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DEUTERON PHOTODISINTEGRATION INDUCED BY MONOCHROMATIC, LINEARLY POLARIZED GAMMA-RAYS.

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ABSTRACT

Monochromatic and linearly polarized γ-rays, obtained by backward Compton scattering of laser light against high energy electrons, have been used to measure the quantity $\Sigma\ (\theta_n = 90°)$ for the $^2H(\gamma,n)\,H$ reaction at the γ-ray energies $E\gamma$ = 10,20,30 and 40 MeV.

1. INTRODUCTION

In this article, we describe an investigation of the $^2H(\gamma,n)H$ reaction at photon energies from $E\gamma$ = 10 MeV to 40 MeV using the monochromatic and linearly polarized γ-rays of the newly developed Ladon facility at Frascati(1).

The differential cross section for the deuteron photodisintegration induced by linearly polarized γ-rays can be written in the form(2):

$$\frac{d\sigma}{d\Omega} = Io(\theta)+P\,I_1(\theta)\cos 2\phi = Io(\theta)\,\left[1+P\,\Sigma(\theta)\cos 2\phi\right]\,, \qquad (1)$$

where θ e ϕ are the angles that one of the ejected nucleons makes with the direction of the momentum and with the electric vector of the incident photon beam, respectively, P represents the degree of linear polarization of the photon beam and $\Sigma(\theta)$ is equal to the ratio of $I_1(\theta)$ and $I_0(\theta)$. The functions $I_0(\theta)$ and $I_1(\theta)$ can be expressed in terms of sin θ and cos θ; including EM multipoles of order $L \leqslant 2$, one obtains:

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$$I_0(\theta) = a+b \sin^2\theta + c \cos\theta + d \sin^2\theta \cos\theta + e \sin^4\theta \ , \tag{2}$$

and

$$I_1(\theta) = f \sin^2\theta + g \sin^2\theta \cos\theta + h \sin^4\theta \ . \tag{3}$$

Measurements of the deuteron photodisintegration cross section using linearly polarized γ-rays ($P\neq 0$) are sensitive both to $I_0(\theta)$ and $I_1(\theta)$; hence polarized γ-rays can be used to obtain informations on the quantity $I_1(\theta)$ not accessible to experiments with unpolarized photons.

The only existing measurements to-date using linearly polarized γ-rays are those of Liu(3) obtained with photon energies ranging from 80 MeV to 230 MeV, those of G. Barbiellini et al.(4) from 200 to 400 MeV and the recent result of Del Bianco et al.(5) at 20.3 MeV. In these experiments the ratio Σ (θ = 90°) has been measured. The result of Del Bianco et al. is in agreement with Partovi's theory, whereas Liu's data, at higher energy, are in substantial disagreement.

The present experiment was designed with the aim to possibly clarify this point and to fill the gap in the available experimental data at lower γ-ray energies. In addition, it was also intended to verify the recent experiment of Hughes et al.(6) where the differential cross section of the $^2H(\gamma,p)n$ reaction at $\theta p = 0°$ has been measured over the γ-ray energy interval from $E\gamma$ = 20 MeV to 120 MeV.

It should be noted that a measurement of $d\sigma/d\Omega$ at $\theta_p = 0°$ determines the sum of the coefficients a and c in the expansion of $I_0(\theta)$. The results of the Mainz group(6) show that (a+c) is lower than the theoretical estimate by about (20-30)%.

At γ-ray energies $E\gamma < 40$ MeV, the following approximate relations $b \simeq f$ and $h \simeq e$ hold. For instance, at $E\gamma$ = 20 MeV Partovi finds $(b-f)/f \simeq 1.2 \times 10^{-2}$ and $(e-h)/h \simeq 1.7 \times 10^{-3}$. Hence, to a good approximation, one can set

$$\Sigma\,(\theta_n = 90°) = \frac{b+e}{a+b+e} \tag{4}$$

and a measurement of the coefficient a with unpolarized photons can be related to the measurement of Σ obtained with polarized γ-rays.

The Ladon photon beam has been employed to determine Σ at the neutron angle $\theta_n = 90°$ by measuring the ratio R of the relative photoneutron yields at the azimuthal angles $\phi_n = 90°$ and $\phi_n = 0°$. The quantity R does not depend on the efficiencies of the neutron and γ-rays detectors and on the geometry of the deuterium target and it can be simply expressed in terms of Σ.

2. EXPERIMENTAL SET-UP AND DATA ANALYSIS

An overall view of the experimental set-up is shown in Fig. 1. The photon beam was obtained by Compton scattering of Laser photons against the high energy electrons circulating in the ADONE storage ring(1). The back scattered γ-rays were collimated, passed through the deuterium target and were monitored by a 12.5 cm diam. x 15.4 cm long Na-I crystal. The properties of the γ-ray beam are given in Table I for the energies of the experiment.

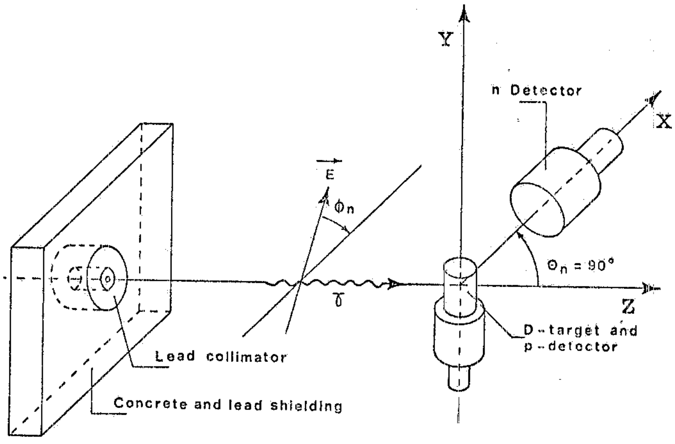

FIG. 1

TABLE I

Photon beam characteristics during data taking. The collimation angle was $\Delta\theta = 1.4 \times 10^{-4}$ for $E\gamma$ = (9.9; 19.8; 29.5) MeV and $\Delta\theta = 8.7 \times 10^{-5}$ for $E\gamma$ = 39.3 MeV.

E	γ/sec.	$\Delta E/E$(FWHM) %	< P>
9.9 ± 0.1	8×10^3	2.2	0.999
19.8 ± 0.3	3×10^4	3.5	0.999
29.5 ± 0.6	5×10^4	4.4	0.998
39.3 ± 0.7	1.1×10^4	3.5	0.999

The photon beam is higly monochromatic, has a duty-cycle and a degree of linear polarization close to unity. The photon intensity varied from $\sim 10^4$ to $5 \times 10^4 \gamma$/sec. over the energy range $E\gamma$ = 10 MeV to 40 MeV and the plane of polarization of the electric vector could be varied continuously from 0° to 180°. A 6.3 cm diam. x 6.3 cm long NE-232 scintillator was used both as a deuterium target and as a proton detector. A 30.5 cm diam. x 15.2 cm long NE-213 scintillator, placed at a distance of 100 cm from the deuterium target was employed to detect the photoneutrons. The energy of the protons and the time of flight of the neutrons from the $^2H(\gamma,n)H$ reaction were measured in coincidence together with the electron bunch in the storage ring and the events recorded in a bidimensional spectrum.

Each measurement at $\phi_n = 90°$ was followed by a measurement at $\phi_n = 0°$ in the same experimental condition. At each γ-ray energy, the band of the bidimensional spectrum which corresponded to the energy of the protons from the $^2H(\gamma,n)H$ reaction, was projected on the time of flight axis. A typical time of flight spectrum is shown in Fig. 2.

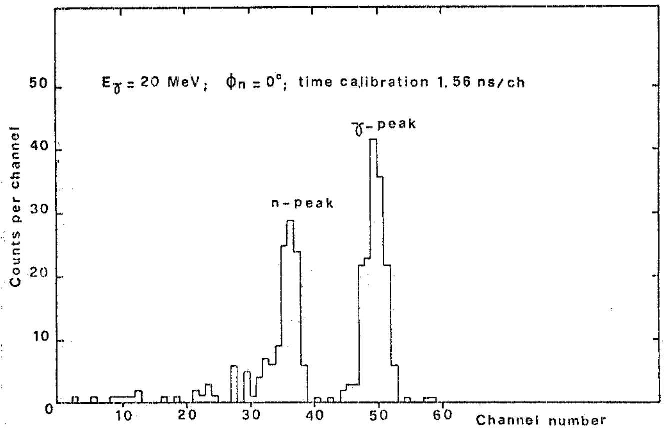

FIG. 2

In the spectrum, the peak at higher channel numbers is produced by γ-rays scattered in the deuterated detector and the other is due to neutrons from the $^2H(\gamma,n)H$ reaction.

The ratio of events in the photoneutron peak of the time projection spectrum to the γ-ray flux recorded by the Na-I spectrometer, gave the relative photoneutron yield $Y_n(\phi_n)$ at the angle ϕ_n and from this the ratio R could simply be obtained.

The quantity Σ (90°) can be expressed in terms of R and is given by:

$$\Sigma\,(90°) \simeq \frac{C_0}{C_1 P}\,\frac{1-R}{1+R} + \frac{1}{C_1 P}\,\frac{1}{1+R}\,\frac{\Gamma(90°)-R\,\Gamma(0°)}{(1-\alpha)I_0(90°)} \qquad (5)$$

where:

C_0,C_1 are two correction factors which take into account the finite size of the neutron detector, α represents the fraction of photoneutrons emitted in the direction of the neutron counter and absorbed in the deuterium target, $\Gamma(\phi_n)$ gives the contribution to the photoneutron yield at the angle ϕ_n, due to neutrons scattered in the deuterium target and in material around the target; $\Gamma(\phi_n)$ is the sum of several terms, the most important being those related to neutron scattering by ^2H and ^{12}C nuclei in the NE-232 scintillator.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

In Table II and Fig. 3 are reported the values for Σ (90°) obtained at the various γ -ray energies.

TABLE II

Obtained experimental values for Σ .

Eγ	Σ
9.9 ± 0.1	0.94 ± 0.06
19.8 ± 0.3	0.89 ± 0.04
29.5 ± 0.6	0.76 ± 0.07
39.3 ± 0.7	0.67 ± 0.11

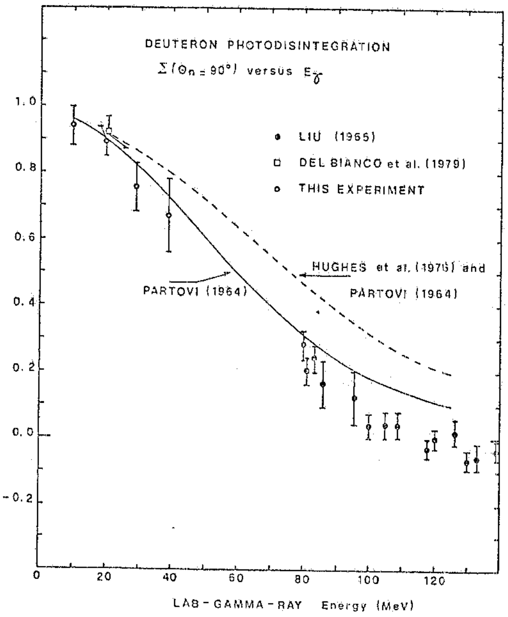

FIG. 3

The error in Σ has been calculated by adding linearly the errors in the various quantities appearing in eq. (5). In Fig. 3 is also reported the result of the experiment of Del Bianco et al.(5) at 20.3 MeV and the points of Liu(3) at γ-ray energies above 80 MeV. In addition, the solid curve has been determined from Partovi coefficients. The dashed line has been obtained by inserting in eq. (4), the coefficients b and e calculated by Partovi, and the coefficient a calculated from Hughes' result. It shoud be noted the good agreement between our result for Σ and that obtained by del Bianco et al.(5) at Eγ = 20.3 MeV. Furthermore at all energies, the values of Σ obtained in this experiment are, within the errors, consistent with Partovi's theory.

Finally, the dashed curve is consistently higher than Partovi's and the results of this experiment. As already explained above this curve was obtained by using for b and e the theoretical values of Partovi; since at lower γ-ray energies, one has e ≪ b, the ratio Σ (90°) is fairly insensitive to the value of the coefficient e; moreover, two recent measurements of the total $^2H(\gamma,n)H$ cross section at γ-ray energies from 10 MeV to 40 MeV, strongly suggest that the absolute value of the coefficient b is in agreement with the theory(7,8).

Hence our choice of the values of the coefficients b and e appears well justified: consequently the value of (a + c) obtained by the Mainz group is possible understimated.

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