Total Neutron Yields from the Proton Bombardment of ^{17,18}O†

J. K. Bair
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830
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The ^{17}O(p, n)^{17}F reaction has been observed for the first time in the energy region from threshold to 5 MeV. Total neutron-production cross sections measured with good resolution are given. The reaction threshold is determined to be 3743± 6 keV. High-resolution total neutron cross sections are also given for the reaction ^{18}O(p, n)^{18}F from threshold to 4 MeV.

I. INTRODUCTION

Ajzenberg-Selove[1] has recently reviewed the level structure of ^{18,19}F. In the case of ^{18}F, in the region of excitation from the (p, n) threshold (which had not been measured) to that corresponding to bombardment by 5-MeV protons (E_{ex} = 9.4 to 10.3 MeV), the review listed some 10 levels of which 4 were in doubt; the (p, n) reaction had not been observed in this energy region. In the case of ^{19}F, precision high-resolution excitation energies and widths were known only up to bombarding proton energies of about 3.3 MeV and no total neutron-production cross sections were available.

II. EXPERIMENTAL TECHNIQUES

During 1969 and 1970, the Oak Ridge National Laboratory 5.5-MV Van de Graaff energy calibration was extensively studied with particular attention being paid to magnet saturation effects. During this same period, the graphite sphere neutron detector[2] was recalibrated by direct comparison to the Bureau of Standards radium-beryllium photoneutron source NBSII. Thus, immediately following a precision (p, n) cross-section measurement by Johnson *et al.*,[3] we found that we were in a position to very easily measure the ^{17,18}O(p, n)-^{17,18}F cross sections using targets which were available from a recent (α, n) experiment.[4]

Data were taken with no lens between the analyzing magnet and the detector, the slowly diverging beam from the exit slits was collimated by apertures near the magnet and then permitted to diverge to a uniform round spot at the target location. Alignment was continually checked by monitoring possible stray beam current to an aperture, very slightly larger than the beam, located near the graphite sphere.

III. ^{17}O(p,n)^{17}F

Figure 1 shows the total neutron-production cross section for the reaction ^{17}O(p, n)^{17}F from threshold to ~5 MeV. The target was a "drive-in" type made by bombarding a tantalum blank with 24-keV oxygen ions and was one of a series originally made for measuring (α, n) neutron yields.[4] Converting the target thickness known from the α-particle experiment, we found that the target thickness was 9 keV for 2.5-MeV protons. The ^{18}O(p, n)^{18}F resonance at 2.6 MeV could be observed due to a 0.08% ^{18}O contamination, these measurements yielded a target energy loss of 8 keV, which is in good agreement with that inferred from the α-particle work. The small yield seen in Fig. 1 below the threshold is due to difficulties in determining the proper tantalum background to be subtracted. Cross-section values are based on the average of the values of the ^{17}O density determined (a) by (α, n) yields measured on this same target and (b) by comparison to the yield obtained from targets anodized in water enriched to 5 at.% of ^{18}O and 15.7 at.% of ^{17}O. Both methods utilize the ^{18}O(α, n)^{21}Ne cross-section measurements made at this laboratory[5] and most of the error is due to that earlier measurement. The cross section calibration is probably reliable to ±(25% +2 mb).

Table I lists, in columns 1, 2, and 3, the maxima of the yield curve of Fig. 1, the corresponding energy of excitation in the compound system [based on E_{ex} (keV) = E_p (keV)×0.94403 + 5609.0 keV] and an estimate of the experimental width. Level structure in this region of excitation in ^{18}F is known mainly from the variation in yield with energy of deuteron-induced reactions on ^{16}O targets. Since much of the deuteron work does not give total cross sections but only differential cross sections at one or more angles, we compare our results in Table I only with the total neutron yields of Bahnsen, Wylie, and Lefevre,[6] who give constructed total cross sections (their Figs. 8 and 9), and with Dietzsch *et al.*[7] who give (their Fig. 17) the total cross sections for the production of (a) ground- and first-excited-state protons, (b) ground-state α particles, and (c) ground- and first-excited-state neutrons. The numbers appearing in Table I have been extracted from the figures

TABLE I. Level parameters in $^{17}O+p$. Columns 1, 2, and 3 give proton energies corresponding to maxima in the yield curve, the corresponding energy of excitation in the compound system, and an estimate of the laboratory width. Columns 4, 5, 6, and 7 give estimates of the widths as read by the present author from the total cross-section curve of Dietzsch *et al.* (Ref. 7), while column 8 gives the corresponding average excitation energy. Columns 9 and 10 give excitation energies and widths as read from the total cross section curves of Bahnsen, Wylie, and Lefevre (Ref. 6). Columns 11 and 12 give level excitations as listed by Mangelson, Harvey, and Glendenning (Ref. 8) as seen in the particle spectra from (α, d) and $(^3He, p)$ reactions, respectively.

Present work			Dietzsch *et al.* (Ref. 7)					Bahnsen *et al.* (Ref. 6)		Mangelson *et al.* (Ref. 8)	
			(d, p_1)	(d, p_0)	(d, α_0)	(d, n_0)				(α, d)	$(^3He, p)$
E_p (keV)	E_{ex} (keV)	Γ (keV)	Γ (keV)	Γ (keV)	Γ (keV)	Γ (keV)	E_{ex} (MeV)	E_{ex} (MeV)	Γ (keV)	E_{ex}	E_{ex}
391_5 [a]	9304 ± 20	100	150	100			9.38	b	b		9404 ± 31
(416_3)	(9539 ± 20)	20			70	40	9.52	9.56	60	9494 ± 31	
423_5	9607 ± 10	35	50	40	50	50	9.59				
433_0	9697 ± 10	35						9.68	40		
449_0	9847 ± 20	≈100		100	100		9.81	(9.82)			982_0 ± 40
										996_0 ± 120	
			250	350		400	10.1_0	10.04	350		1006_0 ± 45
(479_0)	(10 131 ± 10)	30									
490_0	10 234 ± 20	≈150			75		10.2_1	(10.2)	(≈150)	10 268 ± 12	

[a] This notation indicates that the lowered digit is uncertain.
[b] Data do not extend this low.

TABLE II. Level parameters in $^{18}O+p$. Columns 1, 2, and 3 give bombarding proton energy, energy of excitation in the ^{19}F compound system, and center-of-mass widths from the present work. Columns 4 and 5 list the excitation energies and widths from the recent review by Ajzenberg-Selove (Ref. 1). Columns 6 and 7 give the results of the only other high-resolution (p, n) experiment, that of Beard *et al.* (Ref. 12).

	Present work			Ajzenberg-Selove (Ref. 1)		Beard *et al.* (Ref. 12)	
Level	E_p (keV)	E_{ex} (keV)	$\Gamma_{c.m.}$ (keV)	E_{ex} (keV)	$\Gamma_{c.m.}$ (keV)	E_{ex} (keV)	Γ (keV)
1	2644	10 497 ± 2	5.9 ± 0.5	10 496 ± 1	5.1 ± 0.4	10 495 ± 1	6.5 ± 0.5
2	2691	10 541 ± 3	≈2	10 541 ± 1	2.1 ± 0.2	10 541 ± 1	2.6 ± 0.2
3				10 554 ± 3 [a]	6.3 ± 1.6		
4	2719	10 568 ± 3	6 ± 2	10 566 ± 4	4.4 ± 0.4	10 565 ± 1	5.5 ± 0.5
5				(10 580 ± 4) [a]	18 ± 3		
6	2768	10 614 ± 3	6 ± 2	10 613 ± 1.5	4.4 ± 0.4	10 613 ± 1.5	5.0 ± 0.5
7	2923	10 761 ± 4	6 ± 3	10 763 ± 3 [a]	4.5		
8	3027	10 860 ± 3	23 ± 2	10 858 ± 2	21 ± 1	10 857 ± 2	26 ± 1.5
9	(3080)	10 910 ± 20	≈60				
10	3151	10 977 ± 3	14 ± 2	10 972 ± 3	(10)	10 970 ± 3	12 (est.)
11	3165	10 990 ± 3	7 ± 2	10 988 ± 3	~9	10 988 ± 3	11 (est.)
12	3252	11 073 ± 3	38 ± 4	11 070 ± 3	26 ± 4	11 068 ± 3	33 ± 5
13	3370	11 184 ± 4	17 ± 4				
14				11 199 ± 2	36 ± 2		
15	3463	11 273 ± 3	7 ± 2	11 288 ± 9	20		
16	3470	11 279 ± 15	70 ± 20				
17				11 310 ± 9			
18	3653	11 452 ± 4	40 ± 10	1143_0 ± 10	67 ± 16		
19	3680	11 478 ± 5	7 ± 3				
20	3705	11 502 ± 5	4 ± 2	1151_0			
21	3748	11 542 ± 15	50 ± 15	1156_0 ± 10	<40		
22	3775	11 568 ± 7	15 ± 10				
23	(3790)	11 582 ± 20	60 ± 20				
24	3863	11 651 ± 4	45 ± 10	1165_0 ± 10	32		

[a] Not previously seen in neutron channel.

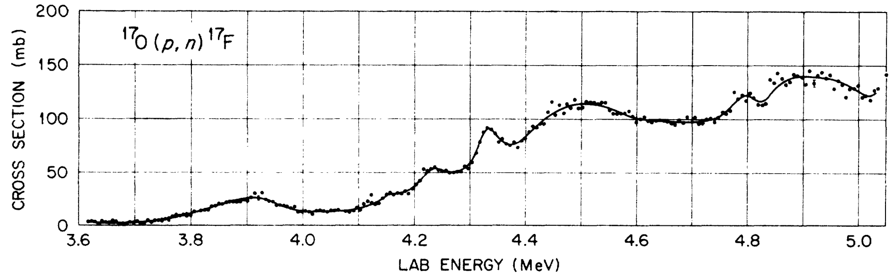

FIG. 1. Shows the total neutron-production cross section for the reaction $^{17}O(p,n)^{17}F$. The target was a "drive-in" type having a thickness of 9 keV for 2.5-MeV protons. The energies are in the laboratory system and have been corrected for target thickness.

in Refs. 6 and 7 by the present author. In addition to the deuteron work, four levels in this region of high excitation have been observed by Mangelson, Harvey, and Glendenning,[8] in the particle spectra emitted in the reactions $^{16}O(^3He,p)^{18}F$ and $^{16}O(\alpha,d)$-^{18}F. The agreement seems reasonable.

We have measured the $^{17}O(p,n)^{17}F$ threshold both by use of the drive-in target and by comparing the yield of tantalum targets anodized in water enriched to 15.7 at.% ^{17}O and 5 at.% of ^{18}O. The average is 3743 ± 6 keV corresponding to a reaction $Q=-3534$ ± 6 keV. No previous experimental threshold is known. The agreement with the value of $Q_m=-3542$ keV calculated from the masses given by Maples, Goth, and Cerny[9] is reasonable considering the slow rise of the yield at threshold as seen with the graphite-sphere neutron detector, the generally low yield, and the large background uncertainty.

IV. $^{18}O(p,n)^{18}F$

Figure 2 shows the total neutron-production cross section for the $^{18}O(p,n)^{18}F$ reaction from threshold to 3.87-MeV proton bombarding energy.

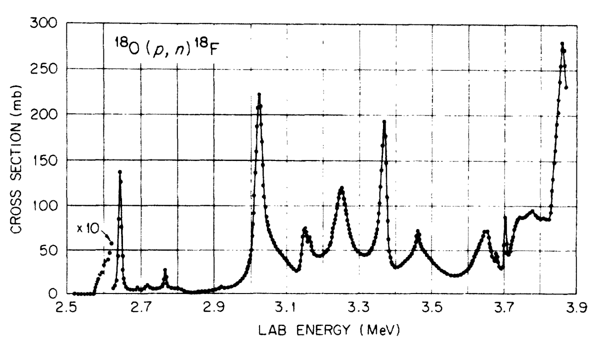

FIG. 2. Shows the total neutron-production cross section for the reaction $^{18}O(p,n)^{18}F$. The target consisted of tantalum anodized in water enriched to 97.2 at.% of ^{18}O. Target thickness was ~3.3 keV thick for 2.6-MeV protons. The energies are in the laboratory system and have been corrected for target thickness.

These data were taken with a target of tantalum anodized in ^{18}O enriched water, target thickness was 3.3 keV for 2.6-MeV protons. The cross-section scale is based on our earlier (α,n) measurements[5] and is estimated to be accurate to ±25%, almost all of the error being that of Ref. 5. The only previous cross sections published are those of Blair and Leigh[10] who obtained a ±50% value for the 2.65-MeV resonance. Their value, after correcting for the effects of resolution, is in reasonable agreement with the present work.

Careful measurements of the $^{18}O(p,n)^{18}F$ threshold, made on the same magnet cycle as observations of the $^7Li(p,n)^7Be$ threshold, give a value of 2574 ± 1 keV in good agreement with the absolute value of 2573.72 ± 0.77 keV obtained by Bondelid and Butler,[11] and in fair agreement with the value of 2576 ± 1 keV obtained by Beard *et al.*[12]

Table II lists, in columns 1, 2, and 3, the maxima of the yield curve, the corresponding energy of excitation (based on $E_{ex}(\text{keV}) = E_p\,(\text{keV}) \times 0.9470 + 7993$ keV) and an estimate of the width in the center-of-mass system (corrected for target thickness). Columns 4 and 5 give for comparison corresponding data taken from Table 19.6 of Ref. 1. Columns 6 and 7 give the results of the only other high-resolution (p,n) experiment, that of Beard *et al.*[12]

The graphite-sphere neutron detector has previous been used at this laboratory[13] to observe the $^{18}O(p,n)^{18}F$ yield at tandem energies with considerably worse energy calibration and resolution. In the region where these data overlap, the old work (data points every 25 keV) reported maxima in the yield curve at 3.64, 3.77, and 3.86 MeV having experimental widths of 60, < 50, and 40 keV, respectively. The present work confirms the first and last of these ($E_p = 3.653$, $\Gamma = 50$ keV and $E_p = 3.862$, $\Gamma = 50$ keV). The anomoly at 3.77 MeV now appears to be at least two unresolved levels. In addition, two narrow levels appear at 3.680 MeV, $\Gamma = 6$ keV and 3.705 MeV, $\Gamma = 6$ keV.

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