Total Cross Section for Deuteron Photodisintegration between 15 and 75 MeV

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The total cross section for deuteron photodisintegration has been measured in the γ-ray energy range between 15 and 75 MeV, by use of the monochromatic LADON photon beam of the Frascati National Laboratories and detection of the proton. The results are in substantial agreement with the standard theory and do not provide evidence for contributions of quark degrees of freedom.

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High-energy experiments[1,2] on the interaction of deuterons with elementary particles and nuclei indicate the existence in the deuteron of strong two-nucleon correlations at short distances, whose origin can be traced to the overlapping of the two nucleonic three-quark bags. In fact, at distances of the order of the natural length scale of QCD (about 1 fm), the *N-N* forces are to be interpreted in terms of quark interchanges and multiple gluon exchanges, rather than on the basis of the conventional meson-nucleon models. It is important to understand at which momentum transfers this short-range quark regime ties in with the standard constraints of nuclear physics at large distance.

In this connection some years ago Hadjimichael and Saylor[3] pointed out that an interesting quantity to explore is the total cross section for deuteron photodisintegration at low energy. By a careful analysis of a selected number of experiments—the most reliable ones, in their opinion—they reached the conclusion that the data cannot be interpreted only in terms of meson and nucleon degrees of freedom, but that the quark structure of the nucleon has to be explicitly taken into account. They proposed to describe the short-distance two-nucleon interaction by quark and gluon exchange, while meson exchange is assumed—as usual—to account for the long and intermediate range. The approach of Ref. 3 to a complete description of the deuteron wave function is too crude, but refinements of this idea can be found in various papers,[4,5] although they are applied only to the deuteron photodisintegration and/or electrodisintegration at intermediate energy.

However, an analysis by Arenhövel[6] of the existing experimental data for the $d(\gamma,p)n$ total cross section—without any particular selection—shows that the standard theory, including meson-exchange currents and isobar configurations, works quite satisfactorily. Furthermore, our critical review,[7] which considers the whole experimental set of total and differential cross sections, does not agree with the results of Ref. 3. In any case, no definite conclusion can be drawn, as a result of the large statistical and systematic uncertainties of the existing data.

In this framework, we carried out a new measurement of the total cross section for deuteron photodisintegration at low energy with good statistical and systematic accuracy. This has been made possible by use of the monochromatic LADON photon beam[8] of the Frascati National Laboratories (obtained by Compton backscattering of laser light by the high-energy electrons circulating in the storage ring ADONE) and by use of a proton detector with a very large angular acceptance ($\sim 4\pi$). The main features of the LADON beam are a satisfactory energy resolution (ranging from approximately 400 keV at 15 MeV to 4 MeV at 80 MeV), an extremely low bremsstrahlung background ($\leq 5\%$ over the whole spectrum), an intensity of about 10^5 γ/s, and an almost complete linear polarization.

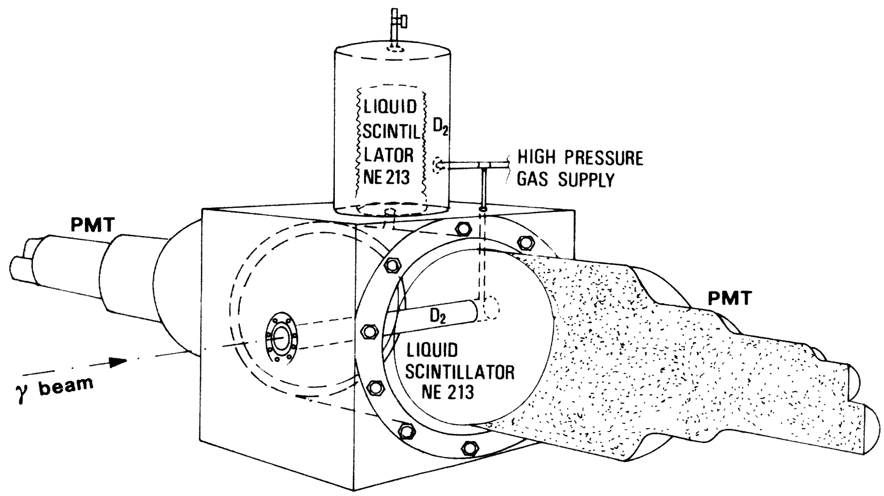

FIG. 1. Schematic diagram of the target and detector system.

The experimental apparatus consists of an integrated system composed of a gas container, surrounded by a 6.75-cm-thick NE213 liquid scintillator which is viewed by two photomultipliers. Its schematic diagram is shown in Fig. 1. A very thin (0.16 mm) aluminum tube (15 cm in length and 1.5 cm in diameter), with end caps of Lexan, was filled with deuterium or hydrogen (in turn) at high pressure (~ 30 atm).

A mechanical device maintained both gas and scintillator at the same pressure. Pressure and temperature were continuously measured and recorded during the running time; deuterium and hydrogen densities were determined off line, by use of the experimental data for a real gas given in Michels *et al.*,[9] interpolated for our experimental conditions.

The event processing was triggered by a threefold coincidence among the two pulses from the proton detector and a signal indicating the passage of an electron bunch through the laser cavity.

The integrated current pulses from the two photomultipliers, their sum, and their corresponding tail contributions were recorded to provide a proton-energy measurement and an off-line p/γ discrimination by the standard head/tail method. In addition, a pulse shape analyzer was used jointly with a time-to-digital converter for a further off-line p/γ discrimination procedure. All relevant information was collected by use of standard CAMAC modules interfaced to a DEC PDP-11/34 minicomputer.

The beam was monitored by a 10-in. $\times$ 10-in. NaI(Tl) crystal, whose threshold stability was periodically checked. The efficiency was calculated by use of a standard Monte Carlo program for electromagnetic showers. In addition, the energy profile of the γ beam was continuously monitored by a magnetic pair spectrometer, while the bremsstrahlung contribution was systematically measured during the running time by a switching off of the laser light. The electron flux in the storage ring, exponentially decreasing with time, was also checked and recorded.

Data were taken in several runs for effective photon mean energies $E_\gamma = 14.7$, 19.3, 28.9, 38.2, 47.5, 57.5, and 74.0 MeV, with deuterium and hydrogen gas (for background measurements) in turn as target. Data

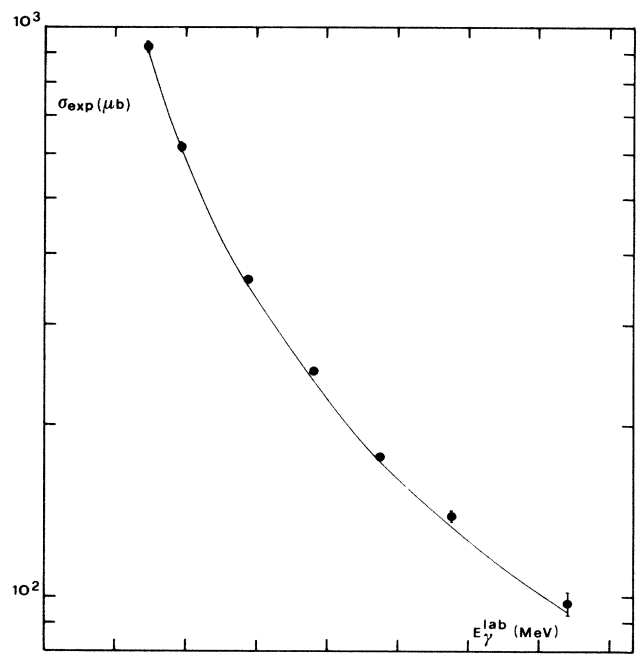

FIG. 2. Plot of the total cross section σ_{expt} for the reaction $^2H(\gamma,n)p$ vs the laboratory gamma-ray energy. Filled circles, our experiment. The solid line represents a theoretical calculation of Ref. 10.

TABLE I. Our experimental results for the $^2H(\gamma,n)p$ total cross section σ_{expt}, theoretical calculations σ_{th} of Ref. 10, ratio $\sigma_{expt}/\sigma_{th}$, and systematic errors $\Delta\sigma_{expt}^{sys}$ as functions of the laboratory gamma-ray energy (MeV).

E_γ (MeV)	σ_{expt} (μb)	σ_{th} (μb)	$\sigma_{expt}/\sigma_{th}$	$\Delta\sigma_{expt}^{sys}$ (μb)
14.7 ±0.1	925 ±20	900.3	1.027 ±0.022	44
19.3 ±0.1	617 ±9	627.3	0.984 ±0.014	31
28.9 ±0.1	361 ±6	356.5	1.013 ±0.017	12
38.2 ±0.1	249 ±3	239.1	1.041 ±0.013	9
47.5 ±0.2	177 ±3	174.7	1.013 ±0.017	6
57.5 ±0.4	139 ±3	133.1	1.044 ±0.023	5
74.0 ±0.5	97.6 ±5.3	94.0	1.038 ±0.056	3

were also taken with use of only the bremsstrahlung component of the beam. The photon polarization was changed several times to look for possible asymmetries in the proton detector. This effect was found to be completely negligible within the statistical uncertainties.

Data were reduced to cross sections in several steps. By use of both pulse-shape-analyzer and head/tail information, we obtained a high-quality p/γ discrimination, so that the largest part of the electromagnetic background was removed. Next, the bremsstrahlung data were normalized to the same total electron flux and subtracted. Then, the net hydrogen yield was subtracted from the net deuterium yield, to get rid of the residual electromagnetic background and the spurious counts from the Lexan windows. Finally, in order to extract the total cross section, corrections were made for the proton detector efficiency, including the effect of the proton energy threshold (0.7 MeV at $E_\gamma = 14.7$ MeV) and the angular acceptance. The efficiency was estimated by a Monte Carlo calculation, assuming for the photoproton angular distribution the theoretical estimates of Cambi *et al.*,[10] and was found to be $\sim 80\%$ at $E_\gamma = 14.7$ MeV and higher than 95% at $E_\gamma \geq 20$ MeV.

The results of our measurements, as a function of the photon energy, are displayed in Fig. 2 and listed in Table I together with the corresponding statistical errors. In the last column of Table I is also reported our estimate of the systematic errors, which includes an overall uncertainty in the deuterium density, the background subtraction, the total efficiency of the proton detector, and the monitoring of the incident beam. Finally, in Fig. 2 our data are compared with a theoretical calculation obtained by inclusion of explicit meson-exchange current and isobar-configuration exchange contributions and relativistic corrections to the charge density operator.[10] The Paris potential was em-

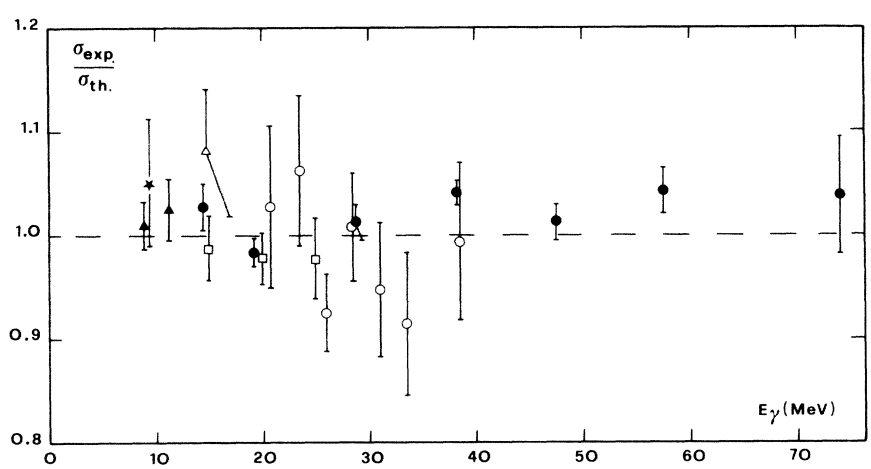

FIG. 3. Plot of the ratio $\sigma_{expt}/\sigma_{th}$, between a set of experimental total cross sections σ_{expt} and the corresponding theoretical data σ_{th} of Ref. 10, vs the laboratory gamma-ray energy. Filled circles, our experiment; open squares, Ahrens *et al.* (Ref. 11); filled triangles, Birenbaum *et al.* (Ref. 12); open circles, Bosman *et al.* (Ref. 13); open triangles, Stiehler *et al.* (Ref. 14); stars, Tudoric-Ghemo (Ref. 15). The last three sets of points are derived from total cross-section measurements of radiative neutron-proton capture by means of the detailed-balance theorem.

ployed. The ratio of our measured cross sections to those calculated is also given in Table I.

Figure 3 shows the ratio between a set of selected experimental cross sections[11-15] and the corresponding theoretical predictions.[10] In addition to our data we have included the results of Ahrens *et al.*,[11] Birenbaum *et al.*,[12] Bosman *et al.*,[13] Stiehler *et al.*,[14] and Tudoric-Ghemo.[15] The first two of these experiments are free from uncertainties due to the standard bremsstrahlung techniques for incident photons, while the data of the last three are derived from measurements of the total cross section for radiative neutron-proton capture by means of the detailed-balance theorem. The general trend of this ratio does not show, in our opinion, any particular structure such as the parabolic behavior in the energy region between 10 and 80 MeV given in Ref. 3. In addition, the difference of the individual points from 1.0 is less than a few percent and disappears if systematic errors are also included. In any case, it is very far from the 15% at 50 MeV reported in Ref. 3. This absence of a striking qualitative or quantitative difference between the standard theory and the experiments below 75 MeV does not support the claim for a real need of further subnucleonic degrees of freedom at low energy. However, it should be pointed out that definite disagreement exists at higher energies.[16] This latter result can be explained in terms of rapidly increasing isobaric contributions and relativistic corrections.

In conclusion, our measurement of the total cross section for deuteron photodisintegration at energies between 15 and 75 MeV confirms, within the obtained accuracy, the substantial validity of the current theory in this energy interval. In fact, the deviations are of the same order of magnitude as the discrepancies expected for different potentials.

This conclusion had been already reached as a result of our previous measurement[17] of the asymmetry parameter $\Sigma(\theta)$ for this reaction, carried out in the same energy range. Therefore, effects involving quark degrees of freedom in nuclear electromagnetic interactions and, in particular, in deuteron photodisintegration seem to be either confined to the higher-momentum-transfer regions or too small to be clearly evidenced at low energy.

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