Photoneutron reaction in ^{17}O: Ground-state differential cross section at 98°

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Photoneutron spectra from ^{17}O have been obtained at bremsstrahlung end-point energies of 13.7, 16, 22, 28, and 34 MeV using the neutron time-of-flight technique. The angle between the incident photon beam and the 49.2-m flight path was 98°. From the measured spectra the differential cross section for the $^{17}O(\gamma,n_0)^{16}O$ reaction between 5 and 33 MeV was obtained. The considerable structure in the cross section is compared with the known spectrum of levels for this nucleus compiled from previous studies using various reactions. In the region below 19 MeV, 18 resonances correspond to levels previously identified. In addition at least 12 other resonances which have not been seen previously have been observed. In the giant dipole resonance region (above 19 MeV) the present results delineate the $T = 1/2$ strength. The measurement is compared to the $^{16}O(p,\gamma_0 + \gamma_1)^{17}F$ reaction with the expected similarities observed. The measurement also is compared to 1p,2p-1h shell-model calculations.

[NUCLEAR REACTIONS $^{17}O(\gamma,n_0)^{16}O$, E_x = 5.0–33.0 MeV; measured photoneutron time-of-flight spectra; deduced $(d\sigma/d\Omega)$ $(E_x, 98°)$, resonant structure; $T=\frac{1}{2}$ strength of the GDR.]

I. INTRODUCTION

The study reported here is part of an extensive investigation of the photonuclear effect in light nuclei with one or two nucleons outside of a closed shell. The investigation of such nuclei is expected to provide information on several aspects of the nuclear photoeffect. For instance, the photonuclear cross section exhibits collective strength below the giant dipole resonance (GDR), termed the "pygmy" resonance; nuclear-structure information on states within this resonance can be gained. Furthermore, the effects of isospin selection rules manifest themselves more obviously in the photonuclear reaction in these nuclei than in self-conjugate nuclei. Specifically, the ^{17}O nucleus can be excited by electromagnetic radiation to $T=\frac{3}{2}$ and $T=\frac{1}{2}$ states; but in the absence of isospin mixing, ground-state neutron transitions from $T=\frac{3}{2}$ states are forbidden. This study then will delineate the distribution of $T=\frac{1}{2}$ strength in this nucleus.

Of particular interest, at least in part because of the theoretical and experimental investigations of ^{16}O, are the nuclei with a few nucleons outside the ^{16}O core. The present investigation fills a gap in the experimental data, and thus allows direct comparison of the family of oxygen isotopes, i.e., ^{16}O, ^{17}O, and ^{18}O.

The experiment reported in this paper is the measurement of the differential cross section at 98° for the reaction $^{17}O(\gamma,n_0)^{16}O$ over the energy range from 5.0 to 33.0 MeV. This measurement is part of a collaborative effort in which the (γ,n_0) cross sections are measured at the University of Toronto and the total photoneutron cross sections are measured at Lawrence Livermore Laboratory. Previously reported (γ,n_0) [and sometimes (γ,n_1)] cross-section measurements have been performed for ^{13}C (Refs. 1 and 2) and ^{18}O (Ref. 3); previously reported total cross-section measurements (γ,n) and $(\gamma,2n)$ [and for ^{18}O, (γ,p)] have been performed for ^{13}C (Ref. 4) and ^{18}O (Refs. 5 and 6). The present measurements were made using the photoneutron time-of-flight technique, with its inherent advantages of excellent energy resolution, precise energy calibration, and the fundamental selectivity of the probe and its products.

In this report the present results will be compared to other experimental data, especially to the analogous reaction $^{16}O(p,\gamma_0+\gamma_1)^{17}F$ (Ref. 7), and also to theoretical predictions.[8]

II. EXPERIMENT

The $^{17}O(\gamma,n_0)^{16}O$ differential cross section (at 98°) was determined from a photoneutron time-of-flight measurement. The source of radiation was the bremsstrahlung beam produced when a pulsed electron beam from the University of Toronto Electron Linear Accelerator was allowed to strike a 0.51-mm thick tungsten target. Details of the time-of-flight technique as applied at this laboratory have appeared elsewhere[9,10] (most recently, for a nearly identical system, in two papers[1,2] on the photoneutron reaction in ^{13}C). Salient features of the method are reviewed below.

In this experiment, measurements were made with four samples: A 112.5-g water sample isotopically enriched in ^{17}O (9.4% ^{16}O, 22.0% ^{17}O, and 68.6% ^{18}O), a 109.5-g water sample isotopically enriched in ^{18}O (1.6% ^{16}O, 1.9% ^{17}O, and 96.5% ^{18}O), and samples of light and heavy water (H_2O and D_2O with the naturally occurring oxygen isotopic abundances). All samples were contained in thin aluminum right circular cylinders 10 cm in diameter; lengths were adjusted so that the containers were nearly full (approximately 1.5 cm in all cases). The faces of the containers were 0.8-mm thick and the cylinder walls were 1.6-mm thick. These samples were mounted so that the axes of the cylindrical containers were collinear with the neutron time-of-flight line. The flight path was collimated so that the neutron detector viewed a 9.8-cm diameter circle at the sample position.

Neutron time-of-flight spectra were measured using a 49.2-m flight path. For bremsstrahlung end-point energies above 19 MeV the accelerator beam-pulse width and neutron-detector electronics were set in a configuration which produced the best possible overall resolution, 0.13 ns/m. Below 19 MeV it was necessary to sacrifice some resolution in order to obtain sufficient counting rate. At these lower end points the overall system resolution was 0.30 ns/m. Neutron energy calibration was obtained by placing a graphite filter in the flight path and then using the well-known absorption resonances in carbon.[11] The error in this calibration was less than 10 keV below 8-MeV neutron energy and increased slowly to 300 keV at the highest energies.

Spectra were obtained from each of the four samples at electron beam energies of 13.7, 16, 22, 28, and 34 MeV. In order to minimize long-term drifts of the experimental apparatus, all samples were cycled through the beam on a schedule of 1 to 4 h per cycle. Because of the limited amount of ^{17}O available, total run times of 8 to 24 h were required. Since the first excited state of ^{16}O is at 6.05 MeV, neutrons from ^{17}O which have energies between the maximum neutron energy and 6 MeV below this must leave ^{16}O in its ground state. However, because the neutron emission thresholds of ^{17}O and ^{18}O differ by only about 4 MeV (4.15 and 8.05 MeV respectively), photoneutrons from the ^{18}O in the sample can contaminate the lowest 2-MeV portion of the useful 6 MeV of each ^{17}O spectrum. To extract this contamination the normalized spectrum for the ^{18}O sample was subtracted from the spectrum of the ^{17}O sample for each end point.

Data from the light- and heavy-water samples were taken in order to determine the shape of the bremsstrahlung spectra.[10] For this purpose the contamination of the deuterium spectra by ^{16}O photoneutrons was removed by subtraction of a normalized light-water spectrum from the heavy-water spectrum for each end point. The corrected ^{17}O and deuterium photoneutron time-of-flight spectra then were converted to neutron energy spectra using relativistically correct expressions.

The relative efficiency of the proton-recoil liquid-scintillation neutron detector was determined experimentally for energies below 19.5 MeV. Time-of-flight spectra for photoneutrons from light and heavy water were obtained at the maximum usuable energy of the accelerator (44 MeV), using a thin bremsstrahlung radiator. The relative efficiency then was extracted by assuming a Schiff[12] thin-target bremsstrahlung spectrum and a deuterium photoneutron cross section calculated in the zero-range approximation. For energies above 19.5 MeV, the detector efficiency was assumed to be constant. This has been shown to be a good approximation both experimentally and theoretically.[13] The relative detector efficiency obtained is nearly the same as that shown in Ref. 1.

Using the detector efficiency as obtained above and the deuterium photoneutron cross section,[14] the shape of the bremsstrahlung spectrum at each end-point energy was determined from the measured deuterium spectra.

As explained above, the highest 6 MeV of each ^{17}O photoneutron energy spectrum results only from ground-state transitions. Collection of the highest 6 MeV from each end point then yields the differential cross section. The cross-section scale was obtained by normalizing to the results of the calculation of Partovi[14] for the deuterium photoneutron cross section. Systematic uncertainties do not exceed 10% for energies below 19.5 MeV, and result primarily from the uncertainty in the photon and neutron scattering in the samples. Above 19.5 MeV, the uncertainty in the detector efficiency increases gradually, and might conceivably become as large as 25% at the highest energies measured.

III. RESULTS

The 98° differential ground-state photoneutron cross section for ^{17}O obtained from the present measurement is shown in Fig. 1. Because of the considerable structure in the cross section which

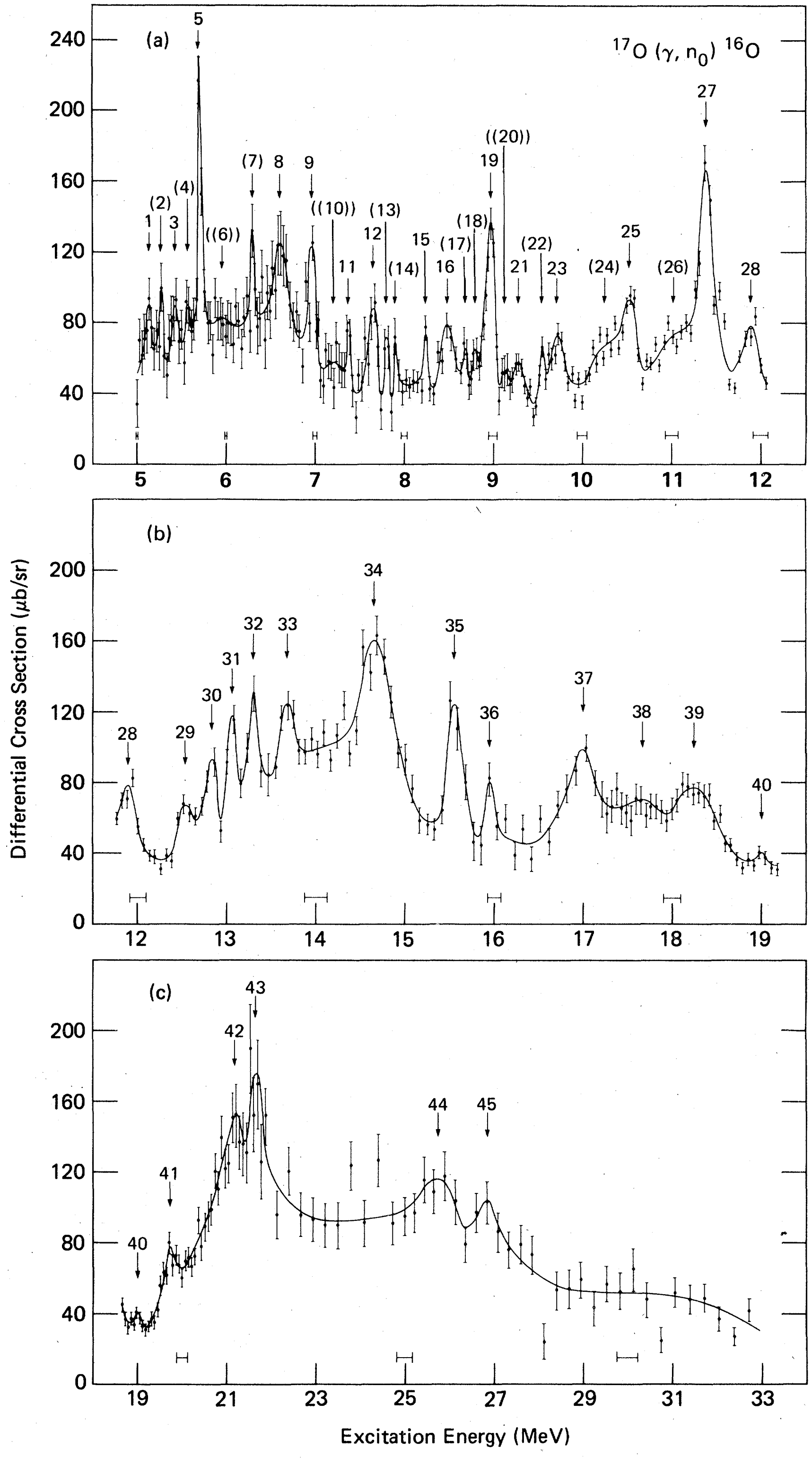

FIG. 1. The $^{17}O(\gamma,n_0)\,^{16}O$ differential cross section at 98°. The solid line is drawn to guide the eye. Numbered arrows indicate possible resonances. Horizontal bars represent the energy resolution of the measurement. (a) Threshold to 12 MeV. (b) 12 to 19 MeV. (c) 19 to 33 MeV (note that the energy scale has been doubled for this part).

TABLE I. Comparison of resonances found in the present measurement with known levels in ^{17}O.

Resonance number [a]	Excitation energy E_x (MeV)	Integrated strength A (MeV μb/sr)	Levels compiled in Ref. 15 E_x (MeV±keV)	J^π	Γ_{cm} (keV)
1	5.14	6.7 ± 2.9	5.086 ± 2	$\frac{3}{2}^+$	95 ± 5
(2) [b]	5.27				
3	5.43	4.9 ± 2.6	5.380 ± 2	$\frac{3}{2}^-$	28 ± 7
(4)	5.57	3.5 ± 2.2			
5	5.71	15.0 ± 4.8	5.698 ± 2	$\frac{7}{2}^-$	3.4 ± 3
((6)) [b]	5.96		{ 5.870 ± 2	$\frac{3}{2}^+$	6.6 ± 0.7
			{ 5.940 ± 4	$\frac{1}{2}^-$	32 ± 3
(7)	6.30	5.5 ± 2.8			
8	6.61	21.3 ± 9.2			
9	6.97	10.0 ± 3.3	6.973 ± 2		<1
((10)) [b]	7.21		7.202 ±10	$\frac{3}{2}^+$	280 ±30
11	7.37	5.3 ± 1.9	{ 7.3831 ± 1.5	$\frac{5}{2}^+$	0.6 ± 0.2
			{ 7.3860 ± 1.5	$\frac{5}{2}^-$	0.9 ± 0.3
12	7.66	11.6 ± 3.8	7.690 ± 4	$\frac{7}{2}^-$	18 ± 2
(13)	7.80	4.2 ± 2.0			
(14)	7.91	3.1 ± 1.5			
15	8.24	4.0 ± 1.5	8.200 ± 7	$\frac{3}{2}^-$	60
16	8.48	14.1 ± 3.8	{ 8.474 ± 3	$\frac{7}{2}^+$	7 ± 3
			{ 8.508 ± 3	$\frac{5}{2}^-$	5 ± 3
(17)	8.69	3.2 ± 1.5	8.700 ± 5	$\frac{3}{2}^-$	50 ± 3
(18)	8.80	3.6 ± 1.8			
19	8.98	21.1 ± 4.2	{ 8.972 ± 4	$\frac{7}{2}^-$	21 ± 3
			{ 9.148 ± 4	$\frac{1}{2}^-$	4 ± 3
((20))	9.13		9.15 ±20	$\frac{9}{2}^-$	
21	9.28	7.0 ± 2.5			
(22)	9.55	3.4 ± 1.4			
23	9.72	13.1 ± 3.1	9.720 ± 5	$\frac{7}{2}^+$	16 ± 1
(24)	10.25	13.1 ± 3.6	{ 10.178 ± 5	$\frac{7}{2}^-$	40
			{ 10.337 ±15	$\frac{5}{2}, \frac{7}{2}^-$	150
25	10.53	17.4 ± 2.9	10.563 ±10	$\frac{7}{2}^-$	47 ±15
(26)	11.02	20.6 ± 4.5	11.03 ± 4		
27	11.39	39.9 ± 6.2			
28	11.89	13.9 ± 3.2			
29	12.53	10.5 ± 3.2			
30	12.83	13.1 ± 4.9	12.81 ±25		
31	13.06	18.2 ± 6.0	13.077 ±15		16 ± 4
32	13.30	31.9 ± 8.1			
33	13.68	46 ±14	13.672		400

Table I. *(Continued)*.

Resonance number [a]	Excitation energy E_x (MeV)	Integrated strength A (MeV μb/sr)	Levels compiled in Ref. 15 E_x (MeV ± keV)	J^π	Γ_{cm} (keV)
34	14.65	125 ±30	14.621		340
35	15.56	32.6 ± 8.3	15.5		broad
(36)	15.95	10.8 ± 4.5			
37	17.00	53 ±13	17.09 ±50 [c]		
((38))	17.67				
39	18.25	42 ±10			
40	19.0	14.5 ± 4.3			
41	19.7	78 ±15			
42	21.2	368 ±79			
43	21.7	27 ±14	21.7 ±100	$\frac{5}{2}^+$	750
44	25.7	171 ±47			
45	26.9	91 ±28			

[a]Parentheses in this column are used to indicate that the evidence for a resonance is not compelling. Double parentheses are used when the evidence is even weaker.
[b]Possibly results from an excited-state transition(s).
[c]From Ref. 20.

was made manifest by the fine experimental resolution, it is displayed in three parts: Figure 1(a) shows the photon energy region from the (γ, n) threshold at 4.15 to 12 MeV, Fig. 1(b) shows the region from 12 to 19 MeV, and Fig. 1(c) shows the region from 19 to 33 MeV (the energy scale for this part has been doubled). The error bars shown in Fig. 1 reflect counting statistics only.

Forty-five resonances are seen in the present data; thirty of these are well resolved and have adequate counting statistics for definite assignment. The energies and strengths of these resonances are listed in Table I. The summed differential cross section from threshold to 33 MeV is 2.16 ± 0.28 MeV mb/sr. A solid line is drawn through the data points of Fig. 1 to guide the eye, and the resonances are numbered for ease of correlation with Table I. In Table I possible resonances where the evidence is not compelling but where there are indications of statistically significant structure are enclosed in parentheses. Where the evidence is even weaker, double parentheses are used. The energy resolution of the measurement varied as shown in Fig. 1 by the horizontal bars below the data points.

Since 13.7 MeV was the lowest end-point energy, non-ground-state transitions are possible up to an excitation energy of about 7.7 MeV. Structures which might result from excited-state transitions are identified in Table I.

TABLE II. Detailed analysis of some ^{17}O negative-parity levels below 9.5-MeV excitation energy.

J^π	Excitation energy E_x (MeV)	Ref. 18 Neutron width Γ_n (keV)	Alpha width Γ_α (keV)	Ref. 19 $B(E3\uparrow)$ (e^2fm^6)	This measurement Excitation energy E_x (MeV)	Gamma width $\Gamma_{\gamma 0}$ (eV)
$\frac{3}{2}^-$	5.377	41.5			5.43	0.7 ± 0.4
$\frac{7}{2}^-$	5.696	3.4		270 ± 32	5.71	1.1 ± 0.4
$\frac{5}{2}^-$	7.380	1.1	0.003	47 ± 38	7.37	0.8 ± 0.4
$\frac{7}{2}^-$	7.685	18	0.01		7.66	1.5 ± 0.5
$\frac{3}{2}^-$	8.197	48	4.0		8.24	1.4 ± 0.5
$\frac{5}{2}^-$	8.505	3.4	1.9	(negligible)	8.48	6.6 ± 1.8
$\frac{3}{2}^-$	8.689	42	1.8		8.69	1.2 ± 0.6
$\frac{7}{2}^-$	8.969	23	2.3		8.98	4.1 ± 0.8

IV. DISCUSSION

In a photodisintegration experiment, the primary excitation multipolarity is electric dipole. Consequently, from the $\frac{5}{2}^+$ ground state of ^{17}O resonances with J^π equal to $\frac{7}{2}^-$, $\frac{5}{2}^-$, and $\frac{3}{2}^-$ are expected to be excited preferentially. Several of the stronger resonances that are seen here correlate very well with known $\frac{7}{2}^-$ levels (see the compilation of Ajzenberg-Selove[15]). In particular, resonances at 5.71, 7.66, 8.98, and 10.53 MeV seem to be in this category. A broad shoulder at 10.25 MeV might also correspond to a known $\frac{7}{2}^-$ level. Weaker resonances at 7.37 and 8.48 MeV appear to correlated with $\frac{5}{2}^-$ levels. For the case of $\frac{3}{2}^-$ levels and for positive-parity resonances owing to absorption of $M1$ radiation (leading to $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{7}{2}^+$ levels) and $E2$ radiation (leading to $\frac{1}{2}^+$ through $\frac{9}{2}^+$ levels), it is very difficult to pick out any unambiguous correspondences. However, resonances at 5.43, 8.24, and 8.69 MeV might very well be identified with known $\frac{3}{2}^-$ levels; similarly, resonances at 5.14, 9.72, and 21.7 MeV correspond closely in energy with known positive-parity states in ^{17}O. There is evidence for further small structure, but the statistical errors are too large to draw definite conclusions. (The statistical accuracy of the data was limited by the amount of enriched isotopic sample and accelerator time available.)

High-resolution neutron total cross-section data for ^{16}O (Ref. 16) and data for the reaction ^{13}C$(\alpha, n)^{16}$O (Ref. 17) are available. The subsequent analysis of these data by a multilevel two-channel R-matrix theory has led to a detailed understanding of many levels below 9.5-MeV excitation energy in ^{17}O.[18] As many as eight of the resonances seen in the present data might correspond to resonances analyzed in the above references. If an angular distribution specified by the assumed J^π of each resonance is applied and if it is further assumed that the total width is the sum of the neutron and alpha-particle widths ($\Gamma = \Gamma_n + \Gamma_\alpha$), the ground-state radiation width $\Gamma_{\gamma 0}$ can be extracted from the present data by using the relation

$$A = 2\pi^2 \lambda\!\!\!^{-2} g \frac{\Gamma_{\gamma 0}\Gamma_n}{\Gamma},$$

where A is the strength of the resonance, $\lambda\!\!\!^- = \hbar c/E_\gamma$, and g is a statistical factor given by $g = (2J+1)/2(2I+1)$, where J is the spin of the excited state and $I = \frac{5}{2}$ is the spin of the ground state. This analysis has been applied to the eight corresponding resonances and the resulting ground-state radiation widths are given in Table II. Note that although an angular distribution was assumed, more unlikely angular distributions would change these results by at most ±40%. A few of these same levels have been examined by electron scattering[19] and the octupole transition strengths extracted. The $B(E3)$ values from Ref. 19 also are listed in Table II. The detailed understanding of levels below 9.5-MeV excitation energy offered by all these experiments provides a stringent test for any theoretical description of ^{17}O.

Further comparison of the cross section with the known level structure reveals several resonances which have been seen but have not been assigned a spin and parity and several resonances which have not been seen previously. The resonance at 17.00 MeV, which is not listed in the compilation,[15] has been seen in the electron-scattering experiment of Norum *et al.*[20] at 17.09 ± 0.05 MeV. Strong resonances which have not been seen previously appear at 6.61, 11.39, 11.89, 13.30, and 18.25 MeV. From the present data alone, the spin and parity of these resonances cannot be determined unambiguously. A complete spectroscopic study using this reaction would require information on the angular distribution and polarization of the emitted photoneutrons. However, because of the strength of these resonances, particularly those at 6.61 and 11.39 MeV, they most likely result from $E1$ absorption, and hence can be assigned $J^\pi = (\frac{7}{2}, \frac{5}{2}, \frac{3}{2})^-$.

In the higher-energy region (above 19 MeV), where the $E1$ giant resonance is located, there is a strong double resonance centered at 21.5 MeV, a smaller resonance at 19.8 MeV, and a very broad double resonance centered at about 26 MeV. In the (γ, n_0) reaction only $T = \frac{1}{2}$ resonances will be observed under the assumption that isospin is a good quantum number.[6] It would be interesting to compare the (γ, n_0) partial cross section with the (γ, n) total cross section, since in the latter reaction both $T = \frac{1}{2}$ and $T = \frac{3}{2}$ resonances would be populated. Unfortunately, only preliminary (γ, n) data are available as yet.[21] However, some data from other reactions which throw light on the GDR of ^{17}O have been reported. In the electron-scattering data of Norum *et al.*,[20] it is found that the main strength of the GDR is centered at about 23 MeV. A reasonable conclusion is that the 23-MeV region of the GDR is mainly $T = \frac{3}{2}$, while the region near 21.5 MeV is mainly $T = \frac{1}{2}$; also, the region near 26 MeV might very well contain appreciable $T = \frac{1}{2}$ strength.

Radiative-capture reactions ^{14}C(τ, γ_0) (Ref. 22), ^{14}N(t, γ_0) (Ref. 23), ^{15}N$(d, \gamma_0 + \gamma_1)$, and ^{13}C(α, γ_0) (Ref. 24) have been used to populate states in ^{17}O in the GDR region. Specifically, levels at 19.9 MeV ($\frac{5}{2}^+$), 20.4 MeV ($\frac{5}{2}^-$), 21.0 MeV ($\frac{3}{2}^-$), 21.7 MeV ($\frac{5}{2}^+$), 22.1 MeV ($\frac{7}{2}^-$), 22.6 MeV ($\frac{3}{2}^{(-)}$), and 23.0 MeV ($\frac{1}{2}^+$) have been seen in one or more of these reactions. Furthermore, several of these levels have been seen in the electron-scattering data of Norum *et al.*[20] as small peaks superimposed on the main resonance centered at 23 MeV. These resonances do not correlate well with the structure seen in the present data, with the possible exception of the resonance at 21.7 MeV. The fact that the positive-parity levels are not in general excited in the present measurement is not surprising since this would require $M1$ or $E2$ photon absorption. The lack of solid evidence for any excitation of the negative-parity levels might indicate that they have $T=\frac{3}{2}$ or that their basic structure is of a more complicated nature. The weakness of the excitation of these states in the electron-scattering data is evidence for the latter. This too is not surprising, since the radiative capture of a multinucleon particle such as a deuteron, triton, helion, or alpha particle should populate preferentially multinucleon states in the compound system (in this case ^{17}O), which would not necessarily be expected to have a large transition strength to the ground state. Indeed, applying detailed balance to the cross sections measured in these radiative-capture reactions shows that the strength of these resonances is typically only one-sixth of the (γ, n_0) cross section measured here.

Because ^{17}F is the mirror nucleus of ^{17}O, the $^{17}F(\gamma, p_0)^{16}O$ reaction should produce results very similar to the $^{17}O(\gamma, n_0)^{16}O$ reaction. Harakeh *et al.*[7] have measured the inverse $^{16}O(p, \gamma_0+\gamma_1)^{17}F$ differential cross section (at 90°). In Fig. 2(a) the present results are compared to those of Ref. 7. The (p,γ) cross section has been converted to (γ, p) by detailed balance, assuming γ_0 transitions only are present. Note that in order to display the present data, some of the resolution in Fig. 1 has been sacrificed. The data have been summed to produce a minimum of approximately 100 keV between points. As expected, the agreement between these reactions is excellent, both for the general shape of the cross sections and for the specific location of resonances. Moreover, in Ref. 7 the negative-parity states up to $J=\frac{7}{2}$ in the $A=17$ system have been calculated in a 1p, 2p-1h basis of good isospin. The residual interactions were computed using the Kuo-Brown interaction.[25] Three cases were considered which differ from each other by the choice of single-particle and single-hole energies used in the basis. The first is a set that has been proposed by Jolly[26] and the second is a set in which the unbound $(1f, 2p)$ orbitals are generated by a potential which fits the bound orbitals.[27] In the third case the $(1f, 2p)$ single-particle states are ignored. These sets differ considerably in their placement of the $(1f, 2p)$ single-particle energies, namely, by ~15 MeV. The theoretical results for the first case are displayed in Fig. 2(b). These results were obtained by assuming a width of 2 MeV for the reduced transition strengths tabulated in Ref. 7. (Only ground-state transition strengths were used, whereas for the cross-section curves of Ref. 7 both ground- and first-excited-state transition strengths were used.) In Ref. 7 it was concluded that the first case was better than the second because the observed strength near 17.5 MeV was reproduced. However, the present data demand that this conclusion be reexamined. Although the first case does produce strength in the region from 16 to 18 MeV, it does not produce adequate strength below 16 MeV which is required by the present measurement. The opposite situation apparently is true for the second case. Consequently, neither case can be excluded by the experimental data.

Albert *et al.*[8] have used a similar theory to calculate the photoabsorption cross section in ^{17}O (and also in ^{13}C). They have used a set of single-particle and single-hole energies which is similar to the first set of Ref. 7. The residual interaction was either a δ-function potential with a Soper exchange mixture or the separable Tabakin potential.[28] Their theoretical results using the zero-range Soper interaction are shown in Fig. 2(c). These results compare more favorably with the experimental data than those for the Tabakin interaction, since the latter places the peak of the cross section too high in energy. For the case of ^{13}C, the same conclusion has been reached.[4] Note that only the $T=\frac{1}{2}$ portion of the theoretical results should be compared with the data. Albert *et al.* conclude that there is no clear-cut isospin splitting of the GDR. However, the theoretical calculation of Ref. 7 does show some splitting into $T=\frac{1}{2}$ strength centered at 21.4 MeV and $T=\frac{3}{2}$ strength centered at 24.8 MeV. Both the $^{17}O(\gamma, n_0)$ and $^{17}F(\gamma, p_0)$ results are not inconsistent with the latter conclusion. Resolution of these conflicting conclusions must await results on the total photoneutron cross section.

Finally, (γ, n_0) cross-section results for the stable oxygen family, i.e., differential cross sections (at 98°) for ^{16}O (from Ref. 29), ^{17}O, and ^{18}O (from Ref. 3) are shown in Fig. 3. All data have been summed to produce a minimum of approximately 100 keV between points. The qualitative similarity of these cross sections is striking. For example, in the region of sharp resonances for ^{17}O and ^{18}O there is nearly a resonance-for-resonance correlation. If photoneutron angular distributions were available to support these correlations both the similarities and differences of these resonances could provide important nuclear-structure information. It is unfortunate that the

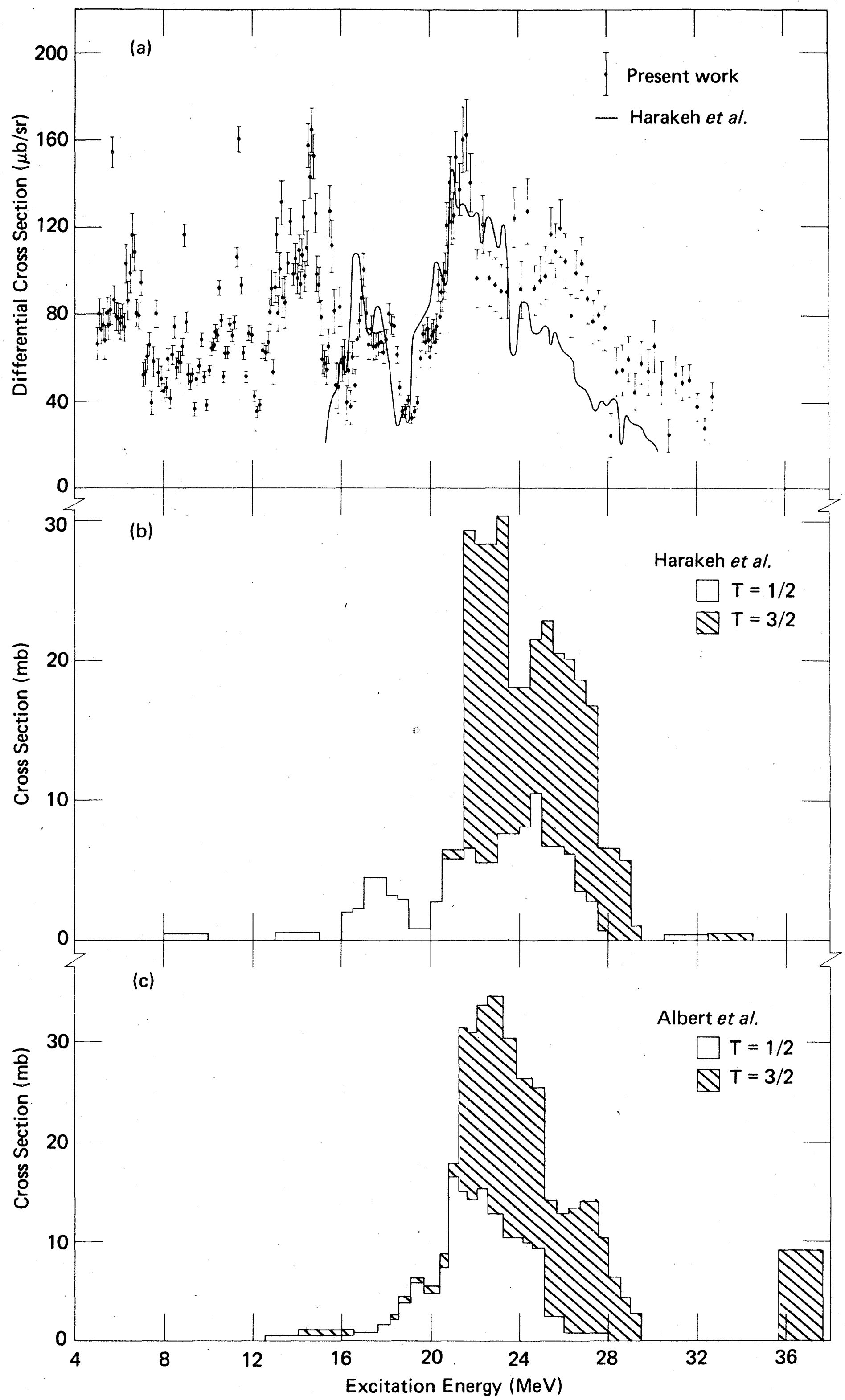

FIG. 2. (a) Comparison of the $^{17}O(\gamma,n_0)\,^{16}O$ differential cross section at 98° with the $^{16}O(p,\gamma_0+\gamma_1)\,^{17}F$ differential cross section at 90°, from Ref. 7. [The (p,γ) cross section has been converted to a (γ,p) cross section by detailed balance.] (b) Theoretical results of Ref. 7. (c) Theoretical results of Ref. 8.

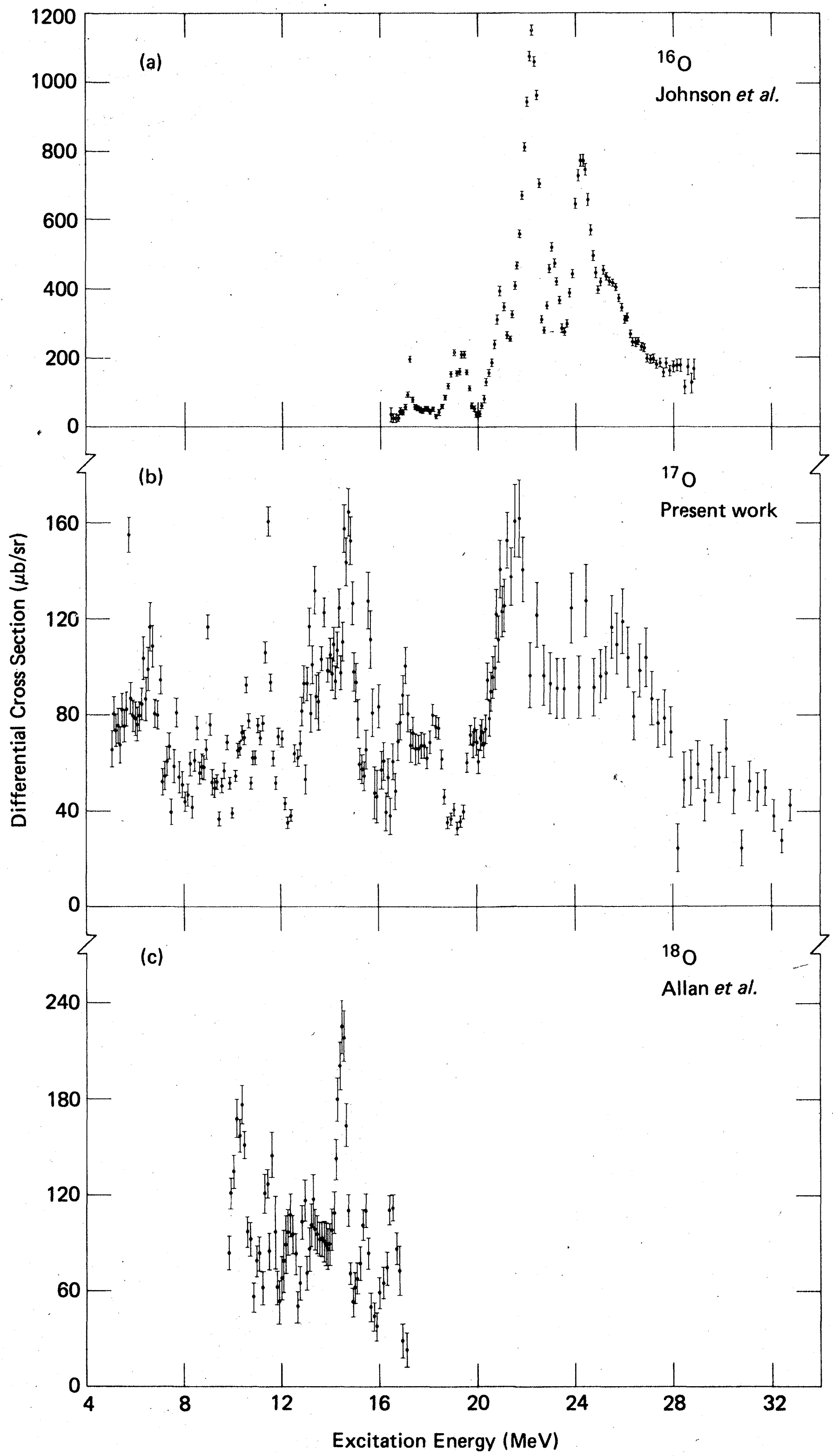

FIG. 3. Comparison of $(d\sigma/d\Omega)(E_x, 98°)$ for the (γ, n_0) reaction for the stable oxygen isotopes. (a) ^{16}O (Ref. 29). (b) ^{17}O (this measurement). (c) ^{18}O (Ref. 3).

(γ, n_0) cross-section data for ^{18}O do not extend to higher energies, since at these energies, particularly in the giant-resonance region, comparison of all three cross sections would provide further important information on the isospin strength distribution as well as on the effect of additional neutrons outside of the ^{16}O core.

V. CONCLUSIONS

The differential cross section (at 98°) for the reaction $^{17}\mathrm{O}(\gamma, n_0)^{16}\mathrm{O}$ has been measured for the first time over the energy range from 5.0 to 33.0 MeV. The measured cross section exhibits considerable structure, the properties of which have been compared to the known levels of ^{17}O. In this comparison, definite correspondences were observed with known $\frac{7}{2}^-$ and $\frac{5}{2}^-$ levels (populated by $E1$ radiation). Possible correspondences with $\frac{3}{2}^-$ levels and with positive-parity levels also have been made. Several resonances were found which apparently do not correspond to previously known levels. Ground-state radiation widths were obtained for the identified resonances below 9.5 MeV.

In the giant-resonance region, $T=\frac{1}{2}$ components were observed at 19.8, 21.5, and ~26 MeV. A variety of radiative-capture reactions for multinucleon particles have been studied in this energy region and interesting resonance behavior has been observed. However, it does not appear that it is the same structure that is being investigated in this experiment. Further information on isospin effects in this nucleus must await data for other reaction channels, especially the total photoneutron cross section.

The data were compared with the cross section for the single-nucleon radiative-capture reaction $^{16}\mathrm{O}(p, \gamma_0+\gamma_1)^{17}\mathrm{F}$, and the expected similarities were observed. The theoretical predictions of Harakeh *et al.*[7] and of Albert *et al.*[8] also were compared with the present data. The conclusion of Ref. 7 concerning the energies of the $(1f, 2p)$ single-particle states was reexamined. The evidence from the present results does not support the single-particle energies of Ref. 26 over Ref. 27. Of the two residual interactions studied in Ref. 8, the Soper exchange mixture appears to give the better agreement with the present data. No support for the claim made in Ref. 8 that there is very little isospin splitting of the GDR was obtained in the present measurement; indeed, comparison of the present data with the electron-scattering results of Ref. 20 indicates a splitting of at least 2 MeV.

Although data concerning the photoeffect in the stable oxygen isotopes are now becoming available, the present study points out the need for even more extensive work both in extending the energy range studied (for ^{18}O) and in measuring angular distributions of the photoneutrons. The benefits to be gained in understanding several aspects of nuclear structure and reactions for these important light nuclei would make such an effort well worthwhile.

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