EXPERIMENTAL STUDY OF SPECIFIC FINAL-STATE DECAY MODES FOLLOWING PHOTOPARTICLE REACTIONS IN O^{16}†

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The present experimental study was performed with monoenergetic photons from the annihilation in flight of fast positrons at the Lawrence Radiation Laboratory Livermore electron linear accelerator. Transitions to specific final states populated following photoparticle reactions in O^{16} were investigated by observing de-excitation γ rays from the residual nuclei. [The results of an independent neutron spectrometer study of $O^{16}(\gamma,n)O^{15}$ decay modes have already been reported.[1]] A $3\frac{1}{2}$-in.-diam by 8-in.-long polyethylene container filled with distilled water served as the O^{16} target, and de-excitation γ rays were detected with two 5-in.-diam NaI(Tl) scintillators placed within a 4π BF_3 polyethylene neutron detector of high efficiency (nearly 40%). This arrangement allowed a γ-ray-neutron coincidence and anticoincidence experiment to be done, and thus led to a separation of $(\gamma,p\gamma')$ and $(\gamma,n\gamma')$ events. Since the level schemes of N^{15} and O^{15} are nearly identical,[2] γ-ray decays from corresponding mirror levels such as the 6.32-MeV N^{15} and 6.18 MeV O^{15} $\frac{3}{2}^-$ states would not normally be resolved with NaI(Tl). The NaI detectors both subtended a 1% solid angle relative to the H_2O sample, and were positioned at 90° to the annihilation-photon-beam line. Neutron-coincident γ-ray signals were routed into one segment of a 4096-channel analyzer, and noncoincident signals into another. An analysis was performed on the raw spectra to correct for random coincidences and the effect of neutron-detector efficiency. In addition, atomic scattering photon backgrounds were estimated from pulse-height spectra taken with a CH_2-oil sample as target.

Annihilation-photon beam monitoring was the same as that employed in previous photonuclear experiments done at this laboratory.[1,3,4] Measurements covered an excitation energy range 17 to 29 MeV, in ≤150-keV intervals. Annihilation-photon energy resolution was 300 to 500 keV for this experiment.

A typical set of background-corrected pulse-height spectra for an O^{16} excitation energy of 23 MeV is shown in Fig. 1(a). The small energy differences between O^{15} and N^{15} mirror-level decays (~140 keV for the 6-MeV $\frac{3}{2}^-$ set) is apparent in these spectra. Non-neutron-associated γ-ray lines at 3.9, 5.3, 6.3, 7.3, and at least two lines above 9 MeV are apparent. (A careful examination of many spectra indicated these 9- to 11-MeV lines to be principally 9.1, 9.9, and 10.8 MeV.) Neutron-associated lines at 5.2, 6.2, and 6.8 MeV are also apparent. These are all decay lines at or near known O^{15}- and N^{15}-state decays.[2] In Fig. 1(b) is shown the high-energy portion of a noncoincidence spectrum taken at an O^{16} excitation energy of 25 MeV. A sizable num-

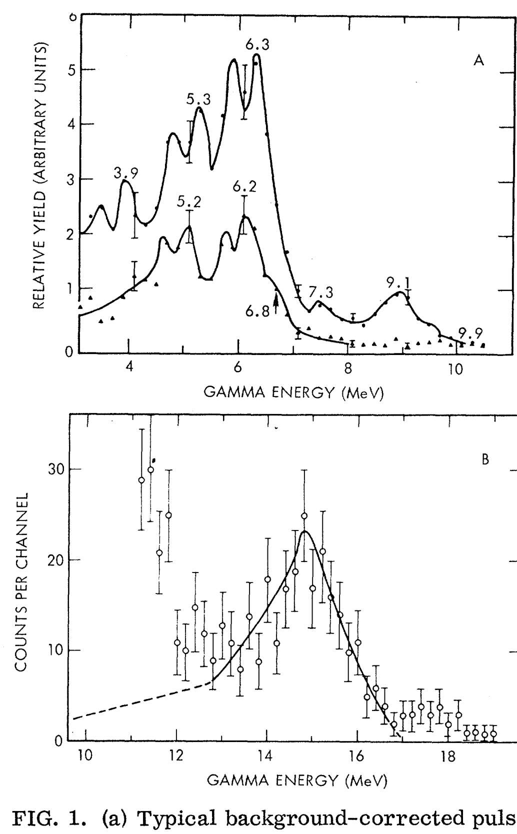

FIG. 1. (a) Typical background-corrected pulse-height spectra accumulated in four hours at an excitation energy of 23 MeV. The solid triangles (lower curve) make up the true neutron-associated spectrum and the solid circles (upper curve) the true spectrum not associated with neutron emission. Total absorption peak energies are indicated. (b) High-energy portion of the pulse-height spectrum accumulated in four hours at an excitation energy of 25 MeV.

ber of 15-MeV γ rays are noticeable in the spectrum. A study of O^{16} photoparticle reaction thresholds indicated that only the reaction $O^{16}(\gamma,\alpha)C^{12}$ with a 7.5-MeV threshold could result in a residual nucleus with as much as 15-MeV excitation. The C^{12} 15.11-MeV, $J^{\pi} = 1^+$, $T=1$ state is known to have a strong ground-state γ-ray decay ($\Gamma_{\gamma 0}/\Gamma_{tot} = 0.84$)[5]; so the 15-MeV γ rays observed in this experiment are attributed to $O^{16}(\gamma,\alpha)$ reactions in which the residual C^{12} nucleus is left in this state.

The background-corrected spectra were subjected to a least-squares, "peel off," response-function analysis. This procedure was found to minimize the least-squares statistical error for components of minor occurrence. A total of 11 de-excitation γ-ray line components were thus determined: one (γ,α), three (γ,n), and seven (γ,p) decay lines. Relative 90° cross sections for all 11 were determined from the data.

By combining the $(\gamma,n\gamma')$ relative cross sections with the total photoneutron cross section and the photoneutron spectral information obtained in a previous experiment,[1] an approximate integrated-over-angle (4π) absolute cross-section scale for the $(\gamma,n\gamma')$ reactions was determined. This approximate 4π cross-section scale was applied to the $(\gamma,p\gamma')$ and $(\gamma,\alpha\gamma')$ reactions as well, by assuming that the de-excitation γ rays from the $(\gamma,p\gamma')$ and $(\gamma,\alpha\gamma')$ reactions follow an isotropic angular distribution. These approximate 4π cross sections integrated to 28.7 MeV are shown in Table I. Also shown in Table I are integrated 4π cross sections for the ground-state reaction $O^{16}(\gamma,p)N^{15}$ from the data of Tanner, Thomas, and Earle,[6] Dodge and Barber,[7] and Finckh and Hegel,[8] and the ground-state reaction $O^{16}(\gamma,n)O^{15}$. The latter was obtained by subtracting the present $O^{16}(\gamma,n)O^{15}$ excited-state cross sections from the total O^{16} photonuclear cross section of Ref. 1 and Bramblett et al.[9] Adding up all decay-mode integrated cross sections results in a value of 120 ± 12 MeV mb, as compared with the total nuclear photoabsorption value of 136 ± 16 MeV mb.[10]

As can be deduced from the data of Table I, the sum of the $\frac{1}{2}^-$ (ground state) and $\frac{3}{2}^-$ (third-excited state) O^{15} and N^{15} final-state cross sections is $78 \pm 8\%$ of the total decay cross section integrated to 28.7 MeV. This must be re-

Table I. Integrated cross sections for O^{16} photoreactions.

Reaction	Final state (MeV)	$\int_0^{28.7}\sigma dE$ (MeV mb)	Fractional $\int_0^{28.7}\sigma dE$
(γ,p)	ground state$(\frac{1}{2}^-)$	34.42[a]	0.286
	$5.3(\frac{1}{2}^+,\frac{5}{2}^+)$	4.94[b]	0.041
	$6.33(\frac{3}{2}^-)$	22.30	0.185
	$7.30(\frac{3}{2}^+)$	5.47	0.047
	9.1	2.03	0.017
	9.22	1.50	0.013
	9.9	2.36	0.020
	10.8	2.34[c]	0.020
(γ,n)	ground state$(\frac{1}{2}^-)$	26.67	0.223
	$5.2(\frac{1}{2}^+,\frac{5}{2}^+)$	3.49	0.029
	$6.18(\frac{3}{2}^-)$	9.43	0.079
	$6.79(\frac{3}{2}^+)$	4.50	0.038
(γ,α)	$15.11(1^+, T=1)$	0.23	0.002
		119.68	1.000

[a]From Refs. 6 to 8.

[b]The 9.22-MeV 100% cascade transition cross section has been subtracted from the observed 5.3-MeV yield cross section.

[c]The 10.8-MeV yields have been multiplied by $\Gamma_{tot}/\Gamma_{\gamma 0} = 3.0 \pm 0.5$ from Ref. 2.

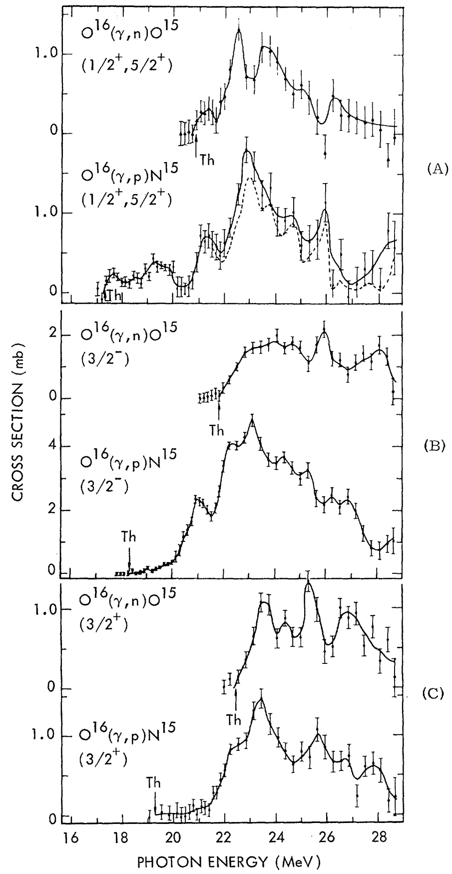

FIG. 2. $O^{16}(\gamma,n\gamma')$ and $(\gamma,p\gamma')$ mirror-level, final-state cross sections. (a) Top: $O^{15}(\frac{1}{2}^+,\frac{5}{2}^+$ unresolved) 5.2-MeV, final-state cross section. Bottom: $N^{15}(\frac{1}{2}^+,\frac{5}{2}^+$ unresolved) 5.3-MeV, final-state cross section. Dashed line shows effect of subtracting 9.22-MeV level cascades (Ref. 2). (b) Top: $O^{15}(\frac{3}{2}^-)$ 6.18-MeV, final-state cross section. Bottom: $N^{15}(\frac{3}{2}^-)$ 6.33-MeV, final-state cross section. (c) Top: $O^{15}(\frac{3}{2}^+)$ 6.79-MeV, final-state cross section. Bottom: $N^{15}(\frac{3}{2}^+)$ 7.30-MeV, final-state cross section.

garded as evidence for the basic validity of the single-particle, single-hole model as applied to O^{16}, since a much smaller value would be expected on the basis of thresholds alone. [At 23-MeV O^{16} excitation, for example, 20 known (γ,p) and seven (γ,n) emission channels are energetically open.[2]] The greatest part of the remaining 22% of the total decay strength is split between the O^{15} and N^{15} $(\frac{1}{2}^+,\frac{5}{2}^+)$ doublet and $(\frac{3}{2}^+)$ final states—roughly, 7 to 8% for each mirror-level set. The rest of the strength (~7%) is divided among four 9- to 11-MeV N^{15} final-state decays.

The ratio $\sigma(\gamma,n)/\sigma(\gamma,p)$ of mirror-level, final-state cross sections is related to the isospin purity of O^{16} states.[11] Using the formula for the $(T=0)/(T=1)$ amplitude ratio deduced by Barker and Mann[11] and the three sets of mirror-level, final-state cross sections shown in Fig. 2, we obtain a $(T=0)/(T=1)$ amplitude ratio of ~0.08 for O^{16} giant resonance states between 22 and 28 MeV. This preliminary analysis also indicates considerable variation in the amplitude ratio with structure width comparable to O^{16} level spacings.

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