Deuteron Photodisintegration Differential Cross Section between 100 and 220 MeV

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Differential cross sections for the reaction $^2H(\gamma,p)n$ were measured at five laboratory angles, from 32° to 130°, for photon energies 100, 140, 180, and 220 MeV. A quasimonochromatic photon beam was used and the photon spectrum was measured on line by a pair spectrometer. The absolute normalization uncertainty is within ±5%. Data agree within the total errors with the recent results of a tagged-photon experiment and of a measurement of the inverse process.

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The photodisintegration of the deuteron is important for the knowledge of the nucleon-nucleon interaction and interaction of electromagnetic radiation with nuclei. In spite of the considerable effort both theoretical and experimental spent up to now on studies of deuteron photodisintegration, knowledge of the cross section for this reaction is still unsatisfactory. This is true particularly in the energy region between the pion emission threshold and the $\Delta(1236)$ resonance, where the range of variation of the results reported by different laboratories[1-3] is well outside the published error limits. On the other hand, in this energy region, where meson-exchange currents and isobar phenomena give relevant contributions, several theoretical approaches[4-10] are able to describe the general features of the cross section, but they still differ from each other. Of course, because of the large discrepancy existing between experiments, a detailed comparison between theory and experiment has not been warranted up to now. Consequently the whole picture is still obscure.

In this Letter we present the results of a new experiment on the deuteron photodisintegration designed to minimize systematic uncertainties in order to produce more reliable data. We have taken advantage of the availability at Frascati of a quasimonochromatic photon beam, which, though not necessary for the measurement of a two-body reaction, obviously offers important advantages. The measurement was carried out using the Laboratorio Esperienze Acceleratore Lineare Elettroni (LEALE) photon beam, produced by inflight positron annihilation on a liquid hydrogen target having a thickness of 0.018 radiation length. The experimental facility has already been described in detail by Capitani *et al.*[11] Particular care was paid to the beam monitoring: The positron intensity was monitored by both a nonintercepting ferrite toroid and a Faraday cup, put in the focal plane of a dumping magnet behind the hydrogen target. The photon energy spectrum was measured on-line by a pair spectrometer.[12] Having passed through the deuterium target, photons were finally absorbed in a Komar-type[13] quantameter which provides a constant sensitivity in our energy range. The target was a vertical Mylar cylinder (4.0 cm diameter, 10 cm high, wall thickness 0.08 mm), filled with liquid deuterium. The deuterium density was kept constant within 2% by a continuous monitoring of the deuterium vapor pressure. The photon beam spot on the target, periodically measured with a beam-profile monitor, had a circular shape of 3.8 cm diameter.

Protons were detected by five telescopes connected on-line to a PDP 15/76 computer. Each telescope employed consisted of a dual scintillator counter system. The front counter, a 3-mm-thick NE102A scintillator, gave a measure of ΔE. The back counter, a 5-cm radius and 12-cm-deep NaI crystal, gave a measurement of the total energy E. The stored data were presented on-line as a plot of ΔE against E and the mass discrimination was found to be sufficiently good to distinguish unambiguously protons from other particles. Proton spectra were simultaneously recorded at lab angles of 32.5°, 55°, 80°, 105°, and 130° with respect to the photon beam and at annihilation photon energies of 100, 120, 140, 180, 200, 220, and 260 MeV. For all these energies and angles the measured proton spectra show evident peaks whose positions and shapes are strictly related to the relevant annihilation photon peaks. The proton energy also being measured, the reaction is kinematically overdetermined. The linear dependence of the proton peak energy versus the photon annihilation peak energy provided a check of the proton energy calibration. Moreover, a Monte Carlo program, having as input the measured photon energy spectrum and the system's geometry, was able to reproduce satisfactorily the observed peaks in the pro-

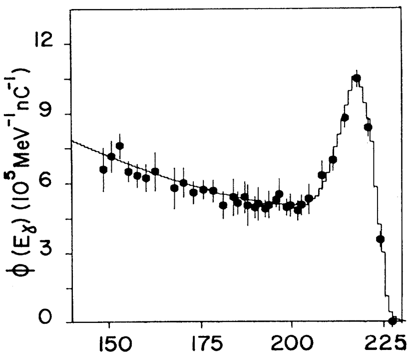

FIG. 1. Photon energy spectrum measured with the pair spectrometer (positron energy 220 MeV, photon collection angle 0.9°, and half-angular geometric photon acceptance 3.9 mrad). The full-line curve is a result of a Monte Carlo calculation.

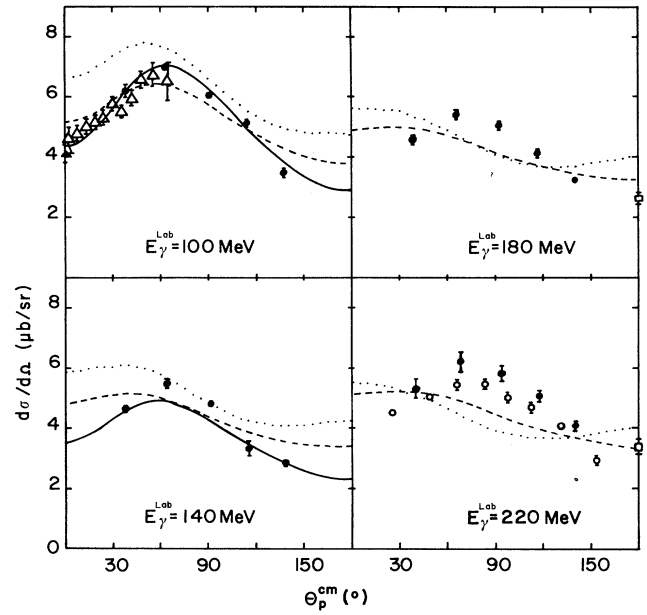

FIG. 2. $d(\gamma,p)n$ differential cross section for the given photon energies. Our data (solid dots) are compared to most recent experimental results and theoretical predictions: open triangles, Ref. 15; closed triangle, Ref. 16; open circles, Ref. 3; open squares, Ref. 17; solid line, Ref. 9; dashed line, Ref. 6; dotted line, Ref. 8. Our points and those of Ref. 3 do not include systematic errors (±5% and ±4%, respectively).

ton spectra.

Only the peaks in the photon and proton spectra were used to determine the cross sections. Moreover, by use of this program, it was also possible to determine the cross section also in the bremsstrahlung tail region. This allowed a cross check on the consistency of cross sections obtained at different positron beam energies: Good agreement was found between values obtained from the annihilation peaks and those from the bremsstrahlung tails.

The measurements were made in several runs distributed over two years and the data from each run were separately analyzed and compared. This provided a check for systematic errors arising from factors in the experimental conditions which might have varied from run to run. The results of different runs were consistent within ±5%.

A more complete account of this experiment and the analysis will be given in a forthcoming publication. Here we present the results obtained in the energy range $100 \leq E_\gamma \leq 220$ MeV, where no monochromatic photon data exist apart from the recent Bonn results[3] at $E_\gamma \geq 200$ MeV.

Figure 1 shows a typical photon energy spectrum measured on-line by the pair spectrometer[12] at the given positron energy and photon collection angle. The full-line curve represents the result of a Monte Carlo simulation[14] which also reproduces the total photon energy measured by the quantameter. The excellent agreement between the computed and the measured spectra was obtained by slight adjustment of the values of two input quantities (positron emittance and photon collection angle) by amounts within the experimental uncertainties.

The results of the differential cross sections in the center-of-mass system are given in Table I and plotted, as solid dots, in Fig. 2 for the given laboratory photon energies. The points have been averaged over an energy bin $\Delta E_\gamma = 10$ MeV. The errors quoted are statistical only and do not include a ±5% systematic uncertainty on the absolute value. Figure 2 also shows the results of other recent measurements, specifically the

TABLE I. Measured differential cross section (μb/sr) for $\gamma d \rightarrow pn$.

E_γ (MeV)	$\theta_p^{lab} = 32.5°$	55°	80°	105°	130°
100	6.32 ±0.14	7.02 ±0.09	6.03 ±0.09	5.25 ±0.08	3.62 ±0.09
140	4.73 ±0.12	5.58 ±0.15	4.92 ±0.09	3.47 ±0.08	2.91 ±0.06
180	4.58 ±0.12	5.46 ±0.20	5.16 ±0.11	4.18 ±0.09	3.28 ±0.12
220	5.45 ±0.23	6.16 ±0.34	5.84 ±0.21	5.09 ±0.18	4.11 ±0.16

radiative neutron-capture experiment of Meyer *et al.*,[15] and three photodisintegration experiments: the tagged-photon study by Arends *et al.*,[3] the 0° experiment by Hughes *et al.*,[16] and the 180° experiment by Altoff *et al.*[17] The data of Meyer *et al.*[15] are found to be in agreement with our results within their experimental errors, which include systematic contributions except for the uncertainty on the nucleon-nucleon cross section. The tagged-photon data[3] include only statistical errors; when we take into account their (±4%) and our (±5%) systematic uncertainties, the two measurements are compatible. Moreover, it may be worthwhile to note that our data in the 100–140-MeV range are very compatible with the fit obtained by De Pascale *et al.*[18] from a critical review of all the $d(\gamma,p)n$ data in the 10–120-MeV range published before 1982. Therefore it is definitely encouraging that the new data obtained by use of different techniques are found to be in agreement with each other within the quoted total errors. Consequently a stronger constraint is offered to the theory.

Also shown in Fig. 2 are the results of the most recent calculations: The dashed line results from a calculation performed by Laget[6] using an expansion of the photodisintegration amplitude in terms of dominant diagrams. Final-state interactions are taken into account by including the neutron-proton rescattering in S and P waves. In this calculation Laget has used the values $\Lambda_\pi = 1.2$ GeV for the cutoff mass of the pion-baryon form factor, and $G_\rho^2/G_\pi^2 = 1.6$ for the ratio between the square of the ρ- and π-baryon coupling constants. The dotted curve is a result from Leidemann and Arenhövel[8] who have extended their low-energy calculation beyond the pion photoproduction threshold with explicit Δ degrees of freedom in a coupled-channels treatment including all final-state interactions. The full-line curve is from Cambi, Mosconi, and Ricci[9] who have studied the effect of higher-order contributions to the one-body (Darwin-Foldy and spin-orbit terms plus relativistic correction to the wave functions) and to the two-body (one-pion exchange both in pseudoscalar and in pseudovector coupling) charge densities. The full-line curve shape seems to agree better with experimental points, particularly at $E_\gamma = 100$ MeV, while the other two curves are systematically higher at forward and backward angles, the discrepancy increasing with the photon energies.

In conclusion, we have shown that there is an agreement among measurements of the $d(\gamma,p)n$ differential cross section performed by using three very different techniques, like quasimonochromatic photons, tagged photons, and inverse reactions (neutron pickup). In this context we stress that the use of a quasimonochromatic photon beam with the simultaneous measurement of profile, energy spectrum, and flux of the photon beam are important improvements for a correct determination of the absolute value of the deuteron photodisintegration cross section.

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[1]P. Dougan *et al.*, Z. Phys. A **276**, 55 (1976), and A **280**, 341 (1977), and references quoted therein for previous experiments.

[2]K. Baba *et al.*, Phys. Rev. C **28**, 286 (1983).

[3]J. Arends *et al.*, Nucl. Phys. **A412**, 509 (1984).

[4]K. Ogawa *et al.*, Nucl. Phys. **A340**, 451 (1980).

[5]M. Anastasio and M. Chemtob, Nucl. Phys. **A364**, 219 (1981).

[6]J. M. Laget, Nucl. Phys. **A312**, 265 (1978), and Can. J. Phys. **62**, 1046 (1984), and private communication.

[7]H. Arenhövel, Nucl. Phys. **A374**, 521c (1982), and Nuovo Cimento **76C**, 256 (1983).

[8]W. Leidemann and H. Arenhövel, Phys. Lett. **139B**, 22 (1984), and Can. J. Phys. **62**, 1036 (1984), and private communication.

[9]A. Cambi, B. Mosconi, and M. Ricci, Phys. Rev. C **26**, 2358 (1982), and J. Phys. **G10**, L11 (1984), and private communication.

[10]W.-Y. P. Hwang, J. T. Londergan, and G. E. Walker, Ann. Phys. (N.Y.) **149**, 335 (1983).

[11]G. P. Capitani *et al.*, Nucl. Instrum. Methods **216**, 307 (1983).

[12]G. P. Capitani *et al.*, Nucl. Instrum. Methods **178**, 61 (1980).

[13]A. P. Komar *et al.*, Nucl. Instrum. Methods **82**, 125 (1970).

[14]G. P. Capitani *et al.*, Nucl. Instrum Methods **203**, 353 (1982).

[15]H. O. Meyer *et al.*, Phys. Rev. Lett. **52**, 1759 (1984), and Phys. Rev. C **31**, 309 (1985).

[16]R. J. Hughes *et al.*, Nucl. Phys. **A276**, 329 (1976).

[17]K. H. Altoff *et al.*, Z. Phys. **21**, 149 (1984).

[18]M. P. De Pascale *et al.*, Phys. Lett. **119B**, 30 (1982).