Photoproton decay of the $E1$ giant resonance in ^{19}F

E. Kerkhove,* R. Van de Vyver, H. Ferdinande, D. Ryckbosch, P. Van Otten, P. Berkvens, and E. Van Camp
Laboratorium voor Kernfysica, Rijksuniversiteit Gent, B-9000 Ghent, Belgium
(Received 1 May 1985)

Photoproton spectra from the $^{19}F(\gamma,p)$ reaction were measured at various bremsstrahlung end point energies in the giant dipole resonance region. Absolute cross sections for eight partial photoproton channels were determined with the use of an artificially constructed quasi-monochromatic photon spectrum. Their integrated cross sections were compared with spectroscopic factors for proton pickup reactions leading to corresponding residual states. The (γ,p_{tot}) cross section was derived from proton yield measurements. These data lead to an estimated semidirect contribution to the photoproton reaction of at least 60%, and to an approximate determination of the configurational splitting.

I. INTRODUCTION

The study of the giant dipole resonance (GDR) is, even after 35 years, for many light nuclei still in the stage of describing global systematics. This has to do with both experimental and theoretical shortcomings: calculations are for odd-mass nuclei still too complex, and the measured data often do not reveal enough details. There has been very little direct experimental evidence, especially concerning the microscopic configurations of the $E1$ giant resonance. Such evidence could come from a careful study of the decay of the GDR.

For light nuclei, the formation and decay of the GDR can be described best in the 1p-1h model. In this model, simple 1p-1h states are created by the photon absorption.[1] These dipole states form the collective GDR through the residual interaction. These so-called "doorway states" will either decay directly by emission of a nucleon, leaving the residual nucleus in a hole state with respect to the ground state of the target nucleus, or the decay will be of a statistical or prestatistical nature.[2] A comparison between spectroscopic factors for direct single-nucleon pickup reactions and cross sections for photonuclear reactions leading to the same residual states, will help to gain more insight in the reaction mechanism.

To make a complete experimental survey of the total dipole strength, one should study the nuclear-absorption cross section. These data, however, as well as the (γ,n_{tot}) or (γ,p_{tot}) cross sections, include too large a number of contributing dipole states in order to resolve them with the energy resolution available. Furthermore, the detailed microscopic structure of the GDR is in some cases masked by the effects of isospin and deformation splitting. One can, instead, study partial cross sections; there, only a few dipole states show up, which can be more easily identified. Unfortunately, one usually has to be satisfied with one partial channel only [(γ,p_0) or (γ,n_0)], or two at the most. These data can of course reveal only part of the dipole states (the ones decaying into the ground state). It is therefore of importance to study several partial (γ,p_i) or (γ,n_i) cross sections with sufficient energy resolution.

One of the most obvious objectives of such measurements is the quantitative study of the configurational splitting (CS) of the GDR in $(2s\text{-}1d)$ shell nuclei. The concept of CS in $(2s\text{-}1d)$ shell nuclei, developed by Neudatchin and Shevchenko,[3] implies that the dipole strength will be spread over two groups of 1p-1h states with different configurations, which are well separated in energy and do not mix appreciably with each other. The low energy group would consist of dipole states with a $(2s\text{-}1d)^{-1}(2p\text{-}1f)$ configuration (so-called "valence excitations"); the higher energy group would have a $(1p)^{-1}(2s\text{-}1d)$ configuration ("core excitations"). The appearance of CS in the GDR of light nuclei is evidently due to the fact that the dipole states in these nuclei are not as collective as in heavy nuclei, and the residual interaction is too weak to group them into one resonance. This is suggested by the large energy spread of the giant resonances in light nuclei, and by the increasing deviation of the GDR energy from the expected value $E_x = 78A^{-1/3}$ MeV. Calculations performed for ^{16}O (Ref. 4) indeed indicate that the residual interaction, although still shifting the dipole state energies, does not mix up the dipole state configurations.

Although a systematic study of (γ,n) cross sections of $(2s\text{-}1d)$ shell nuclei has revealed the influence of shell effects on the main structures of the GDR,[5] there is little experimental evidence that such a configurational splitting does indeed appear. Indications have been found for several nuclei,[6–10] but the conclusions were based on the assumption that the 1h configuration of the residual state is the same as the hole in the 1p-1h dipole state. As there are no theoretical grounds for such an assumption, and moreover, as there is experimental evidence of the contrary,[11] these indications should be interpreted with some caution. On the other hand, the study of the $^{19}F(\gamma,p_0)$ and $^{19}F(\gamma,p_1)$ cross sections allowed us to unambiguously establish in a qualitative way the existence of a configurational splitting.[12] We have now measured the cross sections for various $^{19}F(\gamma,p_i)$ channels, as well as the (γ,p_{tot}) cross section. These results will lead to more information on the reaction mechanism, and to a quantitative estimate of the configurational splitting.

The total absorption cross section has been measured independently by two groups,[13,14] but their results are in complete disagreement with each other. We have constructed an approximate total absorption cross section by adding our (γ,p_{tot}) result to the (γ,n_{tot}) cross section of Veyssière *et al.*[5]

II. EXPERIMENTAL DETAILS AND DATA ANALYSIS

A thin Teflon F.E.P. foil (2.66 mg/cm^2; 76% ^{19}F) was irradiated with a beam of bremsstrahlung photons produced at the 70 MeV linear electron accelerator of the Ghent State University. Photoprotons were detected simultaneously at seven different angles θ between 37° and 143°, by means of uncooled Si(Li) detectors. The experimental setup is described in detail in a previous paper.[15] Photoproton spectra were measured at bremsstrahlung end point energies varying between 15.5 and 26.0 MeV in 0.75 MeV intervals; proton yields were also measured at 26.75 and 27.5 MeV electron energy. Details about the primary data analysis can be found elsewhere.[16]

Since both the energy differences between the ground state and the first excited state in the residual nucleus ^{18}O (1.98 MeV), and between the first and second excited state (1.58 MeV) are larger than the end point energy step, we could directly derive the differential ground state and first excited state cross sections.[12] Using our quasi-monochromatic photon spectrum technique,[2] we obtained proton spectra corresponding to a specific excitation energy in the target nucleus. With the above-mentioned end points, these excitation energies were limited to the interval (16.2–25.1 MeV). In Fig. 1 an example of an integrated-over-angles proton spectrum is given, together with the corresponding quasi-monochromatic photon spectrum. We were able to separate eight (γ,p_i) channels, leading to states or groups of states below 8 MeV residual energy. For each of these reaction channels absolute differential cross sections were derived in the energy region mentioned. Note that the low energy side of the cross sections is further limited by the fact that in the proton spectra only protons with kinetic energy $T_p \geq 5$ MeV were considered.

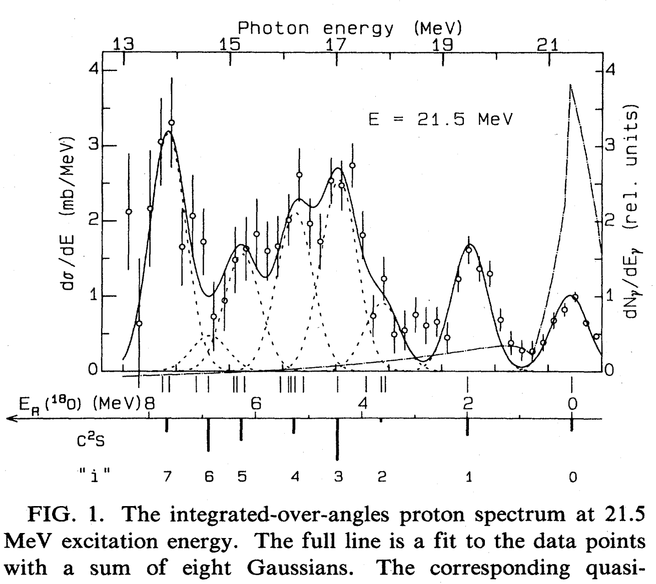

FIG. 1. The integrated-over-angles proton spectrum at 21.5 MeV excitation energy. The full line is a fit to the data points with a sum of eight Gaussians. The corresponding quasi-monochromatic photon spectrum is shown as a dot-dashed line. In the bottom part of the figure the level scheme of the residual nucleus ^{18}O is given. The states (or groups of states) for which the (γ,p_i) cross section could be derived in this experiment, are labeled "i"=0,7. The corresponding proton-pickup spectroscopic factors (Ref. 18) are represented by thick vertical bars, of which the length indicates the relative magnitude of the spectroscopic factors.

From proton yield curves the differential (γ,p_{tot}) cross sections were extracted using the unfolding procedure of Crawford *et al.*[17] In our proton yields only protons with kinetic energy $T_p \geq 3$ MeV were taken into account; the resulting values therefore have to be considered as lower limits for the (γ,p_{tot}) cross sections. However, it will follow from the discussion that our results approximately have the correct magnitude. (Note that the contribution from these low-energy protons cannot be very large anyway, due to the Coulomb barrier).

Using a standard Legendre polynomial fit [up to fourth order for (γ,p_0) and to second order for the other results],

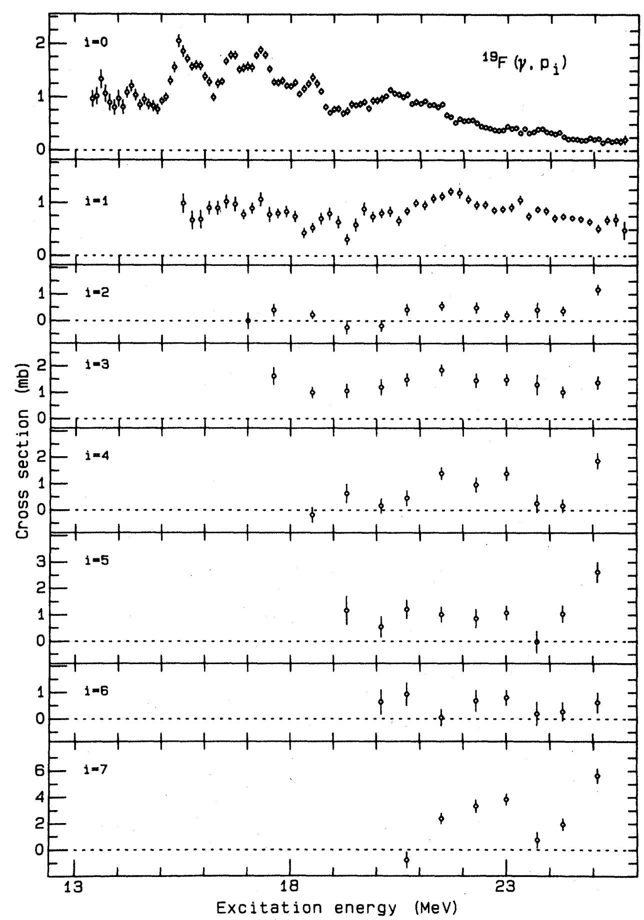

FIG. 2. The ^{19}F(γ,p_i) cross sections, for "i"=0,7. The (γ,p_0) and (γ,p_1) cross sections could be directly derived (Ref. 12). The cross sections for (γ,p_i), $i=2,7$, were deduced using our quasi-monochromatic photon spectrum technique; their energy resolution equals 0.75 MeV.

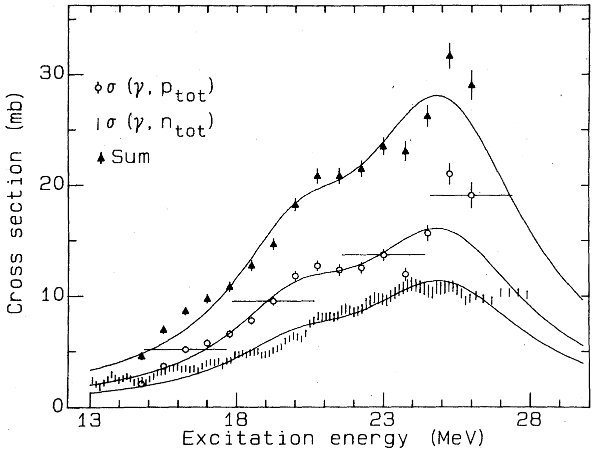

FIG. 3. The ^{19}F(γ,p_{tot}) cross section derived from our yield measurements (open circles), the ^{19}F(γ,n_{tot}) cross section of Veyssière *et al.* (Ref. 5) (points), and their sum (triangles). The full lines represent fits to these results with a sum of two Lorentzians. The energy resolution (1.4 MeV) of the (γ,p_{tot}) result is shown on a few data points as a horizontal error bar.

we could finally obtain integrated-over-angles cross sections from the differential ones. The eight (γ,p_i) cross sections are collected in Fig. 2. Their energy resolution is determined solely by the bremsstrahlung end point step, and amounts to 0.75 MeV. In Fig. 3 the (γ,p_{tot}) cross section is shown. The error bars for all cross sections represent the statistical errors only. The additional systematic uncertainty is less than 10% for $\sigma(\gamma,p_0)$, but can amount to as much as 20% for $\sigma(\gamma,p_7)$ and for the (γ,p_{tot}) cross section. The energy resolution for $\sigma(\gamma,p_{tot})$ is determined by the unfolding procedure, and equals 1.4 MeV.

III. RESULTS AND DISCUSSION

A. The (γ,p) cross section

Photonuclear reactions leading to simple hole states in the residual nucleus, which show a large overlap with the microscopic configurations of the GDR, proceed predominantly through a direct or semidirect mechanism. These simple proton hole states are characterized by their large proton pickup spectroscopic factors. In Table I the (γ,p_i)

TABLE I. Integrated cross sections and spectroscopic factors (Ref. 18).

E_R(^{18}O) (MeV)	J^π	"i"	E_i (MeV)	$(nlj)^{-1}$ (assumed)	$C^2S(i)$	$C^2S(i)/\sum_{i=0}^{7} C^2S(i)$	σ_0 (MeV mb)	$\sigma_0(i)/\sum_{i=0}^{7}\sigma_0(i)$
0	0^+	0	0	$2s_{1/2}$	0.38	0.08	8.7±0.1	0.14±0.01
1.982	2^+	1	1.98	$1d_{5/2}$	0.53	0.11	9.5±0.4	0.15±0.01
3.555	4^+			$1g_{9/2}$	0.04			
3.635	0^+	2	3.63	$2s_{1/2}$	0.05	0.02	2.3±0.4	0.04±0.01
3.921	2^+			$1d_{5/2}$	0.02			
4.456	1^-	3	4.45	$1p_{1/2}$	1.31	0.26	13.4±0.8	0.21±0.01
5.099	3^-							
5.260	2^+			$1d_{5/2}$	0.32			
		4	5.28			0.09	5.7±0.7	0.09±0.01
5.336	0^+			$2s_{1/2}$	0.15			
5.378	3^+							
5.531	2^-							
6.201	1^-							
		5	6.27	$1p_{3/2}$	0.70	0.14	7.6±0.9	0.12±0.01
6.351	?							
6.404	3^-							
6.882	(0^-)	6	6.88	$1p_{1/2}$	1.03	0.21	2.5±0.7	0.04±0.01
7.117	4^+							
7.620	1^-							
		7	7.67	$1p_{3/2}$	0.42	0.08	13.6±1.0	0.21±0.01
7.75	?							
		$\sum_{i=0}^{7}$			4.95		63.3±1.9	
		8	9.76					
		9	11.14	$1p_{3/2}$	0.65			
		10	11.75	$1p_{3/2}$	0.72			
		11	12.25	$1p_{3/2}$	0.89			
		$\sum_{i=0}^{11}$			7.21			

cross sections integrated over excitation energy are compared with the proton pickup spectroscopic factors measured by Kaschl *et al.*[18] (see also Fig. 1). The correspondence is striking. One notes a discrepancy only for the states $i=6$ and $i=7$; however, in both results data concerning state $i=7$ are less reliable due to possible contamination from ^{12}C in the target.

Such a quantitative relation has been found in other light nuclei as well.[8,10,19,20] The significance of such a correlation is not clear. Snover[21] suggested a single nucleon process, but this seems to be in contradiction with the formation of the GDR as an intermediate state.[22]

Because of the close correspondence between our integrated cross sections and the spectroscopic factors, we can define a proportionality coefficient between them:

$$R=\sum_{i=0}^{7}\int \sigma_i(E)dE \Big/ \sum_{i=0}^{7} C^2S(i)=12.8 \text{ MeV mb} .$$

The integration limits are ($S_{p_i}+5$ MeV, 25.1 MeV) [with S_{p_i} the separation energy for the (γ,p$_i$) channel], except for $i=0$ and $i=1$, for which the lower limit equals 16.2 MeV. In view of the good correlation, one can assume that the contributions which would be included in extending the interval to $S_{p_i}+5$ MeV for all channels, will not alter this coefficient appreciably, especially since the (γ,p$_0$) and (γ,p$_1$) cross sections constitute only about 25% of the sum.

This proportionality coefficient allows us to make a better estimate of the total semidirect (SD) cross section. It is clear that the sum of the eight separate (γ,p$_i$) channels only leads to a lower limit for the semidirect cross section, since we have no information on the (γ,p) reactions leading to higher proton hole states. Summing all spectroscopic factors for the states $i=0,11$ (see Table I), and transforming this sum to an integrated cross section, finally gives:

$$\int_{13 \text{ MeV}}^{25.1 \text{ MeV}} \sigma_{\text{SD}}(E)dE = R\sum_{i=0}^{11} C^2S(i) = 92\pm3 \text{ MeV mb} . \quad (1)$$

The (γ,p$_{\text{tot}}$) cross section, integrated over the energy interval (16.2—25.1 MeV) amounts to 103±2 MeV mb. Comparison with the sum of the eight partial integrated cross sections (63.3±1.9 MeV mb; see Table I), reveals a semidirect contribution of about 60%. As was mentioned earlier, this has to be considered as a lower limit. Integrating $\sigma(\gamma,\text{p}_{\text{tot}})$ over the energy region 13—25.1 MeV, leads to a value of 110±2 MeV mb. Using result (1), the semidirect fraction would then be 84%. This might be an overestimate, as the (γ,p$_i$) cross sections could contain a small statistical contribution, but we can certainly state that the semidirect process is strongly dominant. This is indeed what is expected for a light nucleus.[11]

The remaining part of the (γ,p) cross section (<40%) is due to equilibrium or preequilibrium decay of the dipole state. The preequilibrium decay probability is believed to be negligible for such a light nucleus.[22] The remainder can therefore almost entirely be attributed to statistical decay processes.

Our detailed study of the (γ,p$_0$) and (γ,p$_1$) cross sections[12] revealed that the dipole states centered around 17 MeV and the ones around 22 MeV must have different configurations. Early theoretical models[23–25] showed that the low energy ($2s$-$1d$) excitations are located mainly between 17 and 22 MeV, and the high energy $(1p)^{-1}(2s\text{-}1d)$ dipole states mainly between 22 and 27 MeV. This agrees with the conclusions of Veyssière *et al.*[5] We can therefore conclude that the bumps at around 17—18 MeV in the (γ,p$_0$), (γ,p$_1$), (γ,p$_2$), and possibly (γ,p$_3$) cross sections (see Fig. 2), and the shoulder at 17 MeV in $\sigma(\gamma,\text{p}_{\text{tot}})$ (see Fig. 3), correspond to $(2s\text{-}1d)^{-1}(2p\text{-}1f)$ dipole states, while the bumps in the energy region 21—23 MeV in all cross sections, and the suggested maximum around 25 MeV in the (γ,p$_i$) cross sections for $i\geq2$ and in $\sigma(\gamma,\text{p}_{\text{tot}})$, are due to $1p$ excitations. It is, furthermore, obvious from Fig. 2 that the (γ,p$_0$) channel is dominated by the ($2s$-$1d$) excitations, while the $(1p)^{-1}(2s\text{-}1d)$ configurations become more and more important in the cross sections for (γ,p$_i$) reactions leading to the higher excited $1p^{-1}$ residual levels. However, it is clear from our results that the $(1p)^{-1}(2s\text{-}1d)$ dipole states do couple to ($2s$-$1d$)-hole levels in ^{18}O as well, thus again contradicting the assumption of a single particle emission process.[8,21]

B. The total absorption cross section

In photoabsorption reactions, the probability for $E2$ excitations is much smaller than that for $E1$ excitations. One can therefore safely use the (γ,tot) cross section for the study of the GDR. However, we cannot use either of the measured nuclear-absorption cross sections[13,14] since they disagree completely with each other, as can be seen in Fig. 4, and since there is no argument, as yet, to prefer one above the other. We have therefore decided to rely for our discussion on the sum of our (γ,p$_{\text{tot}}$) cross section (Fig. 3) and the (γ,n$_{\text{tot}}$) cross section of Veyssière *et al.*,[5] shown in Fig. 3 as well. Such a sum is known to give a good approximation for the total nuclear-absorption cross section. The result is presented in Fig. 3.

It is obvious from Fig. 3 that the high energy core exci-

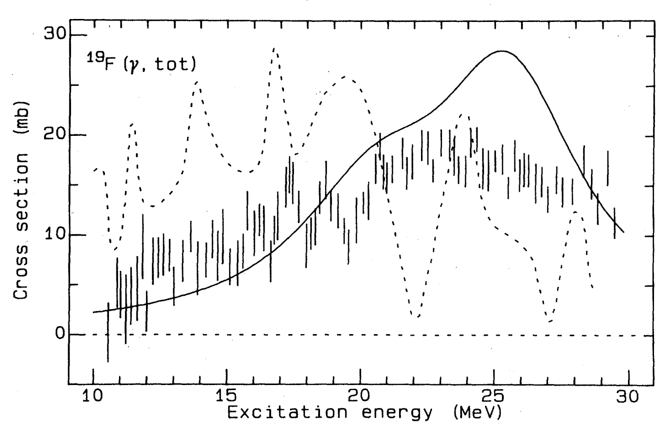

FIG. 4. The fit to the sum of $\sigma(\gamma,\text{p}_{\text{tot}})$ and $\sigma(\gamma,\text{n}_{\text{tot}})$ (full line), as compared with the experimental (γ,tot) cross section of Dolbilkin *et al.* (Ref. 13) (dashed line) and of Bezić *et al.* (Ref. 14) (data points).

TABLE II. Sum rule values and GDR energy.

	Integration interval (MeV)	σ_0 (MeV mb)	σ_{-1} (mb)	σ_{-2} (mb/MeV)	E_x (MeV)
This work	14.75—26.0	211±2	9.9±0.1	0.47±0.01	21.2
	8.0—30.0	291	13.6	0.69	20.5
Bezić et al. (Ref. 14)	10.0—30.0	271±50	14.1±2.7	0.74±0.17	19.1

tations strongly dominate the photoabsorption process. This was suggested in the early theoretical models for the CS in light (2s-1d) shell nuclei.[3,23]

Our estimate of the total absorption cross section finally allows us to evaluate the mean excitation energy of the GDR and to determine the sum rule quantities. Due to the large spreading of the dipole strength, this cannot be done by simply fitting the cross section with one Lorentz line, as for heavy nuclei. For the non-self-conjugate nucleus ^{19}F, the GDR structure is even more complicated due to the effect of isospin splitting.[26] Still, we can approximately describe the total cross section by a sum of two Lorentz lines with an appropriate width, representing the contributions of the two different configurations. Hence, one Lorentzian can be located at about 20 MeV to account for the low energy $(2s\text{-}1d)^{-1}(2p\text{-}1f)$ configurations, and the other around 25 MeV to account for the high energy $(1p)^{-1}(2s\text{-}1d)$ states. This will allow us to estimate quantitatively the configurational splitting, and to extrapolate our results to a sufficiently wide energy interval (up to 30 MeV) for comparison with the available (γ,tot) data. The excitation energy of the GDR can then be defined as[27] $E_x=\sqrt{\sigma_0/\sigma_{-2}}$, whereby

$$\sigma_n=\int_0^{E_m}\sigma(E)E^n dE \ .$$

The fits are also shown in Fig. 3. They suggest a contribution of about 66% from the core excitations to the total absorption cross section, as well as to $\sigma(\gamma,\mathrm{p_{tot}})$ and to $\sigma(\gamma,\mathrm{n_{tot}})$ separately. One notices that our simple description is unable to reproduce the fine structure in the cross sections, as we have argued above. Our fitted total cross section curve is also compared with the measured nuclear-absorption cross sections of Refs. 13 and 14 in Fig. 4. There is a fair agreement between our result and that of Bezić et al.,[14] although our derived cross section has a more pronounced maximum around 25 MeV excitation energy. The curve of Dolbilkin et al. shows no relation at all with either of the other data.

In Table II the values for several moments of the nuclear-absorption cross section (σ_0, σ_{-1}, and σ_{-2}) and the excitation energy E_x, calculated with the fitted results, are compared with the values of Bezić et al.[14] The agreement is in all cases very good. One notices that the Thomas-Reiche-Kuhn sum rule ($60\ NZ/A$, i.e., 284 MeV mb) is completely exhausted and that the excitation energy is indeed much lower than $78A^{-1/3}$ (i.e., 29.2) MeV.

IV. CONCLUSIONS

Photoproton spectra from ^{19}F were measured over the GDR region. From these spectra, absolute cross sections for eight photoproton channels were deduced. These (γ,p_i) reactions lead to low-lying states in ^{18}O, of which the proton hole character had been established by proton pickup measurements, and must therefore proceed mainly through a nonstatistical reaction mechanism.

From yield measurements, also the $(\gamma,\mathrm{p_{tot}})$ cross section could be derived. Comparison of the summed partial (γ,p_i) cross sections with the $(\gamma,\mathrm{p_{tot}})$ result, shows a semidirect contribution of at least 60%. The almost perfect correlation between the (γ,p_i) cross sections and the spectroscopic factors $C^2S(i)$, allows one to estimate from the spectroscopic factors for all residual proton-hole states, a semidirect contribution of 84%. A large nonstatistical contribution was to be expected for such a light nucleus.

From our (γ,p_i) results a qualitative picture emerges for the configurational splitting effect in the photoproton decay channel. The (γ,p_0) cross section is dominated by $(2s\text{-}1d)^{-1}(2p\text{-}1f)$ dipole states, while the $1p$ excitations become more important in the cross sections for (γ,p_i) reactions leading to higher excited states. However, it is clear from our results that the final hole state configuration is not necessarily the same as the hole in the (1p-1h) dipole state. Furthermore, it follows from our data that core excitations contribute much more to the GDR than valence excitations. This explains the success of all microscopic models taking into account the core excitations (see, e.g., Ref. 28).

The sum of our $(\gamma,\mathrm{p_{tot}})$ cross section and the $(\gamma,\mathrm{n_{tot}})$ result of Veyssière et al.[5] served as an alternative for the nuclear-absorption cross section. Our result clearly indicates that the cross section of Bezić et al.[14] is to be regarded as relatively more reliable.

ACKNOWLEDGMENTS

We thank Professor A. J. Deruytter for his interest in this work. We are especially grateful to the linac crew for the operation of the linear electron accelerator. We also acknowledge the financial support lent by the Interuniversity Institute for Nuclear Sciences (I.I.K.W.) and the National Foundation of Scientific Research (N.F.W.O.), Brussels (Belgium).

*Present address: Laboratorium voor Natuurkunde II, Rijksuniversiteit Gent, B-9000 Ghent, Belgium.

[1]G. E. Brown, L. Castillejo, and J. A. Evans, Nucl. Phys. **22**, 1 (1961).

[2]E. Van Camp, R. Van de Vyver, E. Kerkhove, D. Ryckbosch, H. Ferdinande, P. Van Otten, and P. Berkvens, Phys. Rev. C **24**, 2499 (1981).

[3]V. G. Neudatchin and V. G. Shevchenko, Phys. Lett. **12**, 18 (1964).

[4]V. Gillet and N. Vinh Mau, Nucl. Phys. **54**, 321 (1964).

[5]A. Veyssière, H. Beil, R. Bergère, P. Carlos, and A. Leprêtre, Nucl. Phys. **A227**, 513 (1974).

[6]B. S. Ishkhanov, I. M. Kapitonov, V. N. Orlin, I. M. Piskarev, V. I. Shvedunov, and V. V. Varlamov, Nucl. Phys. **A313**, 317 (1979).

[7]V. V. Varlamov, B. S. Ishkhanov, I. M. Kapitonov, Yu. I. Prokopchuk, and V. I. Shvedunov, Yad. Fiz. **30**, 1185 (1979) [Sov. J. Nucl. Phys. **30**, 617 (1979)].

[8]P. J. P. Ryan, M. N. Thompson, K. Shoda, and T. Tanaka, Nucl. Phys. **A371**, 318 (1981).

[9]P. J. Ryan, M. N. Thompson, K. Shoda, and T. Tanaka, Nucl. Phys. **A411**, 105 (1983).

[10]R. A. Sutton, M. N. Thompson, M. Hirooka, T. Tanaka, and K. Shoda (unpublished).

[11]S. S. Hanna, Comments Nucl. Part. Phys. **11**, 79 (1983).

[12]E. Kerkhove, H. Ferdinande, R. Van de Vyver, P. Berkvens, P. Van Otten, E. Van Camp, and D. Ryckbosch, Phys. Rev. C **29**, 2047 (1984).

[13]B. S. Dolbilkin, V. A. Zapevalov, V. I. Korin, L. E. Lazareva, and F. A. Nikolaev, Isv. Akad. Nauk SSSR, Ser. Fiz. **30**, 349 (1966) [Bull. Acad. Sci. USSR, Phys. Ser. **30**, 354 (1966)].

[14]N. Bezić, D. Brajnik, D. Jamnik, and G. Kernel, Nucl. Phys. **A128**, 426 (1969).

[15]R. Carchon, R. Van de Vyver, H. Ferdinande, J. Devos, and E. Van Camp, Phys. Rev. C **14**, 456 (1976).

[16]E. Van Camp, R. Van de Vyver, H. Ferdinande, E. Kerkhove, R. Carchon, and J. Devos, Phys. Rev. C **22**, 2396 (1980).

[17]D. M. Crawford, R. Koch, and H. H. Thies, Nucl. Instrum. Methods **109**, 573 (1973).

[18]G. T. Kaschl, G. J. Wagner, G. Mairle, U. Schmidt-Rohr, and P. Turek, Nucl. Phys. **A155**, 417 (1970).

[19]J. E. M. Thomson, M. N. Thompson, and R. J. Stewart, Nucl. Phys. **A290**, 14 (1977); J. E. M. Thomson and M. N. Thompson, *ibid.* **A285**, 84 (1977).

[20]D. H. Dowell, G. Feldman, K. A. Snover, A. M. Sandorfi, and M. T. Collins, Phys. Rev. Lett. **50**, 1191 (1983).

[21]K. A. Snover, in Proceedings of the International Symposium on Highly Excited States and Nuclear Structure, Orsay, France, 1983, edited by N. Marty and Nguyen Van Giai, J. Phys. (Paris) **45**, C4—337 (1984).

[22]D. Ryckbosch, E. Van Camp, R. Van de Vyver, E. Kerkhove, P. Van Otten, P. Berkvens, and H. Ferdinande, Phys. Rev. C **26**, 448 (1982).

[23]W. H. Bassichis and F. Scheck, Phys. Rev. **145**, 771 (1966).

[24]S. A. Farris and J. M. Eisenberg, Nucl. Phys. **88**, 241 (1966).

[25]J. Blomqvist and T. T. S. Kuo, Phys. Lett. **293**, 544 (1969).

[26]R. O. Akyüz and S. Fallieros, Phys. Rev. Lett. **27**, 1016 (1971).

[27]J. S. Levinger, Phys. Rev. **107**, 554 (1957).

[28]P. D. Allen, E. G. Muirhead, and D. V. Webb, Nucl. Phys. **A357**, 171 (1981).