Neutron Asymmetry Measurements in the Deuteron Photodisintegration between 10 and 70 MeV

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The asymmetries $\Sigma(\theta_{\mathrm{c.m.}}=\pi/2)$ for the reaction $^2\mathrm{H}(\gamma,n)p$ have been measured with use of a monochromatic and linearly polarized γ-ray beam, obtained by backward Compton scattering of laser light against high-energy electrons. Contributions from meson exchange currents must be included in the theoretical calculations to reproduce our data.

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Considerable attention has been given over the past few years to the deuteron photodisintegration process where contributions from meson exchange currents and isobar configurations have been recognized to intervene quite appreciably. This paper reports on neutron asymmetry measurements in such a process as a function of the photon energy, obtained with the Ladon photon beam at the Frascati National Laboratories.[1]

The center-of-mass (c.m.) differential cross section for the reaction $^2\mathrm{H}(\gamma,n)p$ induced by linearly polarized γ rays can be written in the form[2]

$$\frac{d\sigma}{d\Omega}=I_0(\theta)+PI_1(\theta)\cos2\varphi =I_0(\theta)[1+P\Sigma(\theta)\cos2\varphi], \quad (1)$$

where θ is the angle between the neutron and photon momenta in the c.m. system and φ is the angle between the polarization and reaction planes; P represents the degree of linear polarization of the photon beam and

$$\Sigma(\theta)=I_1(\theta)/I_0(\theta) \quad (2)$$

determines the asymmetry of the differential cross section.

Almost all the experiments performed till now have measured the total cross sections and sets of $I_0(\theta)$ values only in the angular region $25°\leq\theta\leq150°$ in the laboratory (see Refs. 3–5 and references quoted therein). Exceptions are the recent measurements of $I_0(0)$ and $I_0(\pi)$ carried out by Hughes *et al.*[6] and by Gilot *et al.*,[7] besides a few measurements of $\Sigma(\theta)$ that we will comment on later. Calculations carried out in the nonrelativistic limit have shown that the bulk of the existing data at photon energies between about 10 and 50 MeV can be reproduced reasonably well employing standard deuteron wave functions and charge-current operators (see Refs. 2, 8, and 9 and references quoted therein). For a more accurate description, meson exchange currents (MEC) and isobar resonance admixtures (IC) must be taken into account. In particular, Arenhövel[9] has pointed out that these contributions sensibly affect the theoretical calculations of $\Sigma(\theta)$ above about 50 MeV.

As is clearly shown by Eq. (1), the asymmetry $\Sigma(\theta)$ and $I_1(\theta)$ are not accessible to experiments with unpolarized photons ($P=0$): They can only be measured with linearly polarized γ-ray beams ($P\neq 0$). The existing measurements of $\Sigma(\theta)$ are those of Liu[10] obtained with photons ranging from 75 to 230 MeV, those of Barbiellini *et al.*[11] from 200 to 400 MeV, and the recent result of Del Bianco *et al.*[12] at 20.3 MeV. Our experiment fills the gap in the available experimental data existing at low γ-ray energies by measuring $\Sigma(\theta)$ at the neutron angle $\theta=\pi/2$ in the energy range $10 \leq E_\gamma \leq 70$ MeV.

The source of monochromatic and linearly polarized γ rays was the Ladon facility recently developed at Frascati[1] and obtained by Compton scattering of laser light against the high-energy electrons circulating in the Adone storage ring. The properties of the beam are summarized in Table I for the energies of the experiment.

The photoneutrons were detected with a 30.5-cm-diam$\times$ 15.2-cm-long NE-213 scintillator; a 6.3-cm-diam$\times$ 6.3-cm-long NE-232 deuterated scintillator was used both as a deuterium target and as a proton detector. In a subsequent series of runs the target was replaced with a 3.8-cm-diam$\times$ 10.2-cm-long NE-230 deuterated scintillator that was made available in order to improve the background rejection by pulse-shape discrimination. The consistency of the two sets of data so obtained has been checked and proved to be fully satisfactory. Both the proton energy and the neutron time of flight were measured in coincidence with the electron bunch in the storage ring. The photon flux was monitored with a 12.5-cm-diam$\times$ 15.4-cm-long NaI(Tl) crystal placed at the end of the photon channel. Data were taken in a series of alternating runs at $\varphi=0$ and $\varphi=\pi/2$ in the same experimental conditions.

A typical time-of-flight spectrum for protons

TABLE I. Photon beam characteristics during data taking and experimental values for $\Sigma(\theta_{\text{c.m.}}=\pi/2)$.

E_γ (MeV)	ΔE_γ (FWHM) (MeV)	γ-ray intensity (γ/sec)	P	$\Sigma(\theta_{\text{c.m.}}=\pi/2)$
9.9	0.3	1.5×10^4	0.999	0.97 ± 0.01
14.8	0.4	2.2×10^4	0.999	0.92 ± 0.02
19.8	0.4	2.3×10^4	0.999	0.92 ± 0.01
29.0	1.0	3.4×10^4	0.999	0.81 ± 0.03
38.3	1.8	3.8×10^4	0.996	0.66 ± 0.03
46.5	3.0	4.6×10^4	0.994	0.57 ± 0.04
54.5	4.5	4.8×10^4	0.991	0.40 ± 0.05
69.0	7.0	4.9×10^4	0.986	0.27 ± 0.07

from the reaction $^2\text{H}(\gamma,n)p$ is shown in Fig. 1 ($E_\gamma = 20$ MeV; $\theta=\pi/2$; $\varphi=0$). The ratio of events in the photoneutron peak to the γ-ray flux gives the relative photoneutron yield $Y(\theta,\varphi)$ at the angles θ and φ. From this one can obtain the ratio $R(\theta)$ defined as follows:

$$R(\theta)=Y(\theta,\pi/2)/Y(\theta,0). \tag{3}$$

This quantity does not depend on the neutron-counter efficiency, on the geometry of the deuterium target, or on the absolute beam monitoring. The quantity $\Sigma(\theta=\pi/2)$ can be expressed in terms of $R(\theta=\pi/2)$ and is given by

$$\Sigma(\theta=\pi/2)=C\frac{1}{P}\frac{1-kR(\pi/2)}{1+kR(\pi/2)}, \tag{4}$$

where C is a finite-solid-angle correction factor whereas k corrects for the neutron multiple scattering and absorption processes in the target and has been evaluated by a Monte Carlo calculation: Effects due both the ^{2}H and ^{12}C have been taken into account.

In Table I and in Fig. 2 the measured $\Sigma(\theta=\pi/2)$ values are shown as a function of the incident γ-ray energy. The quoted errors are from counting statistics only. In addition, a systematic error of about ± 0.02 has to be assigned to the measured values, as a consequence of the uncertainties in the correction-factor evaluation, mainly k. All experimental points have been assigned to the γ-ray beam average energy; the horizontal bars show a conventional energy uncertainty, equal to

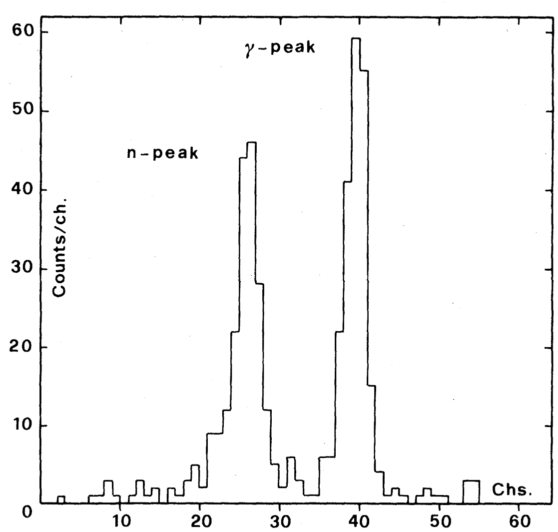

FIG. 1. A typical time-of-flight spectrum obtained at $E_\gamma=19.6$ MeV (1.6 nsec per channel).

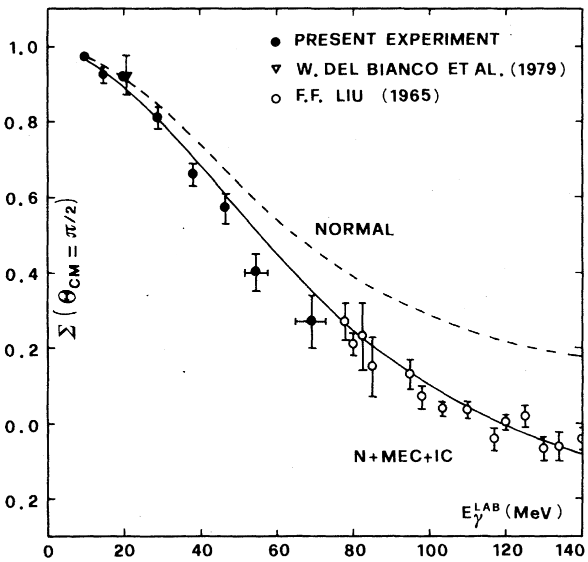

FIG. 2. Plot of the ratio $\Sigma(\theta_{c.m.}=\pi/2)$ vs E_γ for the reaction $^2H(\gamma,n)p$. Dashed and full curves are the Arenhövel calculations in approximations I and II (see text), respectively.

the full width at half maximum (FWHM) of the beam. In the figure we also report the result of the experiment of Del Bianco *et al.*[12] and the points of Liu[10] at γ-ray energies above 80 MeV. Note the good agreement between our result for Σ at 19.8 MeV and that obtained by Del Bianco *et al.*[12] at $E_\gamma = 20.3$ MeV. Furthermore, the trend of our experimental data around 70 MeV matches quite well with Liu's results at higher energies.[10]

Theoretical calculations have been performed by Arenhövel[9] using the Reid soft-core potential and including multipoles up to $L = 4$. It has been shown that large MEC effects are present in the $E1$ transitions, even though most of them are covered by use of the Siegert theorem. Also the $M1$ terms carry appreciable contributions, but for higher multipoles the effects are rather small.

In particular we report two curves following two different approximations: The first (approximation I) follows the standard Partovi theory[2] with the use of the Siegert theorem and Siegert hypothesis in the expression of the multipole operators (dashed curve in Fig. 2). In this way the dominant part of MEC enters the calculation through the commutator between the total nuclear Hamiltonian and the one-body charge density. The second (approximation II) has been obtained by adding to the previous terms the contributions related to the two-body current density associated with the one-pion exchange and Δ-isobar excitations (solid curve in Fig. 2).

The present determination of Σ is consistent within errors with the Arenhövel provisions in approximation II. Therefore our experimental data definitely confirm the need for a complete inclusion of MEC contributions. More detailed information for the understanding of the MEC contributions in the deuteron photodisintegration process can be achieved by measuring Σ at different angles. This experimental program is already in progress at Frascati with the Ladon beam.

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