объединенный
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исследований
дубна

E2-91-296

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THE GOTTFRIED SUM RULE AND MESONIC EXCHANGES IN DEUTERON

Submitted to "Physics Letters B"

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1991

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Правило сумм Готтфрида и мезонные обмены в дейтроне

Рассматривается правило сумм Готтфрида, извлеченное из последних экспериментов группы NMC. Показано, что значение интеграла Готтфрида чувствительно к ядерным поправкам, например, к мезонным обменным эффектам, эффектам связности нуклонов в ядре и пр. Дана новая оценка интеграла Готтфрида. Полученные результаты не противоречат предсказаниям кварк-партонной модели.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1991

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The Gottfried Sum Rule and Mesonic Exchages in Deuteron

Recent NMC data on the experimental value of the Gottfried Sum are discussed. It is shown that the Gottfried Sum is sensitive to the nuclear structure corrections, viz. the mesonic exchanges and binding effects. A new estimation of the Gottfried Sum is given. The obtained result is close to the quark-parton prediction of 1/3.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1991

I. Recently, the NMC data[1, 2] on the ratio F_2^n/F_2^p have been applied to derive the difference $F_2^p - F_2^n$ and to estimate the Gottfried Sum (GS) $S_G \equiv \int(F_2^p - F_2^n)dx/x$[3] experimentally. Its value has been found to be below the quark-parton model expectation of 1/3, namely:

$$S_G = 0.240 \pm 0.016 \tag{1}$$

Serious theoretical speculations have appeared as a consequence of this discrepancy, e.g. the strong isospin violation in the proton sea-quark distributions[4] or the postponement of the onset of the Regge behavior to much smaller x values than have currently been sampled experimentally[5].

Note that the experimental value of the GS is sensitive to the procedure of extraction of the ratio F_2^n/F_2^p from the combined data on the deuteron and proton. Since the deuteron is a more complicated system than a simple sum of two free nucleons, a number of structure factors may change the ratio F_2^n/F_2^p. At least one should be careful while considering the influence of widely discussed nuclear effects, such as fermi motion, binding effects and mesonic exchanges in nuclei. Though in the integral characteristics of nuclear structure functions (SF) these corrections are small, it is not evident that they can be neglected in the procedure of determination of the neutron SF $F_2^n(x)$ from the nuclear data. Moreover, the recent analysis of BCDMS data on the proton and the deuteron performed in ref.[6] has shown the noticeable influence of the deuteron structure factors on the extracted neutron SF and the ratio F_2^n/F_2^p. It seems, the same corrections can also be expected for the NMC data.

The aim of this letter is to demonstrate that in the framework of the theoretical approach suggested in refs.[7] it is possible to extract the neutron SF so that the obtained value of the GS doesn't dramatically contradict the quark-parton predictions. It is shown that the nuclear corrections change the behavior of the difference $(F_2^p - F_2^n)$ as $x \to 0$ as compared with the prediction of the NMC experimental data fit.

II. Since the SF have been measured not in the whole region of the scale variable x, it is useful to define the x-dependent Gottfried integral:

$$I_G(x_1 \div x_2) = \int_{x_1}^{x_2} (F_2^p - F_2^n)\, dx/x, \tag{2}$$

and separately evaluate it in the measured and unmeasured regions of x. Thus, the GS may be written as a sum of three integrals (2) corresponding to three regions considered in ref.[1]:

$$\underset{(0.240\pm0.016)}{S_G} = \underset{(0.011\pm0.003)}{I_G^{NMC}(0 \div 0.004)} + \underset{(0.227\pm0.014)}{I_G^{NMC}(0.004 \div 0.8)} + \underset{(0.002\pm0.001)}{I_G^{NMC}(0.8 \div 1)} \tag{3}$$

The second term in (3) has been estimated experimentally using the F_2^D from the fit of the published deuteron data and the ratio F_2^n/F_2^p has been taken from the *unsmeared* NMC experimental results[2]. The first and third terms correspond to the unmeasured regions and have been estimated by extrapolation procedure. Thus, in all these three integrals the nuclear corrections have been missed. Let $F_2^{D(exp.)}$ be the experimental deuteron SF (that obviously includes all the nuclear and other effects) and $F_2^{p(exp.)}$ the corresponding proton SF. Then the unmeasured neutron SF defined by:

$$\tilde{F}_2^n = 2F_2^{D(exp.)} - F_2^{p(exp.)} \tag{4}$$

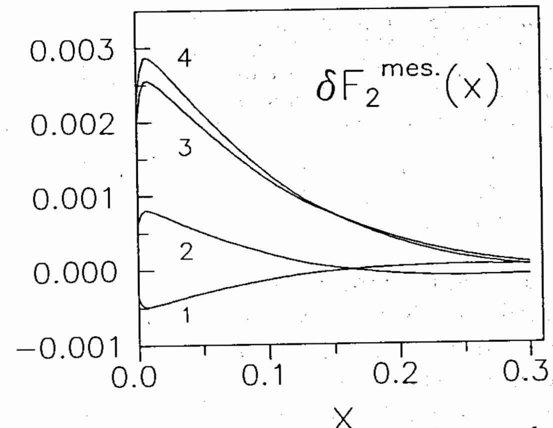

Fig. 1: *The meson exchange currents contribution to the deuteron structure function [7]. Curves 1-3 correspond to the contribution of $\omega-,\sigma-$ and $\pi-$mesons respectively; curve 4 is the sum over al the mesons.*

is overestimated due to the mesonic contributions to the deuteron SF. A more correct way to determine the neutron SF is to solve the integral equation[1]:

$$F_2^n(x,Q^2) = \left[2F_2^{D(exp.)}(x,Q^2) - \delta F_2^{mes.}(x,Q^2) - S_p^{-1}(x,Q^2)F_2^{p(exp.)}(x,Q^2)\right] S_n(x,Q^2), \tag{5}$$

$$S_{p(n)} = \frac{F_2^{p(n)}(x,Q^2)}{\int F_2^{p(n)}(x/y,Q^2) f_{N/D}(y)dy},$$

for $F_2^n(x)$. Here $\delta F_2^{mes.}(x,Q^2)$ is the meson contribution, $f_{N/D}(y)$ is distribution function of the nucleons carrying out the y-fraction of the total deuteron momentum. The distribution function $f_{N/D}(y)$ is straightforward connected with the usual deuteron wave function (computed in a realistic Paris or Bonn group potential) and includes the boundness of the nucleons inside the deuteron. The explicit expression of the $\delta F_2^{mes.}(x,Q^2)$ has been computed in ref.[7]. Fig.1 illustrates the contribution $\delta F_2^{mes.}$ for different mesons π, ω, σ in the deuteron.

To extract the neutron SF by solving the integral equation (5), we should parametrize the proton, deuteron and neutron SF in the full region of x and experimental values of Q^2. At this moment we are free in the choice of the parameters and we can from the very beginning constrain them to obey the Gottfried Sum Rule exactly. That kind of analysis has been done in[6] to extract the

[1] in this approach we take into account the nuclear corrections coming from the fermi-motion and meson exchange currents in the deuteron. A more complete analysis should include also the shadowing as $x \to 0$ and the contributions of other non-nucleon degrees of freedom (multiquarks, Δ-isobar ...) as $x \to 1$.

neutron SF from the combined BCDMS data. From that analysis we can compute the corresponding Gottfried integrals (3):

$$I_G^{BCDMS}(0 \div 0.004) = 0.036$$
$$I_G^{BCDMS}(0.004 \div 0.8) = 0.297$$
$$I_G^{BCDMS}(0.8 \div 1) = 0.0004 \qquad (6)$$

Note that in eq.(6) the Gottfried Sum Rule is exactly fulfilled. Comparison of (6) with (3) shows that here is a systematic difference in the NMC treatment of the experimental data with the results obtained from BCDMS experiments. To achieve the agreement between them, it is necessary to take into account the following:

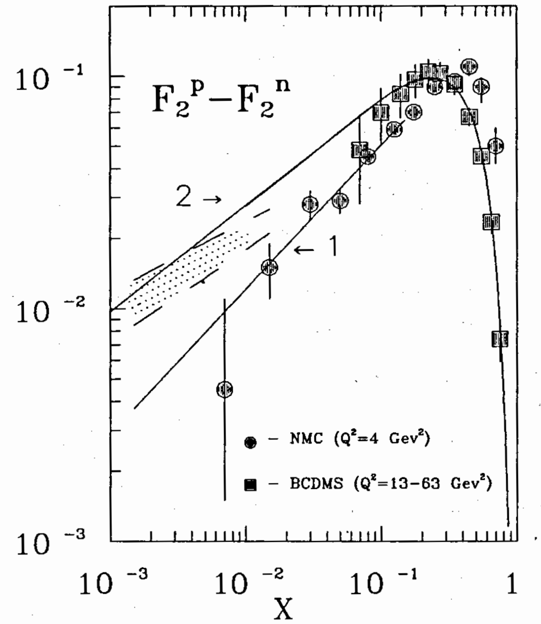

Fig. 2: *The difference $F_2^p(x) - F_2^n(x)$. Solid lines: 1 - NMC data fit[1]; 2 - parametrization from ref.[6]. Dashed lines and shadow area - corrected NMC data fit with the taking into account of the mesonic corrections (see text). Data: circles - NMC[1], squares - BCDMS[8].*

i) In the region $0.004 \le x \le 0.8$ where the role of the fermi motion is negligible small it is sufficient to correct the difference $F_2^p - F_2^n$ by adding the function $\delta F_2^{mes.}(x)$. As a result the Gottfried integral in this region increases by adding:

$$\delta I_G^{(mes.)}(0.004 \div 0.8) = \int_{0.004}^{0.8} \delta F_2^{mes.}(x)\, dx/x = 0.03 \pm 0.01 \qquad (7)$$

To estimate $I_G^{(mes.)}(0.004 \div 0.8)$ (7) we have used the numerical results for the mesonic corrections computed in ref.[7] (see also Fig.1). In ref.[7] it was noted that the numerically mesonic contribution to the deuteron SF $\delta F_2^{mes.}(x)$ was underestimated by $\sim 40\%$, owing to the approximate form of the current operator. This circumstance is reflected in (7) as a systematic error.

ii) Besides, the meson corrections change the behavior of $F_2^p - F_2^n$ as $x \to 0$. Usually in the region $x \le 0.004$ one assumes the "non-singlet" power behavior of the difference $F_2^p - F_2^n$ as ax^α. The fit of the NMC data at small x ($x = 0.004 - 0.15$) gives $a = 0.21 \pm 0.03$, $\alpha = 0.62 \pm 0.05$ [1]. This yields $I_G(0 \div 0.004)$ as is shown in(3). Upon taking into account the mesonic corrections to the NMC data the parameters became $a = 0.143 \pm 0.013$, $\alpha = 0.423 \pm 0.048$.

This situation is shown in the Fig.2 where the dashed lines correspond to the new behavior of the data and the shadow area displays the ambiguities in $\delta F_2^{mes.}(x)$ pointed above.

Thus, the part of the Gottfried integral computed with the new parameters a and α becomes: $I_G(0 \div 0.004) = 0.0340 \pm 0.010$. iii) At last in the region $0.8 \le x \le 1$ the mesonic contribution is negligible. Other nuclear effects, viz. fermi motion and binding effects, in this region may be significant in the functional dependence of SF. However, since here the absolute values of the SF are small, it is clear that their contributions to the integral characteristics are insignificant.

Gathering together the corrected integrals we obtain the corrected estimation of the GS instead of (1):

$$S_G = (0.034 \pm 0.01) + (0.227 \pm 0.014) + (0.03 \pm 0.01) + (0.002 \pm 0.001) = 0.29 \pm 0.03, \qquad (8)$$

that is close to the quark-parton predictions of 1/3.

III. Concluding remarks:

a) The procedure of extraction of the neutron SF from the nuclear data is model-dependent. Thereby the estimation of the Gottfried Sum is model-dependent too. A more accurate analysis should be based on the solution of the integral equation (5). In accordance with the definition of the functions $S_{p(n)}$ in (5), a theoretical model within which one describes the nucleus (deuteron) as well as the main characteristics of deep inelastic processes is required. Obviously, the suggested model is far to be complete. Besides the consideration in (5) of the mesonic corrections, binding and fermi-motion effects, other nuclear structure factors may be relevant (nuclear shadowing[9], six-quark[10], Δ-isobar admixtures in the deuteron[11] ...).

b) The most important factor to be included into our analysis is the nuclear shadowing as $x \to 0$ [9]. This correction is opposite in sign with the mesonic contribution and they may cancel each other at very small x. This circumstance may be checked experimentally by checking the sign of the unsmeared difference $F_2^p - F_2^n$ as $x \to 0$: the sign will be negative (positive) if the shadowing is smaller (larger) than the mesonic contribution.

c) The shadowing effects may modify our prediction concerning the behavior of the difference $F_2^p - F_2^n$ $x \to 0$ given in Fig.2 and may slightly change our estimation of the Gottfried integral $I_G(0 \div 0.004)$.

d) In our opinion, at this time the experimental situation is not quite clear to claim whether the Gottfried Sum Rule is fulfilled experimentally or not. In principle, high precision neutrino experiments may clarify this problem.

IV. We thank Profs. K. Rith and G.I. Smirnov for stimulating discussions.

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Received by Publishing Department
on June 28, 1991.