УДК 539.12

DEEP INELASTIC SCATTERING OF ELECTRONS BY TENSOR POLARIZED DEUTERON. CONTRIBUTION OF ELASTIC RADIATIVE TAIL

G.I. Gakh[1], O. N. Shekhovtsova[1], A.G. Gakh[2]
[1] *National Science Centre, Kharkov Institute of Physics and Technology*
Akademicheskaya 1, 61108 Kharkov, Ukraine
[2] *V. N. Karazin Kharkov National University, Dept. of Physics and Technology*
31 Kurchatov, 61108, Kharkov, Ukraine
E-mail: agakh@mail.ru
Received 11 November 2011

The model-independent part of the radiative corrections, due to the hard-photon emission from the lepton vertex in the elastic electron-deuteron scattering (the so-called elastic radiative tail), has been calculated to the deep inelastic scattering of the electron beam on the deuteron target. The elastic radiative tail has been calculated both for the unpolarized scattering and for the scattering of unpolarized electron beam on the tensor polarized deuteron target.
KEY WORDS: polarization, cross section, deep inelastic, radiative corrections, electron, deuteron.

ГЛИБОКО НЕ ПРУЖНЄ РОЗСІЮВАННЯ ЕЛЕКТРОНІВ НА ТЕНЗОРНО ПОЛЯРИЗОВАНОМУ ДЕЙТРОНІ. ВНЕСОК ПРУЖНОГО РАДІАЦІЙНОГО ХВОСТА

Г.І. Гах[1], О.М. Шеховцова[1], А.Г. Гах[2]
[1] *Національний науковий центр «Харківський фізико-технічний інститут»*
Україна, 61108, Харків, вул. Академічна, 1
[2] *Харківський національний університет імені В.Н. Каразіна, фізико-технічний факультет*
Україна, 61108, Харків, пр. Курчатова, 31
Розрахована модельно-незалежна частина радіаційних поправок, яка обумовлена випромінюванням жорсткого фотону із лептонної вершини у пружному електрон-дейтронному розсіюванні (так званий пружний радіаційний хвіст), до глибоко не пружного розсіювання електронного пучка на дейтронній мішені. Пружний радіаційний хвіст розраховано як для розсіювання неполяризованих частинок, так і для розсіювання неполяризованого електронного пучка на тензорно поляризованій дейтронній мішені.
КЛЮЧОВІ СЛОВА: поляризація, переріз, глибоко не пружне, радіаційні поправки, електрон, дейтрон.

ГЛУБОКО НЕУПРУГОЕ РАССЕЯНИЕ ЭЛЕКТРОНОВ НА ТЕНЗОРНО ПОЛЯРИЗОВАННОМ ДЕЙТРОНЕ. ВКЛАД УПРУГОГО РАДИАЦИОННОГО ХВОСТА

Г.И. Гах[1], О.Н. Шеховцова[1], А.Г. Гах[2]
[1] *Национальный научный центр «Харьковский физико-технический институт»*
Украина, 61108, Харьков, ул. Академическая, 1
[2] *Харьковский национальный университет имени В.Н. Каразина, физико-технический факультет*
Украина, 61108, Харьков, пр. Курчатова, 31
Вычислена модельно независимая часть радиационных поправок, которая обусловлена излучением жесткого фотона из лептонной вершины в упругом электрон-дейтронном рассеянии (так называемый упругий радиационный хвост), к глубоко неупругому рассеянию электронного пучка на дейтронной мишени. Упругий радиационный хвост вычислен как для рассеяния неполяризованных частиц, так и для рассеяния неполяризованного электронного пучка на тензорно поляризованной дейтронной мишени.
КЛЮЧЕВЫЕ СЛОВА: поляризация, сечение, глубоко неупругое, радиационные поправки, электрон, дейтрон.

The structure of the hadrons at small distances (large transfer momentum squared) is described in terms of parton distribution functions. A large part of the information about these functions has up to now come from experimental investigation of the inclusive deep inelastic scattering process. In the experiments of this type only the scattered lepton is detected.

The polarized nuclei of deuterium are used as targets to extract information on the neutron spin-dependent structure function $g_1(x)$ [1]. In analyzing the experimental data on inclusive spin asymmetries for deuterium in order to determine g_1 one should to take into account a small effect due to possible tensor polarization of this spin-one target. This is connected with the presence in a deuteron target of an additional spin-dependent structure functions caused by the deuteron tensor polarization [2].

Different spin physics exists for higher-spin hadrons such as the tensor structure of the deuteron. The measurement of these additional spin-dependent structure functions provides important information about non-nucleonic components in spin-one nuclei and tensor structures on the quark-parton level [3]. A general formalism of the deep inelastic electron-deuteron scattering was discussed in Ref. [4], where new four tensor structure functions $b_i(x)$, $i = 1-4$, were introduced. They can be measured using tensor polarized deuteron target and unpolarized electron beam.

The properties of these new spin-dependent structure functions have been studied in a number of papers [4,5,6,7] in the framework of the different theoretical models. The HERMES experiment with a tensor polarized deuterium target allowed to make a first measurement of tensor structure function $b_1(x)$ [8].

The radiative corrections to deep inelastic scattering of unpolarized and longitudinally polarized electron beam on polarized deuteron target was considered in Ref. [9]. The leading-log model-independent radiative corrections in deep inelastic scattering of unpolarized electron beam off the tensor polarized deuteron target have been considered in Ref. [10]. The model-independent radiative corrections to deep inelastic scattering of an unpolarized electron beam off the tensor polarized deuteron target have been calculated in Ref. [11].

The contribution of the radiative tail from the elastic electron-deuteron scattering (the so-called elastic radiative tail), with the emission of the real hard photon by the initial and scattered electrons, simulates the deep-inelastic scattering. So, to extract the deep inelastic structure functions it is necessary to take into account the contribution of the elastic radiative tail, i. e., to calculate the precess

$$e^-(k_1) + d(p) \to e^-(k_2) + \gamma(k) + d(p'), \tag{1}$$

where the four-momenta of the corresponding particles are indicated in the brackets.

The aim of the paper is to calculate the contribution of the elastic radiative tail to the radiative corrections for the deep inelastic scattering of unpolarized electron beam on the tensor polarized deuteron target.

CONTRIBUTION OF ELASTIC RADIATIVE TAIL

Let us calculate the contribution of the elastic radiative tail to the radiative correction. This process corresponds to the hard-photon emission in the elastic electron-deuteron scattering (1).

The process of the elastic electron-deuteron scattering is determined by one variable only (the electron scattering angle or the energy of the scattered electron) since there exists the relation $Q^2 = 2M(E - E')$, where M is the deuteron mass, $Q^2 = -(k_1 - k_2)^2$ is the four-momentum transfer squared and $E(E')$ is the energy of the initial (scattered) electron. In the case of the hard photon emission this relation does not work anymore. Thus, the elastic radiative events simulate the deep-inelastic scattering events where E' and θ_e (electron scattering angle) variables are independent. We do not take into account the radiative corrections which correspond to the emission of the virtual photons or the real photons with small energy (soft-photon emission) since they do not change the kinematics of the elastic electron-deuteron scattering. Thus, we need only the radiative corrections which correspond to the hard-photon emission. To calculate the part of the radiative corrections due to the elastic radiative tail we use the results of the paper [11].

We use the following general expression for the deuteron spin-density matrix in the coordinate representation [12] for the calculation of the polarization observables in the process (1)

$$\rho_{\mu\nu} = -\frac{1}{3}(g_{\mu\nu} - \frac{p_\mu p_\nu}{M^2}) + \frac{i}{2M}\varepsilon_{\mu\nu\lambda\rho}s_\lambda p_\rho + Q_{\mu\nu}, \quad Q_{\mu\nu} = Q_{\nu\mu}, \quad Q_{\mu\mu} = 0, \quad p_\mu Q_{\mu\nu} = 0, \tag{2}$$

where s_μ is the polarization 4-vector (it satisfies the following conditions: $s^2 = -1,\ s \cdot p = 0$) which describes the vector polarization of the deuteron target and $Q_{\mu\nu}$ tensor (it has five independent components) describes the quadrupole (tensor) polarization of the deuteron target. We use the following convention $\varepsilon_{1234} = 1$.

To calculate the radiative correction to the polarization observables of some process, it is convenient to parameterize the polarization states of the particles in terms of the four-momenta of the particles participating in the reaction under consideration. We use here this approach for the description of the polarization state of the deuteron target.

First, we have to fix the reference system. We choose the axes by the following way: the longitudinal direction **l** is along the electron beam, the transverse one **t** is in the scattering plane and perpendicular to **l** and the **n** direction is normal to the scattering plane:

$$\mathbf{l} = \mathbf{n}_1, \quad \mathbf{t} = \frac{\mathbf{n}_2 - (\mathbf{n}_1\mathbf{n}_2)\mathbf{n}_1}{\sqrt{1-(\mathbf{n}_1\mathbf{n}_2)^2}}, \quad \mathbf{n} = \frac{\mathbf{n}_1 \times \mathbf{n}_2}{\sqrt{1-(\mathbf{n}_1\mathbf{n}_2)^2}}, \quad \mathbf{n}_{1,2} = \frac{\mathbf{k}_{1,2}}{|\,\mathbf{k}_{1,2}\,|}. \tag{3}$$

In the rest system of the target the polarization vector has three components. We will speak about the longitudinal (transverse) or normal polarization if a target is polarized along **l** (**t**) or **n** direction, respectively. In this case the direction of the **l** axis corresponds to the direction of the magnetic field in the experiment [8]. The direction of the magnetic field provides the quantization axis for the nuclear spin in the target. So, let us define the following polarization four-vectors

$$S_\mu^{(l)} = (0,\mathbf{l}), \quad S_\mu^{(t)} = (0,\mathbf{t}), \quad S_\mu^{(n)} = (0,\mathbf{n}). \tag{4}$$

Now we rewrite the expression for the polarization four-vectors $S_\mu^{(i)}$ in covariant form:

$$S_\mu^{(l)} = \frac{2\tau k_{1\mu} - p_\mu}{M}, \quad S_\mu^{(t)} = \frac{k_{2\mu} - (1-y-2xy\tau)k_{1\mu} - xyp_\mu}{d}, \quad S_\mu^{(n)} = \frac{2\varepsilon_{\mu\nu\lambda\rho\sigma} p_\lambda k_{1\rho} k_{2\sigma}}{Vd},$$
$$d = \sqrt{Vxyb}, \quad b = 1-y-xy\tau, \quad V = 2pk_1 \quad \tau = M^2/V, \quad x = \frac{Q^2}{2p\cdot(k_1-k_2)}, \quad y = 2\frac{p\cdot(k_1-k_2)}{V}. \tag{5}$$

One can verify that the set of the four-vectors $S_\mu^{(l,t,n)}$ satisfies the following properties

$$S_\mu^{(\alpha)} S_\mu^{(\beta)} = -\delta_{\alpha\beta}, \quad S_\mu^{(\alpha)} p_\mu = 0, \quad \alpha,\beta = l,t,n, \tag{6}$$

and coincides with (4) for the rest frame system of deuteron.

Adding one more four-vector $S_\mu^{(0)} = p_\mu / M$ to the set (5), we receive the complete set of the orthogonal four-vectors with the following properties

$$S_\mu^{(m)} S_\nu^{(m)} = g_{\mu\nu}, \quad S_\mu^{(m)} S_\mu^{(n)} = g_{mn}, \quad m,n = 0,l,t,n. \tag{7}$$

One can relate the tensor of the deuteron quadrupole polarization $Q_{\mu\nu}$ with its value in the deuteron rest system (we designate it as $R_{\mu\nu}$). As the components $R_{00}, R_{0\alpha}$ and $R_{\alpha 0}$ are identically equal to zero due to condition $R_{\mu\nu} p_\nu = 0$, the deuteron quadrupole polarization tensor can be written down as

$$Q_{\mu\nu} = S_\mu^{(m)} S_\nu^{(n)} R_{mn} \equiv S_\mu^{(\alpha)} S_\nu^{(\beta)} R_{\alpha\beta}, \quad R_{\alpha\beta} = R_{\beta\alpha}, \quad R_{\alpha\alpha} = 0. \tag{8}$$

The R_{ln} and R_{tn} components of the deuteron quadrupole-polarization tensor do not contribute to the observables of the deep inelastic scattering and elastic radiative tail and the expansion (8) is rewritten in the standard form

$$Q_{\mu\nu} = [S_\mu^{(l)} S_\nu^{(l)} - \frac{1}{2} S_\mu^{(t)} S_\nu^{(t)}] R_{ll} + \frac{1}{2} S_\mu^{(t)} S_\nu^{(t)} (R_{tt} - R_{nn}) + (S_\mu^{(l)} S_\nu^{(t)} + S_\mu^{(t)} S_\nu^{(l)}) R_{lt}, \tag{9}$$

where we already have taken into account a relation $R_{ll} + R_{tt} + R_{nn} = 0$.

So, the differential cross section and polarization observables of the elastic radiative tail is determined by the R_{ll}, R_{lt} components of the quadrupole polarization tensor and the combination $(R_{tt} - R_{nn})$.

Now we consider another choice of the coordinate axes which is also often used in the literature: components of the deuteron quadrupole polarization tensor are defined in the coordinate system with the axes along directions **L, T** and **N** in the rest frame of the deuteron, where

$$\mathbf{L} = \frac{\mathbf{k}_1 - \mathbf{k}_2}{|\mathbf{k}_1 - \mathbf{k}_2|}, \quad \mathbf{T} = \frac{\mathbf{n}_1 - (\mathbf{n}_1\mathbf{L})\mathbf{L}}{\sqrt{1-(\mathbf{n}_1\mathbf{L})^2}}, \quad \mathbf{N} = \mathbf{n}. \tag{10}$$

In this case the direction **L** coincides with the momentum transfer **q** (the three-momentum of the virtual photon). The corresponding covariant expressions of these axes can be written as

$$S_\mu^{(L)} = \frac{2\tau(k_1-k_2)_\mu - yp_\mu}{M\sqrt{yh}}, S_\mu^{(T)} = \frac{(1+2x\tau)k_{2\mu} - (1-y-2x\tau)k_{1\mu} - x(2-y)p_\mu}{\sqrt{Vxbh}}, \; S_\mu^{(N)} = S_\mu^{(n)}, h = y + 4x\tau, \tag{11}$$

and the expansion of the deuteron quadrupole polarization tensor over this set of the polarization four-vectors is defined in full analogy with (9)

$$Q_{\mu\nu} = [S_\mu^{(L)} S_\nu^{(L)} - \frac{1}{2} S_\mu^{(T)} S_\nu^{(T)}] R_{LL} + \frac{1}{2} S_\mu^{(T)} S_\nu^{(T)} (R_{TT} - R_{NN}) + (S_\mu^{(L)} S_\nu^{(T)} + S_\mu^{(T)} S_\nu^{(L)}) R_{LT}. \tag{12}$$

These two sets of the orthogonal four-vectors are connected by means of orthogonal matrix which describes the rotation in the plane perpendicular to the direction **n = N**

$$S_\mu^{(L)} = \cos\theta S_\mu^{(l)} + \sin\theta S_\mu^{(t)}, \quad S_\mu^{(T)} = -\sin\theta S_\mu^{(l)} + \cos\theta S_\mu^{(t)}, \quad \cos\theta = \frac{y(1+2x\tau)}{\sqrt{yh}}, \quad \sin\theta = -2\sqrt{\frac{xb\tau}{h}}. \tag{13}$$

Now, consider a part of the cross section that depends on the tensor polarization of the deuteron target. The contribution of the elastic radiative tail to the total radiative correction can be obtained from the formula (51) of the paper [11] by substitution in the hadronic tensor

$$B_i(q^2, x') \to -\frac{1}{q^2}\delta(1-x')B_i^{(el)}, \quad i = 1-4, \tag{14}$$

where $q = k_1 - k_2 - k$, $x' = -q^2 / 2p\cdot q$, and $B_i^{(el)}$ are the tensor structure functions in the elastic limit and they can be expressed in terms of the deuteron electromagnetic form factors as

$$\begin{gathered} B_1^{(el)} = \eta q^2 G_M^2, \qquad B_2^{(el)} = -2\eta^2 q^2 [G_M^2 + \frac{4G_Q}{1+\eta}(G_C + \frac{\eta}{3}G_Q + \eta G_M)], \\ B_3^{(el)} = 2\eta^2 q^2 G_M(G_M + 2G_Q), \qquad B_4^{(el)} = -2\eta q^2(1+\eta)G_M^2, \qquad \eta = -q^2/4M^2. \end{gathered} \tag{15}$$

Here G_C, G_M, and G_Q are the deuteron charge monopole, magnetic dipole and quadrupole form factors, respectively. These form factors have the following normalization:

$$G_C(0) = 1, \qquad G_M(0) = (M/m_n)\mu_d, \qquad G_Q(0) = M^2 Q_d,$$

where m_n is the nucleon mass, $\mu_d(Q_d)$ is the deuteron magnetic (quadrupole) moment and their values are: $\mu_d = 0.857, \quad Q_d = 0.2859\,\text{fm}^2$. After substitution of $B_i^{(el)}$ into the formula (51) we have to integrate over z variable, using a δ -function $\delta(1-x') = xyr\delta(z)$, where $r = -q^2/Q^2$.

After fulfilling of these prescriptions we can obtain the following expression for the contribution of the elastic radiative tail

$$\begin{gathered} \frac{d\sigma_{ERT}^T}{dx\,dQ^2} = -\frac{\alpha}{x(1-x)}\frac{1}{VQ^2}[\alpha^2(q_1^2)F_1(x,Q^2) + \alpha^2(q_2^2)F_2(x,Q^2)] - \\ -\frac{\alpha y}{8x}\frac{1}{M^2V^2}\sum_{i=1}^4\sum_{m,n}R_{mn}\{[\frac{\alpha^2(q_1^2)}{1-xy}H_i(q_1^2)A_i^{mn}(r_1) + \frac{\alpha^2(q_2^2)}{1-y+xy}H_i(q_2^2)B_i^{mn}(r_2)]L + \\ +\frac{P}{1-xy}\int_{r_-}^{r_+}\frac{dr}{(1-r)|r-r_1|}[G_i^{mn}(r) - G_i^{mn}(r_1)] + \frac{P}{1-z_+}\int_{r_-}^{r_+}\frac{dr}{(1-r)|r-r_2|}[\tilde{G}_i^{mn}(r) - \tilde{G}_i^{mn}(r_2)] + \\ +\frac{Q^2}{\sqrt{y^2+4xy\tau}}\int_{r_-}^{r_+}dr\alpha^2(q_r^2)H_i(q_r^2)[C_{0i}^{mn}(r) + i_1C_{1i}^{mn}(r) + i_2C_{2i}^{mn}(r)]\}, \end{gathered} \tag{16}$$

$$\begin{gathered} i_1 = \frac{Q^2}{y^2+4xy\tau}[y(2-y)(1-xr) - (1-r)(y+2xy\tau)], \quad i_2 = \frac{1}{2}[3i_1^2 - \frac{Q^4(1-xy)^2}{y^2+4xy\tau}(r-r_1)^2], \\ r_\pm = \frac{1}{2x(\tau+y-xy)}[2x\tau + (1-x)(y \pm \sqrt{y^2+4xy\tau})], \end{gathered} \tag{17}$$

$$G_i^{mn}(r) = \alpha^2(q_r^2)(1-r)H_i(q_r^2)A_i^{mn}(r), \quad \tilde{G}_i^{mn}(r) = \alpha^2(q_r^2)(1-r)H_i(q_r^2)B_i^{mn}(r),$$

where $\alpha(q^2)$ is the QED running coupling constant, $q_i^2 = r_i q^2, (i = 1,2)$, $r_1 = (1-y)/(1-xy)$, $r_2 = 1/(1-y+xy)$, $q_r^2 = rq^2$, $L = \ln(Q^2/m^2)$, m is the electron mass. The expressions for the functions $A_i^{mn}(r)$, $B_i^{mn}(r)$, $C_{0i}^{mn}(r)$, $C_{1i}^{mn}(r)$, $C_{2i}^{mn}(r)$, $(i = 1-4, mn = ll, tt, lt)$ are given in the Appendix. The symbol *P* denotes the principal value of the integral at the $r = 1$ point.

The functions $H_i(q^2)$ describe the structure of the vertex $\gamma^* d \to d$ (γ^* is the virtual photon) and have the form

$$H_1(q^2)=G_M^2(q^2),\quad H_2(q^2)=-2\eta[G_M^2(q^2)+\frac{4G_Q(q^2)}{1+\eta}(G_C(q^2)+\frac{\eta}{3}G_Q(q^2)+\eta G_M(q^2))],$$
$$H_3(q^2)=2\eta G_M(q^2)(G_M(q^2)+2G_Q(q^2)),\quad H_4(q^2)=-2(1+\eta)G_M^2(q^2). \tag{18}$$

The functions F_1 and F_2 have the following form

$$F_1(x,Q^2)=F_{1ll}R_{ll}+F_{1lt}R_{lt}+F_{1tt}(R_{tt}-R_{nn}),$$
$$F_{1tt}=\frac{b}{2\tau r_1}\{(xy\tau+r_1)G_{1M}^2+4r_1\eta_B(2\tau+\frac{b}{1+r_1\eta_B})G_{1M}G_{1Q}+\frac{4b}{1+r_1\eta_B}G_{1Q}(G_{1C}+\frac{r_1}{3}\eta_B G_{1Q})\},$$
$$F_{1lt}=-\frac{1}{r_1}\sqrt{\frac{b}{xy\tau}}\{xy(xy\tau-b+r_1)[G_{1M}^2+\frac{b}{xy\tau}\frac{4G_{1Q}}{1+r_1\eta_B}(G_{1C}+\frac{r_1}{3}\eta_B G_{1Q})]+$$
$$+4r_1\eta_B[-2b+(xy\tau-b+r_1)(1+\frac{b}{\tau}\frac{1}{1+r_1\eta_B})]G_{1M}G_{1Q}\}, \tag{19}$$
$$F_{1ll}=\frac{1}{2xy\tau r_1}\{\frac{xy}{2}[r_1^2+2xy\tau r_1+(xy\tau-b)^2-2xy\tau b]G_{1M}^2+8br_1\eta_B[b-2xy\tau-r_1-\frac{1}{4\tau}\frac{1}{1+r_1\eta_B}(2xy\tau b-$$
$$-(xy\tau-b+r_1)^2)]G_{1M}G_{1Q}-\frac{2b}{\tau}\frac{1}{1+r_1\eta_B}[2xy\tau b-(xy\tau-b+r_1)^2]G_{1Q}(G_{1C}+\frac{r_1}{3}\eta_B G_{1Q})\},$$

$$F_2(x,Q^2)=F_{2ll}R_{ll}+F_{2lt}R_{lt}+F_{2tt}(R_{tt}-R_{nn}),$$
$$F_{2tt}=\frac{b}{2\tau}\{(1+xy\tau r_2)G_{2M}^2+4r_2\eta_B(2\tau+\frac{br_2}{1+r_2\eta_B})G_{2M}G_{2Q}+\frac{4br_2}{1+r_2\eta_B}G_{2Q}(G_{2C}+\frac{r_2}{3}\eta_B G_{2Q})\},$$
$$F_{2lt}=-4r_2\eta_B\sqrt{\frac{b}{xy\tau}}\{(1+2\tau)[xy\tau G_{2M}^2+\frac{4b}{1+r_2\eta_B}G_{2Q}(G_{2C}+\frac{r_2}{3}\eta_B G_{2Q})]+$$
$$+[xy+2(xy\tau-b)+4br_2\eta_B\frac{1+2\tau}{1+r_2\eta_B}]G_{2M}G_{2Q}\}, \tag{20}$$
$$F_{2ll}=-\frac{1}{2\tau}\{\frac{2b}{\tau}\frac{r_2}{1+r_2\eta_B}[2\tau b-xy(1+2\tau)^2]G_{2Q}(G_{2C}+\frac{r_2}{3}\eta_B G_{2Q})+8b\eta_B r_2[1+3\tau+$$
$$+\frac{r_2}{4\tau}\frac{2\tau b-xy(1+2\tau)^2}{1+r_2\eta_B}]G_{2M}G_{2Q}+[2(xy\tau-b)-4x^2y^2\tau(\tau+1)r_2+b(xy+b)r_2-\frac{x^2y^2}{2}r_2]G_{2M}^2\},$$

where $G_{1i}=G_i(q_1^2),\quad G_{2i}=G_i(q_2^2),\quad i=M,C,Q,$ and $\eta_B=Q^2/4M^2$.

Let us calculate the unpolarized cross section of the $ed\to ed\gamma$ reaction (unpolarized elastic radiative tail) when the photon is emitted from the lepton vertex. The corresponding cross section can be obtained from the formula (61) of the paper [11] by substitution in the hadronic tensor

$$H(z,r)\to-\frac{1}{q^2}\delta(1-x')H(z,r). \tag{21}$$

After this substitution we have to integrate over z variable, using a $\delta(z)$-function.

After fulfilling of these prescriptions we obtain the following expression for the cross section of the unpolarized elastic radiative tail

$$\frac{d\sigma_{ERT}^{un}}{dx\,dQ^2}=\frac{\alpha}{1-x}\frac{y}{VQ^4}\{2(L-1)[\frac{1}{r_1}H(r_1)+\frac{1}{r_2}H(r_2)-2H(1)]+Ly^2(1-x)^2[\frac{H(r_1)}{(1-y)^2}+H(r_2)]\}+ \tag{22}$$

$$+\frac{\alpha y^2}{VQ^4}\int_{r_-}^{r_+} dr\{\frac{2}{r^2}\frac{H(r)}{\sqrt{y^2+4xy\tau}}+C_0[-2\frac{(1-y)(1-r)}{\sqrt{y^2+4xy\tau}}+\frac{r-r_1}{|r-r_1|}(1-r(1-y))-\frac{r-r_2}{|r-r_2|}(1-r-y)]+$$

$$+\frac{P}{1-r}[\frac{1}{(1-xy)|r-r_1|}(\frac{1+r^2}{r^2}H(r)-\frac{1+r_1^2}{r_1^2}H(r_1))-\frac{1}{(1-y+xy)|r-r_2|}(\frac{1+r^2}{r^2}H(r)-\frac{1+r_2^2}{r_2^2}H(r_2))]\},$$

where

$$H(r)=\alpha^2(rQ^2)[2MW_1^{(el)}(rQ^2)+\frac{V}{M}\frac{1-y-xy\tau}{xy}W_2^{(el)}(rQ^2)],$$

$$C_0=\frac{V^2\alpha^2(rQ^2)}{MQ^2r^2(1-r)}W_2^{(el)}(rQ^2),\quad W_1^{(el)}(rQ^2)=\frac{4}{3}Mr\eta_B(1+r\eta_B)G_M^2(rQ^2),\tag{23}$$

$$W_2^{(el)}(rQ^2)=2M[G_C^2(rQ^2)+\frac{2}{3}r\eta_B G_M^2(rQ^2)+\frac{8}{9}r^2\eta_B^2G_Q^2(rQ^2)].$$

CONCLUSION

The model-independent part of the radiative corrections, due to the hard-photon emission from the lepton vertex in the elastic electron-deuteron scattering (the so-called elastic radiative tail), has been calculated to the radiative corrections for the deep inelastic scattering of the electron beam on the deuteron target. The elastic radiative tail has been calculated both for the unpolarized scattering and for the scattering of unpolarized electron beam on the tensor polarized deuteron target.

The expressions for the elastic radiative tail are given in terms of the deuteron electromagnetic form factors. They do not depend on the model for these form factors.

Let us note that the new results, which are obtained in this paper, are the following:

-The expression for the contribution of the elastic radiative tail to the radiatively corrected differential cross section of the deep inelastic scattering of unpolarized particles.

-The expression for the contribution of the elastic radiative tail to the spin-dependent part of the radiatively corrected differential cross section for the deep inelastic scattering of unpolarized electron beam on the tensor polarized deuteron target.

They are represented by formulas (16), (19)-(20), (22) and (23).

APPENDIX

In this Appendix we present the formulae for the coefficients A_k^{ij}, B_k^{ij}, and C_{mk}^{ij}, ($ij=ll,lt,tt,k=1-4$, $m=0,1,2$) that determining the polarization observables of the elastic radiative tail (see formula (16)).

1. Component *ll.*

The coefficients, determining the contribution proportional to the components R_{ll} of the tensor that describe the tensor polarization of the deuteron target, can be written as:

$$A_1^{ll}=-xy(1+r^2)Z,\quad A_2^{ll}=\frac{ZZ_1}{xyr},$$

$$A_3^{ll}=\frac{1}{xy}\{(a+\overline{r})[2Z_1+r\Delta_1(2a+r-\Delta_1)]-\Delta_1[r^2(r-\Delta_1)+2(b+\Delta_1)+r(a+b)(a+r-\Delta_1)]\},$$

$$A_4^{ll}=r\{(b-a)(1+r^2)+\Delta_1[1+r(2a-b)]\},$$

$$B_1^{ll}=xyr(1+r^2)[xyr(1+6\tau)-2\tau(1-3ar)],\quad B_2^{ll}=-\frac{1}{xy}[xyr(1+6\tau)-2\tau(1-3ar)][b(1+r^2)-\Delta_2(\overline{r}-2a)],$$

$$B_3^{ll}=-\frac{1}{xy}\{2Z_2[1+(2a-b)r+\Delta_2]+3a\Delta_2[(b-a)r-1-\Delta_2]\},\quad B_4^{ll}=r[(a-b)(1+r^2)+\Delta_2(a+\overline{r})].$$

$$C_{01}^{ll}=\frac{2}{\tau}\{(\overline{r}-\Delta_1)^2+a[3a(1+r^2)-2(b+\Delta_1)]\},$$

$$C_{02}^{ll}=\frac{2}{xyr}\{(7-3y)(xyr)^2+3a(5-y+r)xyr+3a^2(3+r^2)-ar[5+3(a+b)^2]\},$$

$$C_{03}^{ll}=-xy[r(6a-16+9y)+6\tau(y-3-r)],\quad C_{04}^{ll}=xyr[1+3(b-a)],$$

$$C_{11}^{ll}=12xy(r+2\tau),\quad C_{12}^{ll}=6\frac{\tau}{r}[4(r+\tau)-yr],\quad C_{13}^{ll}=6\tau(2-y),\quad C_{14}^{ll}=0,$$

$$C_{21}^{ll}=6,\quad C_{22}^{ll}=\frac{6\tau}{xyr},\quad C_{23}^{ll}=C_{24}^{ll}=0.$$

2. Component *lt*.

The coefficients, determining the contribution proportional to the components R_{lt} of the tensor that describe the tensor polarization of the deuteron target, can be written as:

$$A_1^{lt}=2a(2\tau+r)(1+r^2)(2b+\Delta_1)\frac{Q^2}{Md},\quad A_2^{lt}=-2(2\tau+r)(2b+\Delta_1)Z_1\frac{\tau}{r}\frac{V}{Md},$$

$$A_3^{lt}=-\tau\frac{V}{Md}\{2Z_1(3b-a-r)+\Delta_1[4r(1+b^2+3ab)-2a(1+r^2)+xyr(ar-3+5br)]\},$$

$$A_4^{lt}=ar\frac{V}{Md}\{2b(1+r^2)+\Delta_1[1-r(3b-a)]\},$$

$$B_1^{lt}=2ar(1+2\tau)(1+r^2)(\Delta_2-2br)\frac{Q^2}{Md},\quad B_2^{lt}=-2\tau(1+2\tau)(\Delta_2-2br)Z_2\frac{V}{Md},$$

$$B_3^{lt}=\tau\frac{V}{Md}\{2Z_2[(3b-a)r-1]+\Delta_2[(1+ar)(a-6b)-(a+3b)(r^2+\Delta_2)+r(b^2-1)+b+\Delta_2(3r-2b)]\},$$

$$B_4^{lt}=ar\frac{V}{Md}[-2b(1+r^2)+\Delta_2(\overline{r}-2b)],$$

$$C_{01}^{lt}=\frac{4Q^2}{Md}[a(1+r^2)(y+2a)-2b\overline{r}-\Delta_1(xyr+2a-2b)],$$

$$C_{02}^{lt}=-\frac{2V}{Md}\frac{1}{xyr}\{2axyr[y\overline{r}+(3b+a)(1+r)-y-8a]-(xyr)^2[2a+(2-y)(y+4a)]+$$
$$+2a[2a(b-a+r)+(y+2a)(r-a(1+r^2)+r(a+b)^2)]\},$$

$$C_{03}^{lt}=-\frac{Q^2}{Md}\{4\tau[2b\overline{r}-y^2+4(b^2-a)]-r[3y(2-y)+8a(1+a+2b)]\},\quad C_{04}^{lt}=xyr\frac{V}{Md}[1+4ab-(a-b)^2],$$

$$C_{11}^{lt}=4\frac{Q^2}{Md}[2\tau(2y+4a-1)+r(y+4a-2\tau)],\quad C_{12}^{lt}=4\frac{\tau}{r}\frac{V}{Md}[(a-b)(4\tau-yr)+2\tau(1-r)+2yr(1+4x\tau)],$$

$$C_{13}^{lt}=4\tau(2-y)(y+2a)\frac{V}{Md},\quad C_{14}^{lt}=0,\quad C_{21}^{lt}=4(y+2a)\frac{V}{Md},\quad C_{22}^{lt}=4\tau\frac{y+2a}{xyr}\frac{V}{Md},\quad C_{23}^{lt}=C_{24}^{lt}=0.$$

3. Component *tt*.

The coefficients, determining the contribution proportional to the components R_{tt} of the tensor that describe the tensor polarization of the deuteron target, can be written as:

$$A_1^{tt}=-\frac{a}{b}(1+r^2)[b^2+(b+\Delta_1)^2],\quad A_2^{tt}=\frac{\tau}{b}\frac{Z_1}{xyr}[2b^2+\Delta_1(2b+\Delta_1)],$$

$$A_3^{tt}=\frac{\tau}{b}\{(\Delta_1-2b)[b(1+r^2)+(1-r+ry)\Delta_1]+b\Delta_1[1+r(b-a+\Delta_1)]\},\quad A_4^{tt}=-ar^2\Delta_1,$$

$$B_1^{tt}=\frac{a}{b}(1+r^2)[2b^2r^2-2br\Delta_2+\Delta_2^2],\quad B_2^{tt}=-\frac{\tau}{b}\frac{Z_2}{xyr}[2b^2r^2-2br\Delta_2+\Delta_2^2],$$

$$B_3^{tt} = \frac{\tau}{b}\{(2br-\Delta_2)Z_2 + b\Delta_2[r(b-a+r)-\Delta_2]\}, \qquad B_4^{tt} = -ar\Delta_2.$$

$$C_{01}^{tt} = \frac{xy}{b}[(1+r^2)(y^2+4a-2ab)+(2b+\Delta_1)^2+\Delta_1^2],$$

$$C_{02}^{tt} = -\frac{1}{bxyr}\{-2(xyr)^2[a+(1+a)(2-y)] + xyr[(3-2y+a^2+b^2)(\overline{r}-2a)+4(ab+b-a^2)+4r(a-b^2)] -$$
$$-2a[(r-a)^2+b^2]+(1+2a-2b+a^2+b^2)[r-a(1+r^2)+(a+b)^2 r]\},$$

$$C_{03}^{tt} = -\frac{1}{b}\{3b-a-(a^2+b^2)(2+a+b)+r[y^2+2y(2b-a)+2a(3-a)]+xyr[y(1+y+3a)-4(1+a)-2ab]\},$$

$$C_{04}^{tt} = xyr(y+2a), \qquad C_{11}^{tt} = -\frac{4}{b}[y(b-a+r)+2a(r-a)-xyr(1+a)],$$

$$C_{12}^{tt} = \frac{1}{bxyr}\{r[1+7a(1+a)-b(1+b)+(a+b)(a^2+b^2)]+4\tau[(a-b)(1-r)+a^2+b^2-r]\},$$

$$C_{13}^{tt} = \frac{1}{bxy}(2-y)[y^2+2a(2-b)], \qquad C_{14}^{tt} = 0,$$

$$C_{21}^{tt} = \frac{1}{ab}[y^2+2a(2-b)], \quad C_{22}^{tt} = \frac{1}{brx^2y^2}[y^2+2a(2-b)], \quad C_{23}^{tt} = C_{24}^{tt} = 0,$$

here we use the following notation

$$\overline{r} = a-b+r, \quad d^2 = bQ^2, \quad \Delta_1 = (1-xy)r-a-b, \quad \Delta_2 = (1-y+xy)r-1,$$
$$Z_1 = b(1+r^2)+\Delta_1(1-r+yr), \quad Z_2 = b(1+r^2)+\Delta_2(1-y-r),$$
$$b = 1-y-a, \quad a = xy\tau, \quad Z = xy(2\tau+r)^2 - 2\tau(b+\Delta_1).$$

REFERENCES

1. Spin Muon Collaboration. Adams D., Adeva B., Arik E. et al. A new measurement of the spin-dependent structure function $g_1(x)$ of the deuteron // Phys. Lett. - 1995. - Vol. B357. - P. 248-254.
2. Ryckbosch D. Recent Spin Physics at HERA // arXiv:hep-ex/0311021.
3. Kumano S. Polarized structure functions of the deuteron // arXiv:hep-ph/0012341.
4. Hoodbhoy P., Jaffe R.L. and Manohar A. Novel effects in deep inelastic scattering from spin-one hadrons // Nucl. Phys. - 1989. - Vol. B312. - P. 571-588.
5. Close F.E., Kumano S. Sum rule for the spin-dependent structure function $b_1(x)$ for spin-one hadrons // Phys. Rev. - 1990. - Vol. D42. - P. 2377-2379.
6. Mankiewicz L. Simple relativistic model for the $b_1(x)$ structure function of the ρ meson // Phys. Rev. - 1989. - Vol. D40. - P. 255-258.
7. Khan H. and Hoodbhoy P. Shadowing of deuteron spin structure functions // Phys. Lett. - 1993. - Vol. B298. - P. 181-186.
8. Contalbrigo M. A First Measurement of the Tensor Structure Function b_1^d // Nucl. Phys. Proc. Suppl. - 2004. - Vol. B126. - P. 41-45.
9. Akushevich I.V. and Shumeiko N.M Radiative effects in deep inelastic scattering of polarized leptons by polarized light nuclei // J. Phys. G: Nucl. Part. Phys. - 1994. - Vol. 20. - P. 513-530.
10. Gakh G.I., Merenkov N.P. QED corrections in deep-inelastic scattering from tensor polarized deuteron target // Pis'ma v ZhETF - 2001. - Vol. 73. - P. 659-663.
11. Gakh G.I., Shekhovtsova O.N. Radiative Corrections to Deep Inelastic Electron-Deuteron Scattering: The Case of Tensor-Polarized Deuteron // JETP - 2001. - Vol. 99. - P. 898-914.
12. Lapidus L.I. Polarization phenomena in intermediate energy hadronic collisions // Fiz. Elem. Chastits At. Yadra. - 1984. -Vol. 15. - P. 493-554.