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ELASTIC eD-SCATTERING WITH ALLOWANCE FOR EXCHANGE MESON CURRENTS WITHIN QCD-VMD MODEL

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The role of meson exchange currents in the elastic eD-scattering is studied. Structure functions $A(q^2)$, $B(q^2)$ and tensor polarization $T_{20}(q^2)$ were calculated within the QCD-VMD model. It is shown that the contributions of meson exchange currents to structure functions $A(q^2)$, $B(q^2)$ at large transfer momenta should be taken into account. The contributions of MEC to $T_{20}(q^2)$ are significant for $q > 2.5$ fm^{-1}. The retardation effects are very small throughout the whole scale of momentum transfers.

The investigation has been performed at the Laboratory of Theoretical Physics, JINR.

Упругое eD-рассеяние с учетом мезонных обменных токов в КХД-ВМД модели

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Исследуется роль мезонных обменных токов в упругом eD-рассеянии. Проведен расчет структурных функций $A(q^2)$, $B(q^2)$ и тензора поляризации $T_{20}(q^2)$ в КХД-ВМД модели. Показана необходимость учета мезонных обменных токов для структурных функций $A(q^2)$, $B(q^2)$ в области больших переданных импульсов. Вклад мезонных обменных токов в $T_{20}(q^2)$ играет существенную роль в области $q > 2,5$ фм$^{-1}$. Эффекты запаздывания малы во всей области импульсов передач.

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1. Introduction

At present there exist many approaches for the description of the strong NN-interaction /1—4/. Among them one group of models attracts our special attention which consists of field-theoretical meson-exchange models. Within these approaches the NN-interaction is described as a one-boson-exchange system where the field-theoretical Hamiltonian is

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a sum of Feynman diagrams including various meson exchanges, the physical nature of which determines the kinematic frames of the potential model. Now three kinematic's scales are determined[5]: «classical» (long-range $r > 2$ fm), «dynamical» (1 fm $< r <$ 2 fm), and «phenomenological» (short-range $r < 1$ fm) regions. The classical region is defined by one-pion exchange. The heavier-meson exchanges dominate the dynamical region. The region of $r < 1$ fm (core region) takes into account different processes, for instance, quark-gluon exchanges. The phenomenological region is the most interesting, for further discussion since it has a direct relation to the problem of the extended structure of the nucleon. Still the question on the hadron size is open. QCD effectively describes the region inside the confinement radius, and the outside dynamics is well described by the interaction of mesons with a core. There is the problem of the consistent description of the in-outside regions. On this way the vertex form factors are introduced. The presence of vertex form factors is dictated, first, by the quark structure of the nucleons, and second, by the mesons dynamics. The form factor is a function of the so-called cut-off mass Λ that governs the range of influence nonnucleon degrees of freedom.

In the paper[6] the model of the nucleus potential describes the *NN*-interaction within a similar QCD-VMD picture[7]. The nucleon structure is calculated in two kinematical scales: the low q^2 (meson exchange) and high q^2 (quark-gluon) exchange. It was shown that higher mass meson exchanges become important when the nucleon structure is taken into account. These exchanges are described by a sort of contact relations, leading to contact interactions of nucleons. We quote the important result of paper[6]: it was shown that the description of meson-exchange nucleon-nucleon interaction leaves little room for a sizeable contribution of a conventional boson-exchange at small distances. Apart from the dominance of the pion-exchange at large distances a heavier (than pion) meson-exchange is overshadowed at the medium range by the direct interaction of the physical nucleons. The nucleon-nucleon interaction has three scales: i) the scale given by the pion mass (140 MeV), ii) the meson scale (800 MeV) which determines the size of the nucleon, and iii) the quark-gluon scale (2.85 GeV).

Experimental data on the structure function $A(q^2)$ in the elastic *eD*-scattering are known in a wide range of transfer momenta[8] which allow one to make calculations within the model taking the deuteron structure into account in detail. At presnt, there are many results on the analysis of the behaviour of $A(q^2)$ with allowance for meson exchange currents (MEC)[9—11].

Experimental data on the structure function $B(q^2)$ are not so rich $q^2 < 75$ fm^{-2} [12], some research was made with meson exchange currents [13—15] taken into account.

In our paper the structure functions $A(q^2)$, $B(q^2)$ and tensor polarization $T_{20}(q^2)$ are calculated within the QCD-VMD model [6].

2. Basic Formulas

The differential cross-section of elastic electron-deuteron scattering has the form:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[A(q^2) + B(q^2)\tan^2\frac{\theta}{2}\right], \tag{1}$$

where

$$A(q^2) = F_C^2(q^2) + F_Q^2(q^2) + \frac{2}{3}\eta\, F_M^2(q^2), \tag{2}$$

$$B(q^2) = \frac{4}{3}\eta\,(1+\eta)\,F_M^2(q^2), \tag{3}$$

where $\eta = q^2/4M^2$ and M is the mass of the deuteron. The charge $F_C(q^2)$, quadrupole $F_Q(q^2)$ and magnetic $F_M(q^2)$ form factors are determined by the following equation:

$$F_{C,Q,M} = F^{imp}_{C,Q,M} + F^{\pi NN}_{C,Q,M} + F^{\rho\pi\gamma}_{C,Q,M} + F^{ret,\pi}_{C,Q,M}, \tag{4}$$

where F^{imp} is the impulse approximation, $F^{\pi NN}$ stands for the pair current, $F^{\rho\pi\gamma}$ denotes the $\rho\pi\gamma$ process, and $F^{ret,\pi}$ stands for the retardation current. Analytical expressions for individual contributions have been calculated in [10]. Here, for example, we determine the impulse parts of $F_{C,Q,M}$

$$F_C^{imp} = G_E^S(q^2)\int_0^\infty (u^2(r) + w^2(r))\, j_0(qr/2)dr, \tag{5}$$

$$F_Q^{imp} = G_E^S(q^2)\int_0^\infty (2u(r)w(r) - w^2(r)/\sqrt{2})\, j_2(qr/2)dr, \tag{6}$$

where $G_E^S(q^2)$ is the electric form factor:

$$G_E^S(q^2) = G_E^p(q^2) + G_E^n(q^2)\,, \tag{7}$$

$G_E^p(q^2)$ $(G_E^n(q^2))$ is the electric form factor of a proton (neutron).

$$\begin{aligned} F_M^{imp} &= 2G_M^S(q^2)\Big\{ \int_0^\infty dr[u^2(r) - w^2(r)/2]\, j_0(qr/2) + \\ &+ \int_0^\infty dr(u(r)w(r)/\sqrt{2} + w^2(r)/2]\, j_2(qr/2)\Big\} + \\ &+ \frac{3}{2} G_E^S \int_0^\infty dr[u^2(r) j_0(qr/2) + w^2(r)\, j_2(qr/2)]. \end{aligned} \tag{8}$$

$$G_M^S(q^2) = G_M^p(q^2) + G_M^n(q^2)\,, \tag{9}$$

where $G_M^p(q^2)$ $(G_M^n(q^2))$ is the magnetic form factor of a proton (neutron) ($u(r)$, $w(r)$ are S, D wave functions of the deuteron).

Tensor polarization of the deuteron can be written as follows

$$T_{20} = -\frac{1}{\sqrt{2}} \frac{1 + X}{1 + \frac{X^2}{8}}\,, \tag{10}$$

where

$$X = 2\sqrt{2}\,\frac{F_C}{F_Q}\,. \tag{11}$$

We use the following approximation for vertex form factors[6]

$$F_{1,2}(q^2) = \frac{\Lambda_1^2}{\Lambda_1^2 + Q^2} \left(\frac{\Lambda_2^2}{\Lambda_2^2 + Q^2}\right)^{1,2}, \tag{12}$$

where

$$Q^2 = q^2 \frac{\log\left((\Lambda_2^2 + q^2)/\Lambda_{QCD}^2\right)}{\log\left(\Lambda_2^2/\Lambda_{QCD}^2\right)}\,. \tag{13}$$

The scale $\Lambda_1^2 = 800$ MeV is taken into account for all mesons. The quark-gluon scale is: $\Lambda_2^2 = 2.85$ GeV, $\Lambda_{QCD} = 0.29$ GeV.

3. The Results and Discussion

The structure function of the deuteron $A(q^2)$ is shown in Fig. 1. It is seen that the contributions of MEC diminish $A(q^2)$ at $80\ \mathrm{fm}^{-2} < q^2 < 150\ \mathrm{fm}^{-2}$, thus making the agreement with experimental data worse (curve 3). One should note the importance of taking account of MEC at $q^2 > 40\ \mathrm{fm}^{-2}$.

The structure function $B(q^2)$ with allowance for MEC is shown in Fig. 2. and the calculation without taking account of MEC (curve 1). Comparing the obtained result with the exparimental data we get that the MEC effects are very important for the transfer momenta $q^2 > 40\ \mathrm{fm}^{-2}$. The retardation effects (curve 3) are not essential at all momentum scale.

The tensor polarization of the deuteron $T_{20}(q^2)$ with allowance for MEC is shown in Fig. 3. Data from: Novosibirsk 87/16/, Bates 84/17/,

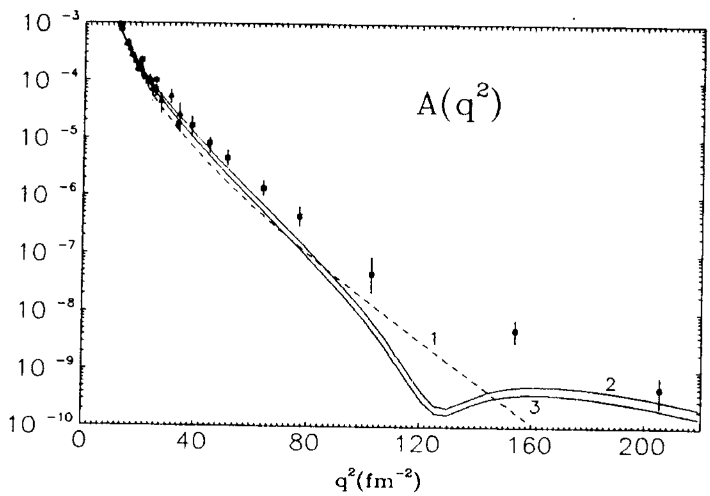

Fig.1. Deuteron structure function $A(q^2)$. The dashed line (1) is the impulse approximation; the solid line (2), with inclusion of MEC ($\pi NN + \rho\pi\gamma$); and solid line (3), with inclusion of MEC ($\pi NN + \rho\pi\gamma$ + retardation effects)

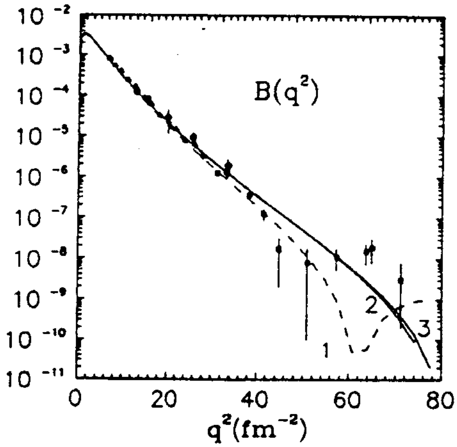

Fig. 2. Deuteron structure function $B(q^2)$. Notation is the same as in Fig.1.

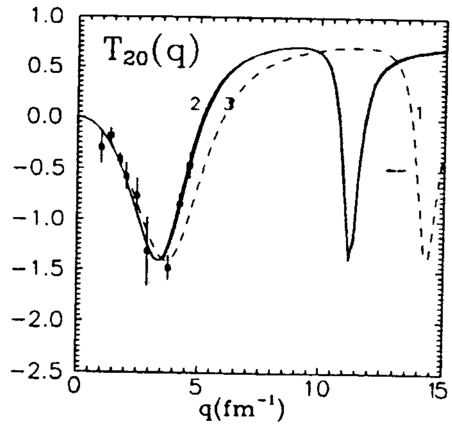

Fig. 3. Deuteron tensor polarization $T_{20}(q^2)$. Notation is the same as in Fig.1

Novosibirsk 90[18], Bates 90[19]. It is seen that in comparison with the impulse approximation (curve 1) the contribution of MEC slowly increases $T_{20}(q^2)$ after the minimum. The inclusion of retardation effects does not change the situation.

The calculations of the structure functions $A(q^2)$, $B(q^2)$ and tensor polarization $T_{20}(q^2)$ allow one to make the following conclusions:

1. The contributions of meson exchange currents to structure functions $A(q^2)$, $B(q^2)$ at large transfer momenta should be taken into account.
2. The contributions of MEC to $T_{20}(q^2)$ are significant for $q >$ > 2.5 fm^{-1}.
3. The retardation effects are very small for all the considered functions in the whole momentum scale.

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