Nuclear Photon Absorption in Carbon and Oxygen*

A. S. PENFOLD† AND E. L. GARWIN‡
The Enrico Fermi Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
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The importance of narrow, isolated, resonances in the photonuclear absorption cross sections of C and O was investigated by means of an absorption experiment performed with 30.7-Mev bremsstrahlung. The experiment yielded values for the cross sections averaged over the (γ,n) cross sections for C^{12} and O^{16}. The results for C were the same as those expected for a cross section without narrow resonances, while for O a definite resonance effect was demonstrated. The O photonuclear absorption cross section, averaged over the $O^{16}(\gamma,n)O^{15}$ cross section, was found to be 26.7 ± 3.5 millibarns, 16 ± 4 millibarns higher than the value expected if narrow resonances contribute insignificantly. Estimated values for the parameters of the O resonances near 22 Mev are: average peak height, 106 ± 14 mb; ratio of the radiative width (to ground state) to total width, $(6.6\pm0.9)\times10^{-3}$; total width about 30 kev. The experimental results are insensitive to uncertainties in the non-nuclear x-ray attenuation cross sections for C and O.

INTRODUCTION

THE bremsstrahlung yield curves for (γ,n) reactions in the light elements exhibit fine structure in the form of sudden, and often large, changes of slope. The sudden changes have been interpreted as manifestations of narrow levels in the total absorption cross section for photons.[1,2]

For carbon and oxygen, the fine structure in the yield curves is observed not only on the low-energy side of the giant resonance, but over the peak of the giant resonance as well. It is not yet clear, however, whether the implied narrow resonances contribute significantly to the total absorption cross section.

Narrow resonances do contribute significantly on the low-energy side of the giant resonance in oxygen. This has been shown by means of an absorption experiment[3] using an oxygen detector and an oxygen absorber. The experiment yielded an average value for the total absorption cross section over the region 17 to 18 Mev, of 13 ± 8 mb. This value is to be compared with the value 2.5 ± 0.3 mb, obtained by adding together the average (γ,n) and (γ,p) cross sections[4,5] from conventional analyses which smooth out the very narrow structure. Thus, the experiment yielded a higher value than can be accounted for by smooth cross sections, and so resonance absorption is indicated. In fact, if narrow resonances are assumed, the experimental value 13 ± 8 mb implies that the average *peak* height of the resonances is 26 ± 16 mb. This value is in good agreement with the value of 17.5 ± 6 mb for the average peak height which can be calculated from the fine structure data given by Penfold and Spicer.[2]

Attempts have been made to determine the importance of narrow resonances throughout the *whole* of the giant resonance region in light elements.[6–8] The results indicate that narrow resonances play a minor role[7,8] in the case of carbon. For oxygen, narrow resonances seem to be more important,[7] but the experiments have not been conclusive.

This paper reports the results of an absorption experiment which studied the influence of narrow resonances near the peak of the giant resonance of carbon and oxygen. The experiment studied the effects on the yields of selected (γ,n) reactions in carbon, oxygen, and copper due to nuclear photon absorption in graphite and water absorbers. The experiment was performed with a 30.7-Mev bremsstrahlung beam, and it yielded average values for the photonuclear absorption cross sections of C^{12} and O^{16} near 23 Mev. The bremsstrahlung energy was chosen large enough to encompass the giant resonance regions for C and O, but not so large as to give high sensitivity to the energy region above the giant resonance.

The experiment was designed to minimize the effects of systematic errors, and the results do not depend on a knowledge of the following quantities: the energy response of the bremsstrahlung monitor, variations of the bremsstrahlung intensity during the irradiations, the stability of the bremsstrahlung monitor for periods longer than 10 min, the shape of the bremsstrahlung spectrum below 11 Mev, the sample thicknesses, the beta-ray counting efficiencies, and the stability of the beta-ray counting system for periods longer than 30 min. In addition, the results do not depend on a knowledge of the non-nuclear x-ray attenuation coefficients for graphite and water, but only on their change between

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† Now at Litton Industries, Beverly Hills, California.
‡ Now at the University of Illinois.
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[2] A. S. Penfold and B. M. Spicer, Phys. Rev. **100**, 1377 (1955).
[3] A. S. Penfold, Ph.D. thesis, University of Illinois, 1955 (unpublished).
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[6] Haslam, Horsley, Johns, and Robinson, Can. J. Phys. **31**, 636 (1953).
[7] A. K. M. Siddiq and R. N. H. Haslam, Can. J. Phys. **36**, 963 (1958).
[8] M. M. Wolff and W. E. Stephens, Phys. Rev. **112**, 890 (1958). A large amount of additional information, including some on absorption in oxygen is contained in: M. M. Wolff, University of Pennsylvania, Department of Physics, Technical Report No. 4, 1958 (unpublished).

17 and 24 Mev. This also means that the results are insensitive to the solid angle which the samples subtended with respect to the absorbers.

EXPERIMENTAL PROCEDURE

The irradiation geometry is shown in Fig. 1. The diameter of the x-ray beam at the absorber position was determined by the secondary collimator and was $\frac{3}{4}$ in. The diameter of the x-ray beam at the ion chamber was determined by the main collimator and was $1\frac{3}{4}$ in. The samples which were irradiated were one inch in diameter. They were placed at the main collimator entrance and just covered it.

Each sample consisted of a Lucite disk and a copper disk, simultaneously irradiated. The activities induced in the samples which are of interest to the experiment are: the 10.0-min activity in copper due to the $Cu^{63}(\gamma,n)Cu^{62}$ reaction; the 2.02-min activity in Lucite due to the $O^{16}(\gamma,n)O^{15}$ reaction; and the 20.1-min activity in Lucite due to the $C^{12}(\gamma,n)C^{11}$ reaction. These activities were measured by means of a single end-window geiger counter, and they were the only ones produced in observable amounts. The samples were all thick compared to the range of the beta rays involved so that minor variations in the individual sample thicknesses did not affect the counting. The samples were counted in the sequence Lucite-copper-Lucite. The carbon and oxygen activities in the Lucite were separated by calculation. The total period of counting was 30 minutes per irradiation, and the irradiations lasted 10 minutes.

The bremsstrahlung intensity was monitored by means of a thick parallel-plate ionization chamber connected to a vibrating reed electrometer, whose output was proportional to the instantaneous bremsstrahlung intensity. This signal was presented to a three-channel activity computer, whose three output voltages were analogs of the 2.02-minute O^{15} activity, the 10.0-minute Cu^{62} activity, and the 20.1-minute C^{11} activity. Hence fluctuations in the instantaneous bremsstrahlung intensity produced similar changes in both the sample activities and the recorded monitor readings.

The experiment employed a 77.2 g/cm² water absorber, and an 89.5 g/cm² graphite absorber. The absorbers had a transmission factor of about 25% for photons of 20 Mev, and they were placed as shown in Fig. 1.

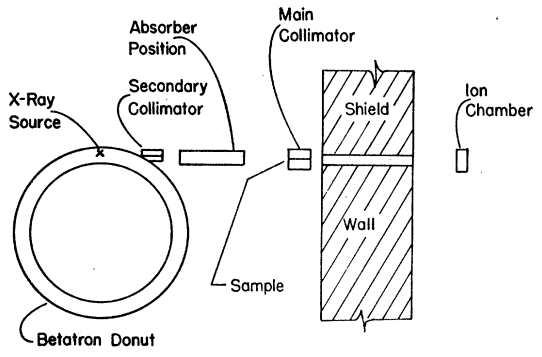

FIG. 1. Irradiation geometry for the experiment.

TABLE I. Experimental results. Each entry in column three is the mean of eight determinations. Column four gives the observed standard deviations from the means, while column five gives the standard deviations expected from counting statistics alone.

Absorber	Quantity measured	Mean of measurements	Observed st'd. dev.	Expected st'd. dev.
None	$\alpha(O)/\alpha(Cu)$	382±1	0.7%	1.3%
	$\alpha(C)/\alpha(Cu)$	301±1.5	1.4%	1.1%
Water	$\alpha^w(O)/\alpha^w(Cu)$	395±3	2.0%	2.7%
	$\alpha^w(C)/\alpha^w(Cu)$	325±2.5	2.3%	2.1%
Graphite	$\alpha^g(O)/\alpha^g(Cu)$	400±3.5	2.5%	2.7%
	$\alpha^g(C)/\alpha^g(Cu)$	322±2	1.9%	2.1%

Each irradiation-count sequence gave values for the relative yields $\alpha^x(C)$, $\alpha^x(O)$, and $\alpha^x(Cu)$ of C^{11}, O^{15}, and Cu^{62}, respectively. The notation which is used is the following: $\alpha^x(a)$ is the recorded number of counts from atoms of type "a" divided by the reading from channel "a" of the activity computer at the beginning of the counting period. The superscript "x" gives the absorber condition and is "w" for the water absorber, "g" for the graphite absorber, and is omitted for no absorber.

A total of eight irradiations were made with the water absorber, eight with the graphite absorber, and eight with no absorber. For each irradiation the yield ratios $\alpha^x(C)/\alpha^x(Cu)$ and $\alpha^x(O)/\alpha^x(Cu)$ were computed. The mean values (for all irradiations with the same absorber condition) were also computed. These mean values appear in Table I, along with the corresponding standard deviations from the mean values. The table also shows the standard deviations expected from counting statistics alone. The two standard deviations are in satisfactory agreement, indicating that the only important source of random error was counting statistics.

An analytic expression for the ratio of the number of counts due to atoms of type "a" to the corresponding reading from channel "a" of the activity computer is

$$\alpha^x(a)=\frac{\epsilon_a}{K_a\lambda_a}\int_0^\infty P(k)f^x(k)\sigma_a(k)dk \Big/ \int_0^\infty P(k)f^x(k)R(k)dk. \quad (1)$$

In Eq. (1): ϵ_a is a constant which depends on the length of the count period, the energy of the beta rays, the density of the sample, and the characteristics of the geiger tube; K_a is a constant, characteristic of channel "a" of the activity computer; λ_a is the time constant to which channel "a" is set and is equal to the radioactive decay constant for atoms of type "a"; $P(k)$ is a function of photon energy, and it has the same shape as the bremsstrahlung spectrum incident on the absorber; $f^x(k)$ is the fractional photon transmission, for photons of energy k and an absorber of type "x";

$\sigma_a(k)$ is the photonuclear cross section for production of atoms of type "a"; $R(k)$ is the charge transferred by the ion chamber per incident photon of energy k.

The experimental data given in Table I are in the form of yield ratios, $\alpha^x(a)/\alpha^x(b)$. An analytic expression for these ratios follows from Eq. (1):

$$\frac{\alpha^x(a)}{\alpha^x(b)}=\left[\frac{K_b\lambda_b\epsilon_a}{K_a\lambda_a\epsilon_b}\right]\int_0^\infty P(k)f^x(k)\sigma_a(k)dk \Big/ \int_0^\infty P(k)f^x(k)\sigma_b(k)dk. \quad (2)$$

Equation (2) is independent of the monitor response, $R(k)$. The good agreement between the observed and the expected standard deviations given in Table I indicates that the bracketed parameters in Eq. (2) remained constant throughout the experiment.

ANALYSIS OF THE DATA

As a first step in analyzing the data of Table I the ratios, $W^x(b/a)$, of $\alpha(a)/\alpha(b)$ to $\alpha^x(a)/\alpha^x(b)$ were formed. An analytic expression for $W^x(b/a)$ follows from Eq. (2):

$$W^x(b/a)=\langle f^x\rangle_b/\langle f^x\rangle_a, \quad (3)$$

where, for example,

$$\langle f^x\rangle_a=\int_0^\infty P(k)f^x(k)\sigma_a(k)dk \Big/ \int_0^\infty P(k)\sigma_a(k)dk. \quad (4)$$

Thus the quantity $W^x(b/a)$ is equal to the ratio of the fractional photon transmission, $f^x(k)$, averaged over the cross section σ_b to the same averaged over the cross section σ_a.

The photon transmission, $f^x(k)$, can be written as the product of a function $f_e{}^x(k)$ which expresses the effects due to non-nuclear, or "electronic", absorption, and a function, $f_n{}^x(k)$, which expresses the effects due to nuclear absorption. The nuclear absorption was never larger than 7% for any of the absorbers used in this experiment, and so it is sufficiently accurate to put $f_n{}^x(k)$ equal to $1-\sigma^x(k)t_x$, where: $\sigma^x(k)$ is the nuclear absorption cross section in cm^2 per atom of type "x" in the absorber; and t_x is the corresponding number of atoms/cm^2.

By using the foregoing, one obtains

$$\langle f^x\rangle_a=\langle f_e{}^x\rangle_a-t_x\langle f_e{}^x\sigma^x\rangle_a, \quad (5)$$

with a similar expression for $\langle f^x\rangle_b$. For the graphite absorber σ^x is equal to σ^C, the total photonuclear absorption cross section for carbon (98.9% C^{12}). For the water absorber σ^x is equal to σ^O, the total photonuclear absorption cross section for oxygen (99.8% O^{16}).

Explicit calculations were made which showed that, for the conditions of this experiment, Eq. (5) can be simplified by putting $\langle f_e{}^x\sigma^x\rangle_a$ equal to $\langle f_e{}^x\rangle_a\langle\sigma^x\rangle_a$. This approximation leads to an error which is considerably smaller than the errors already present in the data due to counting statistics. With this simplification, Eqs. (3) and (5) may be combined to give the following result:

$$\langle\sigma^x\rangle_a-\langle\sigma^x\rangle_b=\frac{1}{t_x}\left[\frac{\langle f_e{}^x\rangle_a}{\langle f_e{}^x\rangle_b}W^x(b/a)-1\right]. \quad (6)$$

Because the (γ,n) cross sections for C^{12}, O^{16}, and Cu^{63} are all strongly peaked, the transmission ratios, $\langle f_e{}^x\rangle_a/\langle f_e{}^x\rangle_b$, of Eq. (6) are approximately equal to $1+[\mu_e{}^x(k_b)-\mu_e{}^x(k_a)]T_x$; where $\mu_e{}^x(k_b)$ and $\mu_e{}^x(k_a)$ are the non-nuclear x-ray attenuation coefficients at the energies for which the cross sections σ_b and σ_a have their peak values, and T_x is the thickness of the absorber. For the present experiment σ_b is the (γ,n) cross section for Cu^{63}, and σ_a is the (γ,n) cross section for either C^{12} or O^{16}. The transmission ratios have values of about 1.1 for both the graphite and the water absorber used in this experiment. It is evident that the transmission ratios are not sensitive to possible uncertainties in the absolute values of the non-nuclear x-ray attenuation coefficients. In fact, the latter could be uncertain to 10% before introducing errors comparable to the statistical errors of the experiment.

The photon transmission ratios, $\langle f_e{}^x\rangle_a/\langle f_e{}^x\rangle_b$, of Eq. (6) were computed for the graphite and the water absorber using the non-nuclear x-ray attenuation coefficients tabulated by White,[9] the bremsstrahlung spectra tabulated by Penfold and Leiss,[10] and the (γ,n) cross sections for C^{12}, O^{16}, and Cu^{63} which are given in Fig. 2. The cross sections of Fig. 2 were obtained by averaging various published measurements.[4,5,11,§]

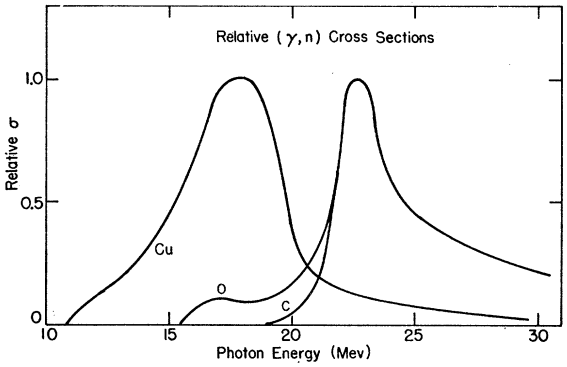

FIG. 2. The (γ,n) cross sections for C^{12}, O^{16}, and Cu^{63} which were used to compute the photon transmission ratios of Eq. (6).

[9] G. R. White, National Bureau of Standards Report No. 1001, 1952 (unpublished).

[10] A. S. Penfold and J. E. Leiss, University of Illinois Report, 1958 (unpublished).

[11] L. Katz and A. G. W. Cameron, Can. J. Phys. **29**, 518 (1951); A. I. Berman and K. L. Brown, Phys. Rev. **96**, 83 (1954); Barber, George, and Reagan, Phys. Rev. **98**, 73 (1955); B. C. Cook, Phys. Rev. **106**, 300 (1957); R. Sagane, Phys. Rev. **84**, 587*L* (1951); Horsley, Haslam, and Johns, Can. J. Phys. **30**, 157 (1952).

§ *Note added in proof.*—In constructing Fig. 2 it was assumed that the peak of the C total cross section occurs at the same

The calculated values of $\langle f_e{}^x\rangle_a/\langle f_e{}^x\rangle_b$, and the measured values of $W^x(b/a)$ were combined as prescribed by Eq. (6) to give the results shown in Table II. The estimated errors in Table II were obtained by compounding the errors from Table I with an estimated 0.6% error on the photon transmission ratios caused by uncertainties in the shapes of the (γ,n) cross sections.

In Table II, $\langle\sigma^O\rangle_O$ is the total absorption cross section for oxygen averaged over the $O^{16}(\gamma,n)O^{15}$ cross section, $\langle\sigma^O\rangle_C$ is the total absorption cross section for oxygen averaged over the $C^{12}(\gamma,n)C^{11}$ cross section, and so on. The averages are of the type prescribed by Eq. (4).

There is a significant difference between the first two entries in Table II. This means that the oxygen photonuclear absorption cross section overlaps the $O^{16}(\gamma,n)O^{15}$ cross section better than it does the $C^{12}(\gamma,n)C^{11}$ cross section. On the other hand, there is no significant difference between the last two entries in Table II, so the carbon photonuclear absorption cross section overlaps the $O^{16}(\gamma,n)O^{15}$, and the $C^{12}(\gamma,n)C^{11}$ cross sections equally well. Thus the experimental results indicate that narrow, isolated, resonances play an important role in the giant resonance region of the oxygen absorption cross section, while they do not do so in that region of the carbon absorption cross section. The copper data serves as a basis for comparing the behavior of carbon and oxygen.

The quantities $\langle\sigma^O\rangle_{Cu}$ and $\langle\sigma^C\rangle_{Cu}$ are expected to be much smaller than the other quantities of Table II since the giant resonance in copper occurs at a lower energy than in carbon and oxygen. If it is assumed that there are no narrow, isolated resonances in the $Cu^{63}(\gamma,n)Cu^{62}$ cross section then the quantities $\langle\sigma^O\rangle_{Cu}$ and $\langle\sigma^C\rangle_{Cu}$ can be calculated. This assumption is supported by the fact that no fine structure is observed in the (γ,n) yield curve for copper, and by the expectation that the level density in the giant resonance region of copper is very high. If the copper cross section is smooth, then $\langle\sigma^x\rangle_{Cu}$ goes over into $\langle\bar{\sigma}^x\rangle_{Cu}$, where the bar designates an average over any narrow resonances in σ^x. Computations were made using the $Cu^{63}(\gamma,n)Cu^{62}$ cross section of Fig. 2, and published data on the (γ,n) and (γ,p) cross sections of oxygen and carbon.[4,5,11] The results were: $\langle\sigma^O\rangle_{Cu}=2.5\pm0.6$ mb; $\langle\sigma^C\rangle_{Cu}=4\pm1$ mb. These were added to the numbers given in Table II, and the results are plotted as the solid points in Fig. 3.

TABLE II. Cross-section differences, in millibarns, obtained from Eq. (6). The cross-section values are averages as prescribed by Eq. (4). The values $\langle\sigma^O\rangle$ were obtained from the data with the water absorber, and the values $\langle\sigma^C\rangle$ from the data with the graphite absorber.

Cross section	Value (mb)	Estimated error (mb)
$\langle\sigma^O\rangle_O-\langle\sigma^O\rangle_{Cu}$	24.2	3.5
$\langle\sigma^O\rangle_C-\langle\sigma^O\rangle_{Cu}$	9.8	4
$\langle\sigma^O\rangle_O-\langle\sigma^C\rangle_{Cu}$	10.9	2.5
$\langle\sigma^C\rangle_C-\langle\sigma^C\rangle_{Cu}$	8.6	2

energy as that of the O cross section. This has now been verified experimentally (H. W. Koch, private communication, 1959).

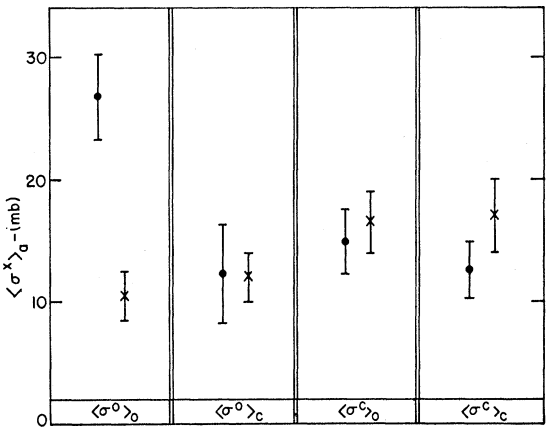

FIG. 3. The experimental results (solid dots) compared to predicted results (crosses). The predicted results were obtained by assuming completely "smooth" cross sections. $\langle\sigma^O\rangle_O$ is the total photon absorption cross section for oxygen averaged over the $O^{16}(\gamma,n)O^{15}$ cross section, $\langle\sigma^O\rangle_C$ is the total photon absorption cross section for oxygen averaged over the $C^{12}(\gamma,n)C^{11}$ cross section, and so on.

DISCUSSION

In order to test whether the experimental results indicate absorption due to narrow, isolated, levels the quantities $\langle\sigma^O\rangle_O$, $\langle\sigma^O\rangle_C$, $\langle\sigma^C\rangle_O$, and $\langle\sigma^C\rangle_C$ were calculated, assuming smooth cross sections. The "smoothed" total absorption cross sections needed for the calculations were obtained by adding together published data on the (γ,n) and (γ,p) cross sections of oxygen and carbon.[4,5,11] The results of these calculations are shown by the points marked by crosses in Fig. 3. The errors on these points result from uncertainties in the absolute values of the published cross sections.

The measured values are in good agreement with the calculated values for all cases except $\langle\sigma^O\rangle_O$. The large difference in this case indicates that narrow, isolated resonances occur in the oxygen photonuclear absorption cross section and contribute significantly to it. On the other hand, no such effect is in evidence for carbon.

As discussed in the introduction, the oxygen total cross section is known to be composed of narrow resonances up to at least 19 Mev. To test the sensitivity of this experiment to these known levels, the quantity $\langle\sigma^O\rangle_O$ was recalculated assuming a completely levelized structure[2] up to 19 Mev, and a smooth cross section thereafter. The recalculated value was only 0.3 mb higher than the value obtained assuming a completely smooth cross section. It was concluded that the present experimental results imply strong level absorption near or at the peak of the oxygen giant resonance.

In order to interpret the experimental value for $\langle\sigma^O\rangle_O$, the following assumptions were made:

(a) The oxygen photonuclear absorption cross section is composed entirely of narrow, isolated, resonances.

(b) The envelope of the resonance peaks has a giant resonance shape.

(c) The giant resonance is due to dipole transitions.

(d) The ratio of proton emission to neutron emission for the narrow resonances is, on the average, equal to the ratio $\sigma(\gamma,p)/\sigma(\gamma,n)$ which is obtained from gross cross-section studies. At present there is no conclusive experimental evidence in regard to this point.

Using assumptions (a) and (b), both of which are consistent with a fine-structure study of the $O^{16}(\gamma,n)O^{15}$ reaction,[2] the ratio of $\langle\sigma^O\rangle_O$ to the average peak height is calculated from an equation having the form of Eq. (4). For an individual Breit-Wigner resonance, the ratio is $\frac{1}{2}$; if the resonance peaks have a resonance envelope, the ratio becomes nearly $\frac{1}{4}$, as was determined by integration over the actual shape of the oxygen giant resonance. Employing this ratio, and the value of $\langle\sigma^O\rangle_O$ from the experiment, a value of 106 ± 14 mb is obtained for the average peak height of the narrow resonances near 22 Mev, in oxygen. If the cross section has an underlying continuum in addition to narrow resonances, the average peak height of the resonances near 22 Mev is larger than 106 ± 14 mb.

In accord with assumption (c), the maximum theoretical value for the peak heights of the narrow resonances is 16 barns ($6\pi\lambda^2$). Γ_γ/Γ, the ratio of the radiative width (to the ground state) to the total width of a resonance is equal to the peak height of the resonance divided by the maximum theoretical value for the peak height. Therefore, this experiment gives $(6.6\pm0.9)\times10^{-3}$ as a minimum value for Γ_γ/Γ for resonances near 22 Mev, in oxygen.

Assumptions (a) and (d) imply that the sum of the areas under the narrow resonances, multiplied by the number of resonances per Mev, must equal 10.5 ± 2 mb, the average value of the absorption cross section; i.e., the value obtained from gross cross-section studies. Therefore, using the value for $\langle\sigma^O\rangle_O$ from this experiment in the relation: $\langle\sigma^O\rangle_O=\sigma(\text{average})/n\pi\Gamma$, a value $n\Gamma=0.12\pm0.02$ is obtained, where n is the number of resonances per Mev, near 22 Mev. A fine-structure study of the (γ,n) reaction in oxygen[2] gives $n\approx4$ in this region, and this value for n applies here. The resulting value, $\Gamma=30\pm5$ kev, should be regarded as an upper limit, however, since some levels may have escaped detection in the fine-structure study.

It is surprising that a resonance effect should be found for oxygen and none for carbon. If carbon had shown a resonance effect then the following changes in Fig. 3 would have been observed:

(a) The measured value for $\langle\sigma^C\rangle_C$ would have been higher than the calculated value.

(b) The measured values of both $\langle\sigma^O\rangle_C$ and $\langle\sigma^C\rangle_O$ would have been *lower* than the calculated values, due to nonoverlap of the levels in carbon and oxygen. Thus our conclusion that carbon shows no detectable resonance effect is based upon three experimental numbers, not just one.

A plausible explanation for the observed behavior of carbon is available. Fine-structure studies of the $C^{12}(\gamma,n)C^{11}$ reaction indicate that only about 50% of the cross section can be accounted for by narrow resonances.[12] (In contrast, similar studies indicate that the entire (γ,n) cross section of oxygen is composed of narrow resonances.[2]) If 50% of the carbon absorption cross section is smooth, and if the resonances are about 150 kev wide, the results of this experiment are to be expected.

CONCLUSIONS

It is concluded that narrow, isolated, resonances occur in the oxygen photonuclear absorption cross section and contribute significantly to it, whereas such resonances do not contribute strongly to the carbon photonuclear cross section. Similar conclusions have also been reached by Siddiq and Haslam.[7]

Although no resonance effect was observed for carbon, the existence of narrow resonances is not out of the question. In fact, if narrow resonances constitute 50% or less of the carbon photonuclear absorption cross section, they might well produce an effect too small to have been observed by this experiment.

[12] L. Katz, Program of 1958 Photonuclear Conference, Washington, D. C. (unpublished).