Proton polarization in the photodisintegration of the deuteron by linearly polarized 400- and 500-MeV γ rays

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(Submitted 22 April 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 11, 489–491 (5 June 1982)

The polarization of the recoil protons at the angle $\theta_p^* = 90°$ has been measured in the photodisintegration of the deuteron by linearly polarized 400- and 500-MeV γ rays. For the first time, all of the following observables have been determined under identical experimental conditions: Σ, the asymmetry of the cross sections; P_y, the polarization of the recoil proton; and T_1, the asymmetry of the nucleon polarization for the case of linearly polarized γ rays.

PACS numbers: 13.60.Hb

The hypothesis of dibaryon resonances has recently attracted increased interest in the photodisintegration of the deuteron. The polarization (P_y) of the recoil proton,[1] the asymmetry (Σ) of the differential cross sections in a beam of linearly polarized photons,[2] and the T asymmetry have all been measured in the energy range 350–700 MeV with a polarized deuterium target[3]. Comparison of these data with the analysis of Ref. 4, which was based exclusively on data for the differential cross sections and the proton polarization P_y, could not finally resolve the question of whether dibaryon resonances exist. Further study, both theoretical and experimental, is required.

In this letter we are reporting the first results of a polarization experiment to measure the polarization of the recoil proton at the angle $\theta_p^* = 90°$ in the reaction $\gamma d \to np$ in a beam of linearly polarized γ rays with an energy $E_\gamma = 400$ or 500 MeV.

The polarization state of the proton during the photodisintegration of the deuteron by linearly polarized photons is described by[5]

$$\rho_N \frac{d\sigma}{d\Omega} = \frac{1}{2}\left(\frac{d\sigma}{d\Omega}\right)_0 [1+\sigma_y P_y - P_\gamma(\Sigma + \sigma_y T_1)\cos 2\varphi + P_\gamma(0_x\sigma_x + 0_z\sigma_z)\sin 2\varphi], \quad (1)$$

where $(d\sigma/d\Omega)_0$ is the cross section for unpolarized γ rays, P_γ is the degree of polarization of the γ ray, φ is the angle between the reaction plane and the γ polarization vector, and $\rho_N = 1 + \vec{\sigma}\mathbf{P}_N/2$ is the polarization density matrix of the nucleon. The coordinate axes are chosen such that $z\|\mathbf{k}$, $y\|\mathbf{k}\times\mathbf{p}$, $x\|\mathbf{k}\times\mathbf{p}\times\mathbf{k}$, where $\mathbf{k}$ and $\mathbf{p}$ are the momenta of the γ ray and the proton in the c.m. frame of the reaction $\gamma d \to np$.

The polarizations $P_y^{\perp}$ and $P_y^{\|}$ of the recoil proton corresponding to two directions of the γ polarization vector, respectively, perpendicular ($\varphi = \pi/2$) and parallel ($\varphi = 0$) to the reaction plane, can be related to the observables P_y, Σ, and T_1 with the help of expression (1):

$$P_y^{\perp} = \frac{P_y + P_\gamma T_1}{1 + P_\gamma \Sigma}, \quad P_y^{\|} = \frac{P_y - P_\gamma T_1}{1 - P_\gamma \Sigma}. \quad (2)$$

The observable T_1 in expressions (1) and (2), which is the asymmetry of the nucleon polarizations in the case of linearly polarized γ rays, differs from the T asymmetry for a polarized deuterium target. The only way to measure T_1 is by a polarization experiment with a polarized beam in which the polarization of the recoil nucleon is measured.

The present experiments were carried out at the Khar'kov linear electron accelerator at an initial energy $E_0 = 1.45$ GeV. The experimental procedure is described in detail elsewhere.[6] A beam of linearly polarized, nearly monoenergetic γ rays from a diamond single-crystal 2 mm thick bombards a liquid-deuterium target 50 mm in diameter and 200 mm long. Protons from the reaction $\gamma d \to np$ are momentum-analyzed by a magnetic spectrometer and detected by a telescope of optical spark chambers with graphite electrodes, which double as scatterers for the measurement of the polarization of the particles. The angular and momentum intervals singled out by the spectrometer are determined by intervals in the γ energy, $\Delta E_\gamma = \pm 15$ and ± 20 MeV for $E_\gamma = 400$ and 500 MeV, respectively. The contribution from the empty target did not exceed 5%. An estimate of the background contributions to the proton yield from the photoproduction of pions at intranuclear nucleons has shown[2] that these contributions are less than 2% for the angle $\theta_p^* = 90°$.

In the experiments we measured the proton yields $C^{\perp}$, $C^{\|}$, and C_0 and the corresponding polarizations, $P_y^{\perp}$, $P_y^{\|}$, and P_y^0 for two directions of the photon polarization vector: perpendicular and parallel to the reaction plane. We also took measurements with an unpolarized γ beam. Using the procedure of Ref. 2, we calculated the effective γ polarization $\bar{P}_\gamma$ from the yield of recoil protons, and we calculated the asymmetry of the differential cross sections:

$$\Sigma = \frac{1}{P_\gamma}\frac{C^{\perp} - C^{\|}}{C^{\perp} + C^{\|}}. \quad (3)$$

The observables T_1 and P_y were calculated from (2). We had previously measured the asymmetry Σ and the polarization P_y in some separate polarization experiments[2,7];

TABLE I.

E_γ, MeV	$\bar{P}_\gamma$	Σ	P_y	T_1
400	0,495 ± 0,030	0,273 ± 0,035 (0,262 ± 0.051) [2]	−0,333 ± 0,047 (−0,414 ± 0,08) [7]	0,073 ± 0,095
500	0,378 ± 0,055	0,122 ± 0,045 (0,150 + 0,057) [2]	−0,402 ± 0,057 (−0,692 + 0,066) [7]	0,255 ± 0,150

we repeated these measurements in the present experiments in order to obtain information on the observables Σ, P_y, and T_1 under identical experimental conditions, with a minimum systematic error.

The experimental results are listed in Table I. Shown for comparison in parentheses are data from Refs. 2 and 7. The only significant discrepancy is for the observable P_y at $E_\gamma = 500$ MeV. The literature reveals no theoretical results with which we might compare the observable T_1, measured here for the first time.

We wish to thank M. P. Rekalo and Yu. V. Kulish for useful discussions, and we also thank V. A. Vishnyakov, V. M. Kobezskiĭ, and the staff of the linear electron accelerator for maintaining the necessary beam parameters.

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Translated by Dave Parsons
Edited by S. J. Amoretty