Polarization observables $\Sigma$, $P_y$, $T_1$ in the reaction $\gamma d \rightarrow \bar{p}n$

at photon energies between 200 and 600 MeV and dibaryon resonances


Kharkov Institute of Physics and Technology, Akademicheskaya 1, SU-310108 Kharkov, USSR

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The polarization observables $\Sigma$, $P_y$, $T_1$, $P_\perp$, $P_\parallel$ are derived in proton polarization measurements of the $\gamma d \rightarrow \bar{p}n$ reaction, using a linearly polarized photon beam of energies between 300 and 600 MeV for c.m.s. proton emission angles of 90° and 120°. A multipole analysis is performed in the framework of the gauge-invariant pole model considering the $\gamma NN \rightarrow \pi N$ amplitudes and the deuteron structure without dibaryon resonances and with different sets of isovector and isoscalar dibaryon resonances. It is shown that the inclusion of dibaryon resonances substantially improves agreement with experimental data.

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1. Introduction

The investigation of polarization observables in the deuteron photodisintegration reaction together with the $pp \rightarrow pp$, $\pi d \rightarrow \pi d$, $pd \rightarrow pp$, $\gamma d \rightarrow \pi^0 d$, $\gamma d \rightarrow pn$ processes provides information on dibaryon resonances (DR) and the quark structure of the deuteron [1-18]. The advantage of the deuteron photodisintegration reaction lies in the possibility of exciting states with the isospin $I=0$ and $I=1$. The nucleon resonance excitation in the intermediate state, $pp \rightarrow pp$, $\pi d \rightarrow \pi d$, $NN \rightarrow \pi d$, $\gamma d \rightarrow \pi^0 d$, may lead to a pseudoresonance ($\Delta N$) [15]. Among nucleon resonances, it is the $\Delta (1232)$-isobar that has the largest excitation amplitude and may give the pseudoresonance, but with $I(\Delta N) \neq 0$. Therefore, the observation of the resonant structure with $I=0$ in the $\gamma d \rightarrow pn$ reaction amplitudes would be an important evidence for the existence of DR.

The analysis of the experimental data on the proton polarization $P_0$, [1] in the $\gamma d \rightarrow pn$ reaction shows that the model considering only the contributions of the pole mechanism and the intermediate $\pi NN$-state fails to describe them. In order to describe the $d\sigma/d\Omega$ amd $P_y$ data in the energy region $E_\gamma = 350 - 700$ MeV, dibaryon resonances were included in the consideration [2]. As a result, two solutions providing a fair description of those data were obtained with different DR sets, corresponding to the quantum numbers $I(J^P) = I(3^-) + O(I^+) \text{ and } I(3^-) + O(3^-)$. However, these solutions are not in agreement with measurements of $\Sigma$, [3, 4, 5] and $T$-asymmetries [6, 7].

Four observables $d\sigma/d\Omega$, $\Sigma$, $P_y$, $T$ in the photon energy region between 160 and 400 MeV were analysed in [8, 9]. It was shown that their description was essentially improved if DR with $I(J^P) = I(0^+)$, $I(1^-)$, $I(2^-)$, $I(3^-)$ were considered. In those works, gauge-invariant amplitudes were obtained. They included the contributions from deuteron and nucleon poles in the phenomenological consideration of the deuteron structure, the intermediate $AN$-state, and a possible DR contribution. The inclusion of additional DR with $I(J^P) = O(1^+)$ and $O(3^-)$ on describing $d\sigma/d\Omega$, $\Sigma$, $P_y$, $T$ at photon energies between 160 and 500 MeV in the frame of the model similar to that of [9] has demonstrated the importance of consideration of isoscalar DR [10].

$T$-asymmetry measurements were made in [11] in the energy range from 350 to 700 MeV. Those data together with the $d\sigma/d\Omega$, $P_y$, $\Sigma$ data were included in the multipole analysis, where in addition to the $I(J^P) = I(2^-)$ and $I(3^-)$ dibaryon resonances, the DR with $I(J^P) = I(4^-)$, $O(1^+)$, $O(3^-)$ were included. The results of the analysis using the nucleon-exchange Born contribution and a single-pion absorption describe $d\sigma/d\Omega$ reasonably well, while for a proper description of $\Sigma$ and $T$ it was necessary to introduce constant background amplitudes. The behaviour of $P_y$ is not described by nonresonant amplitudes but can be explained by the contribution of the mentioned DR.

Systematic measurements of angular distributions of $T$-asymmetry in the $\gamma d \rightarrow pn$ reaction [12] point to the existence of the structure at $E_\gamma = 550$ MeV, interpreted by those authors as manifestation of DR with the angular moment $J_{\max} = 2$.

The models without DR [13, 14] provide a satisfactory description of the cross section $d\sigma/d\Omega$ and the asymmetry $\Sigma$, as opposed to the polarization $P_y$ and the $T$-
asymmetry on a polarized target. The description of the whole set of the \( \frac{d\sigma}{d\Omega}, \Sigma, P_y, T \) data proves to be unsatisfactory.

It was demonstrated in the model [17] that the consideration of DR in addition to the contributions from a set of gauge-invariant pole amplitudes, depending on relativistic deuteron wave functions, and the intermediate \( NN \)-state improves the description of \( \frac{d\sigma}{d\Omega}, \Sigma, P_y, T \) in the energy region between 250 and 600 MeV.

To substantiate the conclusion about the contribution of DR it is necessary to extend the number of the observables involved in the analysis with due improvement of their accuracy. Here, an important role may belong to double polarization experiments, which substantially extend the range of observables.

The state of nucleon polarization in the deuteron disintegration by linearly polarized photons is given by [18]:

\[
(1 + \sigma^p_{\gamma})(1 + \sigma_{\gamma}P_y - \sigma_{\gamma}P_y \Sigma + \sigma_{\gamma} \Sigma T_1) \cos \varphi
+ \sigma_{\gamma}P_y (\sigma_x O_x + \sigma_z O_z) \sin 2\varphi,
\]

where \( \sigma_x, \sigma_y, \sigma_z \) are the Pauli matrices, \( P_y \) is the degree of the photon linear polarization, \( \varphi \) is the angle between the reaction plane and the photon polarization vector, \( \frac{d\sigma}{d\Omega} \) is the differential cross section for unpolarized photons; \( P_y \) is the recoil-nucleon polarization with unpolarized photon and deuteron, \( \Sigma \) is the cross-section asymmetry in the case of linearly polarized photons, \( T_1 \) is the asymmetry of recoil-nucleon polarization due to linearly polarized photons; \( O_x, O_z \) are the components of the recoil-nucleon polarization in the reaction plane for linearly polarized photons.

We use the standard coordinate frame with the axes \( X, Y, Z \) in the c.m.s. of the photon and deuteron. The axes \( Z \) and \( Y \) are, respectively, directed along \( k \) and \( k \times p \), where \( k \) and \( p \) are the c.m.s. photon and proton momenta, correspondingly. The recoil-proton polarization states are described in the \( X', Y', Z' \) coordinate frame, where \( Y' = Y, Z' \parallel p \). The neutron polarization states are described in the \( X'', Y'', Z'' \) coordinate frame, where \( Z'' \parallel -p; Y'' \parallel k \times Z''; X'' \parallel Y'' \times Z'' \).

The recoil-proton polarization measurements at \( \varphi = 0^\circ, 90^\circ \) enabled us to determine the polarization observables \( \Sigma, P_y, T_1 \); the information of \( O_x, O_z \) was derived from measurements at \( \varphi = \pm 45^\circ \).

New measured data on the polarization observables \( \Sigma, P_y, T_1 \) in the \( \gamma d \rightarrow \bar{p}n \) double polarization reaction using a linearly polarized photon beam and the results of multipole analyses of this reaction in the frame of the gauge-invariant pole model (GIPM) [10, 16] including contributions from different sets of DR, are presented here together with some of our results reported previously [8, 16].

2. Experimental equipment and measurement procedure

2.1. A linearly polarized photon beam

The measurements were performed using the Kharkov 2 GeV electron linear accelerator facilities. The experimental layout is shown in Fig. 1. After the bending magnets, the 1.5 GeV electron beam was focused on a single-crystal radiator (3) by a set of magnetic lenses (1) of 3 mm diameter, the angular spread being \( \sim 10^{-4} \) rad. The monochromacy of the electron was \( \Delta E/E \approx 0.01 \). The mean electron beam current (\( \sim 1 \) \( \mu \)A), and size and position of the beam on the single crystal were continuously controlled by a secondary emission system (2).

A beam of linearly polarized quasimonochromatic photons was produced by the process of coherent bremsstrahlung of electrons in a diamond single crystal [19, 20, 21]. The thickness of diamond single crystals was chosen in accordance with the cross section value for the process under study and was 1 and 2 mm. The crystal orientation relative to the momentum of the initial electron was accomplished with a goniometer (3) providing an accuracy of reading the angle of crystal rotation around vertical and horizontal axes to \( 5 \times 10^{-5} \) rad. The direction of the photon polarization vector was changed by rotating the single crystal target around the third azimuthal axis to an accuracy of \( 0.1^\circ \). The highest photon beam polarization was attained with a crystal orientation chosen so that the main contribution to the coherent bremsstrahlung cross section was from a single reciprocal lattice point (2, 2, 0).

The photon beam was formed by an array of cleaning magnets (4) and collimators (5) on a liquid deuterium target (6), which was 200 mm in length along the beam axis and 40 mm in diameter [22]. The intensity of the beam from the 2 mm thick diamond single crystal was measured to be \( 2 \times 10^{10} \) eq.s/s at a collimation angle \( Q_e = 5 \times 10^{-4} \) rad. This value continuously monitored by a Wilson quantameter (7).

2.2. Magnetic spectrometers

The secondary protons in the channel of recoil-proton polarization measurements were detected by their momentum and emission angle using the magnetic spectrom-