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A CRITICAL REVIEW OF THE DEUTERON PHOTODISINTEGRATION DATA BETWEEN 10 AND 120 MeV

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Worldwide data on deuteron photodisintegration between 10 and 120 MeV have been analyzed and compared with the standard theory including MEC+IC contributions. No real effect can be envisaged for the breakdown of the current theory at intermediate energy.

The fascinating assumption that quark–gluon degrees of freedom play a fundamental role in understanding nuclear phenomena has now reached the point in time where it can challenge the standard theory describing matter in terms of nucleon and meson degrees of freedom. Strong two-nucleon correlations at short distances have been put in evidence in the deuteron by interactions of elementary particles and nuclei with a deuteron target at high energy [1–3]. This effect could be tentatively explained by a presence in the deuteron wave-function of a six-quark component, connected to a six-quark system with the deuteron quantum numbers and confined in a bag with a radius of the order of the nuclear core (~0.4 fm) [3–6].

Recently Hadjimichael and Sailor [7] claimed that also the experimental total cross section data on deuteron photodisintegration process at low and medium energy ($E_\gamma \leqslant 100$ MeV) suggest a strong modification of the traditional NN picture for short separation distances. In their model a hole of radius $r_0 = 1.57$ fm was punched into the conventional deuteron wave function and the hole was filled with a non specified non-nucleonic state possibly having a complicated quark structure. On the other hand, Arenhövel [8], after a critical analysis of a more complete set of data on the total cross section, strongly contests the conclusions of the previous authors and invokes more high quality data to assess the validity and limits of the conventional nuclear theory.

Aim of the present paper is to deepen the problem by an accurate analysis and a fit of the existing experimental data on the ^{2}H(γ, n)p reaction in the energy range ($10 \leqslant E_\gamma \leqslant 120$) MeV, taking into account not only the total cross sections but also the very signifying angular distributions. A comparison is then made with the conventional theories including meson exchange and isobaric contributions and using the Siegert theorem (Normal+MEC+IC approximation) [9,10], to draw out some clear evidence of systematic discrepancies. In the framework of these calculations the need for a complete inclusion of the (MEC+IC) contributions has been shown by a recent measurement of the "neutron asymmetry" in the same process between 10 and 70 MeV performed at Frascati by the Ladon group [11].

The fitting expression for the differentical cross section in the center of mass system takes the usual form, including terms up to dipole–octupole interference:

$$\mathrm{d}\sigma(\theta,\phi)/\mathrm{d}\Omega = I_0(\theta) + P I_1(\theta)\cos\phi$$
$$= \sum_{i=0}^{4} A_i(E_\gamma) P_i(\cos\theta)$$
$$+ P\cos 2\phi \sum_{k=0}^{4} B_k(E_\gamma) P_k(\cos\theta), \qquad (1)$$

where θ is the angle between the proton and photon momenta in the CM system and ϕ is the angle between the polarization and reaction planes; P represents the degree of linear polarization of the photon beam. Since the bulk of experimental data has been obtained with unpolarized photons ($P = 0$), our attention will be mainly devoted to the first term of eq. (1). The idea is to give the best experimental evaluation at present available for the coefficient A_i, theoretically determined by the strength of different multipoles contributing to the reaction. Direct comparison with current theories will measure our present understanding of the physics involved in the process. The form of eq. (1) was chosen because the orthogonality of the Legendre polynomials ensures mutual independence of the fitted coefficient A_i.

All the data included in the fit have been taken from refs. [12–31]. In particular, data from refs. [28, 29] disagree of (10–20)% with respect to the average of the others and nevertheless have been included in the fit in relative units. The systematic errors quoted by the authors have been linearly added to the statistical ones. The coefficients A_i ($i = 0, 3$) have been parametrized in function of the incoming photon energy in the laboratory system according to the dependences suggested in ref. [32] with the addition of some polinomial terms. Furthermore the coefficient A_4 in the region $E_\gamma \geqslant 60$ MeV has been found to be largely dependent upon the parametrization used and almost undetermined ($\Delta A_4/A_4 \simeq 0.5$). For these reasons it has been fixed to the theoretical value as given in ref. [10].

The obtained results for the coefficients A_i ($i = 0, 3$) are reported in table 1 together with the values assumed for A_4 and in figs. 1a and 1b. The χ^2 per degree of freedom is 1.45 and the total number of data is 396.

The dashed curves in figs. 1a and 1b report the results for the A_i coefficients obtained in ref. [10] by using the RSC potential under the Siegert hypothesis and in the "Normal+MEC+IC approximation". The agreement for A_0 and A_1 is extremely satisfying everywhere. For A_2 no appreciable disagreement is evidenced in the low energy region, whereas in the region $E_\gamma \geqslant 50$ MeV the fitting curve is definitely higher than the theoretical calculation. This effect can be partially attributed to the great influence that the assumed behaviour for the A_4 coefficient can have on A_2 beyond 50 MeV. Furthermore preliminary estimates [10] of the one body relativistic corrections – ρ_1^{rel} – (Darwin–Foldy and spin orbit terms) and pion exchange contributions – ρ_2^{exch} – to the charge density have been shown to enhance A_2 of a substantial amount. This effect is reported in fig. 1b, where the dot-dashed curve fills quite appreciably the gap between fit and theory beyond 50 MeV. A similar argument holds for A_3 where, on the

Table 1
Fitted values for the coefficients A_i ($i = 0, 1, 2, 3$). The values for the A_4 coefficient come from ref. [10].

E (MeV)	A_0 (μb/sr)	A_1 (μb/sr)	A_2 (μb/sr)	A_3 (μb/st)	A_4 (μb/sr)
10	110.6 ± 3.5	13.8 ± 2.2	−105.9 ± 3.9	−13.6 ± 1.3	−0.9
20	45.5 ± 1.4	8.9 ± 1.0	−40.0 ± 1.3	−8.63 ± 0.77	−0.85
30	25.7 ± 0.9	6.09 ± 0.80	−20.14 ± 0.85	−5.77 ± 0.66	−0.70
40	17.2 ± 0.7	4.60 ± 0.65	−11.84 ± 0.60	−4.16 ± 0.59	−0.59
50	12.7 ± 0.7	3.68 ± 0.58	−7.66 ± 0.54	−3.18 ± 0.54	−0.51
60	10.0 ± 0.6	3.08 ± 0.55	−5.31 ± 0.53	−2.52 ± 0.50	−0.45
70	8.34 ± 0.60	2.66 ± 0.54	−3.87 ± 0.55	−2.05 ± 0.48	−0.39
80	7.19 ± 0.60	2.36 ± 0.53	−2.95 ± 0.56	−1.69 ± 0.47	−0.34
90	6.38 ± 0.60	2.13 ± 0.53	−2.33 ± 0.56	−1.40 ± 0.47	−0.30
100	5.80 ± 0.60	1.95 ± 0.54	−1.89 ± 0.55	−1.16 ± 0.48	−0.26
110	5.38 ± 0.60	1.79 ± 0.56	−1.58 ± 0.53	−0.94 ± 0.50	−0.23
120	5.07 ± 0.60	1.66 ± 0.59	−1.35 ± 0.50	−0.75 ± 0.52	−0.20

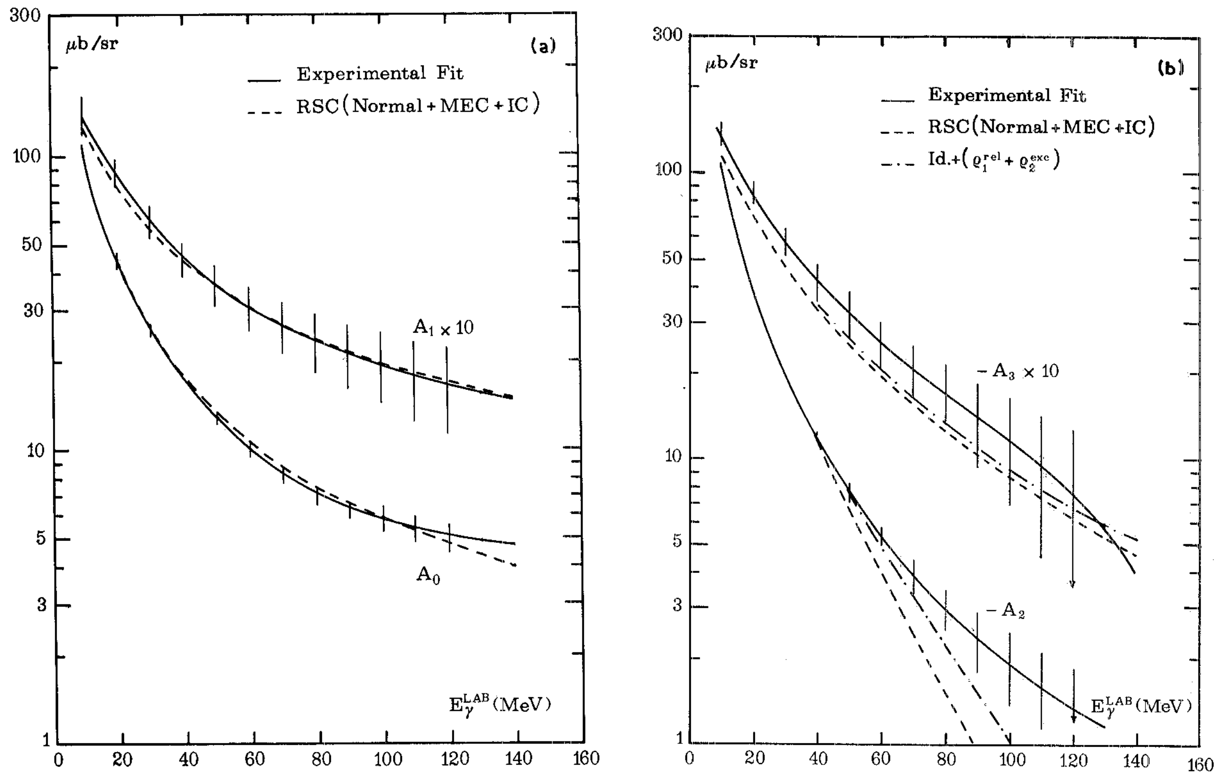

Fig. 1. (a) Obtained results for the coefficients A_i (i = 0, 1). The full lines represent the present fit and the vertical bars account for the statistical uncertainties. The dashed curves are the theoretical results as given by the RSC calculations (N+MEC+IC) [10]. (b) The same as fig. 1a for the coefficients A_i (i = 2, 3). The dotted–dashed curves include relativistic corrections to ρ_1 and pion-exchange contributions to ρ_2 [10].

other hand, no definite disagreement can be evidenced outside the quoted errors of the fit.

Let us examine more in detail the available data on the differential cross section at 0° for emitted proton. The first term of the eq. (1) can be also put in the standard "Partovi" form [33]:

$$d\sigma(\theta)/d\Omega = a + b \sin^2\theta + c \cos\theta + d \cos\theta \sin^2\theta + e \sin^4\theta, \quad (2)$$

where the coefficients a–e can be easily related to the Legendre coefficients of eq. (1). Of course the forward cross section is given by $(a+c)$.

The coefficient a is strongly dependent on the value of the deuteron D-state percentage (P_D) [33,34], and then its knowledge seems to be a sensible probe for the strength of the tensor interaction. Also c gives some information about it, by interference terms between different transitions [33,34].

In fig. 2 the fitted values for a and c are compared with the calculations [10] performed with the RSC and the De Tourreil–Sprung (DTS)-Version B potentials under the Siegert hypothesis and in the "Normal +MEC+IC approximation". As it is very well known, these two potentials mainly differ for the different strength of the tensor force: the D-wave percentage is P_D = 6.47% and P_D = 4.25% for the RSC and DTS-Version B cases, respectively. According to our analysis the fitting curves for a and $(a+c)$ turn out to be lower than theoretical expectations and, as a significant results, the best reproduction of the data is obtained with the DTS-potential. Even c, that is very poorly determined, seems to be better reproduced by the DTS-calculations. In any case these discrepancies cannot be presently considered significative, because they are of the order of the contributions we expected from ρ_1^{rel} and ρ_2^{exch}.

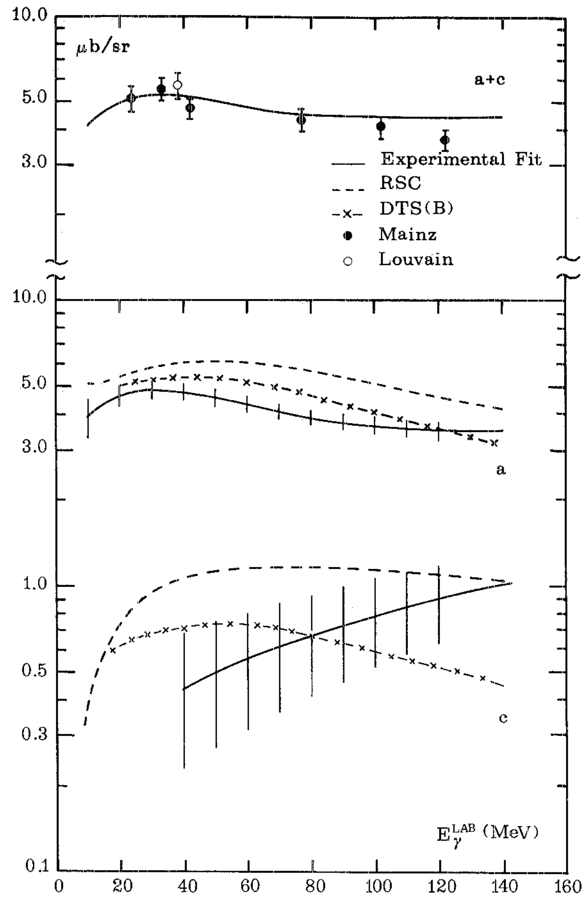

Fig. 2. Obtained results for $a, c, a+c$. Full, dashed and cross-dashed curves represent the fit, the RSC and the DTS-version B calculations [10], respectively. Dots and circles are the Mainz [12] and Louvain [31] experimental results.

In conclusion of this analysis of the deuteron photodisintegration data below π threshold, we can say that in the region $E_\gamma \leqslant (60\text{–}70)$ MeV the current theory including MEC+IC contributions seems to reproduce the data sufficiently well.

In the high energy region ($E_\gamma > 70$ MeV), disagreements are more evident but, before giving particular significance to any of them, more complete calculations outside the limits imposed by the Siegert hypothesis and including relativistic corrections should be made available. It should be noted, however, that the spread of the data points in the energy region examined makes it very difficult to test theories with sufficient accuracy and thus more refined experiments are seriously required.

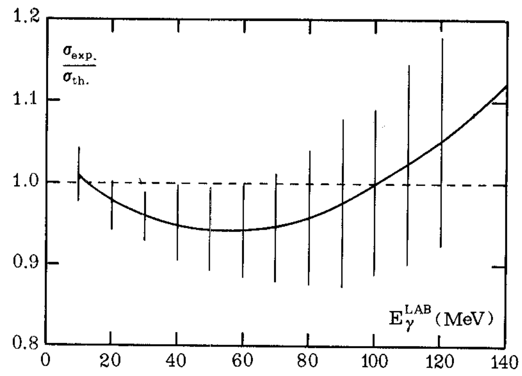

Fig. 3. Ratio σ_{exp}/σ_{th} between the total cross section obtained by the fit ($\sigma_{exp} \equiv 4\pi A_0$) and the theoretical total cross section calculated by the RSC potential.

As a further illustration of the adequacy of the standard theory, we report in fig. 3 a comparison between the total cross sections obtained by the fit ($\sigma_{exp} \equiv 4\pi A_0$) and the theoretical calculation carried out with the RSC potential [10]. The maximum disagreement does not exceed 7% in the energy range (10–120) MeV and in addition is widely contained within the errors.

Therefore, in the framework offered by the present data, no real effect can be envisaged for a breakdown of the current theory at intermediate energy such as to necessarily claim for the introduction in theory of quark–gluon degrees of freedom.

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