Photodisintegration of Light Nuclei

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I. INTRODUCTION

IN the last two or three years several new experimental techniques have been applied to the study of the nuclear photoeffect. As a result we are now beginning to see the main features of the electric-dipole-absorption cross section for light nuclei. In general, this cross section is characterized by a broad maximum, designated as the giant resonance, located at an energy of 12–20 MeV depending on the nucleus under consideration.

For heavy elements, i.e., those above tin in the periodic table, the absorption of a photon in the giant resonance region almost always results in neutron emission. In the initial absorption process the photon energy may be given to a single nucleon, but it is soon shared with the others, thus decreasing the energy carried by the individual nucleons and making the Coulomb barrier very effective in suppressing proton emission. It has therefore been possible to study the giant resonances for the heavy elements by simply counting the total number of neutrons emitted as a function of photon energy. These experiments are difficult because they are almost always performed with bremsstrahlung spectra, but they have led to a few conclusions that may be summarized as follows: (1) The absorption cross section integrated over the giant resonance is at least as large as that required by the electric-dipole sum rule,

$$\int \sigma(E)dE \geqslant \frac{2\pi^2 e^2 \hbar}{Mc}\frac{NZ}{A} = 0.06\frac{NZ}{A}\,\text{MeV-barns}\,.$$

In fact, this integral is experimentally ~20–30% larger indicating the presence of terms in the nuclear Hamiltonian that do not commute with the dipole operator, exchange or velocity-dependent potentials. (2) The giant resonance width is 3–8 MeV depending on the nucleus. (3) The resonance energy varies approximately as $A^{-1/3}$ and, in fact, the expression $E_0 = 82A^{-1/3}$ MeV, predicted by the hydrodynamic model, is in very good accord with experiment. (4) These experiments have also established that, except in very special circumstances,[1] the giant resonances of the heavy elements contain no structure. The levels of which these resonances are composed are so numerous and so broad as to completely coalesce to form a smooth continuum.

The situation with regard to the light elements is quite different. In the energy region below 25 MeV, usually associated with the giant resonance, the (γ,n) and (γ,p) cross sections are of comparable magnitude. This results from the fact that the nuclear extent is so limited that the nucleon usually emerges in a direct interaction. Additionally, the Coulomb barriers are low enough so as to exert no preference for neutron over proton emission. In order to obtain the total absorption cross section as the sum of the (γ,n) and (γ,p) cross sections, it is therefore necessary to measure them both. When this is done, it is found that the total absorption cross section integrated to 25 MeV for these elements accounts for only 50–75% of the classical dipole sum.

Since the electric-dipole sum rule is a conservation law that sets a lower limit on the integrated absorption cross section, it is necessary to look elsewhere for the remainder of the dipole strength. An important contribution can be found in the quasi-deuteron cross section which is important at high energies and results from the high momentum components in the nuclear ground state which are associated with strong two-body forces. The emergence of nucleons of high momenta establishes the existence of these components because even very high energy photons carry very low momenta. Since the neutron–neutron and proton–proton pairs have no dipole moment, the electric-dipole absorption takes place into neutron–proton pairs and is observed as the emission of neutrons and protons having the energy and angular distributions characteristic of the deuteron photodisintegration. These are, of course, smeared out by the momentum distribution characteristic of the nucleons inside the nucleus. Though the experiments relating to this effect are very meager, the results indicate that the integrated absorption cross section associated with the quasi-deuteron effect is of the order of the dipole sum. It is then possible to account for the dipole sum for the light elements when the high-energy phenomena are taken into account.

[1] E. G. Fuller and E. Hayward, Nucl. Phys. **33**, 431 (1962).

Though the giant resonance width for these nuclei is about 3–8 MeV, as for the heavy ones, the resonance energies seem to depend much less strongly on A. In fact, it is almost safe to say that the giant resonance for all these elements (carbon through calcium) peaks near 20 MeV.

These statements concerning the giant resonance width and resonance energy are a bit empty as far as the light elements are concerned, because it is becoming extremely apparent that their absorption cross sections consist of a superposition of a number of resonances. This question, concerning structure in the giant resonance, has a long history. Early experiments, in which nuclear emulsions were most often used as detectors, did, indeed, suggest the presence of structure. These results were not taken seriously until the advent of the ground-state, proton-capture experiments performed at Princeton,[2] Oxford,[3,4] and Chalk River.[5,6] These results have led to a re-examination and appreciation of the older data and have also inspired a number of other high-resolution experiments. We are now entering a new phase with regard to the dipole states in light nuclei. The question is no longer, "is there structure?" but "where is it?"

II. EXPERIMENTAL TECHNIQUES

Two classes of high-resolution experiments are now being used to study the photoeffect in light nuclei, those that measure the total absorption cross section either directly or indirectly and those that determine the partial cross sections out of which the total is composed. Each kind of experiment has its own special problems. In the first class we have the total photon-absorption experiments and the inelastic electron-scattering experiments, both excellent approaches that have yet to be fully exploited. In the total absorption experiment one measures the spectrum of photons transmitted by a long absorber of the material under study when a continuous bremsstrahlung spectrum is incident on it. These data are difficult to interpret because it is necessary to make the proper correction for removal of photons from the beam by nonnuclear processes, such as pair production and Compton scattering. Burgov *et al.*[7] have now succeeded in making a very good quantitative measurement of the total absorption cross section for O^{16} (see Fig. 7). They have used a magnetic, pair spectrometer with an energy resolution of 120 keV.

Inelastic electron scattering is fast being recognized as a very powerful tool for studying all kinds of nuclear energy levels,[8] including the states reached in electric-dipole transitions[9,10] from the ground state. In these experiments the spectra of scattered electrons are measured at several different angles and for several different incident electron energies. From these data one must separate out at any given scattered electron energy the contribution from states of lower excitation energy. These experiments are capable of yielding not only the locations of states and their ground-state transition probabilities but also their spins and parities. They have not yet been refined to the point when a quantitative total absorption cross section has been obtained, though in principle this is possible.

The total cross section in the giant resonance region is usually just the sum of the (γ,n) and (γ,p) cross sections. These partial cross sections have most often been measured with bremsstrahlung with all the attendant problems. They are obtained by measuring the total number of particles emitted or by measuring the radioactivity induced as the bremsstrahlung energy is changed. The resulting activation curve must then be differentiated in order to obtain the cross section; as a result, the latter is subject to very large statistical uncertainties. The energy resolution of such a system is essentially determined by the stability of the accelerator and the counting equipment.

Experiments are now in progress in two laboratories in which positron annihilation radiation is used as a source of monochromatic photons.[11,12] In these experiments monoenergetic positrons in the 10–25 MeV range are allowed to annihilate in flight and the forward radiation is then used as an x-ray

[2] S. G. Cohen, P. S. Fisher, and E. K. Warburton, Phys. Rev. **121**, 858 (1961).
[3] N. W. Tanner, G. C. Thomas, and W. E. Meyerhof, Nuovo Cimento **14**, 257 (1959).
[4] N. W. Tanner, G. C. Thomas, and E. D. Earle, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961*, edited by J. B. Birks (Academic Press Inc., New York, 1961).
[5] H. E. Gove, A. E. Litherland, and R. Batchelor, Nuclear Phys. **26**, 480 (1961).
[6] C. Broude and H. E. Gove, *International Conference on Nuclear Structure Proceedings*, edited by D. A. Bromley and E. W. Vogt (University of Toronto Press, Toronto, 1960), p. 754.
[7] N. A. Burgov, G. V. Danilyan, B. S. Dolbilkin, L. E. Lazareva, and F. A. Nikolaev, J. Exptl. Theoret. Phys. **43**, 70 (1962) [Engl. Transl.: Soviet Phys.—JETP **16**, 50 (1963)].
[8] H. Crannell, R. Helm, H. Kendall, J. Oeser, and M. Yearian, Phys. Rev. **123**, 923 (1961).
[9] D. B. Isabelle and G. R. Bishop, J. Phys. Radium **22**, 548 (1961).
[10] W. C. Barber, F. Berthold, G. Fricke, and F. E. Gudden, Phys. Rev. **120**, 2081 (1960).
[11] C. Schuhl and C. Tzara, Nucl. Instr. and Methods **10**, 217 (1961).
[12] C. P. Jupiter, N. E. Hansen, R. E. Shafer, and S. C. Fultz, Phys. Rev. **121**, 866 (1961).

source. The presently available intensities are such as to provide an energy resolution of about half an MeV. This approach is clearly preferable to the use of bremsstrahlung beams and very interesting results are already beginning to appear.

For light nuclei a great advantage can be derived by measuring the energy spectra of the outgoing neutrons or protons. Recent advances in spectroscopy have been made by the application of magnetic spectrometers[13] and nanosecond time-of-flight techniques[14] to the analysis of proton and neutron groups. In favorable cases the level densities in the residual nuclei are low enough so that these groups can be associated with transitions between specific nuclear states. When this is so, the cross section may be obtained by making bremsstrahlung irradiations at a relatively small number of energies. Unfortunately, this type of experiment has only been performed on rare occasions[15–17]; more often a spectrum of photonucleons is measured at a single bremsstrahlung energy. Then the only thing that can be done is to evaluate the cross section on the assumption that all the nucleons leave the residual nucleus in its ground state. This assumption sometimes turns out to be remarkably good (see Fig. 1) and at other times remarkably bad (see Fig. 3).

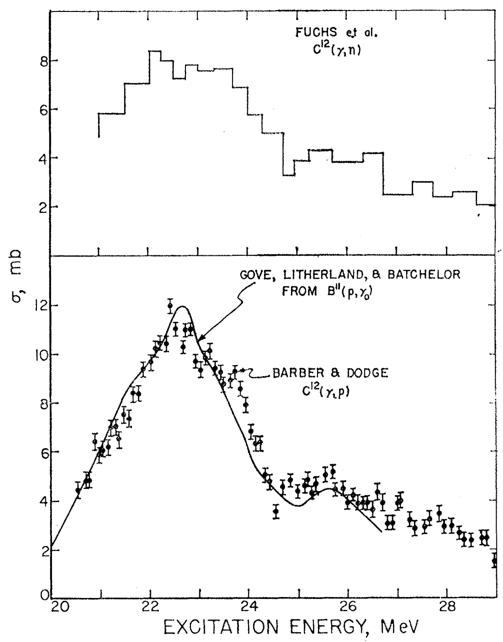

FIG. 1. A comparison of the (γ,n) and (γ,p) cross sections for C^{12}. The (γ,n) cross section[18] was obtained from the spectrum of photoneutrons produced by 31-MeV bremsstrahlung. The cross section was obtained by assuming that only ground-state transitions take place. The lower plot is a superposition of the ground-state (γ,p) cross section[5] and the total (γ,p) cross section.[13]

The validity of this assumption can sometimes be checked by comparing the (γ,p) cross section obtained in this way with the ground-state, proton capture cross section measured in a separate experiment. Both cross sections must be measured in absolute units. The ground-state, proton capture experiments represent an ingenious way of looking at the giant resonance with monoenergetic photons. A gamma-ray spectrometer, usually sodium iodide, is used to measure the intensity of the ground-state gamma ray as the incident proton energy is varied. The ground-state (γ,p) cross section may then be obtained by the principle of detailed balance. Protons obtained from both cyclotron and tandem accelerators have been used for this type of determination. The tandem is to be preferred because it has sufficient energy resolution to show up the existing nuclear structure, but the need for absolute cross sections is still so great that they are worthwhile even with less good resolution.

III. EXPERIMENTAL RESULTS

Figures 1–8 show some examples of recent experimental data for light elements in the energy range when they are apt to display structure, i.e., below 30 MeV. These have been selected from the rather limited supply of reliable data, and the results of different experiments are compared in order to point out their consistencies and inconsistencies. A slight bias has been exercised in favor of data that include absolute cross section magnitudes.

Figure 1 is concerned with C^{12}. The lower half of the figure shows a comparison of the $C^{12}(\gamma,p_0)$ cross section [obtained by detailed balance from the $B^{11}(p,\gamma_0)$ cross section of Gove, Litherland, and Batchelor[5]] with the (γ,p) data of Dodge and Barber.[13] The latter cross section has been derived from the proton spectrum observed at 76° from the reaction $C^{12}(e,e'p)$ on the assumption that the B^{11} nucleus is always left in its ground state. The energy of the incident electrons was 30 MeV. It may be seen that the absolute magnitudes and shapes of the two cross sections are in very good agreement. This indicates that for all practical purposes the outgoing proton does indeed leave the B^{11} nucleus in its ground state. The undulations in the data of Dodge and

[13] W. R. Dodge and W. C. Barber, Phys. Rev. **127**, 1746 (1962).
[14] F. W. K. Firk and K. H. Lokan, Phys. Rev. Letters **8**, 321 (1962).
[15] S. Penner and J. E. Leiss, Phys. Rev. **114**, 1101 (1959).
[16] S. A. E. Johansson and B. Forkman, Arkiv Fysik **12**, 359 (1957).
[17] C. Milone, S. Milone-Tamburino, R. Rinzivillo, and A. Rubbino, Nuovo Cimento **7**, 729 (1958).

Barber suggest that the giant resonance of C^{12} consists of a series of resonances with a spacing of the order of half an MeV.

The histogram in the upper half of the figure is the (γ,n) cross section of Fuchs *et al.*[18] They have measured the pulse-height distribution produced by the proton recoils generated in a stilbene crystal when a graphite target was irradiated by 31-MeV bremsstrahlung. Their analysis also includes the assumption that all the neutrons are emitted in ground-state transitions. Though this cross section is clearly measured with relatively poor energy resolution, it still displays the main qualitative features of the (γ,p) cross section. The apparent dip near 22.6 MeV, where the (γ,p) cross section has its maximum, was suggested by earlier measurements of Day[19] and by Emma, Milone, and Rubbino.[20] More recent experiments performed both by using positron annihilation radiation as an x-ray source[21] and by measuring the neutron spectra[22] by time-of-flight have confirmed this very interesting result. Figure 2 shows the relative (γ,n) cross section derived from the photoneutron spectra measured at two incident bremsstrahlung energies on the assumption that only ground-state transitions are involved. The good agreement between the two cross-section shapes shows this assumption to be valid. The three vertical lines at the bottom of the figure represent the three strongest "breaks" reported by Thorsen and Katz.[23] These may be seen to correspond to the three main maxima in the (γ,n) cross section.

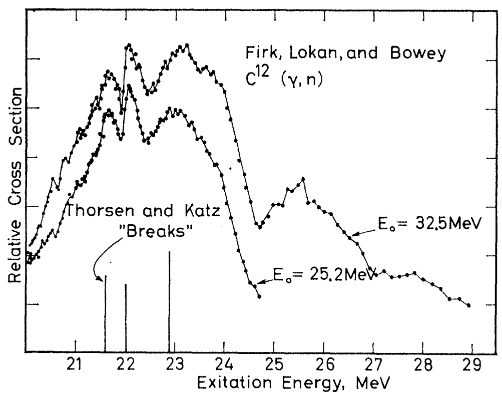

FIG. 2. The relative C^{12} (γ,n) cross section obtained with good energy resolution[22] using bremsstrahlung spectra extending to two different energies. The vertical lines represent the locations and relative intensities of the three strongest breaks reported by Thorsen and Katz.[23]

The most interesting conclusion to be drawn from the data on C^{12} is that not only is there structure in the giant resonance region but that the (γ,p) and (γ,n) cross sections have a different energy dependence. This result implies that the excited states of the C^{12} system have isotopic spin impurities that vary from one state to the next.

Figure 3 shows some data for Si^{28} and is presented in contrast to the C^{12} situation. Here the level density in the residual nucleus is much higher so that photoprotons are frequently emitted in excited-state transitions. As a result, the true cross section is distorted by assuming that exclusively ground-state transitions occur. The smooth curve of Fig. 3 is drawn through the Si^{28} (γ,p) data of Gardener and Gugelot.[24] These were derived from the measured Al^{27} (p,γ_0) cross section by means of the detailed balance relation and represent the true ground-state cross section. The histogram is the result of Shoda *et al.*[25] who have used nuclear emulsions to measure the spectrum of protons emitted when Si^{28} is irradiated by 24-MeV bremsstrahlung. In order to obtain a cross section they assumed that the outgoing proton always leaves the Al^{27} nucleus in its ground state Above 17.5 MeV both cross sections display two

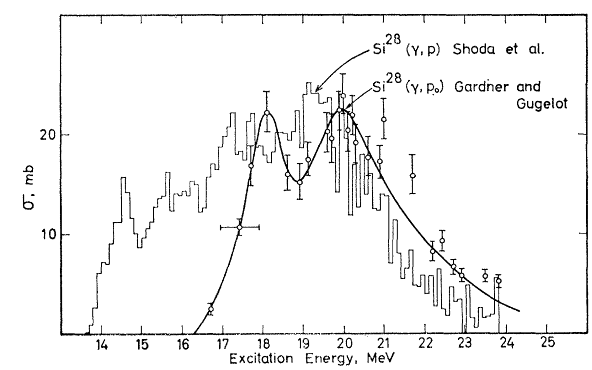

FIG. 3. The ground-state (γ,p) cross section[24] for Si^{28} compared with the (γ,p) cross section obtained in an analysis[25] where it was assumed that only ground-state transitions occur. The large area under the histogram for energies below 17.5 MeV really results from absorption at higher energies resulting in transitions in which the residual nucleus is left in excited states.

[18] H. Fuchs, D. Haag, K. H. Lindenberger, and U. Meyer-Berkhout, Z. Naturforsch. **17a**, 439 (1962).
[19] R. B. Day (private communication).
[20] V. Emma, C. Milone, and A. Rubbino, Phys. Rev. **118**, 1297 (1960).
[21] J. Miller, G. Schuhl, G. Tamas, and C. Tzara, Phys. Letters **2**, 76 (1962).
[22] F. W. K. Firk, K. H. Lokan, and E. M. Bowey, *International Symposium on Direct Interactions and Nuclear Reaction Mechanisms Proceedings, Padua, 1962* (to be published).
[23] M. I. Thorsen and L. Katz, Proc. Phys. Soc. (London) **77**, 166 (1961).
[24] C. C. Gardener and P. C. Gugelot, *Proceedings of the Rutherford Jubilee International Conference, Manchester, 1961*, edited by J. B. Birks (Academic Press Inc., New York, 1961).
[25] K. Shoda, K. Kobayashi, S. Siina, K. Abe, and M. Kimura, J. Phys. Soc. Japan **16**, 103 (1961).

peaks and would coincide perfectly if one were displaced relative to the other by about half an MeV. The area of overlap between the two shows how much of the proton spectrum results from true ground-state transitions. The large magnitude for the cross section placed below 17.5 MeV in reference 25 really results from photon absorption at higher energies with the residual nucleus left in excited states. When the shape of the bremsstrahlung spectrum is taken into account, this contribution would probably make the total (γ,p) cross section integrated to 24 MeV two or three times the ground-state cross section.

The excitation curve for the process Al^{27} (p,γ_0) is also given in the paper of Gove, Litherland, and Batchelor.[5] The absolute cross-section magnitude was not determined but the relative cross section indicates that the one measured by Gardener and Gugelot with less good energy resolution is really the envelope of a curve containing much more structure.

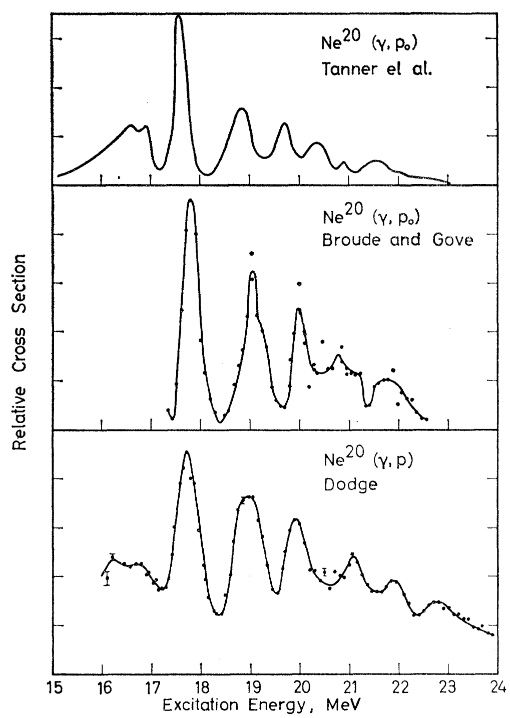

FIG. 4. A comparison of three pieces of data[6,13,26] for Ne^{20}.

Figure 4 shows the existing data[6,13,26] relevant to Ne^{20}; it displays a striking array of structure. The two upper curves show the relative (γ,p_0) cross sections derived from the (p,γ_0) data obtained at Oxford[26] and at Chalk River.[6] The lower curve is that obtained from a proton spectrum[13] from the $(e,e'p)$ process on the assumption that only ground-state transitions take place; other data from the same experiment show that this is a bad assumption.

[26] N. Tanner (private communication).

Figure 5 shows some results for Ca^{40}. The upper plot is the relative (γ,p_0) cross section obtained by detailed balance from the (p,γ_0) data of Tanner, Thomas, and Earle.[4] The lower is the (γ,n) cross

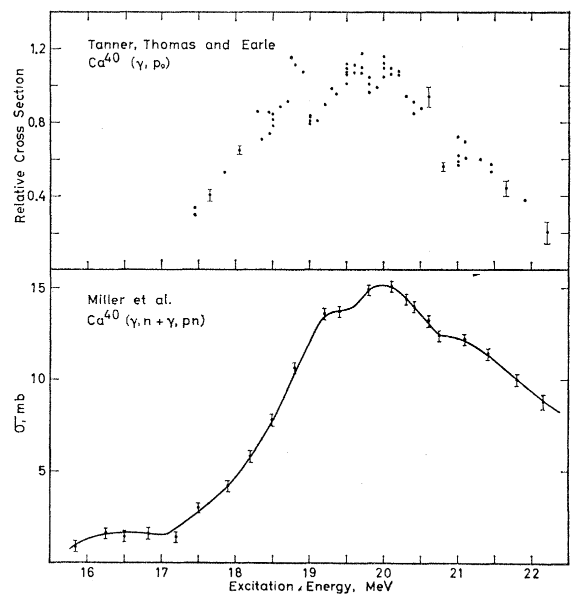

FIG. 5. A comparison of the ground-state (γ,p) cross section[4] and the $(\gamma,n + \gamma,pn)$ cross sections[21] for Ca^{40}.

section obtained[21] using positron annihilation radiation as a source of photons; it is measured with much less good energy resolution. The photoneutron spectra, measured at Harwell[27] with very good energy resolution, are complementary and can be used in the interpretation of the latter. They show not only that the main peak in the (γ,n) cross section is really the envelope of the two narrower ones seen in the proton capture experiment but also that the peak and valley near 17.75 and 19 MeV, respectively, are simply not resolved in the low-resolution experiment. All three pieces of data show the shoulder near 21 MeV.

The O^{16} nucleus has inspired the most interest in the last two or three years, both experimentally and theoretically. Figure 6 shows a comparison of two of its partial cross sections, the ground-state (γ,p) cross section and the (γ,n) cross section. The shape of the ground-state (γ,p) cross section was obtained[28] by

[27] F. W. K. Firk and E. R. Rae, *International Symposium on Direct Interactions and Nuclear Reaction Mechanisms Proceedings, Padua, 1962* (to be published).

[28] E. G. Fuller and E. Hayward, *Nuclear Reactions II*, edited by P. M. Endt and P. B. Smith (North-Holland Publishing Company, Amsterdam, 1962).

combining the nuclear emulsion data of Johansson and Forkman[16] and of Milone *et al.*,[17] the absolute normalization being obtained from the work of Brix and Maschke[29] and of Cohen *et al.*[30] The ground-state cross section derived from the proton capture cross section of Tanner, Thomas, and Earle[4] agrees with the (γ,p) work in absolute magnitude, and since it is measured with much better energy resolution, it shows more structure. The lower curve is the relative (γ,n) cross section[22] obtained from the photoneutron time-of-flight spectrum on the assumption that only ground-state transitions occur. These data reflect the same structure evident in the proton capture results over most of the energy range.

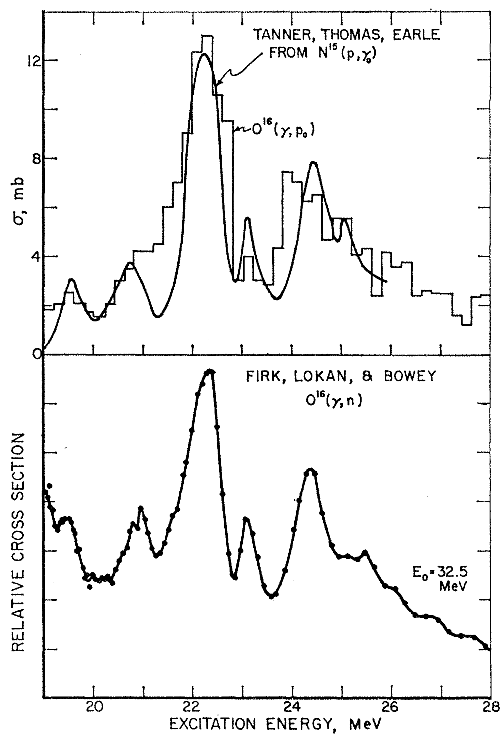

FIG. 6. The upper plot shows a comparison of the ground-state (γ,p) cross section for O^{16} obtained directly[28] with one derived from the ground-state proton-capture experiment.[4] The lower one is the relative $O^{16}(\gamma,n)$ cross section obtained from the time-of-flight experiment[22] on the assumption that only ground-state transitions are involved.

IV. COMPARISON WITH THEORIES

Figure 7 shows a comparison of the total absorption cross section measured by Burgov *et al.*[7] with the results of the calculation of Elliott and Flowers.[31] This experiment has certainly yielded the best single measurement of a total absorption cross section. Not only the cross-section magnitude but also the structure observed is consistent with the data of other experiments in which only partial cross sections were obtained.

The schematic representation of the Elliott and Flowers result resembles the experimental data quite clearly. Here arbitrary widths of 1 MeV have been assigned to the two strongest resonances. These results were obtained in the least approximate, shell-model calculation of the dipole states that included configuration interactions. It is evident that this calculation succeeds where previous[32,33] shell-model calculations failed, in obtaining the transition energies in their experimentally observed locations. It is quite apparent, on the other hand, that the measured distribution contains much more structure.

These general features also characterize the results of the particle–hole calculations on C^{12} and C^{13}. Vinh-Mau and Brown[34] predict that the electric-dipole-absorption cross section for C^{12} is essentially contained in two resonances; the more important located near 22 MeV contains 69% of the integrated absorption cross section, while the second at 34 MeV

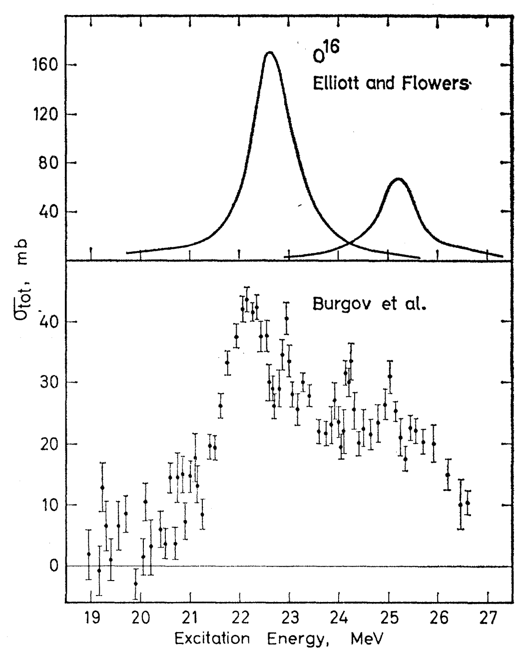

FIG. 7. A comparison of the results of the calculation of Elliott and Flowers[31] with the measured total absorption cross section[7] for O^{16}.

[29] P. Brix and E. K. Mãschke, Z. Physik **155**, 109 (1959).
[30] L. Cohen, A. K. Mann, B. J. Patton, K. Reibel, W. E. Stephens, and E. J. Winhold, Phys. Rev. **104**, 108 (1956).
[31] J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. (London), Ser. A **242**, 57 (1957).
[32] D. H. Wilkinson, Physica **22**, 1039 (1956).
[33] J. L. Burkhardt, Phys. Rev. **91**, 420 (1953).
[34] N. Vinh-Mau and G. E. Brown, Nucl. Phys. **29**, 89 (1962).

contains 25%. In fact, this prediction has probably led to the observation[35] of the 34-MeV state in the B^{11} (p,γ_0) experiment. On the other hand, this calculation provides no mechanism to explain the structure observed in the cross section of Fig. 1.

Easlea[36] has made a similar calculation for C^{13} in which he takes into account the effect of the exterior nucleon. These results are of particular interest because the strengths and transition energies for the $T = 1/2$ and $T = 3/2$ states populated are given separately. These may be compared with the experimental results on the (γ,n) cross section[37] in C^{13} in which both kinds of states are formed, as well as with the C^{12} $(p,\gamma_0)N^{13}$ data[38] in which only $T = 1/2$ states are produced. The results of these two experiments are compared with the calculation in Fig. 8. It can

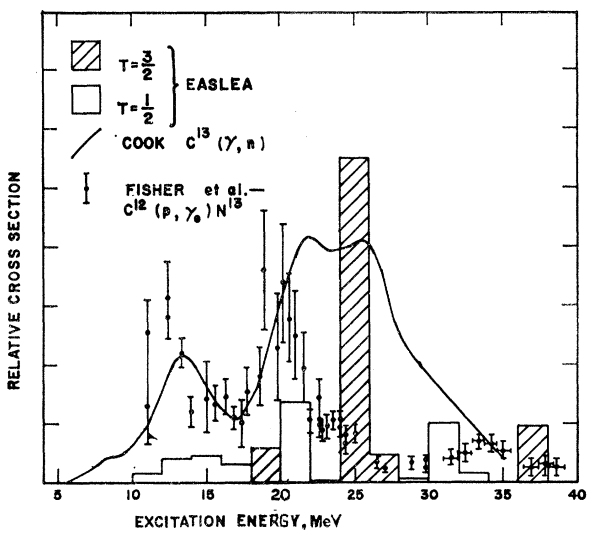

FIG. 8. A comparison of the results of the calculation of Easlea[36] with the experimental results of Cook[37] and of Fisher.[38] Both $T = 1/2$ and $T = 3/2$ states were populated in the former; while only $T = 1/2$ states were populated in the latter.

be seen that the oscillator strength near 12 MeV, usually associated with transitions of the exterior nucleon, is observed in both experiments. The large contribution at 25 MeV, resulting from the transitions to the $T = 3/2$ states of C^{13} is only seen in the appropriate experiment.

In calculations of this type the absolute cross section magnitudes are necessarily in disagreement with experiment, the theoretical integrated cross section being more than twice as large as the experimental one. This discrepancy is easily understood since the calculation assumes that all of the dipole strength is concentrated, for example in O^{16}, in the five possible shell-model transitions. Elliott and Flowers' integrated absorption cross section amounts to 1.61 times the classical dipole sum. This results from the use of the Rosenfeld force which contains a sizeable exchange contribution. The corresponding experimental integral is only

$$0.63\left[\frac{2\pi^2 e^2 \hbar}{Mc}\,\frac{NZ}{A}\right].$$

In nature the high-energy quasideuteron effect robs the single-particle transitions of a large fraction of their strength. In order to explain the observed phenomena it is therefore necessary at the very least to develop a theory to encompass both of these effects.

In this connection it is worthwhile to ask how much of the dipole sum can be accounted for on the basis of examples such as we have seen here and how much we must attribute to the quasideuteron process. Table I contains a list of integrated cross sections[39,40] in units of the classical dipole sum,

$$\frac{2\pi^2 e^2 \hbar}{Mc}\,\frac{NZ}{A}.$$

The exponents are energies in MeV and denote the upper limits of the integration. Some older measurements[41,42] have been included in order to fill up the empty spaces. It can be seen that for the nuclei considered here the absorption cross section integrated over the giant resonance never exceeds 80% of the dipole sum.

The partial cross sections integrated to 170 MeV are included for oxygen and neon. These data were obtained in a cloud chamber experiment,[43] and the results are intended to be only rough estimates. They show that the total absorption cross section integrated to such a high energy is approximately twice the dipole sum. Part of this absorption may, however, result from higher multipole transitions. The quasideuteron effect designated here as (γ,pn) is an electric dipole phenomenon which is observed and identified experimentally as the emission of a neutron–

[35] N. W. Reay, N. M. Hintz, and L. L. Lee, Jr., Nucl. Phys. (to be published).
[36] B. R. Easlea, Phys. Letters 1, 163 (1962).
[37] B. C. Cook, Phys. Rev. 106, 300 (1957).
[38] P. S. Fisher, D. F. Measday, F. A. Nikolaev, A. Kalmykov, and A. B. Clegg, Nucl. Phys. (to be published).

[39] W. C. Barber, W. D. George, and D. D. Reagan, Phys. Rev. 98, 73 (1955).
[40] H. Breuer and W. Pohlit, Nucl. Phys. 30, 417 (1962).
[41] S. A. E. Johansson, Phys. Rev. 97, 1186 (1955).
[42] R. G. Summers-Gill, R. N. H. Haslam, and L. Katz, Can. J. Phys. 31, 70 (1953).
[43] A. Gorbunov, V. A. Dubrovina, V. A. Osipora, V. S. Silaeva, and P. A. Çerenkov, J. Exptl. Theoret. Phys. USSR 42, 747 (1962) [English transl.: Soviet Phys.—JETP 15, 520 (1962)].

TABLE I. Integrated cross sections in units of $(2\pi^2 e^2 \hbar/Mc)/(NZ/A)$. The exponents represent the upper limits of the integration in MeV. The symbol (γ,S) stands for those events in which more than two particles are emitted.

	(γ,n)	(γ,p_0)	(γ,p)	Total	(γ,pn)	(γ,S)	Σ	Reference
C^{12}	0.18^{25}	$0.24^{25.5}$	0.28^{29}				0.47^{25}	39 5 16
O^{16}	$0.22^{32.5}$	0.18^{30}	0.46^{30}	0.63^{30}			0.68^{30}	40 4 28 7
	0.44^{170}		0.54^{170}		0.25^{170}	0.60^{170}	1.83^{170}	43
Ne^{20}	0.38^{170}		0.55^{170}		0.22^{170}	0.85^{170}	2.00^{170}	43
Si^{28}	0.15^{24}	0.24^{24}	0.64^{28}				0.79^{25}	42 24 41
Ca^{40}	0.09^{22}		0.73^{28}				0.82^{25}	21 41

proton pair with the angular correlation characteristic of the deuteron photodisintegration. Only a small fraction of these pairs of particles emerge from the nucleus undeflected. For the sake of discussion, let us assume that when one of the outgoing nucleons scatters inside the nucleus, it knocks out at least one other particle. These events are labeled (γ,S) in the table. Using these numbers we obtain a value of 4-5 for the factor by which the quasideuteron absorption cross section is attenuated in these nuclei. This number is certainly consistent with the factor obtained in the only other measurement of this effect.[44] These speculations lead to the conclusion that in light elements the quasideuteron cross section is responsible for slightly more than the dipole sum and the giant resonance absorption for slightly less.

[44] P. C. Stein, A. C. Odian, A. Wattenberg, and R. Weinstein, Phys. Rev. 119, 348 (1960).

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