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GENERAL ANALYSIS OF POLARIZATION OBSERVABLES IN THE REACTION $e^- + d \to e^- + \pi^0 + d$

A.G. Gakh
V.N. Karazin Kharkov National University, Dept. of Physics and Technology
31 Kurchatov, 61108, Kharkov, Ukraine
E-mail: agakh@mail.ru
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A general analysis of expressions for polarization observables in the reaction of coherent pseudoscalar meson electroproduction on deuteron has been derived. This analysis does not depend on details of reaction mechanisms since it based on general symmetry properties of the electromagnetic interaction with hadrons. Expressions for the following polarization observables have been obtained: the asymmetries caused by the vector or tensor polarized deuteron target, the spin correlation coefficients which describe the dependence of the cross section on deuteron target polarization and longitudinal polarization of the electron beam and the asymmetry due to the longitudinal polarization of the electron beam. The experimental situation, when final deuteron and scattered electron are detected in coincidence, has been considered.
KEY WORDS: polarization observables, cross section, asymmetry, electron, deuteron, meson electroproduction.

ОБЩИЙ АНАЛИЗ ПОЛЯРИЗАЦИОННЫХ НАБЛЮДАЕМЫХ В РЕАКЦИИ $e^- + d \to e^- + \pi^0 + d$

А.Г. Гах
Харьковский национальный университет им. В.Н. Каразина, физико-технический факультет
пр. Курчатова 31, 61108, Харьков

Выполнен общий анализ выражений для поляризационных наблюдаемых в реакции когерентного электрообразования псевдоскалярного мезона на дейтроне. Этот анализ не зависит от деталей механизмов реакции, так как он основан на общих свойствах симметрии электромагнитного взаимодействия адронов. Получены выражения для следующих поляризационных наблюдаемых: асимметрии, обусловленные векторной или тензорной поляризациями дейтронной мишени; коэффициенты спиновой корреляции, которые описывают зависимость сечения от поляризации дейтронной мишени и продольной поляризации электронного пучка; асимметрия, обусловленная продольной поляризацией электронного пучка. Рассмотрена экспериментальная постановка опыта, когда конечный дейтрон и рассеянный электрон детектируются на совпадение.
КЛЮЧЕВЫЕ СЛОВА: поляризационные наблюдаемые, сечение, асимметрия, электрон, дейтрон, электрообразование мезона.

ЗАГАЛЬНИЙ АНАЛІЗ ПОЛЯРИЗАЦІЙНИХ СПОСТЕРЕЖУВАНИХ У РЕАКЦІЇ $e^- + d \to e^- + \pi^0 + d$

А.Г. Гах
Харківський національний університет ім. В.Н. Каразіна, фізико-технічний факультет
пр. Курчатова 31, 61108, Харків

Виконано загальний аналіз виразів для поляризаційних спостережуваних у реакції когерентного електроутворення псевдоскалярного мезона на дейтроні. Цей аналіз не залежить від деталей механізмів реакції тому що він базується на загальних властивостях симетрії електромагнітної взаємодії адронів. Отримані вирази для наступних поляризаційних спостережуваних: асиметрії, які обумовлені векторною або тензорною поляризаціями дейтронної мішені; коефіцієнти спінової кореляції, які описують залежність переріза від поляризації дейтронної мішені та повздовжньої поляризації електронного пучка; асиметрія, яка обумовлена повздовжньою поляризацією електронного пучка. Розглянута експериментальна постановка коли кінцевий дейтрон і електрон який розсіюється детектуються на збіг.
КЛЮЧОВІ СЛОВА: поляризаційні спостережувані, переріз, асиметрія, електрон, дейтрон, електроутворення мезона.

A complete characterization of the photo- and electroproduction amplitudes for mesons requires measurements off the neutron which must rely on meson production by real or virtual photons from light nuclei. It is known that deuteron is used as neutron target. The experiments with deuteron targets have been done and are being performed. Recent studies of the meson photoproduction are reviewed in [1].

In the last decade the progress in the investigation of the meson production by the electromagnetic probes has been substantial and we moved forward in understanding of the resonance properties.

The data on pion production in electron-deuteron collisions are scarce. The experimental studies of this reaction is now possible at Mainz and JLab due to the high-duty cycle of the accelerators. Threshold π^0-meson electroproduction on protons and deuteron has been investigated by the A1 collaboration at Mainz [2] at small $Q^2 \le 0.1$ GeV^2. The first experimental results for the coherent π^0-meson electroproduction off the deuteron at large Q^2, $1.1 < Q^2 < 1.8$ GeV^2, from the threshold to 200 MeV excitation energy in the $d\pi^0$ system, are reported in Ref. [3]. This data were collected during the t_{20} experiment, the primary aim of which was the measurement of the deuteron tensor polarization in elastic electron-deuteron scattering [4].

A theoretical study of the coherent pseudoscalar meson photo- and electroproduction on the deuteron target was considered in a number of papers [5-13]. The reaction of the neutral pion photoproduction on deuterons in the threshold region was considered in Ref. [5]. The reaction was studied in the framework of baryon chiral perturbation theory beyond next-to-leading order in the chiral expansion. A general analysis limited to coherent pion photoproduction on deuterons was first published in Ref. [6], where the analysis of different polarization observables was done searching sensitivity to possible dibaryon contributions. A study of the polarization phenomena in this reaction was continued in Refs. [7, 8]. Spin observables for electro- and photoproduction of neutral pions on the deuteron have been derived in Ref. [7]. The expression of the observables in terms of ratios of cross section combinations was given. But there is no expression for the reaction amplitude in terms of 13 independent amplitudes and polarization observables were not represented in terms of independent amplitudes. The cross section and polarization observables corresponding to the polarized photon beam and/or the deuteron target were calculated in the Δ resonance region using a nonrelativistic model based on time-ordered perturbation theory without rescattering [8]. The coherent neutral pion production on deuterons by virtual photon, electroproduction, was considered in Refs. [9-13]. Near threshold neutral pion electroproduction on deuterons was studied in Ref. [9] in the framework of approach similar to one used in Ref. [5]. A new form of the multipole expansion particularly suited for the threshold region was presented in this paper. In the next paper [10] these authors improved their previous analysis of the reaction $\mathrm{e^-d \to e^-\pi^0 d}$. They include the next-to-leading order corrections to the three-body (meson exchange currents) contributions. An improved description of the total and differential cross section data measurements at MAMI has been obtained. A general analysis which independent on the structure of a spin-one target has been done in Refs. [11, 12]. In first paper, a set of 13 linearly independent invariant amplitudes for the reaction $\mathrm{e^-d \to e^-\pi^0 d}$ were derived which respect Lorentz and gauge invariance. A reduction of these amplitudes to operators acting in non-relativistic spin space was given. The helicity amplitudes were derived also. In second paper, the crossing properties of the invariant amplitudes were discussed in detail. The multipole decomposition was given also. The differential cross section and polarization observables were considered in the general form. There are no expressions of the corresponding polarization observables (such as asymmetries and analyzing powers) in terms of the reaction amplitudes. A general analysis of various observables for coherent pion electroproduction on deuterons was done in Ref. [13]. The spin and isospin structures of the $\mathrm{e^-d \to e^-\pi^0 d}$ amplitudes were established and relationships between meson electroproduction on deuterons and on nucleons were given in the framework of the impulse approximation. This reaction has been investigated in detail both at threshold and in the region of Δ- isobar excitation. There are also no corresponding observables in terms of the reaction amplitudes. Some formulas of this paper must be corrected since there are some mistakes.

The experimental investigation of the nucleon resonance properties by means of the meson production processes can be used for the verification of the modern models of the hadron structure. The production of the neutral mesons by the real or virtual photons is of special interest since background contributions in these reactions are suppressed due to the weak coupling of the photon with neutral mesons.

The aim of this paper is to perform the model independent analysis of the polarization observables using the formalism which is based on general properties of the electromagnetic interaction with hadrons. We derive the expressions of the polarization observables (such as the asymmetry due to the longitudinal polarization of the electron beam and analyzing powers caused by the vector- and tensor-polarized deuteron target) in terms of the reaction scalar amplitudes. We obtain the explicit dependence of the polarization observables on the azimuthal angle (the angle between the electron scattering plane and the pion production plane) and on the virtual photon linear polarization.

MATRIX ELEMENT AND DIFFERENTIAL CROSS SECTION

The general structure of the differential cross section for the $e^- + d \to e^- + d + P^0$ reaction, where P^0 is a neutral pseudoscalar meson (π^0 or η), can be determined in the framework of the one–photon–exchange mechanism. The formalism in this section is based on the most general symmetry properties of the electromagnetic interaction with hadrons, such as the gauge invariance (the conservation of the hadronic and leptonic electromagnetic currents) and P–invariance (the invariance with respect to the space reflections) and does not depend on the deuteron structure and on the details of the reaction mechanism for $e^- + d \to e^- + d + P^0$. In the one–photon–exchange approximation, the matrix element for the process of the coherent P^0–meson electroproduction on the deuteron

$$e^-(k_1) + d(p_1) \to e^-(k_2) + d(p_2) + P^0(q) \tag{1}$$

(the four–momenta of the corresponding particles are indicated in the brackets) can be written as

$$M(ed\to edP)=\frac{e^2}{k^2}j_\mu J_\mu,\quad j_\mu=\overline{u}(k_2)\gamma_\mu u(k_1),\quad J_\mu=<dP|\hat{J}_\mu|d>, \tag{2}$$

where $k=k_1-k_2$ is the virtual–photon four–momentum and J_μ is the electromagnetic current describing the transition $\gamma^*+d\to d+P^0$ (γ^* is the virtual photon).

The electromagnetic structure of nuclei, as probed by elastic and inelastic electron scattering by nuclei, can be characterized by a set of response functions or structure functions [14]. Each of these structure functions is determined by different combinations of the longitudinal and transverse components of the electromagnetic current J_μ, thus providing different information about the nuclear structure or possible mechanisms of the reaction under consideration. Those ones, which are determined by the real parts of the bilinear combinations of the reaction amplitudes, are nonzero in the impulse approximation, other ones, which originate from the imaginary part of structure functions, vanish if the final state interaction is not taken into account.

The formalism of the structure functions is especially convenient for the investigation of polarization phenomena in the reaction (1).

Using the conservation of the leptonic j_μ and hadronic J_μ electromagnetic currents ($k\cdot j=k\cdot J=0$), one can rewrite the matrix element (2) in terms of space components of these currents only

$$M(ed\to edP)=\frac{e^2}{k^2}\vec{e}\vec{J},\quad \vec{e}=\frac{\vec{j}\cdot\vec{k}}{k_0^2}\vec{k}-\vec{j}, \tag{3}$$

where $k=(k_0,\vec{k})$ and $k_0(\vec{k})$ is the energy (three–momentum) of the virtual photon in CMS of the $\gamma^*+d\to d+P^0$ reaction. All observables will be determined by bilinear combinations of the space components of the hadronic current $\vec{J}: H_{ab}=J_aJ_b^*$. As a result, we obtain the following general structure of the differential cross section for the reaction (1), when the scattered electron and P^0–meson are detected in coincidence, and the electron beam is longitudinally polarized (the polarization states of the deuteron target and scattered deuteron can be any)

$$\frac{d^3\sigma}{dE'd\Omega_e d\Omega_P}=N\Big[H_{xx}+H_{yy}+\varepsilon\cos(2\varphi)(H_{xx}-H_{yy})+\varepsilon\sin(2\varphi)(H_{xy}+H_{yx})-2\varepsilon\frac{k^2}{k_0^2}H_{zz}-$$
$$-\frac{\sqrt{-k^2}}{k_0}\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi(H_{xz}+H_{zx})-\frac{\sqrt{-k^2}}{k_0}\sqrt{2\varepsilon(1+\varepsilon)}\sin\varphi(H_{yz}+H_{zy})\mp i\lambda\sqrt{1-\varepsilon^2}(H_{xy}-H_{yx})\mp$$
$$\mp i\lambda\frac{\sqrt{-k^2}}{k_0}\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi(H_{yz}-H_{zy})\pm i\lambda\frac{\sqrt{-k^2}}{k_0}\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi(H_{xz}-H_{zx})\Big], \tag{4}$$

$$N=\frac{\alpha^2}{64\pi^3}\frac{E'}{E}\frac{|\vec{q}\,|}{MW}\frac{1}{1-\varepsilon}\frac{1}{(-k^2)},\qquad \varepsilon^{-1}=1-2\frac{\vec{k}^2_{Lab}}{k^2}\tan^2\left(\frac{\theta_e}{2}\right),$$
$$|\vec{k}\,|=\frac{1}{2W}\sqrt{(W^2+M^2-k^2)^2-4M^2W^2},\qquad |\vec{q}\,|=\frac{1}{2W}\sqrt{(W^2+M_P^2-M^2)^2-4M_P^2W^2}.$$

The z axis is directed along the virtual photon momentum $\vec{k}$, the momentum of the detected *P*–meson $\vec{q}$ lies in the xz plane (reaction plane); $E(E')$ is the energy of the initial (scattered) electron in the deuteron rest frame (laboratory system); $d\Omega_e$ is the solid angle of the scattered electron in the laboratory (Lab) system, $d\Omega_P(q)$ is the solid angle (value of the three-momentum) of the detected *P*–meson in the *Pd*–pair center–of–mass system (CMS), M_P ,M are the masses of the *P*–meson, deuteron, respectively; φ is the azimuthal angle between the electron scattering plane and the plane where the detected *P*–meson lies (*xz*), $k_0=(W^2+k^2-M^2)/2W$ is the virtual photon energy in the *Pd*–pair CMS, W is the invariant mass of the final hadrons, $W^2=M^2+k^2+2M(E-E')$; λ is the degree of the electron longitudinal polarization, ε is the degree of the linear polarization of the virtual photon. The upper (bottom) sign in this formula corresponds to the electron (positron) scattering. This expression is valid for zero electron mass. Below we will neglect it wherever possible.

Let us introduce, for convenience and simplifying of following calculations of polarization characteristics, the orthonormal system of basic unit $\vec{m}$, $\vec{n}$, and $\hat{\vec{k}}$ vectors which are built from the momenta of the particles participating in the reaction under consideration

$$\hat{\vec{k}} = \frac{\vec{k}}{|\vec{k}|}, \qquad \vec{n} = \frac{\vec{k}\times\vec{q}}{|\vec{k}\times\vec{q}|}, \qquad \vec{m} = \vec{n}\times\hat{\vec{k}}\ . \tag{5}$$

The unit vectors $\hat{\vec{k}}$ and $\vec{m}$ define the $\gamma^* + d \to d + P$ reaction *xz*–plane (*z* axis is directed along the three–momentum of the virtual photon $\vec{k}$, and *x* axis is directed along the unit vector $\vec{m}$), and the unit vector $\vec{n}$ is perpendicular to the reaction plane.

First of all, let us establish the spin structure of the matrix element for the $\gamma^* + d \to d + P$ reaction without any constraint on the kinematical conditions.

The amplitude spin structure can be parameterized by different (and equivalent) methods, but for the analysis of the polarization phenomena the choice of the *transverse amplitudes* is sometimes preferable. Taking into account the *P*–invariance of the electromagnetic interaction with hadrons, the dependence of the $\gamma^* + d \to d + P$ amplitude on the virtual–photon polarization vector and polarization three vectors $\vec{D}_1$ and $\vec{D}_2$ of the initial and final deuterons is given by

$$\begin{aligned} F\left(\gamma^* d \to dP\right) = {} & \vec{e}\cdot\vec{m}\left(g_1\vec{m}\cdot\vec{D}_1\vec{n}\cdot\vec{D}_2^* + g_2\hat{\vec{k}}\cdot\vec{D}_1\vec{n}\cdot\vec{D}_2^* + g_3\vec{n}\cdot\vec{D}_1\vec{m}\cdot\vec{D}_2^* + g_4\vec{n}\cdot\vec{D}_1\hat{\vec{k}}\cdot\vec{D}_2^*\right) + \\ & + \vec{e}\cdot\vec{n}\left(g_5\vec{m}\cdot\vec{D}_1\vec{m}\cdot\vec{D}_2^* + g_6\vec{n}\cdot\vec{D}_1\vec{n}\cdot\vec{D}_2^* + g_7\hat{\vec{k}}\cdot\vec{D}_1\hat{\vec{k}}\cdot\vec{D}_2^* + g_8\vec{m}\cdot\vec{D}_1\hat{\vec{k}}\cdot\vec{D}_2^* + g_9\hat{\vec{k}}\cdot\vec{D}_1\vec{m}\cdot\vec{D}_2^*\right) + \\ & + \vec{e}\cdot\hat{\vec{k}}\left(g_{10}\vec{m}\cdot\vec{D}_1\vec{n}\cdot\vec{D}_2^* + g_{11}\hat{\vec{k}}\cdot\vec{D}_1\vec{n}\cdot\vec{D}_2^* + g_{12}\vec{n}\cdot\vec{D}_1\vec{m}\cdot\vec{D}_2^* + g_{13}\vec{n}\cdot\vec{D}_1\hat{\vec{k}}\cdot\vec{D}_2^*\right), \end{aligned} \tag{6}$$

where g_i (i = 1 − 13) are the scalar amplitudes, depending on three variables k^2, W and ϑ (ϑ is the angle between the virtual photon and *P*–meson momenta in the $\gamma^* + d \to d + P$ reaction CMS), which completely determine the reaction dynamics. If we single out the virtual–photon polarization vector $\vec{e}$, we can write down the amplitude *F* as follows $F = F_i e_i$ and the hadronic tensor can be written in terms of F_i as

$$H_{ij} = F_i F_j^*\ . \tag{7}$$

The process $\gamma^* + d \to d + P$ is described in the general case by a set of nine amplitudes for the absorption of a virtual photon with transverse polarization and four amplitudes for the absorption of a virtual photon with longitudinal polarization. Number of these amplitudes is determined by the values of the spins of the particles and by the *P*–invariance of hadron electrodynamics. Therefore, the complete experiment requires, at least, the measurement of 25 observables. Let us mention in this respect specific properties of polarization phenomena for inelastic electron– hadron scattering: in exclusive $e^- + d \to e^- + d + P$ processes the virtual photon has a nonzero linear polarization, even for the scattering of unpolarized electrons by an unpolarized deuterons target.

POLARIZATION STATE OF DEUTERON TARGET

Let us consider the general case of the polarization state for the deuteron target which is described by the spin–density matrix. We use the following general expression for the deuteron spin–density matrix in the coordinate representation [15]

$$\rho_{\mu\nu} = -\frac{1}{3}\left(g_{\mu\nu} - \frac{p_{1\mu}p_{1\nu}}{M^2}\right) - \frac{i}{2M}\varepsilon_{\mu\nu\alpha\beta}s_\alpha p_{1\beta} + S_{\mu\nu}\ , \tag{8}$$

where s_α is the four–vector describing the vector polarization of the target, $s^2 = -1$, $s\cdot p_1 = 0$ and $S_{\mu\nu}$ is the tensor describing the tensor (quadrupole) polarization of the target, $S_{\mu\nu} = S_{\nu\mu}$, $p_{1\mu}S_{\mu\nu} = 0$, $S_{\mu\mu} = 0$ (due to these properties the tensor $S_{\mu\nu}$ has only five independent components). In Lab system all time components of the tensor $S_{\mu\nu}$ are zero and the tensor polarization of the target is described by five independent space components ($S_{ij} = S_{ji}$, $S_{ii} = 0$; $i, j = x, y, z$). The four–vector s_α is related to the unit vector $\vec{\xi}$ of the deuteron vector polarization in its rest system: $s_0 = -\vec{k}\vec{\xi}/M$, $\vec{s} = \vec{\xi} + \vec{k}\left(\vec{k}\vec{\xi}\right)/M\left(M + E_1\right)$, E_1 is the deuteron– target energy in the $\gamma^* + d \to d + P$ reaction CMS.

The hadronic tensor H_{ij} ($i, j = x, y, z$) depends linearly on the target polarization and it can be represented as follows

$$H_{ij} = H_{ij}(0) + H_{ij}(\xi) + H_{ij}(S), \tag{9}$$

where the term $H_{ij}(0)$ corresponds to the case of the unpolarized deuteron target, and the term $H_{ij}(\xi)$ ($H_{ij}(S)$) corresponds to the case of the vector (tensor-)-polarized target.

UNPOLARIZED DEUTERON TARGET

The general structure of the part of the hadronic tensor which corresponds to the unpolarized deuteron target has following form

$$H_{ij}(0) = h_1 m_i m_j + h_2 n_i n_j + h_3 \hat{k}_i \hat{k}_j + h_4 \left\{m, \hat{k}\right\}_{ij} + i h_5 \left[m, \hat{k}\right]_{ij}, \tag{10}$$

where $\{a,b\}_{ij} = a_i b_j + a_j b_i$, $[a,b]_{ij} = a_i b_j - a_j b_i$ and the real structure functions h_i depend on three invariant variables $s = W^2 = (k + p_1)^2$, k^2 and $t = (k - p_1)^2$. The structure functions $h_1 - h_4$ determine the cross section for the $e^- + d \to e^- + d + P$ reaction with unpolarized particles. Let us emphasize that the structure function h_5 (the so–called fifth structure function) determines the asymmetry of longitudinally polarized electrons scattered by an unpolarized target and is determined by the strong interaction effects of the *P*–meson and deuteron in the final state and it vanishes for the pole diagram contribution in all kinematic range (independently on the particular parametrization of the $\gamma^* N \to NP$ amplitude and *dnp*–vertex). This is true for the nonrelativistic approach and for the relativistic one as well, in describing the $\gamma^* + d \to d + P$ reaction. The scattering of longitudinally polarized electrons by unpolarized deuteron target allows to determine the h_5 contribution. Then the corresponding asymmetry is determined only by the strong interaction effects. More exactly, it is determined by the effects arising from nonpole mechanisms of various nature (meson exchange currents can also induce nonzero asymmetry).

The structure functions $h_1 - h_5$ corresponding to the interaction of the virtual photon with an unpolarized deuteron target can be written, in terms of the scalar amplitudes $g_1 - g_{13}$ describing the $\gamma^* + d \to d + P$ reaction, as

$$\begin{aligned}
h_1 &= \frac{1}{3}\left[|g_1|^2 + \gamma_1^2 |g_2|^2 + a|g_3|^2 + b|g_4|^2 + 2c\,\mathrm{Re}\,g_3 g_4^*\right],\\
h_2 &= \frac{1}{3}\left[|g_6|^2 + a\left(|g_5|^2 + \gamma_1^2|g_9|^2\right) + b\left(|g_8|^2 + \gamma_1^2|g_7|^2\right) + 2c\,\mathrm{Re}\left(g_5 g_9^* + \gamma_1^2 g_7 g_9^*\right)\right],\\
h_3 &= \frac{1}{3}\left[|g_{10}|^2 + \gamma_1^2|g_{11}|^2 + a|g_{12}|^2 + b|g_{13}|^2 + 2c\,\mathrm{Re}\,g_{12} g_{13}^*\right],\\
h_4 &= \mathrm{Re}\,A_1, \qquad h_5 = \mathrm{Im}\,A_1, \qquad A_1 = \frac{1}{3}\left[g_1 g_{10}^* + \gamma_1^2 g_2 g_{11}^* + a g_3 g_{12}^* + b g_4 g_{13}^* + c\left(g_3 g_{13}^* + g_4 g_{12}^*\right)\right],\\
a &= 1 + \frac{\vec{q}^{\,2}}{M^2}\sin^2\vartheta, \qquad b = 1 + \frac{\vec{q}^{\,2}}{M^2}\cos^2\vartheta, \qquad c = \frac{\vec{q}^{\,2}}{M^2}\cos\vartheta\sin\vartheta, \qquad \gamma_1 = \frac{E_1}{M},
\end{aligned} \tag{11}$$

where $\vec{q}$ is the *P*–meson momentum in the $\gamma^* + d \to d + P$ reaction CMS and ϑ is the angle between the pseudoscalar meson and virtual photon momenta in this system.

In the one–photon–exchange approximation, the general structure of the differential cross section for the reaction $d(\vec{e}, e'P)d$ (in the case of longitudinally polarized electron beam and unpolarized deuteron target) can be written in terms of five independent contributions [15]

$$\frac{d^3\sigma}{dE' d\Omega_e d\Omega_P} = N\left[\sigma_T + \varepsilon\sigma_L + \varepsilon\cos(2\varphi)\sigma_P + \sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi\,\sigma_I + \lambda\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi\,\sigma_I'\right], \tag{12}$$

where the individual contributions are related to the structure functions of the spin–independent hadronic tensor, Eq. (10), by:

$$\sigma_T = h_1 + h_2, \quad \sigma_P = h_1 - h_2, \quad \sigma_L = -2\frac{k^2}{k_0^2}h_3, \quad \sigma_I = -2\frac{\sqrt{-k^2}}{k_0}h_4, \quad \sigma_I' = -2\frac{\sqrt{-k^2}}{k_0}h_5. \tag{13}$$

One can see from this equation that there exists the single–spin asymmetry caused by the longitudinal polarization of the electron beam and it is defined as [15]

$$\Sigma_e(\varphi)=\frac{d\sigma(\lambda=+1)-d\sigma(\lambda=-1)}{d\sigma(\lambda=+1)+d\sigma(\lambda=-1)}=\frac{\sin\varphi\sqrt{2\varepsilon(1-\varepsilon)}\,\sigma_I'}{\sigma_T+\varepsilon\sigma_L+\varepsilon\cos(2\varphi)\sigma_P+\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi\sigma_I}. \quad (14)$$

Due to the φ–dependence, this asymmetry has to be measured in noncoplanar geometry (out– of–plane kinematics).

We see that this asymmetry is determined by the structure function h_5 which is defined by the interference of the reaction amplitudes that characterize the absorption of virtual photons with nonzero longitudinal and transverse components of the electromagnetic current corresponding to the process $\gamma^*+d\to d+P$. One finds that $h_5\propto\sin\vartheta$ for any mechanism of the $\gamma^*+d\to d+P$ reaction. It vanishes at *P*–meson emission angles $\vartheta=0^0$ and $\vartheta=180^0$ due to the conservation of the total helicity of the interacting particles in the $\gamma^*+d\to d+P$ reaction. The structure function h_5 is nonzero only if the complex amplitudes of the $\gamma^*+d\to d+P$ reaction have nonzero relative phases. This is a very specific observable, which has no corresponding quantity in the process of the *P*–meson photoexcitation on the deuteron $\gamma+d\to d+P$.

VECTOR–POLARIZED DEUTERON TARGET

The part of the hadronic tensor depending on the deuteron vector polarization has following general structure:

$$\begin{aligned}H_{ij}(\xi)&=\vec{\xi}\vec{m}\left(h_6\{m,n\}_{ij}+h_7\{\hat{k},n\}_{ij}+ih_8[m,n]_{ij}+ih_9[\hat{k},n]_{ij}\right)+\\&+\vec{\xi}\vec{n}\left(h_{10}m_im_j+h_{11}n_in_j+h_{12}\hat{k}_i\hat{k}_j+h_{13}\{m,\hat{k}\}_{ij}+ih_{14}[m,\hat{k}]_{ij}\right)+\\&+\vec{\xi}\hat{\vec{k}}\left(h_{15}\{m,n\}_{ij}+h_{16}\{\hat{k},n\}_{ij}+ih_{17}[m,n]_{ij}+ih_{18}[\hat{k},n]_{ij}\right).\end{aligned} \quad (15)$$

The structure functions h_6-h_{18} which describe the effects of the vector polarization of the deuteron target can be written, in terms of the scalar amplitudes g_1-g_{13} describing the $\gamma^*+d\to d+P$ reaction, as

$$\begin{aligned}&h_6=-\frac{1}{2}\mathrm{Im}A_2,\quad h_7=-\frac{1}{2}\mathrm{Im}A_3,\quad h_8=\frac{1}{2}\mathrm{Re}A_2,\quad h_9=-\frac{1}{2}\mathrm{Re}A_3,\\&A_2=g_2g_6^*-ag_3g_9^*-bg_4g_7^*-c(g_3g_7^*+g_4g_9^*),\quad A_3=-g_6g_{11}^*+ag_9g_{12}^*+bg_7g_{13}^*+c(g_9g_{13}^*+g_7g_{12}^*),\\&h_{10}=-\mathrm{Im}\,g_1g_2^*,\quad h_{11}=\mathrm{Im}[-ag_5g_9^*+bg_7g_8^*-c(g_5g_7^*+g_8g_9^*)],\\&h_{12}=-\mathrm{Im}\,g_{10}g_{11}^*,\quad h_{13}=-\frac{1}{2}\mathrm{Im}(g_1g_{11}^*-g_2g_{10}^*),\quad h_{14}=\frac{1}{2}\mathrm{Re}(g_1g_{11}^*-g_2g_{10}^*),\\&h_{15}=-\frac{1}{2}\mathrm{Im}A_4,\quad h_{16}=-\frac{1}{2}\mathrm{Im}A_5,\quad h_{17}=\frac{1}{2}\mathrm{Re}A_4,\quad h_{18}=-\frac{1}{2}\mathrm{Re}A_5,\\&A_4=-g_1g_6^*+ag_3g_5^*+bg_4g_8^*+c(g_3g_8^*+g_4g_5^*),\quad A_5=g_6g_{10}^*-ag_5g_{12}^*-bg_8g_{13}^*-c(g_5g_{13}^*+g_8g_{12}^*).\end{aligned} \quad (16)$$

Therefore, the dependence of the polarization observables on the deuteron vector polarization is determined by 13 structure functions. On the basis of this formula one can make the following general conclusions:

1. If the deuteron is vector–polarized and the vector of this polarization is perpendicular to the $\gamma^*+d\to d+P$ reaction plane, then the dependence of the differential cross section of the $e^-+d\to e^-+d+P$ reaction on the ε and φ variables is the same as in the case of the unpolarized target, and the nonvanishing components of the $H_{ij}(\xi)$ tensor are:

$$\begin{aligned}&H_{xx}(\xi)\pm H_{yy}(\xi)=(h_{10}\pm h_{11})\vec{\xi}\vec{n},\qquad H_{zz}(\xi)=h_{12}\vec{\xi}\vec{n},\\&H_{xz}(\xi)+H_{zx}(\xi)=2h_{13}\vec{\xi}\vec{n},\qquad H_{xz}(\xi)-H_{zx}(\xi)=2ih_{14}\vec{\xi}\vec{n}.\end{aligned} \quad (17)$$

2. If the deuteron target is polarized in the $\gamma^*+d\to d+P$ reaction plane (in direction of the vector $\vec{k}$ or $\vec{m}$), then the dependence of the differential cross section of the $e^-+d\to e^-+d+P$ reaction on the ε and φ variables is:

• for deuteron disintegration by unpolarized electron beam:

$$\varepsilon\sin(2\varphi),\qquad \sqrt{2\varepsilon(1+\varepsilon)}\sin\varphi, \quad (18)$$

• for deuteron disintegration by longitudinally polarized electron beam:

$$\pm i\lambda\sqrt{1-\varepsilon^2}, \qquad \mp i\lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi. \tag{19}$$

The differential cross section of the reaction $\vec{d}(\vec{e},e'P)d$, where the electron beam is longitudinally polarized and the deuteron target is vector–polarized, can be written as follows:

$$\frac{d^3\sigma}{dE'd\Omega_e d\Omega_P} = \sigma_0\left[1+\lambda\Sigma_e + \left(A_x^d+\lambda A_x^{ed}\right)\xi_x + \left(A_y^d+\lambda A_y^{ed}\right)\xi_y + \left(A_z^d+\lambda A_z^{ed}\right)\xi_z\right], \tag{20}$$

where σ_0 is the unpolarized differential cross section, Σ_e is the beam analyzing power (the asymmetry induced by the electron–beam polarization), A_i^d ($i=x,y,z$) are the analyzing powers due to the vector polarization of the deuteron target, and A_i^{ed} ($i=x,y,z$) are the spin– correlation parameters. The direction of the deuteron polarization vector is defined by the angles ϑ^*, φ^* in the frame where the z axis is along the direction of the three–momentum transfer $\vec{k}$ and the y axis is defined by the vector product of the detected P– meson and virtual photon momenta (along the unit vector $\vec{n}$). The target analyzing powers and spin–correlation parameters depend on the orientation of the deuteron polarization vector. The quantities $\sum_e$ and A_i^d are T–odd observables and they are completely determined by the reaction mechanism beyond the impulse approximation, for example, by the final–state interaction effects. On the contrary, the quantities A_i^{ed} are T–even observables and they do not vanish in the absence of the final–state interaction effects.

The expressions of the A_i^d and A_i^{ed} asymmetries can be explicitly written as functions of the azimuthal angle φ, of the virtual–photon linear polarization ε, and of contributions of the longitudinal (L) and transverse (T) components (relative to the virtual–photon momentum $\vec{k}$) of the hadron electromagnetic current of the $\gamma^*+d\to d+P$ reaction:

$$\begin{aligned}
A_x^d\sigma_0 &= N\sin\varphi\left[\sqrt{2\varepsilon(1+\varepsilon)}A_x^{(LT)}+\varepsilon\cos\varphi A_x^{(TT)}\right],\\
A_z^d\sigma_0 &= N\sin\varphi\left[\sqrt{2\varepsilon(1+\varepsilon)}A_z^{(LT)}+\varepsilon\cos\varphi A_z^{(TT)}\right],\\
A_y^d\sigma_0 &= N\left[A_y^{(TT)}+\varepsilon A_y^{(LL)}+\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi A_y^{(LT)}+\varepsilon\cos(2\varphi)\overline{A}_y^{(TT)}\right],\\
A_x^{ed}\sigma_0 &= N\left[\sqrt{1-\varepsilon^2}B_x^{(TT)}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi B_x^{(LT)}\right],\\
A_z^{ed}\sigma_0 &= N\left[\sqrt{1-\varepsilon^2}B_z^{(TT)}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi B_z^{(LT)}\right],\\
A_y^{ed}\sigma_0 &= N\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi B_y^{(LT)},
\end{aligned} \tag{21}$$

where the individual contributions to the considered asymmetries in terms of the structure functions h_i are given by

$$\begin{aligned}
&A_x^{(TT)}=4h_6,\quad A_y^{(TT)}=h_{10}+h_{11},\quad \overline{A}_y^{(TT)}=h_{10}-h_{11},\quad A_z^{(TT)}=4h_{15},\\
&A_x^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_7,\quad A_y^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_{13},\quad A_z^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_{16},\quad A_y^{(LL)}=2\frac{Q^2}{k_0^2}h_{12},\\
&B_x^{(TT)}=2h_8,\quad B_z^{(TT)}=2h_{17},\quad B_x^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_9,\quad B_y^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_{14},\quad B_z^{(LT)}=-2\frac{\sqrt{Q^2}}{k_0}h_{18},
\end{aligned} \tag{22}$$

where $Q^2=-k^2$. At this stage, the general model–independent analysis of the polarization observables in the reactions $\vec{d}(e,e'P)d$ and $\vec{d}(\vec{e},e'P)d$ is completed. To proceed further in the calculation of the observables, one needs a model for the reaction mechanism and for the deuteron structure.

TENSOR–POLARIZED DEUTERON TARGET

The part of the hadronic tensor $H_{ij}(S)$, which depends on the deuteron tensor polarization, has the following general structure:

$$H_{ij}(S) = S_{ab}m_a m_b\left(h_{19}m_i m_j + h_{20}n_i n_j + h_{21}\hat{k}_i\hat{k}_j + h_{22}\left\{m,\hat{k}\right\}_{ij} + ih_{23}\left[m,\hat{k}\right]_{ij}\right) +$$
$$+ S_{ab}n_a n_b\left(h_{24}m_i m_j + h_{25}n_i n_j + h_{26}\hat{k}_i\hat{k}_j + h_{27}\left\{m,\hat{k}\right\}_{ij} + ih_{28}\left[m,\hat{k}\right]_{ij}\right) +$$
$$+ S_{ab}m_a\hat{k}_b\left(h_{29}m_i m_j + h_{30}n_i n_j + h_{31}\hat{k}_i\hat{k}_j + h_{32}\left\{m,\hat{k}\right\}_{ij} + ih_{33}\left[m,\hat{k}\right]_{ij}\right) + \quad (23)$$
$$+ S_{ab}m_a n_b\left(h_{34}\left\{m,n\right\}_{ij} + h_{35}\left\{\hat{k},n\right\}_{ij} + ih_{36}\left[m,n\right]_{ij} + ih_{37}\left[\hat{k},n\right]_{ij}\right) +$$
$$+ S_{ab}\hat{k}_a n_b\left(h_{38}\left\{m,n\right\}_{ij} + h_{39}\left\{\hat{k},n\right\}_{ij} + ih_{40}\left[m,n\right]_{ij} + ih_{41}\left[\hat{k},n\right]_{ij}\right).$$

The structure functions $h_{19} - h_{41}$ which describe the effects of the tensor polarization of the deuteron target can be written, in terms of the scalar amplitudes $g_1 - g_{13}$ describing the $\gamma^* + d \to d + P$ reaction, as

$$h_{19} = |g_1|^2 - \gamma_1^2 |g_2|^2, \quad h_{20} = a|g_5|^2 + b|g_8|^2 + 2c\,\mathrm{Re}\,g_5 g_8^* - \gamma_1^2\left(a|g_9|^2 + b|g_7|^2 + 2c\,\mathrm{Re}\,g_7 g_9^*\right),$$
$$h_{21} = |g_{10}|^2 - \gamma_1^2 |g_{11}|^2, \quad h_{22} = \mathrm{Re}\left(g_1 g_{10}^* - \gamma_1^2 g_2 g_{11}^*\right), \quad h_{23} = \mathrm{Im}\left(g_1 g_{10}^* - \gamma_1^2 g_2 g_{11}^*\right),$$
$$h_{24} = a|g_3|^2 + b|g_4|^2 + 2c\,\mathrm{Re}\,g_3 g_4^* - \gamma_1^2 |g_2|^2, \quad h_{25} = |g_6|^2 - \gamma_1^2\left(a|g_9|^2 + b|g_7|^2 + 2c\,\mathrm{Re}\,g_7 g_9^*\right),$$
$$h_{26} = a|g_{12}|^2 + b|g_{13}|^2 + 2c\,\mathrm{Re}\,g_{12} g_{13}^* - \gamma_1^2 |g_{11}|^2, \quad h_{27} = \mathrm{Re}\,A_6, \quad h_{28} = \mathrm{Im}\,A_6,$$
$$A_6 = a g_3 g_{12}^* + b g_4 g_{13}^* + c\left(g_3 g_{13}^* + g_4 g_{12}^*\right) - \gamma_1^2 g_2 g_{11}^*, \quad (24)$$
$$h_{29} = 2\,\mathrm{Re}\,g_1 g_2^*, \quad h_{30} = 2\,\mathrm{Re}\left(a g_5 g_9^* + b g_7 g_8^* + c\left(g_5 g_7^* + g_8 g_9^*\right)\right), \quad h_{31} = 2\,\mathrm{Re}\,g_{10} g_{11}^*,$$
$$h_{32} = 2\,\mathrm{Re}\left(g_2 g_{10}^* + g_1 g_{11}^*\right), \quad h_{33} = 2\,\mathrm{Im}\left(g_2 g_{10}^* + g_1 g_{11}^*\right), \quad h_{34} = \mathrm{Re}\,A_7, \quad h_{35} = \mathrm{Re}\,A_8, \quad h_{36} = \mathrm{Im}\,A_7, \quad h_{37} = -\mathrm{Im}\,A_8,$$
$$A_7 = a g_3 g_5^* + b g_4 g_8^* + c\left(g_3 g_8^* + g_4 g_5^*\right) + g_1 g_6^*, \quad A_8 = a g_5 g_{12}^* + b g_8 g_{13}^* + c\left(g_5 g_{13}^* + g_8 g_{12}^*\right) + g_6 g_{10}^*,$$
$$h_{38} = \mathrm{Re}\,A_9, \quad h_{39} = \mathrm{Re}\,A_{10}, \quad h_{40} = \mathrm{Im}\,A_9, \quad h_{41} = -\mathrm{Im}\,A_{10},$$
$$A_9 = a g_3 g_9^* + b g_4 g_7^* + c\left(g_3 g_7^* + g_4 g_9^*\right) + g_2 g_6^*, \quad A_8 = a g_9 g_{12}^* + b g_7 g_{13}^* + c\left(g_9 g_{13}^* + g_7 g_{12}^*\right) + g_6 g_{11}^*.$$

In this case, the dependence of the polarization observables on the deuteron tensor polarization is determined by 23 structure functions.

From equation Eq. (23) one can conclude that:

1. If the deuteron is tensor polarized so that only S_{zz}, S_{yy} and $\left(S_{xz} + S_{zx}\right)$ components of the quadrupole polarization tensor are nonzero, then the dependence of the differential cross section of the $e^- + d \to e^- + d + P$ reaction on the parameter *ε* and on the azimuthal angle *φ* must be the same as in the case of the unpolarized target (more exactly, with similar *ε*– and *φ*– dependent terms).

2. If the deuteron is polarized so that only $\left(S_{xy} + S_{yx}\right)$ and $\left(S_{yz} + S_{zy}\right)$ components of the quadrupole polarization tensor are nonzero, then the typical terms follow $\sin\varphi$ and $\sin(2\varphi)$ dependencies - for deuteron disintegration by unpolarized electron beam, and terms which do not depend on *ε*, *φ*, and $\cos\varphi$ - for deuteron disintegration by longitudinally polarized electron beam.

The reaction amplitude is real in the Born (impulse) approximation. So, assuming the T-invariance of the electromagnetic interaction with hadronss, we can do the following statements, according to the deuteron polarization state:

1. The deuteron is unpolarized. Since the hadronic tensor $H_{ij}(0)$ has to be symmetric (over *i*, *j* indices) in this case, the asymmetry in the scattering of longitudinally polarized electrons vanishes.

2. The deuteron is vector polarized. Since the hadronic tensor $H_{ij}(\xi)$ has to be antisymmetric in this case, then the deuteron vector polarization can manifest itself in the scattering of longitudinally polarized electrons. The perpendicular target polarization (normal to the $\gamma^* + d \to d + P$ reaction plane) leads to a correlation of the following type: $\pm i\lambda\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi$. The longitudinal and transverse (along or perpendicular to the virtual–photon momentum) target polarization (lying in the $\gamma^* + d \to d + P$ reaction plane) leads to two correlations of the following type:

$\mp i\lambda\sqrt{1-\varepsilon^2}$ and $\mp i\lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi$.

3. The deuteron is tensor polarized. The hadronic tensor $H_{ij}(S)$ is symmetric in this case. In the scattering of longitudinally polarized electrons the contribution proportional to λS_{ab} vanishes. If the target is polarized so that only the $(S_{xy}+S_{yx})$ or $(S_{yz}+S_{zy})$ components of the quadrupole polarization tensor are nonzero, then in the differential cross section only the following two terms are present: $\varepsilon\sin(2\varphi)$ and $\sqrt{2\varepsilon(1+\varepsilon)}\sin\varphi$. For all other target polarizations the following structures are present: a term which does not depend on ε and φ variables as well as terms with the following dependencies: 2ε, $\varepsilon\cos(2\varphi)$, and $\sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi$.

The differential cross section of the *P*–meson production in the scattering of longitudinally polarized electrons by tensor polarized deuteron target (in the coincidence experimental setup) has the following general structure

$$\begin{aligned}\frac{d^3\sigma}{dE'd\Omega_e d\Omega_P} &= N\{\sigma_T + A^T_{xz}Q_{xz} + A^T_{xx}(Q_{xx}-Q_{yy}) + A^T_{zz}Q_{zz} + \varepsilon[\sigma_L + A^L_{xz}Q_{xz} + A^L_{xx}(Q_{xx}-Q_{yy}) + A^L_{zz}Q_{zz}] + \\ &+ \sqrt{2\varepsilon(1+\varepsilon)}\cos\varphi[\sigma_I + A^I_{xz}Q_{xz} + A^I_{xx}(Q_{xx}-Q_{yy}) + A^I_{zz}Q_{zz}] + \sqrt{2\varepsilon(1+\varepsilon)}\sin\varphi(A^I_{xy}Q_{xy} + A^I_{yz}Q_{yz}) + \\ &+ \varepsilon\sin(2\varphi)(A^P_{xy}Q_{xy} + A^P_{yz}Q_{yz}) + \varepsilon\cos(2\varphi)[\sigma_P + A^P_{xz}Q_{xz} + A^P_{xx}(Q_{xx}-Q_{yy}) + A^P_{zz}Q_{zz}] + \\ &+ \lambda\sqrt{2\varepsilon(1-\varepsilon)}\sin\varphi[\sigma'_I + \overline{A}^I_{xz}Q_{xz} + \overline{A}^I_{xx}(Q_{xx}-Q_{yy}) + \overline{A}^I_{zz}Q_{zz}] + \\ &+ \lambda\sqrt{2\varepsilon(1-\varepsilon)}\cos\varphi(\overline{A}^I_{xy}Q_{xy} + \overline{A}^I_{yz}Q_{yz}) + \lambda\sqrt{1-\varepsilon^2}\cos\varphi(A^T_{xy}Q_{xy} + A^T_{yz}Q_{yz})\},\end{aligned} \tag{25}$$

where the quantities Q_{ij} ($i,j=x,y,z$) are the components of the quadrupole polarization tensor of the deuteron in its rest system (the coordinate system is specified similarly to the case of the *Pd*–pair CMS). These components satisfy to the following conditions: $Q_{ij}=Q_{ji}$, $Q_{ii}=0$. By writing this formula we take into account that $Q_{xx}+Q_{yy}+Q_{zz}=0$.

Thus, in the general case the exclusive cross section of the *P*–meson production in the scattering of longitudinally polarized electrons by tensor polarized deuteron target is determined by 23 independent asymmetries (16 (7) ones in the scattering of unpolarized (longitudinally polarized) electrons) $A^m_{ij}(W,k^2,\vartheta)$, where $i,j=x,y,z$; $m=T,P,L,I$. These asymmetries can be related to the structure functions h_i which are the bilinear combinations of the 13 independent scalar amplitudes describing the $\gamma^*+d\to d+P$ reaction. These relations are:

$$\begin{aligned}&A^T_{xz}=2\frac{\omega}{M}(h_{30}+h_{31}),\quad A^T_{xx}=\frac{1}{2}(h_{25}+h_{26}),\quad A^T_{zz}=\frac{\omega^2}{M^2}(h_{20}+h_{21})-\frac{1}{2}(h_{25}+h_{26}),\quad A^T_{xy}=4h_{41},\quad A^T_{yz}=4\frac{\omega}{M}h_{37},\\ &A^L_{xz}=-4\frac{\omega}{M}\frac{k^2}{k_0^2}h_{29},\quad A^L_{xx}=-\frac{k^2}{k_0^2}h_{24},\quad A^L_{zz}=-\frac{k^2}{k_0^2}\left(2\frac{\omega^2}{M^2}h_{19}-h_{24}\right),\quad A^I_{xz}=-4\frac{\omega}{M}\frac{\sqrt{-k^2}}{k_0}h_{32},\quad A^I_{xx}=-\frac{\sqrt{-k^2}}{k_0}h_{27},\\ &A^I_{zz}=-\frac{\sqrt{-k^2}}{k_0}\left(2\frac{\omega^2}{M^2}h_{22}-h_{27}\right),\quad A^I_{xy}=-4\frac{\sqrt{-k^2}}{k_0}h_{38},\quad A^I_{yz}=-4\frac{\omega}{M}\frac{\sqrt{-k^2}}{k_0}h_{34},\quad A^P_{xy}=4h_{39},\quad A^P_{yz}=4\frac{\omega}{M}h_{35},\\ &A^P_{xz}=2\frac{\omega}{M}(h_{30}-h_{31}),\quad A^P_{xx}=\frac{1}{2}(h_{25}-h_{26}),\quad A^P_{zz}=\frac{\omega^2}{M^2}(h_{20}-h_{21})-\frac{1}{2}(h_{25}-h_{26}),\quad \overline{A}^I_{xz}=4\frac{\omega}{M}\frac{\sqrt{-k^2}}{k_0}h_{33},\\ &\overline{A}^I_{xx}=\frac{\sqrt{-k^2}}{k_0}h_{28},\quad \overline{A}^I_{zz}=\frac{\sqrt{-k^2}}{k_0}\left(2\frac{\omega^2}{M^2}h_{23}-h_{28}\right),\quad \overline{A}^I_{xy}=-4\frac{\sqrt{-k^2}}{k_0}h_{40},\quad \overline{A}^I_{yz}=-4\frac{\omega}{M}\frac{\sqrt{-k^2}}{k_0}h_{36},\end{aligned} \tag{26}$$

where ω is the *P*-meson energy in the CMS of the reaction considered.

One can see from this formula that the scattering of unpolarized electrons by a tensor polarized deuteron target with components $Q_{xy}=Q_{yz}=0$, is characterized by the same φ– and ε– dependences as in the case of the scattering of unpolarized electrons by the unpolarized deuteron target. If $Q_{xy}\neq 0$, $Q_{yz}\neq 0$, then new terms of the type $\sqrt{2\varepsilon(1+\varepsilon)}\sin\varphi$ and $\varepsilon\sin(2\varphi)$ are present in the cross section. The asymmetries with upper indices *T*, *P*(*L*) are determined only by the transverse (longitudinal) components of the electromagnetic current for the $\gamma^*+d\to d+P$ reaction, while the asymmetries with upper index *I* are determined by the interference of the longitudinal and transverse components of the electromagnetic current.

CONCLUSION

The model-independent analysis of the process of coherent electroproduction of pseudoscalar meson on deuteron has been done. This analysis does not depend on the details of the reaction mechanism and does not require the knowledge of the deuteron structure. The formalism used in the analysis is based on the most general symmetry properties of the electromagnetic interaction with hadrons, such as the gauge invariance and P-invariance.

The polarization observables for the reaction considered are expressed in terms of the scalar amplitudes of the reaction. The explicit dependence of the polarization observables on the azimuthal angle between the electron scattering plane and the hadron reaction plane and on the degree of linear polarization of the virtual photon has been obtained. The following experimental set-ups have been considered:

- the electron beam is longitudinally polarized;
- the deuteron target is vector polarized;
- the deuteron target is tensor polarized.

Let us note that the new results, which are obtained in this paper, are the relations of the structure functions, determining the hadronic tensor, with reaction scalar amplitudes. They are represented by formulas (11), (16) and (24).

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