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ON THE MESON EXCHANGE CURRENTS CONTRIBUTION IN DEEP INELASTIC SCATTERING ON DEUTERON

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1. It seems evident that the meson exchange currents (MEC) have to contribute to the deep inelastic scattering (DIS) of leptons on nuclei just as the corresponding contributions of MEC in different well-known electromagnetic and electroweak nuclear processes[1-4]. Therefore it is not surprising that the "mesons" had been just the first candidate for the explanation of the EMC-effect the observed deviation from unity of the ratio of the structure functions of a heavy nucleus and the deuteron $R^{A/D}$. It was supposed that as compared to the free nucleons, some enhancement of mesons (pions) δn_m in the heavy nucleus arose because of strong interactions of the bound nucleons. This enhancement δn_m explained some bump of $R^{A/D}$ at small x ($x \lesssim 0.2$) [5-7]. Unfortunately the value of δn_m had not been calculated: it had been introduced either as a free parameter or as a function of unknown quantities, effective parameters of the theory. This means that the question about a quantitative contribution of the mesonic currents to the nuclear structure function remains still open. We hope that the consistent theory of MEC in the DIS on heavy nuclei will be produced in the future, but the main qualitative features of the theory may be established with a simple example-DIS on a deuteron which is a nucleon "exactly solvable model". To the calculation of the MEC-corrections to the DIS on a deuteron is the object of our consideration.

2. All the information about DIS is contained in the hadronic tensor $W^D_{\mu\nu}$ defined by the imaginary part of the amplitude of the elastic $\gamma^* D$ -scattering. This circumstance allows us to use for our problem the theory of MEC developed for the elastic scattering (ES) of electrons by the lightest nuclei[1,2,4]. Like in the ES, different diagrams contribute to the DIS cross section: impulse approximation (IA), mesonic currents (MC), retardation currents, renormalization, etc.[4]. It can be shown[4] that a part of the diagrams cancels out and the remaining part can be included into the IA-diagram. Finally, $W^D_{\mu\nu}$ is defined as a sum of two diagrams: the IA and MC (see fig.1a,b). In calculating the MC-diagrams we have to use the mesons which "generate" the NN-interaction in a deuteron, because only in this case the considerations will be self-consistent. Below two potentials are used: the one-boson exchange potential ($\pi + \sigma + \omega + \delta + \eta + \rho$) of Bonn's group[8] and the "Paris potential" which for $r \geqslant 0.8$ fm is defined by the sum of $\pi + 2\pi + \omega$ - exchanges, and for $r < 0.8$ fm it containes phenomenological repulsion.

3. The deuteron structure function in IA has the usual convolution form:

$$F_2^{ND}(x) = \int F_2^N(x/\xi)\,\varphi(\xi)\,d\xi, \qquad (1)$$

where $F_2^N(x)$ is the nucleon structure function, $\varphi(\xi)$ is the longitudinal momentum distribution function of nucleons in the deuteron, $\xi = (P_0 + P_3)/m$, $P_0 = M_D - (\vec{P}^2 - m^2)^{1/2}$. The distribution $\varphi(\xi)$ obeys the "baryon number conservation" [10]:

$$\int \varphi(\xi)\,d\xi = 1 \qquad (2)$$

and is expressed through the deuteron wave function (WF)[11]:

$$\varphi(\xi) = \int \frac{d^3P}{(2\pi)^3}\left(1 + P_3/m\right)|\Psi_D(P)|^2\,\delta\!\left(\xi - \frac{P_0 + P_3}{m}\right). \qquad (3)$$

For $F_2^N(x)$ we use the parametrization

$$F_2^N(x) = \{[5x^{0,58}(2,69(1-x)^{2,7} + 1,56(1-x)^{5,7}] + 40\cdot 0.1(1-x)^7\}/18. \qquad (4)$$

The result of the calculation of $F_2^{ND}(x)$ is shown in fig.2 (curve 1) as the ratio $R^{ND/N} = F_2^{ND}/F^N$. The behaviour of $R^{ND/N}(x)$ is qualitatively the same as for the $R^{A/D}(x)$ case, however, the depth of the minimum of $R^{ND/N}(x)$ at $x \simeq 0,5 - 0,7$ relatively small because of the deuteron binding energy being small. The nucleon binding effect leads to known (see, for example [10, 11]) breaking of the energy sum rule:

$$\int F_2^{ND}(x)\,dx = (1-\delta)\int F_2^N(x)\,dx\,. \qquad (5)$$

The calculations with Bonn and Paris potentials give $\delta_B = 4,7\cdot 10^{-3}$ and $\delta_P = 5,0\cdot 10^{-3}$, respectively.

Fig.1. Graphs for the deep inelastic scattering on the deuteron.

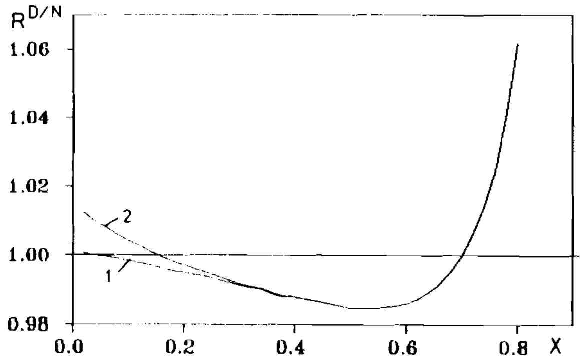

Fig.2. Ratio of the structure functions of the deuteron and free nucleon (the calculation with the Bonn WF of the deuteron). Curves: $1 - R^{ND/N} = F_2^{ND}/F_2^N$, $2 - R^{D/N} = (F_2^{ND} + \delta F_2^{\pi D} + \delta F_2^{2\pi D})/F_2^N$.

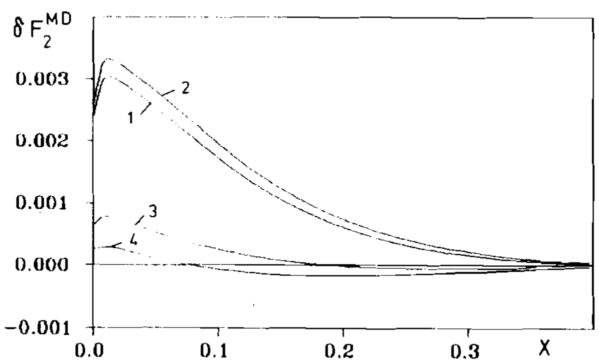

Fig.3. The MT contribution to the deuteron structure function. Curves: $1,2 - \delta F_2^{\pi D}(x)$; $3,4 - \delta F_2^{2\pi D}(x)$. **(1,3 - Bonn potential, 2,4 - Paris potential).**

4. The contribution of one-pion exchange (isovector, pseudoscalar) to the structure function $F_2^D(x)$ is

$$\delta F_2^{\pi D}(x) = \int \frac{d\vec{P}_1\, d\vec{P}_2}{(2\pi)^6} \frac{(\varkappa_0+\varkappa_3)}{\sqrt{2E_1 2E_2}\, M} F_2^{\pi}\left(\frac{xM}{\varkappa_0+\varkappa_3}\right) \frac{g_\pi^2(\varkappa)}{(\varkappa^2-m_\pi^2)^2}\, \Phi(P_1,P_2)\, \theta(\varkappa_0+\varkappa_3), \qquad (6)$$

where m_π is the pion mass, $\varkappa = (\varkappa_0, \vec{\varkappa}) = (M_D - E_1 - E_2,\ \vec{P}_1 + \vec{P}_2)$ is the pion 4-momentum, $g_\pi(\varkappa)$ is the pion-nucleon vertex function [8,9], M is the nucleon mass, M_D is the deuteron mass, $E_{1,2} = (\vec{P}_{1,2}^{\,2} + M^2)^{1/2}$. We use the parametrization of the $F_2^\pi(x)$ in the form

$$F_2^{\pi}(x) = [5\cdot 0{,}75\, x(1-x) + 20\cdot 0{,}075(1-x)^5]/9. \qquad (7)$$

The function $\Phi(\vec{P}_1,\vec{P}_2)$ is expressed through U and W components (S- and D-wave) of the deuteron WF:

$$\Phi(\vec{P}_1,\vec{P}_2) = 4\pi[\vec{\varkappa}^2(2f(P_1)f(P_2) - 3(U(P_1)U(P_2) + W(P_1)W(P_2)P_2(\cos\theta))) + 2(P_2(\cos\theta)-1)(\vec{P}_1^2 f(P_1)W(P_2) + \vec{P}_2^2 f(P_2)W(P_1))], \qquad (8)$$

where $f(P) = W(P) + \sqrt{2}\,U(P)$, $P = |\vec{P}|$, θ is the angle between $\vec{P}_1$ and $\vec{P}_2$, $P_2(z)$ is the Legendre polynomial. The numerical results of the $\delta F_2^{\pi D}(x)$ calculations are shown in fig. 3 (curves 1,2). Note that the mesonic correction is proportional to the overlap integrals of the meson vertex functions and the deuteron WF, where the short-range part of the integrand is removed because of the repulsion in NN-interaction at short distances. It means that the contributions of the 2π and ω -exchanges are negligible as compared to the one-pion exchange. For the illustration the contribution of the 2π -exchange is shown in fig. 3 (curves 3,4) where 2π -exchange is as usual approximated by the σ -meson exchange [8]. The result for $R^{D/N}(x) = (F_2^{ND}(x) + \delta F_2^{\pi D}(x) + \delta F_2^{2\pi D}(x))/F_2^N$ is shown in fig. 2 (curve 2). One can see that the MC contribution leads to the enhancement of $R^{D/N}(x)$ at small x: $x \le 0,25$. The MC-corrections restore only 60% of the energy sum rule (5) because $[\langle x\rangle_D^{\pi} + \langle x\rangle_D^{2\pi}]/\langle x_N\rangle \simeq 3\cdot 10^{-3}$. It seems to us that the deviation of $\langle x\rangle_D/\langle x_N\rangle$ from unity comes from some breaking of the self-consistency of our consideration. The short-range part of the "realistic" potentials is introduced phenomenologically.

So, the present investigation shows that the nucleon picture of the nucleus is incomplete. The same conclusion was obtained in ref./13/ as a result of the qualitative consideration of the EMC-effect. The MEC contribution to DIS on the deuteron is defined by two diagrams: IA and MC. The deuteron structure function $F_2^D(x)$ in IA qualitatively behaves like the EMC-effect with the breaking the energy sum rule. The MC contribution removes this breaking partially and reserves possibility other mechanisms: the "defreezing" of the convolution model, the renormalization of πNN- vertex functions and taking into account the multiquark structure of the deuteron at short NN-distances.

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Каптарь Л.П. и др. E2-88-105
Мезонные обменные токи в глубоконеупругом рассеянии на дейтроне

Получены основные диаграммы, определяющие мезонные поправки к структурной функции дейтрона $F_2^D(x)$. Вычислен вклад одно- и двухпионных обменов в $F_2^D(x)$ и в энергетическое правило сумм для кварковых распределений. Показано, что учет мезонных токов не восстанавливает полностью энергетическое правило сумм, нарушаемое внемассовостью нуклонов.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

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Kaptari L.P. et al. E2-88-105
On the Meson Exchange Currents Contribution in Deep Inelastic Scattering on Deuteron

The contribution of the one- and two-pion exchange currents to the deep inelastic deuteron structure function $F_2^D(x)$ is considered. It is shown that the mesonic corrections do not restore the energy sum rule violated by the off-mass-shell properties of the bound nucleons.

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

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