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MAGNETIC FORM FACTOR OF THE DEUTERON IN THE ELASTIC eD-SCATTERING WITH ALLOWANCE FOR RETARDATION EFFECTS IN EXCHANGE MESON CURRENTS

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Retardation effects on the deuteron magnetic form factor are studied. The contribution of these effects is negligible when $q^2 < 30\ \mathrm{fm}^{-2}$. At a larger q^2 the retardation effects are shown to be important.

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

Магнитный формфактор дейтрона в упругом eD-рассеянии с учетом эффектов запаздывания в обменных мезонных токах

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Исследовано влияние эффектов запаздывания на магнитный формфактор дейтрона. Показано, что вклад этих эффектов пренебрежимо мал в области импульсов передач $q^2 < 30\ \Phi\mathrm{м}^{-2}$. В области больших переданных импульсов эффекты запаздывания играют существенную роль.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

1. The magnetic form factor of the deuteron in the elastic eD-scattering with inclusion of exchange meson currents has been discussed in refs.[1,2]. The most detailed calculations have been made for the pair isoscalar exchange currents due to π, ρ, ω and $\rho\pi\gamma$ processes. It was shown that the structure function $B(q^2)$ allowing for the meson exchange currents can be satisfactorily described up to $q^2 < 30\ \mathrm{fm}^{-2}$. However, these calculations have not been completed. So, the investigation of retardation effects was not examined. Experiments available at present on the structure function $B(q^2)$ provoke the most detailed analysis of the deuteron structure in a broad range of measured momentum transfers.

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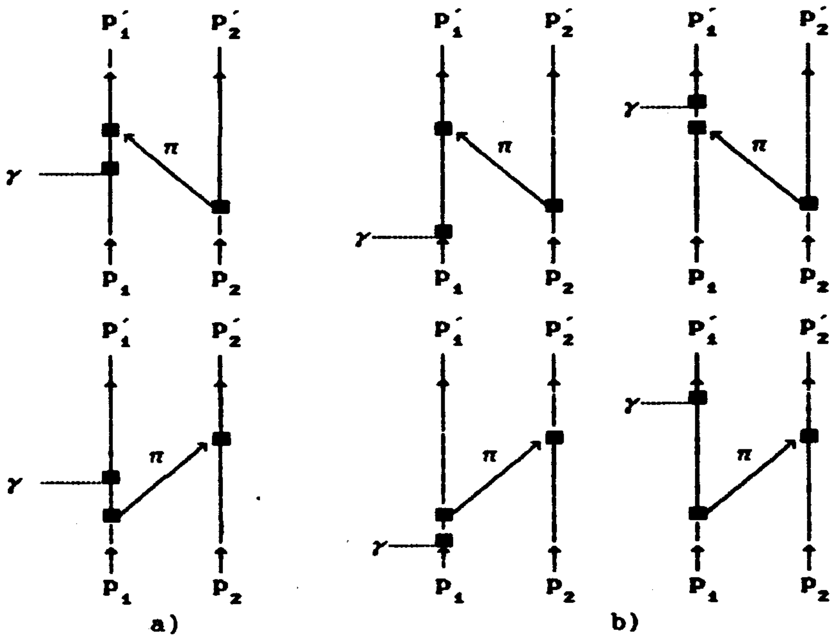

Fig.1. Diagrams of recoil (a) and wave function reorthonormalization (b).

Our research is devoted to retardation effects in exchange meson currents.

The retardation currents consisting of the recoil (RC) and wave function reorthonormalization (WFR) currents (fig.1) were discussed in refs.[3-6].

In ref.3 the retardation currents were defined. It was shown that the RC and WFR currents cancel out completely in the nonrelativistic limit (up to an order of $O(1/M^2)$). However in the $O(1/M^3)$-limit (relativistic currents) the retardation effects do exist. In paper [4] the expressions for the charge densities ($\rho^{ret,a}$, $a = \pi, \rho, \omega$) of order ($O(1/M^3)$) were calculated. In the present paper we derived an expression for the retardation isoscalar current ($\vec{j}^{\,ret,\pi}$) up to an order of $O(1/M^4)$ and a general expression for the magnetic form factor of the deuteron ($F_M^{ret,\pi}$). Note that these expressions have not been derived before. The numerical calculations were carried out with the use of the "Bonn" wave functions. The experimental data are taken from refs.[7-9]. The structure function $B(q^2)$ is defined by the expression $B(q^2) = 4\eta(1+\eta)F_M^2/3$, where $\eta = q^2/4M^2$ (M is the deuteron mass) and $F_M = F_M^{imp} + F_M^{\pi NN} + F_M^{\rho\pi\gamma} + F_M^{ret,\pi}$ is given by the impulse approximation, pair current, $\rho\pi\gamma$-process and retardation effects respectively.

2. The retardation exchange current has been extracted from the S-matrix of the process from fig.1:

$$S_{fi} = -(2\pi)^{-2}\, i\,\delta^4(p_1' + p_2' - p_1 - p_2 - q_0)\, j_\mu^{ret}\, V^\mu . \qquad (1)$$

Applying the time-order perturbation theory and an expansion of the energy denominators of the RC and WFR-currents we have obtained the expression for retardation isoscalar current due to π-exchange:

$$\vec{j}^{\,ret,\pi} = \vec{j}_a^{\,ret,\pi} + \vec{j}_b^{\,ret,\pi} + (1 \Longleftrightarrow 2)\,, \qquad (2)$$

where

$$\vec{j}_a^{\,ret,\pi} = -i\,\frac{G_M^s}{8m^2}\left(\frac{g_{\pi NN}}{2m}\right)^2 (\vec{\tau}_1\cdot\vec{\tau}_2)(\vec{k}_2\times\vec{q})(\vec{q}\cdot\vec{k}_2)(\vec{\sigma}_2\cdot\vec{k}_2)\,\frac{K^2_{\pi NN}(k_2^2)}{(k_2^2+m_\pi)^2}, \qquad (2a)$$

$$\vec{j}_b^{\,ret,\pi} = \frac{1}{8m^2}\left(\frac{g_{\pi NN}}{2m}\right)^2 (\vec{\tau}_1\cdot\vec{\tau}_2)\{G_M^s(\vec{k}_2(\vec{q}\cdot\vec{k}_2)(\vec{\sigma}_1\cdot\vec{q})(\vec{\sigma}_2\cdot\vec{k}_2) -$$

$$-\vec{\sigma}_1(\vec{q}\cdot\vec{k}_2)^2(\vec{\sigma}_2\cdot\vec{k}_2)) - F_1^s\vec{k}_2(\vec{q}\cdot\vec{k}_2)(\vec{\sigma}_1\cdot\vec{k}_2)(\vec{\sigma}_2\cdot\vec{k}_2)\}\,\frac{K^2_{\pi NN}(k_2^2)}{(k_2^2+m_\pi^2)^2}, \qquad (2b)$$

$$\vec{k}_2 = \vec{p}_2' - \vec{p}_2 .$$

Here, $q_{\pi NN}$ is the coupling constant: G_M^s, the isoscalar magnetic form factor ($G_M^s = (1+k_s)(1+q^2/0.71\ \mathrm{GeV}^2)^{-2}$, $k_s = -0.12$); m, the nucleon mass; $K_{\pi NN}(k_2^2)$, the meson-nucleon form factor; F_1^s, the form factor of the nucleon.

The magnetic form factor is defined by

$$F_M(q^2) = -\langle D|\,\frac{3im}{2\pi q^2}\int\frac{d\vec{k}}{(2\pi)^3}\int d\Omega_q\, e^{i(\vec{q}\vec{r}/2-\vec{k}\vec{r})}(\vec{q}\times\vec{j}(\vec{k},\vec{q}))_0\,|D\rangle, \qquad (3)$$

where $|D\rangle$ is the deuteron wave function; $\vec{r} = \vec{r}_1 - \vec{r}_2$ ($\vec{r}_1$ and $\vec{r}_2$ are the spatial coordinates of the nucleus); $\vec{j}(\vec{k},\vec{q})$, the spatial current. Taking into accout expression (2) we give the final general expression for $F_M^{ret,\pi}$:

$$F_M^{ret,\pi} = \frac{9}{5}q\left(\frac{1}{m}\right)^3\left(\frac{g_{\pi NN}}{4\pi}\right)^2 G_M^s\int_0^\infty dr\,\{j_1(qr/2)A_1(r) + j_3(qr/2)A_2(r)\},$$

$$A_1(r) = 2/3\, U^2(r)\, I_1(r) + 1/5\, \{ \sqrt{2}\, U(r)\, W(r)\, (1/3\, I_1(r) - 3 I_3(r)) -$$
$$- W^2(r)\, (4/3\, I_1(r) + 3 I_3(r)) \},$$
$$A_2(r) = - 2/3\, U^2(r)\, I_3(r) + 1/5\, \{ \sqrt{2}\, U(r)\, W(r)\, (2 I_1(r) - 4/3\, I_3(r)) + \tag{4}$$
$$+ W^2(r)\, (2 I_1(r) + 1/3 I_3(r)) \},$$

where U(r) and W(r) are S and D-waves, respectively. The functions $I_1(r)$, $I_3(r)$ depend on the meson-nucleon form factor.

$$I_1(r) = \int_0^\infty dk\, k^5 j_1(kr)\, \frac{K^2_{\pi NN}(k^2)}{(k^2 + m^2_\pi)^2}, \tag{4a}$$

$$I_3(r) = \int_0^\infty dk\, k^5 j_3(kr)\, \frac{K^2_{\pi NN}(k^2)}{(k^2 + m^2_\pi)^2}. \tag{4b}$$

Note that result (4) is independent of $\vec{j}_b^{\,ret,\pi}$.

3. The results of numerical calculations are shown in figs.2,3. Here, we give the results obtained with the following parameterization of the meson-nucleon form factor:

$$K_\alpha(k^2) = \frac{1}{(1 + k^2/\Lambda^2_{1,\alpha})(1 + k^4/\Lambda^4_{2,\alpha})} \quad (\alpha = \pi NN,\ \rho NN). \tag{5}$$

The parameter values are: $\Lambda_{1,\pi NN}$= 0.99 GeV and $\Lambda_{2,\pi NN}$= 2.58 GeV. This, choice of the meson-nucleon form factor assures that $K_{\pi NN}(k^2) \sim$ $\sim (k^2)^{-3}$ will apply at a large momentum transfer, which is prescribed by quantum chromodynamics.

Applying parameterization (5) we have to make the following substitution for the coupling constant of the Bonn meson-exchange model for the correct normalization of its meson-nucleon form factor at zero momentum:

$$g_\alpha \to g_\alpha \left(1 - \frac{m^2_\alpha}{\Lambda^2_\alpha}\right), \tag{6}$$

where the coupling constant is: in the case of the Bonn meson-exchange full model $q_{\pi NN}$ = 13.45 and in the case of the Bonn energy-independent one-boson-exchange potential (OBEP) $q_{\pi NN}$ = 13.55, Λ_π = 1.3 GeV.

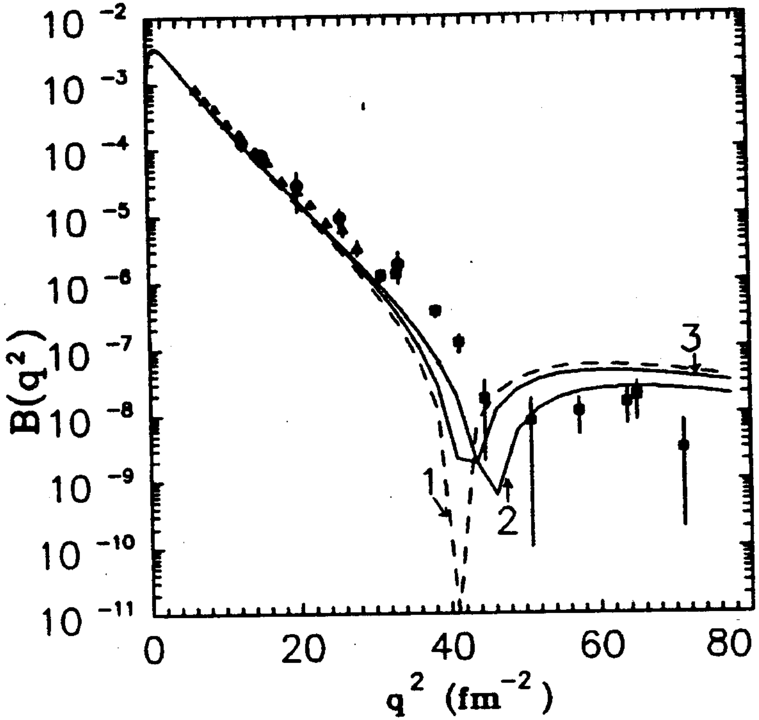

Fig.2. Deuteron structure function $B(q^2)$. The dashed line (1) is the impulse approximation with the Bonn wave functions (relativistic model), the solid line (2) – with inclusion of MEC ($\pi NN + \rho\pi\gamma$) and the solid line (3) – with inclusion of MEC ($\pi NN + \rho\pi\gamma$ + retardation effects). The experimental data are taken from /7-9/ .

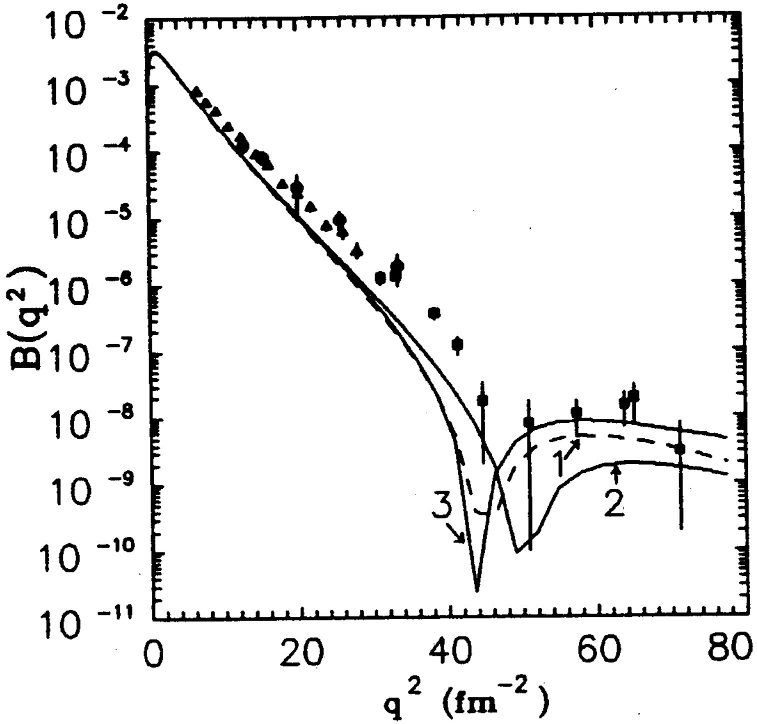

Fig.3. Deuteron structure function $B(q^2)$. The calculations are made with Bonn wave functions (full model). Notation is the same as in Fig.2.

Now we discuss the calculated results.

As we can see from fig.2, the retardation effects are negligible for $q^2 < 30\ fm^{-2}$, whereas for a larger momentum transfer the retardation current shifts the minimum towards smaller q^2 and essentially increases $B(q^2)$ for $q^2 > 45\ fm^{-2}$ breaking the agreement with experimental data. Figure 3 shows that the structure function $B(q^2)$ is described well when $q^2 > 50\ fm^{-2}$ if the retardation current is taken into account. In this case, for $q^2 < 30\ fm^{-2}$ the retardation effects are very small too. For a larger q^2 we can see a considerable shift of the minimum of $B(q^2)$ towards a smaller momentum transfer and the rapid increase towards experimental data.

Thus, we have shown that the inclusion of the retardation meson current into the structure function $B(q^2)$ has a considerable effect at a large momentum transfer.

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