the $Li^6(d,p)Li^7$ reaction. Other groups in the upper plot are elastically scattered protons from the contaminating beam of molecular hydrogen which is mixed with the deuteron beam. All the groups except those leading to O^{17} are labelled with the symbol of the residual nucleus. The groups associated with reactions with carbon show double peaks because of the presence of carbon contaminating the target material as well as carbon in the Formvar target backing. Figure 2 shows two plots of data taken at 7.49 Mev and 30 degrees with a LiOH target and with a SiO_2 target. These spectra cover the region of excitation from about 4 Mev to 6.8 Mev. The groups leading to O^{17} are num-

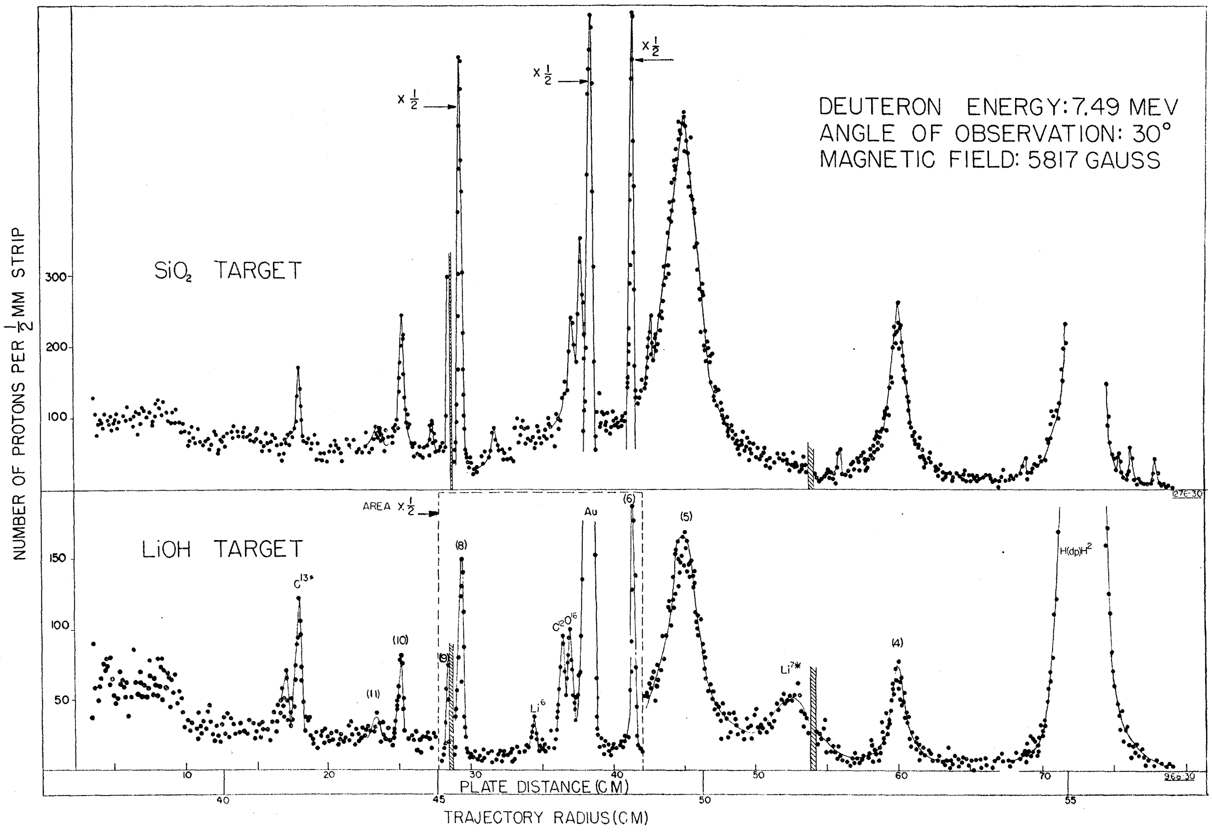

FIG. 2. Spectra of protons emitted at 30° with 7.49-Mev bombarding energy. Lower plot; LiOH target. Upper plot; SiO_2 target.

TABLE I. Q values and excitation energies.

Bombarding energy (Mev) Observation angle Target	7.011 90° LiOH		7.494 60° LiOH		7.495 30° LiOH		7.491 30° SiO_2		6.495 30° Fe_2O_3		Average excitation energy $\langle E_x\rangle_{Av}$
Level	Q (Mev)	E_x (Mev)	Q	E_x	Q	E_x[a]	Q	E_x[a]	Q	E_x	
0	1.918										
1	1.047	0.871									0.871±0.004
2	−1.136	3.054	−1.139	3.057							3.055±0.004
3	−1.927	3.845	−1.930	3.848							3.846±0.005
4[b]	−2.635	4.553	−2.637	4.555	−2.638	4.554	−2.635	4.551			4.553±0.006
5[b]	−3.155	5.073	c	...	−3.171	5.087	−3.173	5.089			5.083±0.010
6	−3.298	5.216	−3.295	5.213	−3.298	5.214	−3.300	5.216	−3.297	5.215	5.215±0.005
7[b]	−3.460	5.378	c	...	c	...	c	...	−3.461	5.379	5.378±0.007
8	−3.777	5.695	−3.777	5.695	−3.779	5.695	−3.780	5.696	−3.779	5.697	5.695±0.005
9	−3.812	5.730	−3.813	5.731	(−3.816)	(5.732)	c	...	−3.815	5.733	5.731±0.005
10	−3.948	5.866	−3.947	5.865	−3.951	5.866	−3.950	5.866	−3.946	5.865	5.866±0.005
11							−4.03	5.95	−4.02	5.93	5.94 ±0.015

[a] Excitation energies adjusted by 0.0025 Mev (see text).
[b] Values given are for the center of the observed wide group (see text).
[c] Group obscured by groups from other reactions.

bered in the lower plot. The presence of the same groups with the same relative intensities in the upper spectrum where a different target was used helps to confirm the identification. Both plots show a broad, extremely intense group of knock-on protons from deuteron scattering of the beam by hydrogen in the target backing and groups from elastic scattering of the molecular hydrogen beam. As in Fig. 1 these are labelled with the symbol of the scattering nucleus. The seventh O^{17} level is obscured by these groups at this angle and bombarding energy. A group from the $C^{12}(d,p)C^{13*}$ reaction leading to the 6.86-Mev level in C^{13} is seen at a plate distance of 18 cm. On the lower plot a broad group from the $Li^6(d,p)Li^{7*}$ reaction leading to the 7.46-Mev level of Li^7 is seen at a plate distance of 52 cm. The weak, unlabelled groups seen only in the upper spectrum presumably are groups from silicon.

The best Q values obtained for all the O^{17} levels observed are listed in Table I along with the corresponding calculated excitation energies. Data from other runs with thicker targets aided in identification of groups but were not included in the Q value averages.

In calculating excitation energies the usual procedure is to subtract from the Q value the ground state Q value observed at the same bombarding energy and angle of observation. Errors caused by uncertainty in bombarding energy and by energy loss in possible surface layers on the target tend to cancel out in this way and the excitation energy is more accurate than the Q value itself. In the present experiment the ground state Q value was accurately measured in one run only. Furthermore, in the runs at 30° where particles passed through the target, energy loss in the target introduced some uncertainty in the Q value. All runs give the spacing between the observed levels to high precision but when taken separately give no more accurate values for the excitations than for the individual Q values. For this reason the sum of the Q values for levels (4), (6), (8), and (10) observed in a given run was compared with the sum of the Q values for the same levels from the run in which the ground state group was measured. In two runs a small (2.5 kev) adjustment was made in the excitation energies to bring these sums into agreement. In other words the run in which the ground state group was observed served to give the energy difference between the ground state and the average position of the group of levels here observed whereas all the runs were used to find the spacings of these levels. The runs for which adjustments were made are noted in Table I.

The individual Q values from the various runs agree well and the sums of the Q values agree excellently. The fact that the various runs were taken over a period of nearly two years and under various conditions gives added confidence in the accuracy of the results and the probable errors given in the table.

TABLE II. Relative intensities.

Bombarding energy (Mev) Observation angle Level	7.011 90°	7.006 70°	7.494 60°	7.491 30°	6.495 30°
0	100				
1	166				
2	14				
3	48				
4	23	100	100	100	
5	57	...	440	274	
6	13	113	68	33	100
7	5.4	...	...	26	95
8	20	112	75	44	210
9	11	58	...	27	80
10	7.9	16	18	17	50
11	<2	...	(5)	(10)	(8)

B. Intensities

No effort was made in this experiment to measure absolute cross sections or angular distributions. The broad-range spectrograph, however, automatically provides an accurate measure of the relative intensities of all groups recorded on one exposure. The relative in-

TABLE III. Level widths.[a]

Level		4			5			7			11		
Bombarding energy (Mev)	Observation angle (degrees)	ΔT_0	ΔT_N	ΔQ	ΔT_0	ΔT_N	ΔQ	ΔT_0	ΔT_N	ΔQ	ΔT_0	ΔT_N	ΔQ
7.011	90	35.2	34.5	36.5	90.0	89.5	95.0	(20)	(19)	(20)			
7.006	70							34.0	29.7	30.1	29	23	23
7.494	60	43.7	42.1	42.2									
7.495	30	42.1	40.8	39.5	96.0	95.4	92						
7.491	30	42.5	42.0	41.0	103.7	103.5	99.5				26	23	23
6.495	30	45	45	43	95	95	91	29.2	28.4	27	24	23	22
Average				40±5			95±5			28±7			23±10

[a] All energy spreads are in kev.

tensities of the groups observed at each bombarding energy and angle are listed in Table II. The intensities are abritrarily referred to the level of lowest excitation observed in each case. Thus numbers in different columns have no relation to one another.

It was difficult to observe the weak proton group corresponding to the level previously reported[3,4] near 5.94 Mev. A weak group appears at the proper position on some of the exposures but the small number of tracks above background plus the appreciable width of the group reduce the accuracy of the measurement of position and intensity.

No other groups that could be ascribed to oxygen were seen. The upper limit of intensity of other groups was about 10% of the intensity of level (4).

C. Level Widths

In observing the widths of the groups, shown in Figs. 1 and 2, two of the spectrograph characteristics should be borne in mind. First, it is the ratio $\Delta E/E$, where E is the group energy, that is fixed for a given position on the plate (given trajectory radius) and second, this ratio varies markedly from one end of the plate to the other. The first fact means that for a given spread in energy the group width on the plate is larger for a lower energy group and the second fact means that a given particle group has a greater width when placed at a larger trajectory radius.

It is immediately obvious from the spectrum plots that the O^{17} levels labeled (4), (5), and (7) have an appreciable natural width. The presence, on the same plate, of narrow groups from levels of higher excitation shows conclusively that the observed width arises from natural level width rather than from instrumental effects.

Table III gives the data on the widths of levels (4), (5), (7), and (11). The column labeled ΔT_0 gives the energy spread equivalent to the observed half-width of the emitted particle group, the column labeled ΔT_N gives the part of this energy spread associated with the natural level width, i.e., the result of subtracting the instrumental widths by the process outlined in the section on procedure, and the column labeled ΔQ gives the width of the nuclear energy level calculated from ΔT_N. The averages of the various runs are given together with the probable errors.

All other levels measured appear to have widths less than the instrumental width. In view of the recent suggestion[6] that there may in fact be two levels separated by 11 kev at the position of the first excited state of O^{17}, it is of interest to examine the present data on this level. Figure 3 is a large-scale plot of the particle groups corresponding to the first excited state, and to the ground state. It is seen that the shapes and widths of the two peaks are essentially identical. The energy in kev equivalent to the observed half-width corrected for the finite source size is given in the figure. Here the

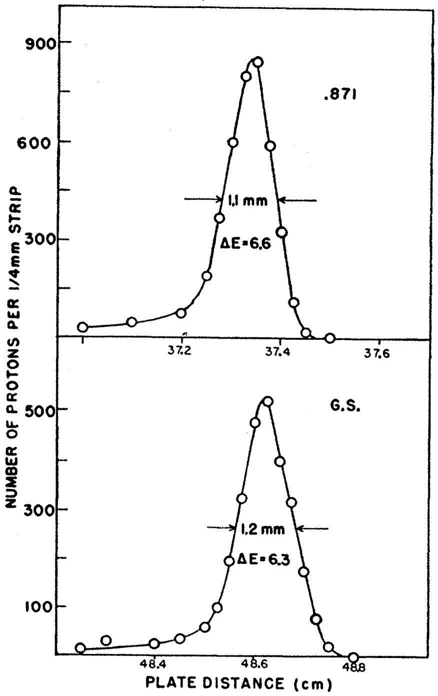

FIG. 3. Proton groups leading to the ground state and first excited state of O^{17}.

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[6] Douglas, Broer, Chiba, Herring, and Silverstein, Phys. Rev. **104**, 1059 (1956).

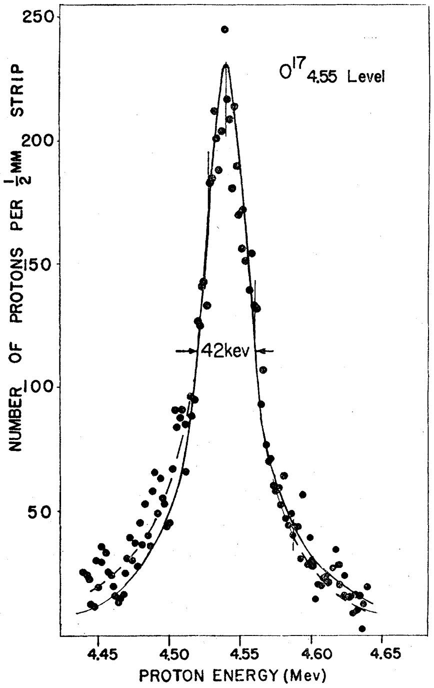

FIG. 4. Proton group leading to the 4.55-Mev level of O^{17}. Curves are theoretical and are discussed in the text.

source size contributes appreciably to the observed width. The spread in energy of the incoming beam required to give the average energy spread of 6.4 kev in the emitted particle groups is 7.6 kev. This agrees excellently with the figure of 7.0 kev calculated from the slit settings of the beam-deflecting magnet.

Since the excited state group and ground state group lie close together on the same nuclear track plate, the conclusion drawn from the similarity of shape and width is independent of the details of correction for source size, etc. It is apparent that the peak corresponding to the excited state is a single group of particles. If there is a second level 10 kev or more from this one it contributes less than 4% to the observed intensity. A level as close as 5 kev and contributing 20% of the observed intensity would be seen through an appreciable broadening of the peak.

The upper limit for the widths of other O^{17} levels observed here is estimated to be 8 kev.

IV. DISCUSSION

A. Level Shape

The ability to record an entire particle group simultaneously with high resolution makes it possible to observe directly the energy distribution of particles emitted in the formation of a wide nuclear level and hence to measure directly the level "shape." The particle groups from the 4.5- and 5.0-Mev levels in O^{17} were sufficiently wide compared to the instrumental effects and also sufficiently intense to give good representations of the natural energy distributions.

It is particularly interesting to compare results so obtained with theoretical expectations for the shape and with the level widths obtained from neutron scattering. Although the theory has not been developed for the general case of charged particles emitted in a nuclear reaction, a good approximation should be given by existing resonance theory, for levels with widths of the order of magnitude under consideration here. Above 4.14 Mev O^{17} is unstable to neutron emission, so the two levels in question decay predominantly in this way. Thus, the partial width for neutron emission may be taken as the total width. To a first approximation the variation of this partial width over the relatively small energy spread of the levels may be ignored. The energy distribution curve for the emitted neutrons in the decay of O^{17} should then be of the form $1/[(E-E_s)^2+\frac{1}{4}\Gamma^2]$ where Γ is the total width, E is the neutron energy, and E_s the resonance energy. The probability for formation of the state from the compound system (F^{18}) is assumed constant for the relatively small change in the energy of the emitted proton across the width of the residual level. The energy distribution of the protons leading to the O^{17} level should have the same form but be reversed with respect to the resonance energy because the sum of the energies of the proton emitted in formation of the level, E_p, and the neutron emitted in the decay, E_n, is a constant. $E_p+E_n=E_d+Q=$ constant, where Q represents the energy difference between the initial particles, O^{16} and the deuteron, and the final particles, O^{16}, the neutron and the proton. E_d is the energy of the bombarding deuteron. The small variation in the recoil energy of the residual O^{16} nucleus is neglected.

Large-scale plots of proton groups leading to the 4.5- and 5.0-Mev levels are shown in Figs. 4 and 5 respectively. These plots are taken from the run giving the highest intensity where the statistical uncertainties are small. These uncertainties are indicated on representative points on the plots. By using the very nearly linear variation of energy with distance along the plate, the abscissas have been labeled with the corresponding proton energies. The solid curves are calculated from the resonance formula given above with Γ and E_s read from the experimental plot.

It is seen that the resonance curve in this approximate form fits the data very well. The deviation on the low-energy side of the 5.0-Mev level may be caused mostly by the superimposed weak silicon group and the tail of the intense 5.2-Mev level. A similar plot of data from a LiOH target gives a better fit down to the position of the 5.2-Mev level.

The two levels in question are not far above the neutron binding energy so the neutron width will vary considerably across the levels. A better approximation of the expected shape may be made by computing this variation. From the neutron scattering data it is known that the orbital angular momentum of the outgoing neutron is given by $l_n=2$ for the 5.0-Mev level and $l_n=1$ for the 4.5-Mev level, so the penetration factors v_{ln} may be evaluated. The neutron width Γ_n has the form $\Gamma_n=2k_nRv_{ln}\gamma_n$ where γ_n is the reduced width, here assumed constant, R is the interaction radius and k_n is the wave number of the neutron. The number of neutrons emitted as a function of energy is then proportional to $\Gamma_n/[(E-E_s)^2+\frac{1}{4}\Gamma^2]$. The proton spectrum will again have this shape but will be reversed with respect to the resonance energy. The resulting curves are shown on Figs. 4 and 5 as dashed lines. The shape is almost indistinguishable from that obtained by neglecting the variation in neutron width. A slightly different value for E_s must be used in the resonance formula to obtain a fit, which means that the center of the observed peak should not be used in calculating the level position but rather this latter value of E_s. The difference amounts to about 7 kev in the case of the 5.08-Mev level, and about 1.5 kev in the case of the 4.55-Mev level. This would give values of 5.081 and 4.550 Mev for the excitation energies calculated for these particular groups rather than the values listed in Table I.

Inclusion in the resonance formula of the term[7] giving the variation in the "formal resonance energy" makes a negligible change in the shape of the energy distribution for the groups considered here. The choice of the point taken on the peak to give the observed level position is therefore not affected. The result here is of course the actual level position and not the formal resonance energy of scattering theory.

The errors listed in Table I are larger for the wide levels to take account of the uncertainties arising in the choice of the particular point of the peak used to represent the level position. From the fact that no more than a 7-kev shift in E_s is made and the shape is only slightly altered by neglecting the large change in neutron width across the 5.08-Mev level, it seems that other effects such as variation in the probability for formation of the level from the highly excited compound system will make a negligible difference in the shape and hence in the observed level position. The observed level position and width should be the same for formation through a reaction or by neutron scattering under the assumptions that the width is due predominantly to neutron decay and that the neutron width is the controlling factor in the shape of the energy distribution.

B. Comparison with Previous Results

The Q value for the ground state agrees within 1 kev with the accepted average of previous measurements[8] which is 1.919±0.004 Mev. This average does not include the value of 1.915±0.010 Mev given in reference 1 which is also in good agreement.

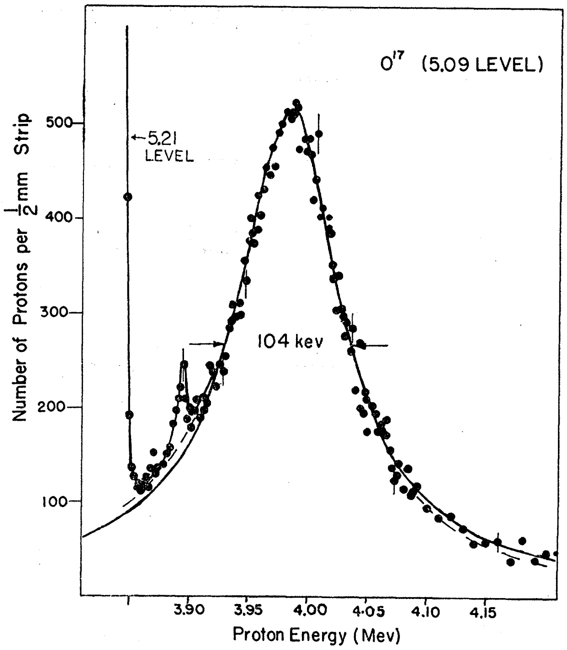

FIG. 5. Proton group leading to the 5.08-Mev level of O^{17}. Curves are theoretical and are discussed in the text.

The excitation energy for the first state agrees well with the value of 0.875±0.012 given in reference 1 and the Q value for this level is within 1 and 2 kev, respectively, of recent precision measurements of 1.0490 ±0.0022 Mev[9] and 1.048±0.002 Mev.[6]

The data strongly support the conclusion that the first excited state is a single level and set a somewhat lower limit on its width than that set by other recent work.[9]

Figure 6 compares the results of the present experiment with the results of the previous experiments cited. It is seen that the three experiments using precision energy measurements agree about the positions of all levels seen in two or more of the experiments. In the case of the $F^{19}(d,\alpha)O^{17}$ magnetic spectrograph data the discrepancies with the present experiment may be understood in the light of the level widths. Examination of the published[3] α-particle spectrum reveals the existence of a broad group at the expected position of the 5.08 level. Because of the narrow range of the 180° spectrograph this broad group was easily confused with background although the possibility that it corresponded to a level in O^{17} was recognized by the authors. It is also evident that the broad group interpreted as a wide level at 5.70-Mev excitation is in reality an overlapping of the groups leading to the 5.695- and 5.731-Mev levels. With the rather high energy loss of α particles in the targets used in the (d,α) work, accurate

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[7] R. G. Thomas, Phys. Rev. **81**, 148 (1951).

[8] D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954).

[9] F. S. Mozer and F. B. Hagedorn, Phys. Rev. **105**, 1270 (1957).

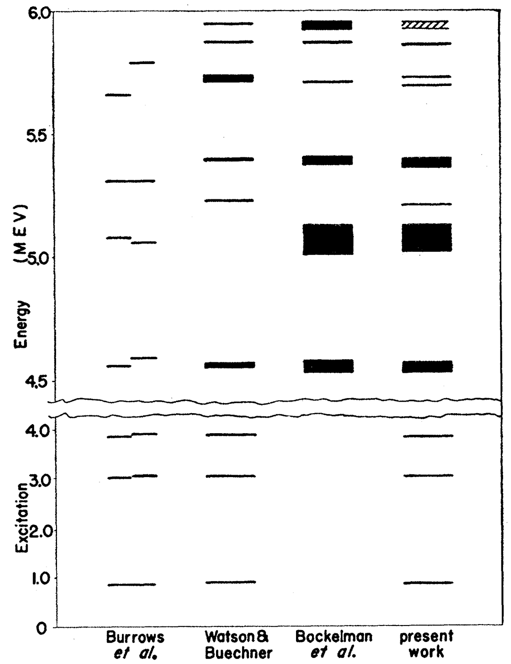

FIG. 6. Energy levels of O^{17} seen in various experiments. The width of the lines indicates the observed widths of the levels.

measurement of the natural energy spread of the emitted groups apparently was impossible.

In the case of the neutron scattering data the level positions and widths observed agree very well with the present experiment for all levels mutually observed, as may be seen in Fig. 6 and in Table IV. The 5.215- and 5.731-Mev levels were not seen in the neutron scattering. These levels are narrow and very probably have high angular momenta so that there is a low probability of forming them by scattering neutrons from O^{16}.

TABLE IV. Comparison of results from $O^{16}(d,p)O^{17}$ and $O^{16}(n,n)O^{16}$.

Level	Excitation energy (Mev) $O^{16}(d,p)$[a]	$O^{16}(n,n)$[b]	Width (kev) $O^{16}(d,p)$[a]	$O^{16}(n,n)$[b]
4	4.553±0.006	4.54	40±5	40
5	5.083±0.010	5.07	95±5	100
6	5.215±0.005	...	<8	...
7	5.378±0.007	5.37	28±7	35
8	5.695±0.005	5.69	<8	7
9	5.731±0.005	...	<8	...
10	5.866±0.005	5.86	<8	10
11	5.94 ±0.012	5.93	23±10	30

[a] $O^{16}(d,p)$ present work.
[b] $O^{16}(n,n)$ reference 4.

It is not surprising that the present experiment showed no levels above 6 Mev, considering that the outgoing proton energy here was only about 2.5 Mev whereas the Coulomb barrier is about 3.0 Mev. This fact also makes observation of the level at 5.94 Mev difficult, particularly as the appreciable width of this level causes the few particles in the group to be spread over a considerable distance on the plate.

The agreement as to the width that is shown in the table is of particular interest in view of the radically different ways in which the O^{17} levels are formed in the two experiments. This agreement strongly supports the assumption that the determining factor in the widths here is the decay of the states by neutron emission.

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