Energy Levels in F^{19} from a Study of the $O^{18}(d,n)F^{19}$ Reaction†

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A counter ratio investigation has been made of the $O^{18}(d,n)F^{19}$ reaction, using oxygen targets enriched to 40 percent O^{18}. A search was made for energy levels in F^{19} between excitation energies of 6.1 and 9.8 Mev. In this region, levels were found at 6.184 and 6.48 Mev. A resonance in the forward yield of neutrons from the deuteron bombardment of O^{18} was found at 1.64 Mev. The cross section for the $O^{18}(d,n)$ reaction was measured by comparing the yield with that from the $O^{16}(d,n)$ reaction, the cross section for which is known.

INTRODUCTION

THE level structure of the F^{19} nucleus below excitations of about 5 Mev has been extensively investigated[1] by inelastic scattering techniques. Most of the levels observed in this manner have also been detected by measurements made with photographic plates on the neutron groups from the $O^{18}(d,n)F^{19}$ reaction.[2] A number of levels above 10.5 Mev have been found by observing resonances in the yield of neutrons from the $O^{18}(p,n)F^{18}$ reaction.[3–5] The energy region between excitations of 8.5 and 10.5 Mev has been investigated by observing resonances in the yield of α particles[5–8] and γ rays[9] from the proton bombardment of O^{18}. No previous experiments have examined the level structure between about 5 and 8.5 Mev.

The region of excitation of the F^{19} nucleus above 6 Mev may be studied with the $O^{18}(d,n)F^{19}$ reaction by measuring the bombarding energies at which the emission of neutrons to excited states first beome possible (neutron thresholds). The technique of detecting these thresholds by measuring with two BF_3 counters of different sensitivities the ratio of the number of slow neutrons to the number of fast neutrons emitted in a reaction is called the "counter ratio" technique and has been previously described in detail.[10–13]

EXPERIMENTAL

Oxygen targets, enriched[14] in O^{18}, were prepared by heating tungsten blanks in an induction heater. The blanks were heated to a temperature of 700–1000°C for a period of 5–25 sec in the presence of a pressure of about 1 inch of Hg of the enriched oxygen. The composition of the O^{18}-enriched sample is given in Table I. The thickness of the targets was estimated by observing the rise in the counter ratio at the $O^{16}(d,n)$ threshold. The target used in this experiment was found to be about 40-kev thick at a deuteron energy of 1.84 Mev. Since the cross section for the $O^{16}(d,n)$ reaction is known,[11] the change in the counting rate at this threshold was used to determine the number of O^{16} atoms/cm^2 present in the target. From the known ratio of O^{16} to O^{18} in the sample, it was then calculated that there were approximately 2.4×10^{18} atoms/cm^2 of O^{18} in the target, assuming no dilution of the purity of the O^{18} during the target making procedure.

Deuterons from the Rice Institute 6-Mev Van de Graaff accelerator were used, and the counter ratio and yield of neutrons in the forward direction were measured for the range of deuteron energies from 0.4 to 4.5 Mev. The results are presented in Fig. 1. Five thresholds, marked *A* through *E*, were observed. Thresholds *B* and *D* are due to the reaction $O^{16}(d,n)F^{17}$ and threshold *C* is due to the reaction $N^{14}(d,n)O^{15}$ on the small amount of nitrogen present in the target. These thresholds have been observed previously.[11]

The pronounced threshold at 0.50 Mev (marked *A*) and the weak threshold at 3.05 Mev (marked *E*) are attributed to the $O^{18}(d,n)F^{19}$ reaction. No deviation from a smooth counter ratio curve was observed[11] at 3.05 Mev in the deuteron bombardment of O^{16} and N^{14}. The possibility that the weak threshold *E* is due to O^{17} is not excluded but is unlikely because of the small amount of this isotope present. A summary of the ob-

TABLE I. Composition of the O^{18}-enriched sample.[a]

Element or isotope	Atomic percent
O^{16}	56.8
O^{17}	0.8
O^{18}	37.3
N	3.8
A	1.3
CO_2	trace

[a] Furnished by Professor A. O. C. Nier.

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served threshold energies, Q-values, and excitation energies in F^{19} is given in Table II.

The forward yield of neutrons from the O^{18}-enriched target is shown in Fig. 1. The background, obtained by bombarding a clean tungsten blank, has been subtracted. A number of resonances was observed; however, the energies and widths of all of these resonances that occurred above 1.83 Mev agree with those obtained[11] with a natural oxygen target, containing 99.8 percent O^{16}, and are therefore due to the $O^{16}(d,n)$ reaction. One resonance below the $O^{16}(d,n)$ threshold, and therefore due to the $O^{18}(d,n)$ reaction, was observed at 1.64 Mev. Below this energy the neutron yield rises almost exponentially.

Since the number of O^{16} and N^{14} atoms/cm^2 in the target was known, the yield of neutrons due to the

TABLE II. Neutron thresholds in the reaction $O^{18}(d,n)F^{19}$.

	Threshold energy (Mev)	Q-Value (Mev)	Excitation energy in F^{19} (Mev) Present work	Other measurements
A	0.497 ± 0.015	-0.447 ± 0.015	6.184 ± 0.018[a]	
B	1.830 (O^{16})[b]			
C	1.967 (N^{14})[b]			
D	2.393 (O^{16})[b]			
E	3.05 ± 0.02	-2.74 ± 0.02	8.48 ± 0.02	8.48[c]

[a] The error assignment includes the uncertainty in the ground-state Q-value, calculated from the mass defect uncertainties listed by A. H. Wapstra, Physica 21, 367 (1955).
[b] See reference 11.
[c] See references 6 and 8.

$O^{16}(d,n)$ and $N^{14}(d,n)$ reactions could be calculated from the known[11] cross sections and subtracted from the observed yield curve. The dashed curve of Fig. 1 results when the subtractions are made and represents the yield of neutrons from the $O^{18}(d,n)$ reaction. A cross section for this reaction was obtained by comparing the decomposed curves due to the reactions $O^{16}(d,n)$ and $O^{18}(d,n)$. The values thus obtained are given in Fig. 1 in units of millibarns per steradian in the laboratory system for neutron emission into the forward cone of half-angle 10°. Since the subtractions were necessary to obtain the $O^{18}(d,n)$ yield curve and since the cross section was obtained by comparison with the $O^{16}(d,n)$ cross section, the absolute values are probably accurate only within a factor of 2.

DISCUSSION

The counter ratio technique has been used with the $O^{18}(d,n)F^{19}$ reaction to investigate the region of excitation in F^{19} from 6.1 to 9.8 Mev. In this energy region, a number of states are known to exist[5–9]; however, of

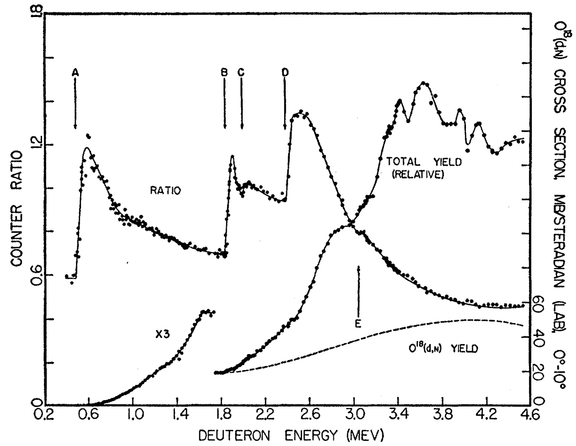

FIG. 1. Counter ratio and relative forward yield of neutrons from an oxygen target enriched to 40 percent O^{18} as a function of deuteron energy. The dashed curve represents the yield from the $O^{18}(d,n)$ reaction and was obtained by subtracting the $O^{16}(d,n)$ and $N^{14}(d,n)$ contributions from the total yield curve. The cross-section values apply only to the $O^{18}(d,n)$ curve.

the levels previously observed, only the state based on a weak resonance reported[6,8] at 8.48 Mev was found in the $O^{18}(d,n)F^{19}$ reaction. An additional level was detected at an excitation of 6.184 Mev.

The previous observation of the 8.48-Mev state was made using the $O^{18}(p,\alpha)N^{15}$ reaction and was found to be extremely weak[6,8]; the threshold corresponding to this level was also found to be very weak. No indication was found for the emission of neutrons to the 8.76-Mev state near threshold, although the $O^{18}(p,\alpha)N^{15}$ reaction showed an intensity at least 50 times greater for this state than for the 8.48-Mev state.[8]

Both of the thresholds observed in the $O^{18}(d,n)F^{19}$ reaction required an energy interval approximately equal to target thickness for the counter ratio to reach its peak value. This indicates that the emitted neutrons have zero angular momentum.[10–13] At the 0.497-Mev threshold, the deuterons also probably have zero angular momentum due to their low energy. Since the ground state of O^{18} is 0^+, the 6.184-Mev state of F^{19} probably has spin and parity of $\frac{1}{2}^+$ or $\frac{3}{2}^+$. This state is unstable to the emission of an α particle to the ground state of N^{15} by 2.2 Mev. Such an emission from a $\frac{1}{2}^+$ or a $\frac{3}{2}^+$ state with $T=\frac{1}{2}$ would require the α particle to carry one unit of angular momentum and would make the excited state reasonably narrow. If this were a pure $T=\frac{3}{2}$ state, α-particle emission would be forbidden and the level width would be quite small. Either case would be consistent with the observed rise in the counter ratio which can be attributed entirely to target thickness.