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Nuclear pions and the Gottfried and Bjorken sum rules

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Abstract. An extremely simple but instructive, "toy" model is presented which shows that a small excess of pions in the nucleus can produce a significant change in the values expected for the Gottfried sum rule. The general question of the convergence of the sum rule and of the convergence of the experimental integral is also discussed. It is demonstrated that conclusions about the sum rule, based on deuterium data, are surprisingly model dependent. In contrast, it is stressed, that the Bjorken sum rule can be tested significantly using deuterium data.

Introduction

Recently the NMC Group at CERN presented [1] results on the comparison of deep inelastic scattering on protons and neutrons which purported to show a significant discrepancy between the data and the Gottfried sum rule [2]

$$I_G \equiv \int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x} \, dx = \frac{1}{3} \tag{1}$$

Their results have stimulated a great deal of discussion [3] concerning both the correctness of the sum rule and the interpretation of what is actually measured.

In this paper we address the following issues. Firstly we discuss the general conditions for the convergence of the Gottfried integral I_G and we comment upon models which attempt to replace (1) by the result

$$I_G < \tfrac{1}{3} \tag{2}$$

which would apparently be compatible with the NMC result. Secondly, assuming the convergence of I_G, we argue that experiments on deuterium cannot provide a simple and direct test of (1); moreover that the experimental integral[1]

$$I_{pD}(x_{\min}) = 2 \int_{x_{\min}}^1 \frac{F_2^p(x) - F_2^D(x)}{x} \, dx \tag{3}$$

almost certainly diverges as $x_{\min} \to 0$.

We then construct an extremely simple, but instructive, toy model of the pion excess in nuclei. With this we show that even a tiny excess, with the pions carrying $\simeq 2\%$ of the momentum of the deuteron, leads to a significant difference between the experimental integral I_{pD} and the true Gottfried integral I_G. Thus we conclude that the testing of the Gottfried sum rule using deuterium is surprisingly model dependent, and we offer a simple formula for extracting $F_2^p(x) - F_2^n(x)$ from $F_2^D(x)$ in a more correct fashion.

In our conclusion we draw attention to the fact that, despite its naive simplicity, our toy model appears to give a reasonable description of both the Q^2 variation of F_2^n/F_2^p and of deep inelastic and Drell–Yan scattering on nuclei. Finally we explain why the analogous, but much more fundamental, Bjorken sum rule [4] can be adequately tested using deuterium.

Convergence of the Gottfried sum rule

The scaling functions $F_2^{p,n}(x)$ are directly proportional to the total cross-section for the scattering of a virtual photon (4-momentum q^μ) of $(\text{mass})^2 = -Q^2$ and laboratory energy ν on a stationary proton or neutron (4-momentum P^μ). At fixed Q^2 the high energy regime corresponds to

$$s \equiv (q + P)^2 \gg Q^2 \tag{4}$$

i.e. to

$$\frac{2m\nu}{Q^2} \gg 1 \tag{5}$$

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[1]Recall that F_2^D is defined per nucleon

or, in terms of Bjorken x, to

$$x \to 0 \tag{6}$$

At fixed Q^2 it is believed that, provided (5) is satisfied, the behaviour of the cross-section for virtual photon on nucleons will be similar to that of real photon-nucleon scattering. We shall assume this to be true in what follows.

Now experimentally [5] $\sigma_{\gamma p}$ appears to be growing like a typical hadronic cross-section at very high energies i.e.

$$\sigma_{\gamma p} = a \ln^2 s + b_p + \ldots \tag{7}$$

The neutron cross-section has not been measured at high energies to see the Froissart $\ln^2 s$ growth, but undoubtedly one will find analogously that

$$\sigma_{\gamma n} = a \ln^2 s + b_n + \ldots \tag{8}$$

such that

$$\lim_{s\to\infty} \frac{\sigma_{\gamma p}}{\sigma_{\gamma n}} = 1 \tag{9}$$

The convergence of the Gottfried integral I_G requires that as $s \to \infty$

$$\sigma_{\gamma p} - \sigma_{\gamma n} \propto s^{\alpha - 1} \tag{10}$$

with $\alpha < 1$, a behaviour which is very natural in Regge theory where $\alpha = \alpha_\rho(0) \approx \frac{1}{2}$. However it is feasible, even if unlikely, that $b_n \neq b_p$ in (7) and (8), which would imply, as $s \to \infty$

$$\sigma_{\gamma p} - \sigma_{\gamma n} \approx \text{const} \tag{11}$$

which would lead to a divergent I_G [6].

Thus the Gottfried sum rule is by no means self-evident or sacrosanct and its failure to converge would not at all be a catastrophe. It would simply be telling us something interesting about $\sigma_{\gamma p} - \sigma_{\gamma n}$ or in parton language, about the difference between the up sea $\bar{u}(x)$ and the down sea $\bar{\mathrm{d}}(x)$ inside a proton.

In the conventional parton model I_G is given by [7]

$$I_G = \int_0^1 \mathrm{d}x \, \tfrac{1}{3} [u_v(x) - \mathrm{d}_v(x)] + \tfrac{2}{3} [\bar{u}(x) - \bar{\mathrm{d}}(x)] \tag{12}$$

The value $I_G = \frac{1}{3}$ comes from assuming $\bar{u}(x) = \bar{\mathrm{d}}(x)$ and from the charge conservation sum rules which imply

$$\int_0^1 \mathrm{d}x [u_v(x) - \mathrm{d}_v(x)] = 1 \tag{13}$$

Both $\bar{u}(x)$ and $\bar{\mathrm{d}}(x)$ are supposed to grow without limit as $x \to 0$, and the convergence of I_G requires that

$$\lim_{x\to 0} \frac{\bar{u}(x)}{\bar{\mathrm{d}}(x)} = 1 \tag{14}$$

in such a way that as $x \to 0$

$$\bar{u}(x) - \bar{\mathrm{d}}(x) \propto x^{-\alpha} \tag{15}$$

with $\alpha < 1$ in correspondence with (10).

Prior to the NMC experiment the best fits for the quark distributions[8] seemed to prefer the equality of $\bar{u}(x)$ and $\bar{\mathrm{d}}(x)$ but, there is no fundamental reason to have $\bar{u}(x) = \bar{\mathrm{d}}(x)$ for *all* x, although in the past this was taken to be a reasonable approximation. Indeed it has been argued [9] that the Pauli principle ought to make $\bar{u}(x) < \bar{\mathrm{d}}(x)$ which would lower the value of I_G.

Eichten, Hinchliffe and Quigg [10] have produced a model, based on chiral perturbation theory, in which valence quarks split into π-mesons and quarks and the π-mesons then populate the sea when they split into quark-antiquark pairs. The fact that $u_v(x) > \mathrm{d}_v(x)$ then leads to an imbalance such that one expects more $\bar{\mathrm{d}}$ produced than $\bar{u}(x)$ i.e. $\bar{u}(x) < \bar{\mathrm{d}}(x)$ and therefore $I_G < \frac{1}{3}$. But more recent data on Drell–Yan production in nuclei [11] rules out a large asymmetry in the sea in the kinematical region of the NMC measurements and suggests that $\bar{u}$ and $\bar{\mathrm{d}}$ are equal for $x \geq 0.01$. Aside from the question of detailed parametrisations we feel that this model reflects an important physical effect, but that the treatment is not quite consistent.

Once it is admitted that there is a non-negligible $qq\pi$ coupling this will be reflected in the nucleon wave function, part of which will then contain pions as constituents. The expressions for $F_2^{p,n}(x)$ will be modified to include the contribution of the pion constituents. In taking the difference $F_2^p(x) - F_2^n(x)$ the pion contribution cancels out and one is left with (12). However the result of integrating (12) is *different* because the charge conservation sum rules must reflect the existence of the pionic constituents. Thus one has for the proton

$$1 = \int_0^1 \mathrm{d}x \, [\tfrac{2}{3} u_v(x) - \tfrac{1}{3} \mathrm{d}_v(x) + f_{\pi^+/p}(x) - f_{\pi^-/p}(x)] \tag{16}$$

where $f_{\pi/p}(x)$ is the number density of pions in a proton. Similarly, for the neutron,

$$0 = \int_0^1 \mathrm{d}x \, [\tfrac{2}{3} \mathrm{d}_v(x) - \tfrac{1}{3} u_v(x) + f_{\pi^-/p}(x) - f_{\pi^+/p}(x)] \tag{17}$$

where, via isosopin invariance, we have used

$$f_{\pi^+/n}(x) = f_{\pi^-/p}(x), \quad f_{\pi^-/n}(x) = f_{\pi^+/p}(x) \tag{18}$$

From these it follows that (13) is replaced by

$$\int_0^1 \mathrm{d}x [u_v(x) - \mathrm{d}_v(x)] = 1 - 2 \int_0^1 \mathrm{d}x [f_{\pi^+/p}(x) - f_{\pi^-/p}(x)] \tag{19}$$

so that

$$I_G = \tfrac{1}{3} - \tfrac{2}{3} \int_0^1 \mathrm{d}x [f_{\pi^+/p}(x) - f_{\pi^-/p}(x) + \bar{\mathrm{d}}(x) - \bar{u}(x)] \tag{20}$$

Since there will be more π^+ than π^- in a proton the new term in (20) will make $I_G < \frac{1}{3}$ even if $\bar{\mathrm{d}}(x) = \bar{u}(x)$.

However as we shall now argue, we do not think that NMC experiment yields a significant test of the Gottfried sum rule, so that it is perhaps premature to assess models of the degree to which $\bar{u}(x) \neq \bar{\mathrm{d}}(x)$

The deuterium sum rule

The use of I_{pD} in (3) as a test for the Gottfried sum rule is based upon the assumption that is safe to take

$$2F_2^D(x) = F_2^p(x) + F_2^n(x) \tag{21}$$

in which case I_{pD} reduces to I_G. But, as we shall now discuss, it is virtually certain that $I_{pD}(x_{\min})$ diverges as $x_{\min} \to 0$ even if I_G itself is convergent.

There are very strong arguments [12] to believe that shadowing persists at asymptotic energies, so that as $s \to \infty$,

$$\sigma_{\gamma D} < \sigma_{\gamma p} + \sigma_{\gamma n} \tag{22}$$

For not too large fixed Q^2 there seems no reason to expect that (22) ceases to be valid. It follows that

$$\lim_{x\to 0}[F_2^p(x) - F_2^D(x)] \neq 0 \tag{23}$$

leading to the divergence of I_{pD} as $x_{\min} \to 0$.

In the original NMC paper [1] there was no sign of any such divergence. In their most recent paper [13] NMC report some indication of shadowing, in that the quantity $F_2^n/F_2^p|_{\exp} - 1$ does not go to zero as $x \to 0$. Given that $F_2^n/F_2^p|_{\exp}$ is obtained from the data by using (21), this is tantamount to having a non-zero limit in (23). As we shall show in the next section by means of a very simple toy model, there are nuclear effects in deuterium which, although minute, are not negligible compared with the very small difference $2[F_2^p(x) - F_2^D(x)]$. These have two consequences. On the one hand they make the connection between I_{pD} and I_G more model dependent than hoped for. On the other they tend to hide the effect of geometrical shadowing so that presumably the divergence in I_{pD} will show up at still smaller values of x.

We should stress that the argument for the divergenceof I_{pD} is not a rigorous one. But if I_{pD} really does *not* diverge that will be a major physical puzzle, requiring some very subtle dynamical explanation.

Extracting $F_2^p - F_2^n$ from the deuterium measurement

Let us first recall the origin of the simple-minded expression (21). If the deuteron consists *only* of a proton and a neutron and if we ignore shadowing then one has

$$2F_2^D(x) = \int_x^2 dy \left[F_2^p\left(\frac{x}{y}\right) f_{p/D}(y) + F_2^n\left(\frac{x}{y}\right) f_{n/D}(y)\right] \tag{24}$$

where $f_{p/D}(y)$ is the number density of protons in the deutron whose momentum is a fraction $\frac{y}{2}$ of the momentum of the deutron. As usual x for the deuteron is defined by

$$x = 2\left(\frac{Q^2}{2P\cdot q}\right) \tag{25}$$

where P is the deuteron 4-momentum. In principle x can thus run between 0 and 2.

Isospin invariance gives

$$f_{n/D}(y) = f_{p/D}(y) \tag{26}$$

and charge conservation implies

$$1 = \int_0^2 dy\, f_{p/D}(y) \tag{27}$$

Now in the simplest possible picture both the proton and the neutron carry exactly one half of the momentum of the deuteron, so that

$$f_{p/D}(y) = \delta(1-y) \tag{28}$$

Insertion of this into (24) yields (21), or more correctly

$$\begin{aligned} 2F_2^D(x) &= F_2^p(x) + F_2^n(x) \quad x \le 1 \\ &= 0 \quad x > 1 \end{aligned} \tag{29}$$

Many arguments have been given that the pionic content of nuclei is not negligible [14]. Let us therefore suppose that the deuteron wave-function contains a pionic component. In that case, ignoring shadowing, (24) is replaced by

$$\begin{aligned} 2F_2^D(x) &= \int_x^2 dy \left[F_2^p\left(\frac{x}{y}\right) + F_2^n\left(\frac{x}{y}\right)\right] f_{p/D}(y) \\ &+ 3\int_x^2 dy\, F_2^\pi\left(\frac{x}{y}\right) f_{\pi/D}(y) \end{aligned} \tag{30}$$

where

$$F_2^\pi(z) \equiv \tfrac{1}{3}[F_2^{\pi^+}(z) + F_2^{\pi^0}(z) + F_2^{\pi^-}(z)] \tag{31}$$

is the average pion structure function. In (30) we have, via isospin invariance, taken for the number density of pions, whose momentum is $\frac{y}{2}$ of the deuteron momentum,

$$f_{\pi^+/D} = f_{\pi^0/D} = f_{\pi^-/D} \equiv f_{\pi/D} \tag{32}$$

Baryon number conservation implies that (27) is unchanged, but momentum conservation now requires

$$1 = \int_0^2 dy \frac{y}{2}[2f_{p/D}(y) + 3f_{\pi/D}(y)] \tag{33}$$

In the spirit of the simple picture that led to (21) let us now assume that the proton and neutron each carry exactly $\frac{1}{2}(1-\varepsilon)$ of the deuteron's momentum, so that (28) is replaced by

$$f_{p/D}(y) = \delta(1-\varepsilon-y) \tag{34}$$

Using this in (33) and (27), one has as expected

$$\int_0^2 dy \frac{y}{2} 3f_{\pi/D}(y) = \varepsilon \tag{35}$$

i.e. ε is the fraction of the deuteron's momentum carried by its pionic constituents and is expected to be very small.

Substitution of (34) into (30) yields

$$2F_2^D(x) = \left[F_2^p\left(\frac{x}{1-\varepsilon}\right) + F_2^n\left(\frac{x}{1-\varepsilon}\right) \right] \theta(1-\varepsilon-x) + 3\int_x^2 \mathrm{d}y\, F_2^\pi\left(\frac{x}{y}\right) f_{\pi/D}(y) \quad (36)$$

Since our primary aim is to learn about $F_2^p(x) - F_2^n(x)$, let us now write

$$F_2^p(x) - F_2^n(x) = [2F_2^p(x) - 2F_2^D(x)] + [2F_2^D(x) - F_2^p(x) - F_2^n(x)] \equiv [2F_2^p(x) - 2F_2^D(x)] + \delta F_2^D(x) \quad (37)$$

The first term of the R.H.S. of (37) is what is measured in the NMC experiment. The term $\delta F_2^D(x)$ is the correction needed to extract $F_2^p(x) - F_2^n(x)$.

From (37) and (36) we see that

$$\delta F_2^D(x) = \left[F_2^p\left(\frac{x}{1-\varepsilon}\right) + F_2^n\left(\frac{x}{1-\varepsilon}\right) \right] \theta(1-\varepsilon-x) - [F_2^p(x) + F_2^n(x)]\theta(1-x) + 3\int_x^2 \mathrm{d}y F_2^\pi\left(\frac{x}{y}\right) f_{\pi/D}(y)$$
$$\simeq \varepsilon x \left[\frac{\mathrm{d}F_2^p}{\mathrm{d}x} + \frac{\mathrm{d}F_2^n}{\mathrm{d}x} \right] \theta(1-x) + 3\int_x^2 \mathrm{d}y F_2^\pi\left(\frac{x}{y}\right) f_{\pi/D}(y) \quad (38)$$

We shall now attempt to estimate the terms on the R.H.S. of (38). Since we are dealing with a small correction it should be safe to take $\mathrm{d}F_2^n/\mathrm{d}x$ from the naive expression

$$F_2^n(x) = [2F_2^D(x) - F_2^p(x)] \quad (39)$$

using NMC's parametrizations [15] for the deuteron and the proton structure functions. The pion structure function is supposed to be known from experiment. We take for it the Q^2-dependent parametrization given in [16]. It is shown in Fig. 1 for $Q^2 = 5\,(\mathrm{GeV}/c)^2$.

We do not have very convincing evidence for the shape of the pion distribution in the deuteron, so apart from a slight modification we follow the estimate of Berger et al. [17] and take[2]

$$3f_{\pi/D}(y) = \frac{\varepsilon}{2} \frac{\Gamma(a+b+3)}{\Gamma(a+2)\Gamma(b+1)} \left(\frac{y}{2}\right)^a \left(1-\frac{y}{2}\right)^b \quad 0 \le y \le 2 \quad (40)$$

which is designed to satisfy (35). We fix $a=2$, $b=5$ as reasonable estimates. The resulting distribution is shown in Fig. 2.

The whole of the R.H.S. of (38) is then proportional to ε and this is the only free parameter. Models suggest that ε cannot be larger than a few percent. Let us therefore take $\varepsilon = 2\%$ and see whether $\delta F_2^D(x)$ has a significant effect in (37). In Fig. 3 we show values of

$$[F_2^p(x) - F_2^n(x)]_{\text{naive}} \equiv F_2^p(x)\left[1 - \frac{F_2^n(x)}{F_2^p(x)}\right] \quad (41)$$

from the previously mentioned parametrizations and the result of adding $\delta F_2^D(x)$ to these. In Fig. 4 we show the integrand of the Gottfried sum rule, i.e., the same functions divided by x. We are assuming the convergence of the Gottfried sum rule, so we extrapolate the R.H.S. of (37) to zero at $x=0$. It is seen that even with ε of just 1% there is a non-trivial modification at small values of x. In Fig. 5 we show the effect of taking $\varepsilon = 1, 2, 3\%$ on the estimate of $\delta F_2^D(x)$.

It should be noted that even if we assume convergence of the real Gottfried sum rule, the two individual terms on the R.H.S. of (37) will each give rise to a divergent integral.

[2] In our notation $3f_{\pi/D}$ corresponds to $f_{\pi/D}$ in [17]

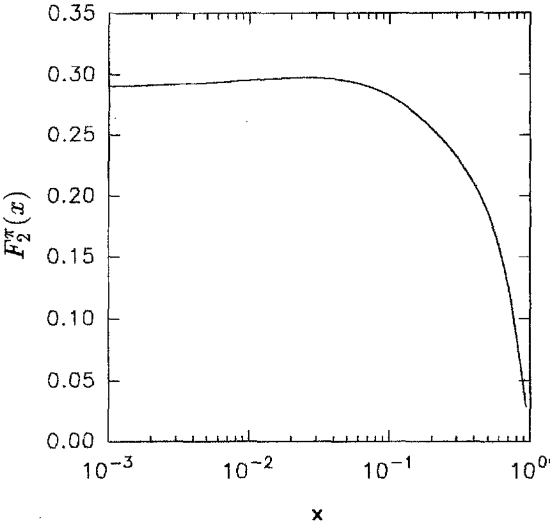

Fig. 1. The pion structure function, (31)

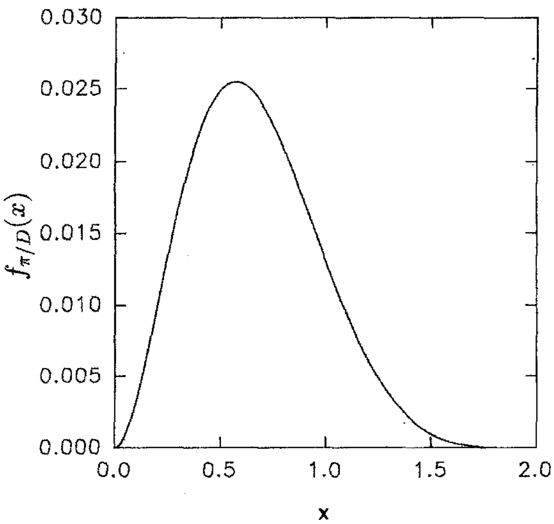

Fig. 2. The number density of pions in the deuteron, (40)

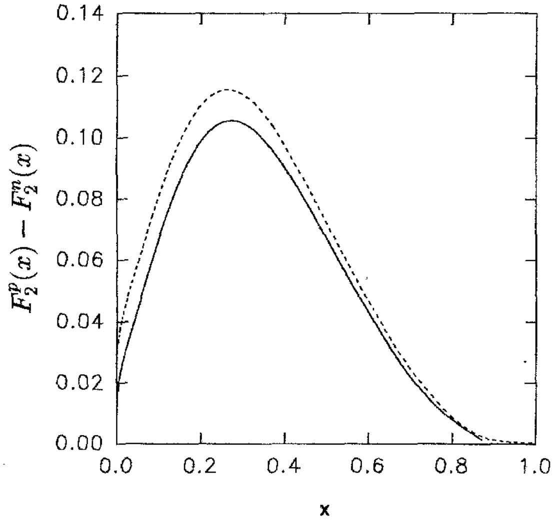

Fig. 3. Values for the difference between the proton and neutron structure functions, (37), ($\varepsilon = 0$ continuous line, $\varepsilon = 0.02$ dashes)

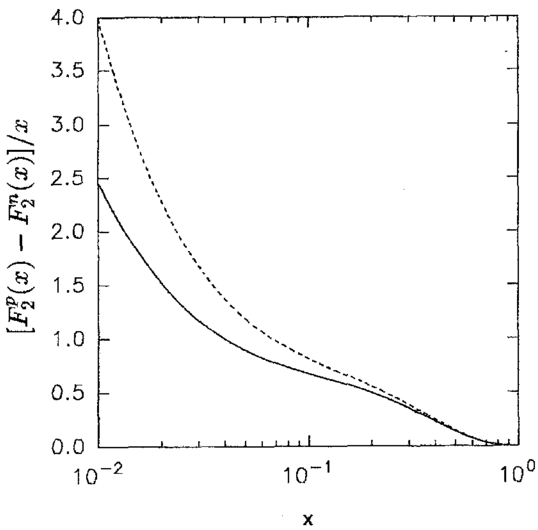

Fig. 4. The same differences divided by x

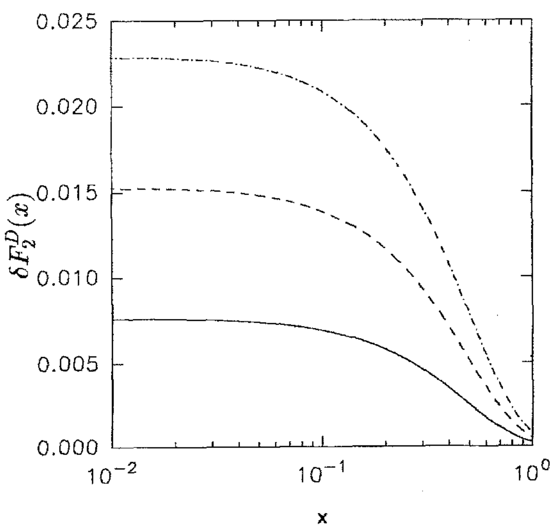

Fig. 5. $F_2^D(x)$, (38), for $\varepsilon = 0.01$, $\varepsilon = 0.02$ and $\varepsilon = 0.03$ (continuous line, dashed and dot-dashed lines respectively

Thus without resorting to a detailed model as to how the separate divergences cancel we cannot simply compute the Gottfried integral all the way down to $x = 0$. However we note that using $x_{MIN} = 0.004$ it is possible to make the Gottfried integral take on the value $\frac{1}{3}$ by choosing $\varepsilon \approx 2\%$. However, since there are some arguments for having $\bar{u} \neq \bar{d}$ for all x (even if the *detailed* models are not convicing) we do not believe that ε should be fixed in this fashion. The point we wish to emphasize is that (37), and not (21), is the correct relation between $F_2^p(x) - F_2^n(x)$ and the measured observable and that this relation, unfortunately, is somewhat model dependent. Hence until one has a more convincing description of the (pionic content of) the deuteron, one cannot use the NMC measurement to make definitive statements about the Gottfried sum rule.

Parton fusion effects and shadowing

In the above analysis we have neglected shadowing and also the possibility that in the dense cloud of small-x partons fusion may take place between partons from *different* nucleons.

Close, Qiu and Roberts [18] have estimated the correction $\Delta F_2^A(x)$ per nucleon arising from parton fusion for $A = 56$. Because the deuteron is a very loosely bound large structure, the effects coming from the proximity of the nucleons to each other will be smaller than expected on the basis of the $A^{1/3}$ behaviour of $\Delta F_2^A(x)$. A naive $A^{1/3}$ scaling extrapolation gives for the deuteron $\Delta F_2^D \approx \frac{1}{3} \Delta F_2^{56}$ whereas estimates based on a more realistic deuteron radius suggest an even smaller value. In that case, the values of ΔF_2^{56} given in [18], yields a correction to (38) of the same sign as δF_2^D which is small compared to δF_2^D for $\varepsilon \sim 2\%$.

A heroic attempt to estimate shadowing, based upon a mixture of vector dominance and parton fusion, has been made by Badelek and Kwiecinsky [19]. The correction term $\delta F_2^D|_{shadowing}$ found by them, negative for $x < 0.1$, is negligible compared to the positive pionic correction for $\varepsilon = 2\%$. However it is comparable in magnitude to the pionic correction for $x \leq 0.01$ if $\varepsilon \approx 1\%$.

Although all these effects are very small correction to F_2^D their rôle in the difference $2[F_2^p(x) - F_2^D(x)]$ is much amplified. Thus the extraction of $F_2^p(x) - F_2^n(x)$ is really very model dependent.

The Bjorken sum rule

There is a profound and much more fundamental sum rule due to Bjorken [4], that relates the spin-dependent structure functions $g_1^p(x)$ and $g_1^n(x)$, namely

$$\int_0^1 dx[g_1^p(x) - g_1^n(x)] = \frac{1}{6}\left|\frac{G_A}{G_V}\right| \tag{42}$$

Strenuous efforts have been made at CERN and SLAC to test this sum rule, using deuterium and helium targets, respectively [21]. On the basis of our analysis of the Gottfried sum rule one might worry whether the deuteron measurement is able to yield any real test of the Bjorken sum rule.

We believe that the two cases are very different. For the Gottfried sum rule the correction term δF_2^D is extremely small but is a correction to the tiny difference between $F_2^p(x)$ and $F_2^n(x)$. On the contrary, as was remarked in [20], for the Bjorken sum rule the analogous correction term $\delta g_1^D(x)$ will be negligible since $g_1^p(x)$ and $g_1^n(x)$ are expected to have opposite signs for most of the range of x-values and therefore the difference $g_1^p(x) - g_1^n(x)$ will be relatively large, of the order of $|g_1^p(x)| + |g_1^n(x)|$.

Moreover the leading correction will not come from the pionic constituents, since these, being scalar, do not possess spin dependent inelastic form factors. So the analogous correction terms could only come from rarer, nonzero spin constituents.

It seems, therefore, that the use of deuteron targets to test the Bjorken sum rule should suffer no serious difficulties of interpretation.

Other reactions

Despite its naive simplicity, our toy model for excess pions in deuterons gives a surprisingly good description of the Q^2-dependence of the ratio $F_2^n/F_2^p|_{exp}$ as measured by NMC [22]. The observed dependence disagrees with the result obtained by evolving F_2^p and F_2^n as obtained at some Q_0^2, to higher Q^2 via usual QCD evolution equations, and clearly cannot be understood as a consequence of $\bar{u} \neq \bar{d}$. As there are no theoretical reasons for having different higher twist contributons for the proton and the neutron, the model provides a reasonable theoretical mechanism for the observed behaviour.

The model has also been applied successfully to heavy nuclei for both deep inelastic ad Drell-Yan processes [23]. There is, perhaps surprisingly, a remarkable agreement between the available Drell-Yan data, which rule out large asymmetries in the sea, and the predictions given by the model. The same can be said about deep inelastic data for different nuclei. In generalising the model to a nucleus A, the only change made is to allow the pion momentum fraction ε to be a free parameter. One then finds that ε behaving as $A^{1/3}$ gives an accurate description of the ratios between heavy nucleus and deuteron structure functions in a wide range of the Bjorken variable ($x > 0.01$). We would like to draw attention not only to the simplicity of the model but aso to the consistency in describing different phenomena.

Summary and conclusions

- We have discussed the physical implications of the convergence of the Gottfried sum rule. It seems liklely that it does converge, but there are no fundamental reasons for this, and it wold not be a catastrophe if it were found to diverge.
- Assuming the convergence of the Gottfried sum rule we have shown via a very simple model that the extraction of $F_2^p(x) - F_2^n(x)$ from the data on deuterium is really quite model-dependent. Although the corrections to the naive expressions $F_2^D(x) = \frac{1}{2}[F_2^p(x) + F_2^n(x)]$ are small related to $F_2^D(x)$, they are highly amplified when taking the difference $2[F_2^p(x) - F_2^D(x)]$, which is used as an estimate for $F_2^p(x) - F_2^n(x)$, since this difference is extremely small. Thus we have concluded that significant tests of the Gottfried sum rule *cannot* be made on the basis of the deuteron data without consideration of detailed nuclear models.
- Despite its naive simplicity our "toy" model seems to explain some unexpected features in DIS and Drell-Yan scattering on nuclear targets.
- In the case of the Bjorken sum rule we stress, contrary to the Gottfried case, that the use of deuteron data to estimate $g_1^p(x) - g_1^n(x)$ should be quite reliable. This follows because the dominant pionic effects which affect the Gottfried case are inoperative for spin-dependent structure functions and because the difference $g_1^p(x) - g_1^n(x)$ is expected to be large.

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References

1. P. Amaudruz et al. (NMC): Phys. Rev. Lett. 66 (1991) 2716
2. K. Gottfried: Phys. Rev. Lett. 18 (1967) 1174
3. L.N. Epele et al.: Phys. Rev. Lett. B275 (1992) 155
4. J.D. Bjorken: Phys. Rev. Lett. 148 (1966) 1467, D1 (1970) 1376
5. H. Abramowicz et al.: Phys. Rev. Lett. B269 (1991) 465
6. Studies of the np charge exchange many years ago suggested that analogous to (11), $\sigma_{pp} - \sigma_{np}$ might not approach zero asymptotically. This would correspond, in modern parlance, to the existence of some kind of isospin-one odderon
7. E. Leader, E. Predazzi: An introduction to gauge theories and the new physics. Cambridge: Cambridge University Press (1982)
8. J. Morfin, Wu-Ki Tung: Z. Phys. C52 (1991) 13
9. R.D. Field, R.P. Feynman: Phys. Rev. D15 (1977) 2590
10. E.J. Eichten, I. Hinchliffe, C. Quigg: Phys. Rev. D45 (1992) 2269; Phys. Rev. D47 (1993) R747
11. P.L. McGaughey et al.: Phys. Rev. Lett. 69 (1992) 1726
12. R.G. Roberts, M.R. Whalley: J. Phys. G: Nucl. Part. Phys. 17 (1991)
13. M. Arneodo et al. (NMC): CERN-PPE/93-117 (1993)
14. See [10] and references therein
15. P. Amaudruz et al. (NMC): Phys. Lett. B295 (1992) 159
16. P.J. Sutton, A.D. Martin, R.G. Roberts, W.J. Stirling: Phys. Rev. D45 (1992) 2349
17. E.L. Berger, F. Coster, R.B. Wiringa: Phys. Rev. D29 (1984) 368
18. F. Close, J Qiu, R.G. Roberts: Phys. Rev. D40 (1989) 2820
19. B. Badelek, J. Kwiecinski: Nucl. Phys. B. 370 (1992) 278
20. L.N. Epele et al.: Phys. Lett. 287 (1992) 247
21. B. Adeva et al. (SMC): Phys. Lett. B302 (1993) 533; P.L. Anthony et al. (E142): SLAC-PUB-6101 (1993)
22. L.N. Epele et al.: Phys. Rev. D47 (1993) R2648
23. D. de Florian et al.: La Plata preprint 93-06, (1993) Phys. Rev. Lett. (submitted for publiction)