Magnetic Analysis of the $F^{19}(d, p)F^{20}$ and $F^{19}(d, \alpha)O^{17}$ Reactions*

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The energy spectrum of protons from the $F^{19}(d, p)F^{20}$ reaction has been analyzed at 90 degrees to the incident deuteron beam, using an annular magnetic spectrograph with photographic detection. Nineteen proton groups have been observed and identified with this reaction. These correspond to the ground state of F^{20} and eighteen excited states in the range of excitation from 0 to 5.1 Mev. Deuteron bombarding energies ranging from 1.5 to 2.1 Mev were used.

Tracks of alpha-particles, arising from the $F^{19}(d, \alpha)O^{17}$ reaction, were also observed on the photographic plates. Alpha-particle groups corresponding to the ground state and ten excited levels of O^{17} in the range of excitation from 0 to 6.9 Mev were identified. Some of the groups corresponding to O^{17} levels of sufficient excitation to be unstable against neutron decay exhibited a broadening which may result from the natural width of the corresponding O^{17} levels.

I. INTRODUCTION

THE present investigation has been undertaken to measure the excited states of F^{20} using the $F^{19}(d, p)F^{20}$ reaction. The levels of this nucleus are of particular interest since they have been reported[1] to be spaced by integral multiples of 320 kev. Additional information, however, has been obtained about the excited states of O^{17} from observations on the energy spectrum of alpha-particles from the $F^{19}(d, \alpha)O^{17}$ reaction. The O^{17} nucleus and its mirror nucleus F^{17} are one of the few pairs of mirror nuclei whose energy levels are not difficult to observe. It is of particular interest, therefore, that their energy levels should be carefully measured in order that one might compare their energy-level diagrams.

Of the previous investigations of the F^{20} energy levels, the largest number of levels observed thus far are those recently reported by Burrows, Powell, and Rotblat,[2] who used 8.0-Mev cyclotron deuterons and measured the proton ranges in photographic emulsions. The ground-state Q-value was measured to be 4.39 Mev, and excitation energies of 0.63, 0.83, 1.00, 1.37, 2.55, 2.91, 3.49, 4.06, 4.31, and 4.73 Mev with errors of ± 0.05 Mev were reported for the ten excited F^{20} levels.

Other recent measurements have been made by Shull[3] and by Allen and Rall.[4] Shull made a magnetic analysis at 90 degrees of the proton spectrum using 10.3-Mev deuterons and identified proton groups corresponding to seven excited F^{20} states. A ground-state Q-value of 4.55 Mev was measured, and excitation energies of 0.69, 0.98, 2.20, 2.70, 3.12, 3.74, and 4.41 Mev were assigned to the seven excited states. Allen and Rall, using 3.76-Mev deuterons and range measurements, reported eight excited levels in approximately the same range having excitation energies of 0.64, 0.97, 1.31, 1.91, 2.52, 2.83, 3.45, and 4.01 Mev. The ground-state Q-value was measured to be 4.16 Mev. The results of these investigations are tabulated in Table II, together with those obtained in the present investigation.

Burrows, Powell, and Rotblat[2] have also investigated the energy levels of O^{17}. Measurements were made of the range in photographic emulsions of protons from the $O^{16}(d, p)O^{17}$ reaction and of alpha-particles from the $F^{19}(d, \alpha)O^{17}$ reaction. Eleven proton groups arising from the $O^{16}(d, p)O^{17}$ reaction and fourteen alpha-particle groups arising from the $F^{19}(d, \alpha)O^{17}$ reaction were identified. Excitation energies of 0.87, 3.06, 3.85, 4.58, 5.07, 5.31, 5.76, 6.24, 6.89, 7.51, 8.27, 8.59, and 9.06 Mev were calculated for thirteen O^{17} states by averaging the results of the two reactions. The ground-state Q-value for the $F^{19}(d, \alpha)O^{17}$ reaction was measured to be 10.04 ± 0.02 Mev.

Bockelman *et al.*[5] at Wisconsin observed seven resonances in the scattering of neutrons by O^{16}. Using a binding energy of 4.14 Mev for the neutron, these resonances correspond to excitation energies of 4.55, 5.08, 5.38, 5.70, 5.87, 5.94, and 6.37 Mev. The results obtained by Burrows, Powell, and Rotblat and by Bockelman are tabulated in Table III, together with those obtained in the present investigation.

Range measurements on the alpha-particle spectrum from the $F^{19}(d, \alpha)O^{17}$ reaction were also made by French, Meyer, and Treacy,[6] who observed four alpha-particle groups corresponding to excited O^{17} states and calculated their Q-values to be 6.79, 6.03, 5.26, and 2.81 Mev. The ground-state Q-value has previously been measured by this laboratory[7] to be 10.050 ± 0.010 Mev. In addition, French, Meyer, and Treacy also

* This work has been assisted by the joint program of the ONR and AEC.
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[1] R. C. Allen and W. Rall, Phys. Rev. **78**, 337 (1950).
[2] Burrows, Powell, and Rotblat, Proc. Roy. Soc. (London) **A209**, 478 (1951).
[3] F. B. Shull, Phys. Rev. **83**, 875 (1951).
[4] R. C. Allen and W. Rall, Phys. Rev. **81**, 60 (1951).
[5] Bockelman, Miller, Adair, and Barschall, Phys. Rev. **84**, 69 (1951).
[6] French, Meyer, and Treacy, Proc. Phys. Soc. (London) **A63**, 666 (1950).
[7] Strait, Van Patter, Buechner, and Sperduto, Phys. Rev. **81**, 747 (1951).

observed an alpha-particle group that they identified with the $F^{19}(d,n)Ne^{20*}\rightarrow O^{16}+\alpha$-reaction. An excitation energy of 9.7 Mev was calculated for the Ne^{20} state, which gave rise to the group.

The present investigation with the magnetic spectrograph was undertaken to determine whether earlier investigations had been unable to resolve some of the levels in the regions surveyed and to obtain more accurately the excitation energies. The development of thin nickel-foil backings for targets made it possible to investigate the F^{20} levels up to excitations of about 4.8 Mev, using the magnetic spectrograph. The relatively high ground-state Q-value of the $F^{19}(d,\alpha)O^{17}$ reaction, on the other hand, permitted measurement of the O^{17} levels up to an excitation of 7.5 Mev. Thus, it was possible to check most of the regions covered in the previous investigations.

The measurements on the proton energy spectrum were carried out over a period of about a year starting in July, 1950. When this was completed, a number of additional exposures were taken to survey the alpha-particle spectrum from the (d,α) reaction at bombarding energies of 1.8 and 2.0 Mev. When these exposures were completed and before the data were analyzed, the spectrograph was dismantled and moved to another generator. As will be discussed in a later section, there are indications that appreciable surface contamination may have been present on the targets during these exposures for the alpha-particle groups. The results, however, are reported here since it may be some time before there is an opportunity to repeat this portion of the work.

II. APPARATUS AND EXPERIMENTAL PROCEDURE

The apparatus and experimental procedures used in the investigation are similar to those that have been described in earlier papers.[7–9]

The apparatus consisted essentially of the MIT 2.0-Mev air-insulated electrostatic generator, a deflecting magnet and slit system to define the energy of the deuteron beam, and an annular-magnet spectrograph with which the observations on the spectrum of charged particles leaving the reactions were made. Eastman NTA photographic plates were used to detect the charged particles deflected by the spectrograph. All observations were made at 90 degrees to the incident beam. The fluxmeter for the spectrograph was calibrated through measurements on the deflection of polonium alpha-particles. The energy of the incident beam was determined by measuring the energy of the deuterons scattered elastically by C^{12} and O^{16} nuclei in thin Formvar targets.

Several types of targets were used. In the investigation of proton groups having momenta between 210 and 350 kilogauss-centimeters at 1.8-Mev bombarding energy, thin layers of PbF_2 evaporated onto 10-mil platinum sheets were employed. In the range of $H\rho$ values below 272 kilogauss-centimeters, thin aluminum foils were placed in front of the photographic plates to absorb deuterons scattered elastically by the platinum nuclei in the target backing. These foils were of such a thickness that they would pass the protons at reduced velocity and absorb all the deuterons.

At still lower $H\rho$ values, below 210 kilogauss-centimeters, a thin-target technique was employed. The use of thin nickel foils as target backings has already been described by Bashkin and Goldhaber.[10] A somewhat modified method of using these foils has been found satisfactory for the present investigation.

Nickel foils of thicknesses 1000A and 750A, with attached copper backings, were obtained from the Chromium Corporation of America, Waterbury, Connecticut. In the present investigation, these were fixed to $\frac{5}{8}\times\frac{5}{8}$-inch wire frames with glyptal, the latter being in contact with the nickel rather than the copper. The frame was then mounted vertically in a jig and lowered into a chromic-acid solution which dissolved away the copper. While still wet, it was then successively immersed in several beakers of water to wash away the acid. By using extreme care in raising and lowering the foils in and out of the liquid, it was found that only about 10 percent of them were ruptured by the surface tension of the water, despite their extremely small thickness. Thin layers of BaF_2 were then evaporated onto the foils. Targets made in this manner seemed capable of withstanding almost indefinite bombardment (at least several thousand microcoulombs) at a beam intensity of 0.4 microampere.

In the investigation of the higher energy part of the alpha-particle spectrum, targets of BaF_2 and PbF_2 on platinum backings were used. The BaF_2 targets with thin nickel backings were again used in the study of the region in which elastically scattered deuterons would otherwise have covered the photographic plates.

In calculating the Q-values for the various groups, small corrections were applied, which took into account the following:

(1) A small measured departure of the median angle of observation from 90 degrees.

(2) The effect of the finite angle of acceptance of the spectrograph magnet ($\pm 0.2°$ about the median angle).

(3) The approximation in using the nonrelativistic Q-equation.

The first of these corrections arose from an earlier measurement which indicated that the incident deuteron beam was not quite perpendicular to the planes of the pole faces of the magnetic spectrograph and, hence, that the median angle of observation was not quite 90 degrees.

[8] Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).

[9] Buechner, Strait, Sperduto, and Malm, Phys. Rev. **76**, 1543 (1949).

[10] S. Bashkin and G. Goldhaber, Rev. Sci. Instr. **22**, 112 (1951).

III. RESULTS AND CONCLUSIONS

A. The $F^{19}(d, p)F^{20}$ Reaction

The spectrum of protons observed from the bombardment of fluorine targets with 1.8-Mev deuterons is shown in Figs. 1 and 2 as a function of their momentum in kilogauss-centimeters. In Fig. 1 the group of protons on the right, marked F^{19}(O), results from individual events in which the ground state of F^{20} has been formed. Groups arising from eighteen excited states of the F^{20} nucleus are marked with the numbers 1 through 18. Other groups resulting from reactions with contaminant elements are marked according to the contaminant nuclei. The spectrum was surveyed using several targets so that it was necessary to normalize the yield of the various fluorine groups. This was done by taking exposures on the ground-state group for each target.

The energy of each group has been taken to be that corresponding to the point at one-third height on the high energy side of the peak. Selection of this point has been previously discussed.[8] Each of the fluorine groups was observed at two different bombarding energies. In the case of all except groups (6) and (15), a change in bombarding energy of 0.3 Mev or more was used. For groups (6) and (15), a change of 0.2 Mev was used. Bombarding energies of 1.5, 1.8, 2.0, and 2.1 Mev were used at various times during the investigation.

The two intense groups at $H\rho$ values of 287 and 150 kilogauss-centimeters have been observed in all previous surveys of this energy region and result from the $C^{12}(d, p)C^{13}$ reaction, leading to the formation of the ground state and first excited state, respectively, of C^{13}. Similarly, the two intense groups with $H\rho$ values of 263 and 228 result from the $O^{16}(d, p)O^{17}$ reaction, leading to the formation of the ground state and first excited state of O^{17}.

Identification of the weaker contaminant groups was made through calculation of their Q-values, assuming a given reaction, and comparison with the results previously measured for the same reaction. A list of the Q-values observed for the reactions leading to the weaker contaminant groups, together with those previously measured at this Laboratory for the same reactions, is given in Table I.[7,11-13]

Each contaminant group was also observed at a different bombarding energy to make certain that there was not a weak fluorine group superimposed on it. By changing the bombarding energy, groups resulting from reactions with contaminant elements shift in energy by different amounts than do the fluorine groups, because the residual nucleus in the case of a reaction with a contaminant element is of different mass than that of the F^{20} nucleus and carries away a different proportion of the change in bombarding energy. For an 0.3-Mev

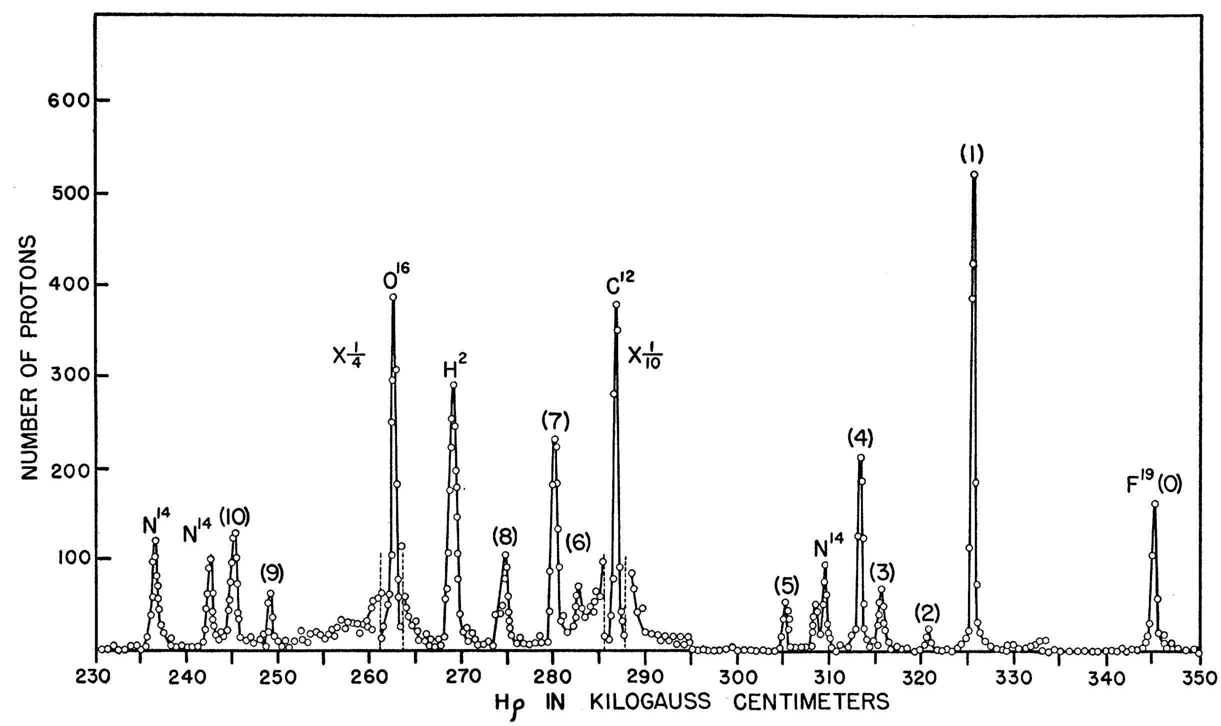

FIG. 1. Spectrum of protons from PbF_2 target bombarded with 1.8-Mev deuterons.

[11] R. Malm and W. W. Buechner, Phys. Rev. **80**, 771 (1950).

[12] Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Progress Report, May 31 (1951) (unpublished). The Q-value for this level, erroneously listed as -0.316 ± 0.006, should be -0.136 ± 0.006.

[13] Sperduto, Holland, Van Patter, and Buechner, Phys. Rev. **80**, 769 (1950).

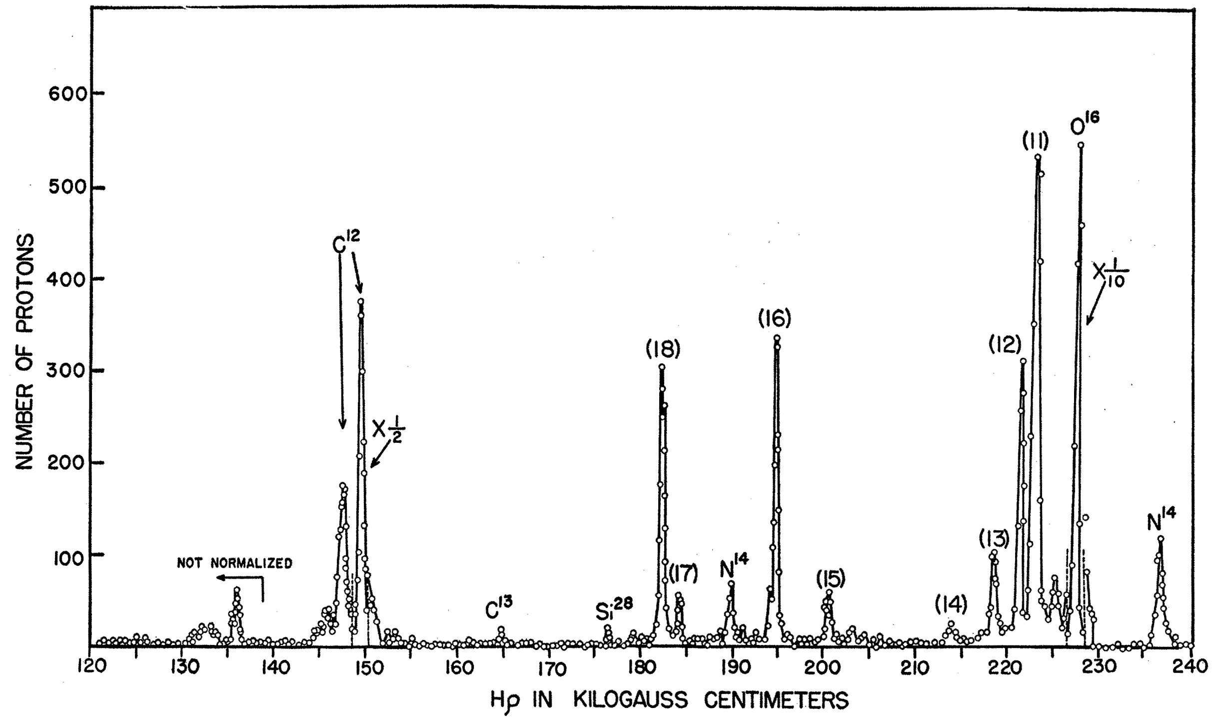

FIG. 2. Spectrum of protons from fluorine targets bombarded with 1.8-Mevdeuterons.

increase in deuteron energy, a Si^{28} group would increase in energy by 12.9 kev more than a F^{19} group, while a N^{14} group would increase 13.5 kev less than the F^{19} group. Since the widths of the fluorine and contaminant groups were usually between 9 and 15 kev, this shift in bombarding energy should have produced a definite structure to the observed group if it were comprised of a superposition of groups from two reactions. No such structure was observed, however.

The proton group at an $H\rho$ value of 226 kilogauss-centimeters in Fig. 2 was not observed when exposures were taken with targets having thin nickel backings. It is concluded therefore that this group definitely does not result from the $F^{19}(d,p)F^{20}$ reaction. It may be related in some manner to the oxygen group at an $H\rho$ of 228 kilogauss-centimeters, since no other contaminant groups are known to exist in this region; the reason for its appearance, however, does not seem easy to explain.

The proton groups with $H\rho$ values 133 and 136 kilogauss-centimeters were first observed on two exposures made with a PbF_2 target having a thin nickel backing. Later, the higher-energy group was again observed on an exposure taken with a BaF_2 target at the same bombarding energy. Several other attempts to observe these groups yielded no tracks at all on the photographic plates. Further efforts to determine the origin of the groups were not pursued, since extremely long exposures were needed, and the proton tracks in this energy region were sufficiently short so that counting was difficult and inaccurate. The group with the lower energy probably results from a reaction with a contaminant element which has accumulated on both sides of the target, since its width is considerably greater than would be expected for a fluorine group. The higher energy group, however, may quite possibly be another fluorine group. Its Q-value has been calculated on this assumption and is tabulated in Table II, along with the Q-values calculated for the other eighteen proton groups.

Also shown in Table II are the F^{20} excitation energies, together with those observed by Burrows *et al.*, by Shull, and by Allen and Rall. The excitation energies measured by these latter observers are listed on the same line as the closest excitation energy measured in the present investigation. In some cases, however, these observers may actually have been observing neighboring levels of greater intensity or were not able to resolve two or more closely spaced levels. The

TABLE I. Q-values of contaminant groups.

Contaminant	Kilogauss cm	Obs. Q-value (Mev)	Previously measured Q-value (Mev)	Reference
N^{14}	310	3.336	3.339±0.005	11
N^{14}	309	3.310	3.310±0.005	11
H^2	270	4.031	4.030±0.006	7
N^{14}	243	1.447	1.451±0.005	11
N^{14}	237	1.309	1.306±0.005	11
N^{14}	191	0.295	0.300±0.005	11
Si^{28}	177	−0.134	−0.136±0.006	12
C^{13}	165	−0.145	−0.148±0.005	13

TABLE II. Q-values and excited states in F^{20} from $F^{19}(d, p)F^{20}$ reaction.

Level	Q-value (Mev)	Excitation	Rel int.	Burrows *et al.*[a] excitation	Shull[b] excitation	Allen and Rall[c] excitation
(0)	4.373 ± 0.007	0	1.0	0 ($Q=4.39$)	0 ($Q=4.55$)	0 ($Q=4.16$)
(1)	3.721 ± 0.006	0.652 ± 0.008	2.3	0.63 ± 0.05	0.69	0.64 ± 0.03
(2)	3.545 ± 0.007	0.828 ± 0.008	0.18	0.83 ± 0.05		
(3)	3.385 ± 0.007	0.988 ± 0.008	0.44	1.00 ± 0.05	0.98	0.97 ± 0.05
(4)	3.314 ± 0.006	1.059 ± 0.008	1.2			
(5)	3.064 ± 0.006	1.309 ± 0.008	0.38	1.37 ± 0.05		1.31 ± 0.05
(6)	2.403 ± 0.005	1.970 ± 0.008	0.25			1.91 ± 0.04
(7)	2.325 ± 0.005	2.048 ± 0.008	2.0			
(8)	2.178 ± 0.005	2.195 ± 0.008	0.85		2.20	
				2.55 ± 0.05		2.52 ± 0.04
(9)	1.503 ± 0.005	2.870 ± 0.008	0.53	2.91 ± 0.05	2.70	2.83 ± 0.04
(10)	1.407 ± 0.005	2.966 ± 0.008	1.2		3.12	
(11)	0.882 ± 0.005	3.491 ± 0.008	4.6	3.49 ± 0.05		3.45 ± 0.03
(12)	0.845 ± 0.004	3.528 ± 0.008	1.3			
(13)	0.787 ± 0.004	3.586 ± 0.008	0.37			
(14)	0.692 ± 0.004	3.681 ± 0.008	0.18		3.74	
(15)	0.412 ± 0.004	3.961 ± 0.009	0.61			
(16)	0.294 ± 0.004	4.079 ± 0.009	3.0	4.06 ± 0.05		4.01 ± 0.15
(17)	0.098 ± 0.004	4.275 ± 0.009	0.50			
(18)	0.063 ± 0.004	4.310 ± 0.009	3.2	4.31 ± 0.05	4.41	
(19)	(-0.689 ± 0.006)	(5.062 ± 0.011)		4.73 ± 0.05		

[a] See reference 2.
[b] See reference 3.
[c] See reference 4.

relative intensities of the proton groups observed at 1.8-Mev bombarding energy are also tabulated. These are probably correct only to within about 30 percent, since a number of targets were used and normalization of the intensities was difficult.

From Table II, it is evident that about six of the excited levels observed in the present investigation have not previously been reported. Some of these are fairly close to other levels, and it might be expected that the corresponding proton groups would not be detected with the lower resolution characteristic of methods used by other observers.

An energy-level diagram for the F^{20} nucleus is shown in Fig. 3. A scale indicating excitation energy in Mev is plotted on the left-hand side, while the measured excitations of the various levels are shown on the right.

Some of the separations between levels show an interesting regularity within the region of excitation investigated. As is shown to the right of the energy-level diagram in Fig. 3, separations having mean values of 0.661, 0.820, 0.989, 1.317, and 1.980 Mev are repeated a number of times. It is interesting to note that multiplying the energy 0.165 Mev by the integers 4, 5, 6, 8, and 12 yields the values 0.660, 0.825, 0.990, 1.320, and 1.980 Mev, respectively, which are in surprisingly good agreement with the observed spacings. It is unfortunate that it was not possible to investigate the levels in the region of higher excitations to see whether the regularity continued. One would hesitate to suggest, however, that the apparent repetition of the spacings between some of the levels and the evident agreement between the repeated spacings and integral multiples of 0.165 Mev is anything more than a coincidence of nature. The 165-kev spacing is approximately one-half the 320-kev spacing reported by Allen and Rall.[1]

B. The $F^{19}(d, \alpha)O^{17}$ Reaction

The spectrum of alpha-particles from thin layers of BaF_2 bombarded with 1.8-Mev deuterons is shown in Fig. 4 as a function of their momentum in kilogauss-centimeters. Here the group marked F^{19}(O) at the right-hand side of the plot results from individual events in which the ground state of O^{17} has been formed. Ten more groups arising from the $F^{19}(d, \alpha)$ reaction are numbered from 1 through 10. Figure 5 shows the track distribution observed on an exposure taken for an additional survey of this spectrum, indicating more clearly that groups (8) and (9) are two separate groups.

A broad distribution of alpha-particles having an upper limit at an $H\rho$ of 351.7 kilogauss-centimeters can be seen in the plot. These particles probably result from the alpha-particle decay of excited Ne^{20} nuclei formed by the $F^{19}(d, n)Ne^{20}$ reaction. Assuming this to be the case, an excitation energy of 11.85 Mev has been calculated for the Ne^{20} state of greatest excitation, giving rise to the distribution. This calculation is based on a ground-state Q-value of 10.72 Mev[14] for the $F^{19}(d, n)$ reaction and a mass-difference equivalent to 4.78 Mev[14] between an O^{16} nucleus plus an alpha-particle and an unexcited Ne^{20} nucleus. It also assumes that the Ne^{20} state does not exhibit a natural width.

At an $H\rho$ of 373 in the plot shown in Fig. 4, a group of particles was observed that were found to be tritons from the $C^{13}(d, t)C^{12}$ reaction. At a given value of $H\rho$, tracks made by tritons are approximately the same

[14] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. 22, 291 (1950).

length as those made by alpha-particles. A group of tritons may be easily distinguished, however, using a change in bombarding energy.

As has been mentioned, the exposures for the $F^{19}(d,\alpha)O^{17}$ groups were made shortly before the spectrograph was disassembled. While the operation of the apparatus appeared normal during this period, subsequent analysis of the data gave Q-values for the alpha-particle groups from this reaction and from reactions of various contaminants which were consistently lower than those previously measured at this Laboratory.

The Q-values obtained are listed in Table III,[7,15] the values given for each of the contaminant reactions being an average of two results that agreed within 3 kev or less in each case.

While further measurements will be required to determine with certainty the reason for the discrepancy between the present values and those previously obtained, there are definite indications that the present low values were caused by layers of carbon contamination on the targets used. Two photographic plates that were exposed during the present survey were also read for proton tracks from the $C^{12}(d,p)C^{13}$ ground-state reaction. The ground-state Q-value for the $C^{12}(d,p)C^{13}$ reaction has been measured[7] to be 2.716 ± 0.005 Mev. The mean Q-value obtained from these two plates was 2.717 Mev. It seems probable, then, that the lower Q-values measured for the first, second, and fourth reactions listed above resulted from C^{12} contamination which accumulated on the target. The $C^{13}(d,t)C^{12}$ ground-state Q-value may have measured low because the observed triton groups used for the calculations were weak and poorly defined, making it difficult to estimate their energy.

Since the excitation energies as calculated from the observed Q-values are less affected by the presence of contamination than are the Q-values themselves, we have listed in Table IV only the excited states in O^{17} as determined from the present investigation. In calculating the probable error of these excitation energies, an estimate was made of the uncertainty caused by the target contamination. This amounted to 4 kev for the lower excited states and 8 kev for the six highest ones.

Also listed are the mean values obtained by Burrows *et al.*[2] from the $O^{16}(d,p)O^{17}$ and $F^{19}(d,\alpha)O^{17}$ reactions, together with the excitation energies obtained by Bockelman[5] from measurements on the scattering of neutrons by O^{16}. These latter excitation energies are obtained using a value of 4.14 Mev for the neutron binding energy in O^{17}. This binding energy is obtained from the sum of the $O^{16}(d,p)O^{17}$ ground-state Q-value measured at this Laboratory[7] and the binding energy of the deuteron measured by Mobley and Laubenstein.[16]

Because the binding energy of the last neutron of the

[15] R. Malm and W. W. Buechner, Phys. Rev. **81**, 519 (1951).

[16] R. C. Mobley and R. A. Laubenstein, Phys. Rev. **80**, 309 (1950).

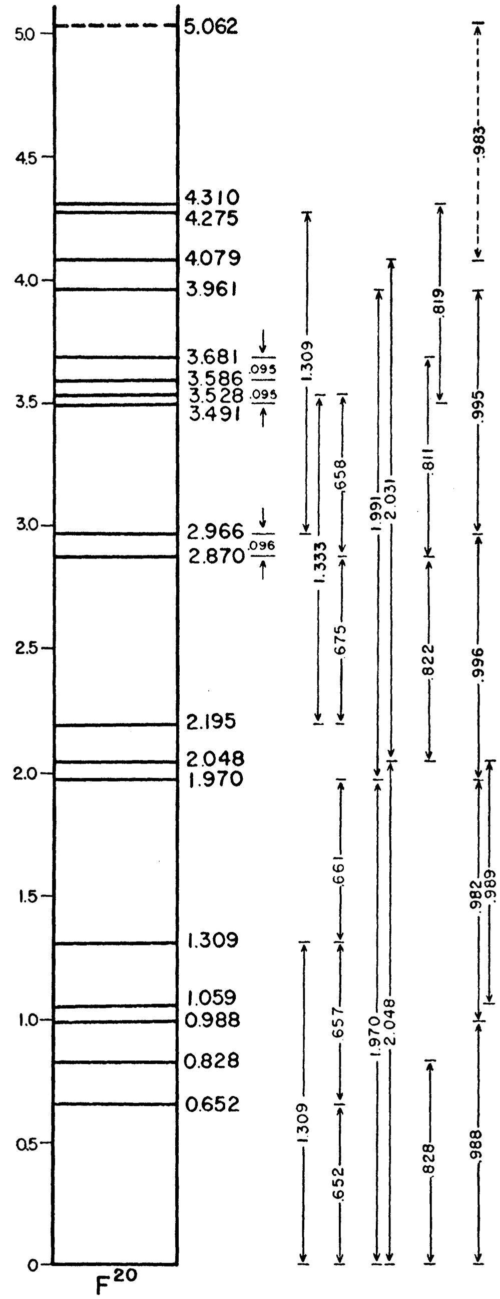

FIG. 3. Energy-level diagram for F^{20}. Excitation energies in Mev.

O^{17} nucleus is only 4.14 Mev, neutron decay is at least energetically possible for most of the O^{17} levels that were observed in the present investigation. If neutron decay did take place from these levels, one might expect the alpha-particle groups involved to show widths greater than those usually observed with the particular experimental arrangement used. In the spectrum shown in Fig. 4, it is evident that group (7) is broader than others of approximately the same energy. Closer examination showed a small but finite broadening of

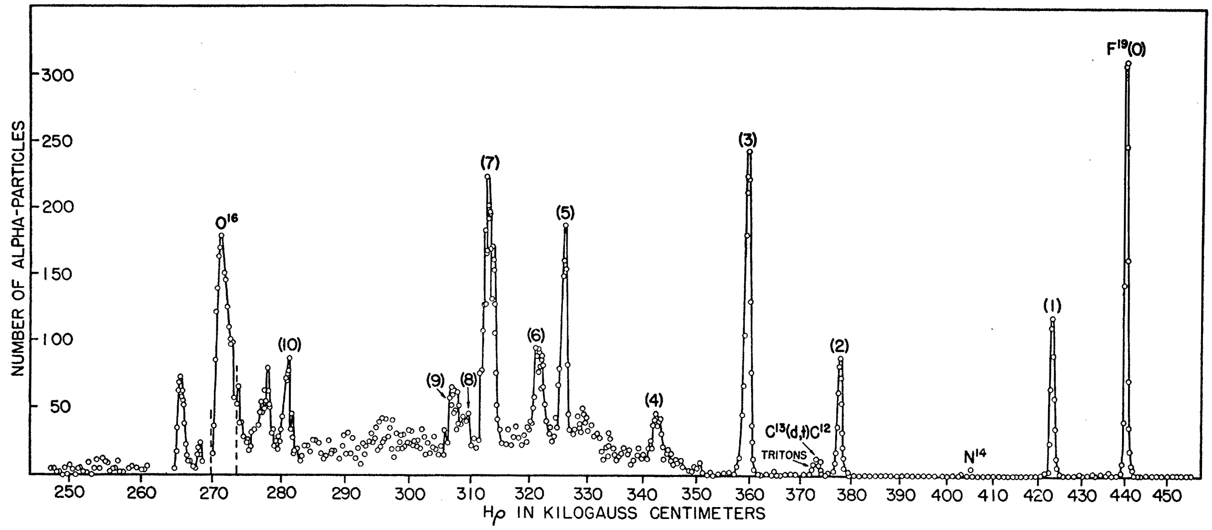

Fig. 4. Spectrum of alpha-particles from BaF_2 target bombarded with 1.8-Mev deuterons.

several of the other groups. The possibility cannot be ruled out, however, that group (7) and possibly some of the others are really superpositions of two or more closely spaced groups of approximately the same intensity. On the assumption that the observed groups are single groups of particles, the quantity Y listed in Table IV has been calculated as an indication of the relative widths of the O^{17} levels observed. It is the width in kilovolts that must be added to the spread in energy of the alpha-particles leaving the target in the case of a narrow level in order to give the observed width of the track distributions on the photographic plates.

In general, there is reasonable agreement between the values listed in Table IV for the excited states of O^{17}. The value of 0.883 ± 0.011 Mev for the first level is in good agreement with the value 0.876 ± 0.009 Mev previously measured at this laboratory using the $O^{16}(d,p)O^{17}$ reaction. However, there are several discrepancies between the results of the three experiments listed. The level at 5.1 Mev, which was not observed in the present work, was found by Bockelman to have a width of 100 kev. If the alpha-particle group associated with this level has a corresponding spread in energy, it is probable it would be obscured by the background from the $F^{19}(d,n)Ne^{20*}\rightarrow O^{16}+\alpha$-reaction. Similarly, it is probable that alpha-particles corresponding to the broad level found by Bockelman at 6.37 Mev would also not have been observed. The level reported by Burrows *et al.*, at 6.24 Mev, which was not observed in either the present work or in that of Bockelman, may possibly correspond with this broad level.

The levels listed in Table IV as (11) and (12) are shown in parenthesis, since they were observed at only one bombarding energy. Although no contaminant nuclei are known to give rise to groups in the region of $H\rho$ of 278 and 267 kilogauss-centimeters where the groups corresponding to (11) and (12) were observed, there remains a question as to whether they arise from the $F^{19}(d,\alpha)O^{17}$ reaction. In a survey taken at a bombarding energy of 2.0 Mev, the groups were obscured by elastically scattered deuterons.

It is evident that the relative widths measured in

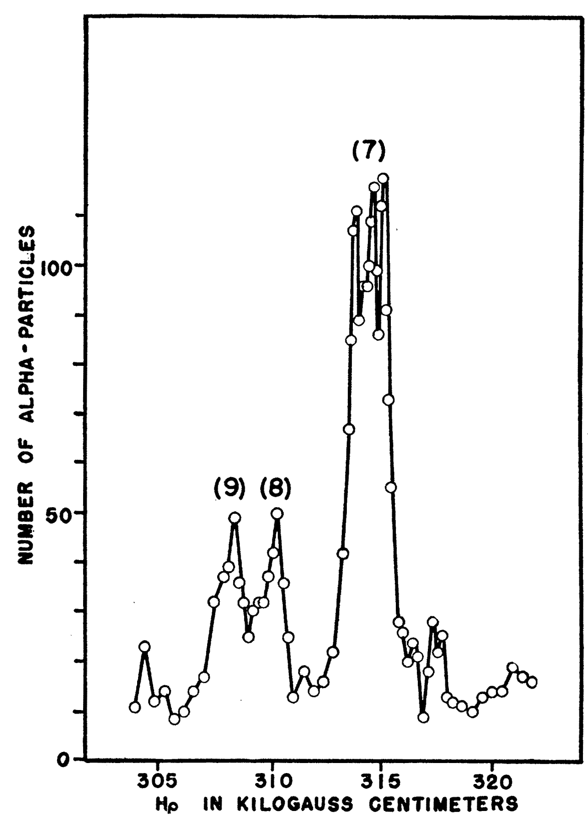

Fig. 5. Track distribution on single exposure showing groups (7), (8), and (9).

the present investigation show little agreement with those obtained for the same levels from the scattering measurements of Bockelman. Group (7), which was the widest observed in the present work, corresponds to an O^{17} level that showed relatively little width in the scattering measurements of Bockelman. It is possible that the $F^{19}(d,\alpha)O^{17}$ reaction is able to excite two or more closely spaced levels in this region that are not

TABLE III. Comparison of Q-values with previous determinations.

Reaction	Calc Q Mev	Previously measured value at MIT	Reference
$F^{19}(d,\alpha)O^{17}$ ground state	10.028	10.050±0.010	7
$N^{14}(d,\alpha)C^{12}$ first excited state	9.116	9.137±0.006	15
$C^{13}(d,t)C^{12}$ ground state	1.300	1.310±0.006	7
$O^{16}(d,\alpha)N^{14}$ ground state	3.099	3.112±0.006	7

TABLE IV. Excited states in O^{17}. [Present results are from the $F^{19}(d,\alpha)O^{17}$ reaction; Burrows *et al.*, from $O^{16}(d,p)O^{17}$ and $F^{19}(d,\alpha)O^{17}$; Bockelman *et al.*, from neutron scattering from O^{16}.]

Present results				Burrows *et al.*[a]	Bockelman[b]	
Level	Excitation	Rel int	Y kev	excitation	Excit.	Width in kev
(0)	0 (Q=10.028)	1.0		0		
(1)	0.883±0.011	0.40		0.87±0.02		
(2)	3.069±0.010	0.36		3.06±0.03		
(3)	3.856±0.011	1.3		3.85±0.03		
(4)	4.567±0.014	0.23	22±8	4.58±0.02	4.55	40
				5.07±0.02	5.08	100
(5)	5.229±0.013	0.79	8±6	5.31±0.02		
(6)	5.397±0.014	0.46	15±8		5.38	35
(7)	5.723±0.014	0.87	28±7	5.76±0.02	5.70	≤ 7
(8)	5.875±0.015	0.16			5.87	≤ 10
(9)	5.947±0.015	0.31	$3<Y\leq 12$		5.94	30
				6.24±0.02		
					6.37	120
(10)	6.869±0.014	0.39		6.89±0.03		
(11)	(6.986±0.015)	(0.33)	20±11			
(12)	(7.371±0.015)	(0.44)				
				7.51±0.03		
				8.27±0.04		
				8.59±0.04		
				9.06±0.04		

[a] See reference 2.
[b] See reference 5.

excited by neutron scattering. If these levels are sufficiently close, the alpha-particle groups arising from them would be superimposed and give the appearance of a single broad group. It is also interesting to note that level (5), which corresponds to a fairly intense group of alpha-particle tracks in Fig. 4, was not detected by Bockelman.

An energy-level diagram for the O^{17} nucleus, constructed from the results of the present investigation,

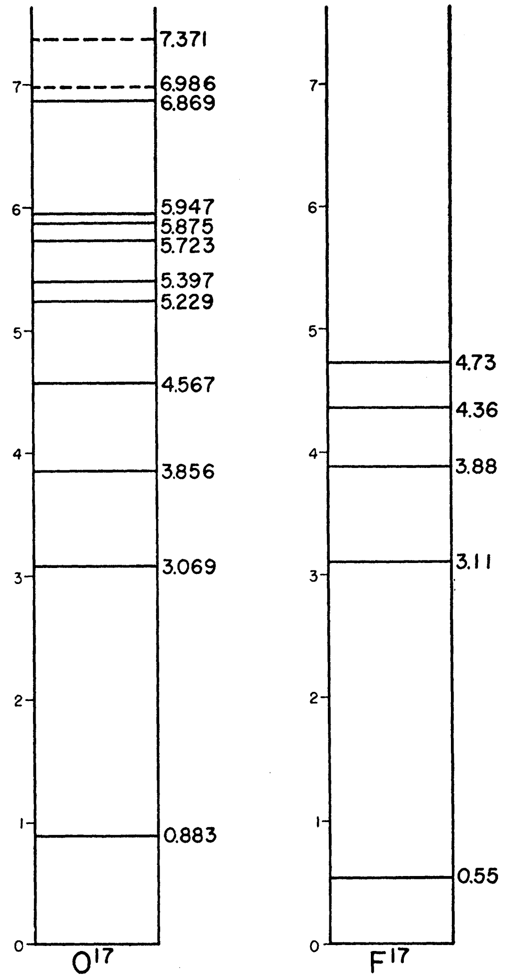

FIG. 6. Energy-level diagram for O^{17} and F^{17}. Excitation energies in Mev.

is given in Fig. 6. On the right-hand side is shown the energy-level diagram for the mirror nucleus F^{17} constructed from the recent measurements of Laubenstein and Laubenstein.[17] Some correspondence seems to be present between the levels of the two nuclei.

It is a pleasure to acknowledge the assistance of the staff of the High Voltage Laboratory. Particular thanks are due Mr. Wilton Tripp, Miss Jane Pann, and Miss Helene Schwartz for reading the photographic plates.

[17] R. A. Laubenstein and M. S. Laubenstein, Phys. Rev. 84, 18 (1951).