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Charm as a signature of the EMC spin effect

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We re-examine the hypothesis that the Ellis–Jaffe sum-rule might hold at some low scale (appropriate to a quark model) but that the singlet axial charge rapidly evolves to zero at the scale of the EMC experiment. Not only does such an explanation generate a significant polarised strange sea, but also a polarised charmed quark sea. The latter should be clearly visible as a sudden decrease in the integral of g_{1p} above the threshold for charm production.

The recent measurement of the spin structure function of the proton, $g_{1p}(x)$, by the European Muon Collaboration [1,2] has sparked enormous theoretical interest [3–9]. Much of this work has been aimed at understanding why the first moment (G_{1p}) is much smaller than suggested by the Ellis–Jaffe sum-rule [10]. Fundamental work by Kodaira had shown that the two-loop anomalous dimension for G_{1p} was non-zero [11,12]. This was exploited by Jaffe [13] in an early explanation of how the discrepancy in the sum-rule might arise. His proposition was that the polarised strange quark content of the proton, Δs, might indeed be zero at a relatively low scale (say μ_0^2) appropriate to a typical quark model [14]. However, the potentially rapid evolution of the flavour singlet component of G_{1p} (i.e., Δq_0) could lead to a significant negative value of Δs at 1–2 GeV^2 or higher.

In a closely related investigation, Manohar [15] extended the earlier work of Witten [16] and Abbott and Wise [17] to estimate the contributions of heavy quarks (c and b) to G_{1p}. Following ref. [15] we define $\Lambda_{ab}^{(n_f)}$ as $\Lambda(m_a, m_b; n_f)$, which is the scale factor

$$\ln \Lambda(Q_1, Q_2; n_f) = n_f \frac{\alpha_s(Q_1)}{\pi} \frac{\alpha_s(Q_2)}{\pi} \ln\left(\frac{Q_1}{Q_2}\right) \qquad (1)$$

derived from Kodaira's two-loop anomalous dimension. Let us suppose that there is a negligible heavy quark component in the proton $\langle p,s|\bar{b}\gamma_\mu\gamma_5 b|p,s\rangle$ and $\langle p,s|\bar{c}\gamma_\mu\gamma_5 c|p,s\rangle$ at the beauty and charm threshold respectively. Then one finds for $Q^2 >> m_b^2$

$$\Delta b(Q^2) = \Lambda_{Q_0c}^{(3)}[\Lambda_{cb}^{(4)} \tfrac{1}{5}(\Lambda_{bQ}^{(5)} - 1)]\Delta q_0(Q_0^2) \qquad (2)$$

and

$$\Delta c(Q^2) = \Lambda_{Q_0c}^{(3)}[\tfrac{1}{4}(\Lambda_{cb}^{(4)} - 1) + \Lambda_{cb}^{(4)} \tfrac{1}{5}(\Lambda_{bQ}^{(5)} - 1)]\Delta q_0(Q_0^2) . \qquad (3)$$

Using the value of Δq_0 measured by EMC at the scale $Q_0^2 \sim 10$ GeV^2 [viz. $\Delta q_0(Q_0^2) = 0.13 \pm 0.19$] eqs. (2) and (3) yield

$$\Delta b(Q^2) \sim -(1.4 \pm 2.1) \times 10^{-3},$$

$$\Delta c(Q^2) \sim -(2.4 \pm 3.5) \times 10^{-3} \qquad (4)$$

in the limit $Q^2 >> m_b^2$ (neglecting t-quark effects). Clearly in this scenario charm and beauty play a negligible role in g_{1p}.

Obviously it would be very valuable to have an experimental measure of the contribution of strange (and heavier) quarks to the spin structure function. A number of authors [18–21] have suggested that neutrino–proton (νp) elastic scattering through the neutral current could provide a measure of Δs. While

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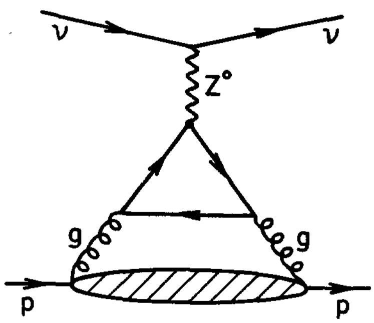

Fig. 1. Contribution to the neutrino proton cross section where the Z^0 couples through two gluons.

this is true it is not the complete story. In fact, restricting consideration to two generations for simplicity, the Z^0 couples to the combination $\Delta u - \Delta d + \Delta c - \Delta s$, which is non-singlet and therefore *not* scale dependent.

Omission of the Δc term can lead to some confusion. Consider the intrinsic piece of the νp cross section involving the Z^0 coupling to two gluons as shown in fig. 1. Because of the famous Adler–Bell–Jackiw anomaly [22,23] all flavours must be included in the quark triangle. Gauge invariance at each vertex of the $Z^0 gg$ triangle requires an anomaly free (non-singlet) axial coupling at the Z^0 vertex. (The anomaly is a flavour independent effect.) Indeed, this is why we believe in the top quark: it is needed to cancel the anomaly associated with beauty. (The mass terms which occur when we consider current conservation at the Z^0 vertex are the manifestation of the spontaneously broken gauge symmetry. The apparent loss of gauge invariance is restored via the Higgs mechanism.)

Suppose that Δs were to evolve rapidly between the quark model scale (μ_0^2) and the scale at which the EMC measurement was made (Q_0^2) – say Δs becomes $\Delta s - \delta$. Then not only must Δu and Δd decrease by the same amount but so must Δc. If, for example, $\Delta c(\mu_0^2)$ were zero (in the spirit of Ellis and Jaffe) then $\Delta c(Q_0^2)$ would be $-\delta$ – so that the non-singlet combination $\Delta c - \Delta s$ remains scale independent.

Apparently this remarkable consequence of Jaffe's hypothesis has not been noticed before. Indeed it appears to be in contradiction with the analysis of Manohar. In the rest of this article we shall first explain why this has been missed and how the present work can be reconciled with earlier results. Finally we shall explore the experimental consequences of our findings.

Let us begin the reconciliation of our result with the earlier work by considering νp elastic scattering. The quantity Δc defined there is the matrix element of the heavy quark axial current operator $\bar{c}\gamma^\mu\gamma_5 c$. It involves a loop integral over *virtual* charmed quarks which is non-zero at *all* scales. It contains no threshold factor. This is why Δc can be non-zero even at a scale of zero momentum transfer.

On the other hand, for deep inelastic scattering we require an on-mass-shell intermediate state. In the formal description using the operator product expansion this means that the coefficient function of the charm induced quark and gluon operators must vanish at and below the $c\bar{c}$ threshold (i.e., $s \leqslant 4m_c^2$, where s is the centre of mass energy squared in the $\gamma^* g$ collision).

Now it is clear where our analysis differs from that of Manohar. He assumed that the charm quark operators can be integrated out into some gluon operator matrix elements at the charm threshold ($Q^2 \sim 4m_c^2$). Since the spin-one gluon operators in the operator product expansion start at twist 4 he argued that heavy quark matrix elements should vanish at threshold, which is in line with the original Ellis–Jaffe hypothesis. It is clear from our discussion of νp scattering that this integration procedure is not valid in the presence of the anomaly. If it were applied to the process of fig. 1 then gauge invariance would be lost at the Z^0 vertex.

While the arguments of ref. [15] are not technically correct in the presence of the anomaly, it nevertheless remains plausible that the matrix element of $\bar{c}\gamma_\mu\gamma_5 c$ could be small at the charm threshold. While the coefficient function will always guarantee that the charmed quark contribution to deep inelastic scattering vanishes below threshold, it is clear that under the Jaffe hypothesis the matrix element of the charmed quark operator will not.

Above the charmed quark threshold ($Q^2 >> 4m_c^2$) the expression for $g_{1p}(x)$ is

$$g_{1p}(x) = \tfrac{1}{2}\{\tfrac{4}{9}[\Delta u(x) + \Delta c(x)] + \tfrac{1}{9}[\Delta d(x) + \Delta s(x)]\}, \tag{5}$$

so that the first moment becomes

$$G_{1p} = \tfrac{1}{2}[\tfrac{4}{9}(\Delta u + \Delta c) + \tfrac{1}{9}(\Delta d + \Delta s)]. \tag{6}$$

Under the scenario proposed by Jaffe one would therefore expect a relatively dramatic decrease in G_{1p} as one passes through the threshold for charm production. That is, G_{1p} should change from the value measured by EMC, $G_{1p}(\mathrm{EMC})$ to $G_{1p}(\mathrm{EMC}) - \frac{2}{9}\delta$ as we pass into the region $Q^2 >> 4m_c^2$. Numerically this means a drop from about 0.12 to about 0.08 – a very dramatic shift! Clearly it is very important to test this idea by extending the EMC measurement of $g_{1p}(x, Q^2)$ at a value of Q^2 of order 15–20 GeV^2 (or higher) into the low x region as soon as possible. (EMC found no evidence for any dramatic scale change in the large x bins where this Q^2 was attained.)

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References

[1] J. Ashman et al., Phys. Lett B 206 (1988) 364; Nucl. Phys. B 328 (1990) 1.
[2] V. Hughes et al., Phys. Lett. B 212 (1988) 511.
[3] A.V. Efremov and O.V. Teryaev, Dubna preprint E2-88-287 (1988);
A.V. Efremov, J. Soffer and O.V. Teryaev, Nucl. Phys. B 246 (1990) 97.
[4] G. Altarelli and G.G. Ross, Phys. Lett. B 212 (1988) 391.
[5] G.T. Bodwin and J. Qiu, Phys. Rev. D 41 (1990) 2755.
[6] G. Altarelli and W.J. Stirling, Particle World 1 (1989) 40.
[7] L. Mankiewicz and A. Schafer, Phys. Lett. B 242 (1989) 455;
L. Mankiewicz, Phys. Rev. D 43 (1991) 64.
[8] S.D. Bass, B.L. Ioffe, N.N. Nikolaev and A.W. Thomas, J. Moscow Phys. Soc. 1 (1991) 317;
S.D. Bass, Rutherford preprint RAL-92-015, Z. Phys. C (1992), to appear;
S.D. Bass and A.W. Thomas, Proc. PANIC XII, Nucl. Phys. A 527 (1991) 519c.
[9] For recent reviews with a complete summary of the literature see
S.D. Bass and A.W. Thomas, University of Adelaide preprint ADP-92-183/T115, J. Phys. G, to appear;
A.E. Dorokhov, N.I. Kochelev and Yu. A. Zubov, Dubna preprint (July 1992), Intern. J. Mod. Phys., to appear;
R. Windmolders, Intern. J. Mod. Phys. A 7 (1992) 639.
[10] J. Ellis and R. Jaffe, Phys. Rev. D 9 (1974) 1444.
[11] J. Kodaira et al., Phys. Rev. D 20 (1979) 627; Nucl. Phys. B 159 (1979) 99.
[12] J. Kodaira, Nucl. Phys. B 165 (1980) 129.
[13] R.L. Jaffe, Phys. Lett. B 193 (1987) 101.
[14] F.E. Close, R.G. Roberts and G.G. Ross, Phys. Lett. B 129 (1983) 346;
A.W. Schreiber, A.W. Thomas and J.T. Londergan, Phys. Lett. B 237 (1990) 120; Phys. Rev. D 42 (1990) 2226.
[15] A.V. Manohar, Phys. Lett. B 242 (1990) 94.
[16] E. Witten, Nucl. Phys. B 104 (1976) 445.
[17] L.F. Abbott and M.B. Wise, Nucl. Phys. B 176 (1980) 373.
[18] D.B. Kaplan and A.V. Manohar, Nucl. Phys. B 310 (1988) 527;
R.L. Jaffe and A.V. Manohar, Nucl. Phys. B 337 (1990) 509.
[19] F.E. Close, Phys. Rev. Lett. 64 (1990) 361.
[20] E.M. Henley et al., Few Body Syst. Suppl. 6 (1992) 66.
[21] R.D. Carlitz and A.V. Manohar, Summary of Penn State Polarised Collider Workshop, San Diego preprint UCSD/PTH 90-32 (1990).
[22] J.S. Bell and R. Jackiw, Nuovo Cimento 51A (1969) 47.
[23] S.L. Adler, Phys. Rev. 177 (1969) 2426.