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DIQUARKS IN DEEP INELASTIC SCATTERING AND THE GOTTFRIED SUM RULE

by

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ABSTRACT

Previous attempts to invoke diquarks in deep inelastic scattering are based upon a specific model of the proton wave-function, involving either a pure quark–diquark structure or a superposition of three–quark and quark–diquark structures. In this paper diquarks are introduced in a general way without recourse to any wave–functions. Allowance is made both for their elastic and their inelastic scattering. It is argued that previous attempts to do this are incorrect. It is demonstrated, with complete generality, that diquarks cannot resolve the current disagreement between theory and experiment in the Gottfried sum rule.

Key-words: Diquarks; Deep inelastic scattering.

There are many theoretical and experimental hints that diquark structures inside the nucleon are important [1]. Attempts to introduce diquarks into deep-inelastic scattering at some point appeal to a specific model of the nucleon wave-function [2-6]; treating the nucleon either as a bound state of a quark and diquark [2-4] or as a superposition of a 3-quark and a quark-diquark state [5-6]. Usually, as suggested by the static properties of the hadrons, an $SU(6)$ wave-function or a specific broken $SU(6)$ structure is assumed. Moreover, it is usually argued that asymptotically (in Q^2) only a 3-quark sector of the wave-function should survive. The latter argument we believe to be incorrect. The nucleon wave-function is an eigenfunction of the strong hamiltonian, in which there is no reference to Q^2. The erroneous statement arises from a confusion of the concept of a wave-function with the currently popular concept of a Q^2- dependent parton distribution which is related to an integral over $k_\perp^2$ (between 0 and Q^2) of the modulus squared of the wave-functions. We shall introduce diquarks via their distribution functions in a nucleon, in a completely general fashion, without recourse to wave-functions.

A diquark when struck by a hard photon will either scatter elastically or will disintegrate. We suggest that previous attempt [6] to allow for these two possibilities is incorrect and we show how to handle them in a consistent fashion.

Finally, as an application of the whole picture, we study the Gottfried sum rule and prove, quite generally, that diquarks cannot help to resolve the current discrepancy between theory and experiment.

The relevant, electrically charged, constituents of a nucleon will be taken to be u, d, s quarks and their antiquarks, a scalar (spin-zero) isoscalar diquark S, whose quark content is (ud), and an isotriplet of vector (spin-one) diquarks with $I_z = 1, 0, -1$, which we shall label V^{uu}, V^{ud} and V^{dd} to indicate their quark content. For the distribution functions in protons and neutrons, based upon isospin invariance, we take the following:

$$proton: \quad u(x), \bar{u}(x), d(x), \bar{d}(x), s(x) = \bar{s}(x), S(x), V^{ud}(x), V^{uu}(x)$$

$$neutron: \quad \begin{aligned} & u_n(x) = d(x), d_n(x) = u(x), s_n(x) = s(x), S_n(x) = S(x), \\ & V_n^{ud}(x) = V^{ud}(x), V_n^{dd}(x) = V^{uu}(x) \end{aligned} \tag{1}$$

Because the diquarks are considered as constituents, the sum–rules satisfied by the proton distributions will be different from the usual case. For example charge conservation implies:

$$proton: \quad \int_0^1 dx \left\{ \frac{2}{3}u_v(x) - \frac{1}{3}d_v(x) + \frac{1}{3}\left[S(x) + V^{ud}(x)\right] + \frac{4}{3}V^{uu}(x) \right\} = 1 \tag{2}$$

$$neutron: \quad \int_0^1 dx \left\{ \frac{2}{3}d_v(x) - \frac{1}{3}u_v(x) + \frac{1}{3}\left[S(x) + V^{ud}(x)\right] - \frac{2}{3}V^{uu}(x) \right\} = 1 \tag{3}$$

where we have introduced the valence distributions $u_v = u - \bar{u}$, $d_v = d - \bar{d}$. From (2) and (3) follows the new result

$$\int_0^1 dx \left[u_v(x) - d_v(x) + 2V^{uu}(x)\right] = 1 \tag{5}$$

This equation will be crucial in the discussion of the Gottfried sum rule.

Consider now the interaction of the hard photon with a diquark (generically labelled D) of momentum $x'P$ where P is the nucleon momentum. Analogously to a proton, the diquark may be scattered elastically or may undergo deep inelastic scattering. In the collision "γ" $(q) + D(x''P)$, elastic scattering occurs when $(q + x'P)^2 = (x'P)^2$, *i.e.* when $x' = Q^2/2q.P \equiv x$ (Bjorken x) and will be controlled by an elastic form factor; the deep inelastic scattering of the diquark D is expressed in terms of the distribution functions of its constituent quarks, namely $u_D(y)$ and $d_D(y)$ (we ignore any antiquark content). The quarks carry a fraction y of the diquark momentum and thus have momentum $yx'P$ (See Figure). The "γ" $q \to q$ vertex forces $y = x/x'$.

The interaction of the photon and diquark (analogously to the interaction of a photon and proton) is then described by a total hadronic tensor

$$W^{\mu\nu}_{\gamma D}(x'/x, Q^2) = W^{\mu\nu}_{inel.} + W^{\mu\nu}_{el.} \tag{5}$$

where $W^{\mu\nu}_{el.} \propto \delta\left(x'/x - 1\right)$.

The description of the elastic scattering depends upon the generality of the assumed γDD vertex and could, in principle, involve 5 elastic form factors and an unkown anomalous magnetic moment parameter k [3]. In addition it is possible to have the pseudo–elastic reaction "γ" $S \to V^{ud}$, which is analogous to N^* resonance production in "γ"N scattering. Happily, it will turn out that these details are irrelevant to the present discussion. The expressions for the proton and neutron scaling functions $F_2^{p,n}$ become:

$$\begin{aligned}\frac{1}{x}F_2^p(x,Q^2) = \frac{4}{9}\left[u(x)+\bar{u}(x)\right] + \frac{1}{9}\left[d(x)+\bar{d}(x)\right] + \frac{16}{9}V^{uu}(x)f_2^2(x,Q^2) + \\ + \int_x^1 \frac{dx'}{x'}\frac{4}{9}u_{V^{uu}}(x/x')V^{uu}(x') + R_2(x,Q^2)\end{aligned} \tag{7}$$

$$\begin{aligned}\frac{1}{x}F_2^n(x,Q^2) = \frac{4}{9}\left[d(x)+\bar{d}(x)\right] + \frac{1}{9}\left[u(x)+\bar{u}(x)\right] + \frac{4}{9}V^{uu}(x)f_2^2(x,Q^2) + \\ + \int_x^1 \frac{dx'}{x'}\frac{1}{9}u_{V^{uu}}(x/x')V^{uu}(x') + R_2(x,Q^2)\end{aligned} \tag{8}$$

where we have assumed that V^{uu} contains no d quarks and, by isospin invariance, taken $d_{V^{dd}}(x) = u_{V^{uu}}(x)$. The term $R_2(x,Q^2)$ represents the contributions from the isoscalar diquark S and the $I_z = 0$ diquark V^{ud}, and has a structure in obvious analogy to the V^{uu} contribution. All the freedom in the γDD vertex is hidden in $f_2^2(x,Q^2)$ which is something like the square of an elastic form factor. Its crucial properties are: *a)* that it is positive, and *b)* that it must vanish as $Q^2 \to \infty$ on account of the composite nature of the diquarks. Expressions (7) and (8) should be contrasted with those of Ref. [5] where the inelastic term appears multiplied by what is effectively $\left[1 - f_2^2(x,Q^2)\right]$.

Charge conservation for the diquark V^{uu} requires that

$$\int_0^1 \frac{2}{3} u_{V^{uu}}(x) dx = \frac{4}{3}$$

i.e.

$$\int_0^1 u_{V^{uu}}(x) dx = 2 \tag{9}$$

Taking the 1^{st} moment of (7) and (8) and using the fact that the moment of a convolution is the product of the moments, yields, via (9),

$$\begin{aligned} \int_0^1 \frac{F_2^p(x,Q^2) - F_2^n(x,Q^2)}{x} dx &= \int_0^1 \left[\frac{1}{3} u_v(x) - \frac{1}{3} d_v(x) + \frac{2}{3} V^{uu}(x)\right] + \\ &+ \frac{2}{3} \int_0^1 dx [\bar{u}(x) - \bar{d}(x)] + \frac{4}{3} \int_0^1 dx V^{uu}(x) f_2^2(x,Q^2) \\ &= \frac{1}{3} + \frac{2}{3} \int_0^1 dx [\bar{u}(x) - \bar{d}(x)] + \frac{4}{3} \int_0^1 dx V^{uu}(x) f_2^2(x,Q^2) \end{aligned} \tag{10}$$

where we have used (5). With the assumption of an isotropically neutral sea, *i.e.*, $\bar{u}(x) = \bar{d}(x)$ we see that as $Q^2 \to \infty$ we recover the standard Gottfried result of 1/3. But since V^{uu} and f_2^2 are both positive, (10) indicates, in complete generality, that diquarks cannot help to achieve the value 0.240 ± 0.016 at $Q^2 = 4\ GeV^2$ found experimentally [7] for the *L.H.S.* of (10).

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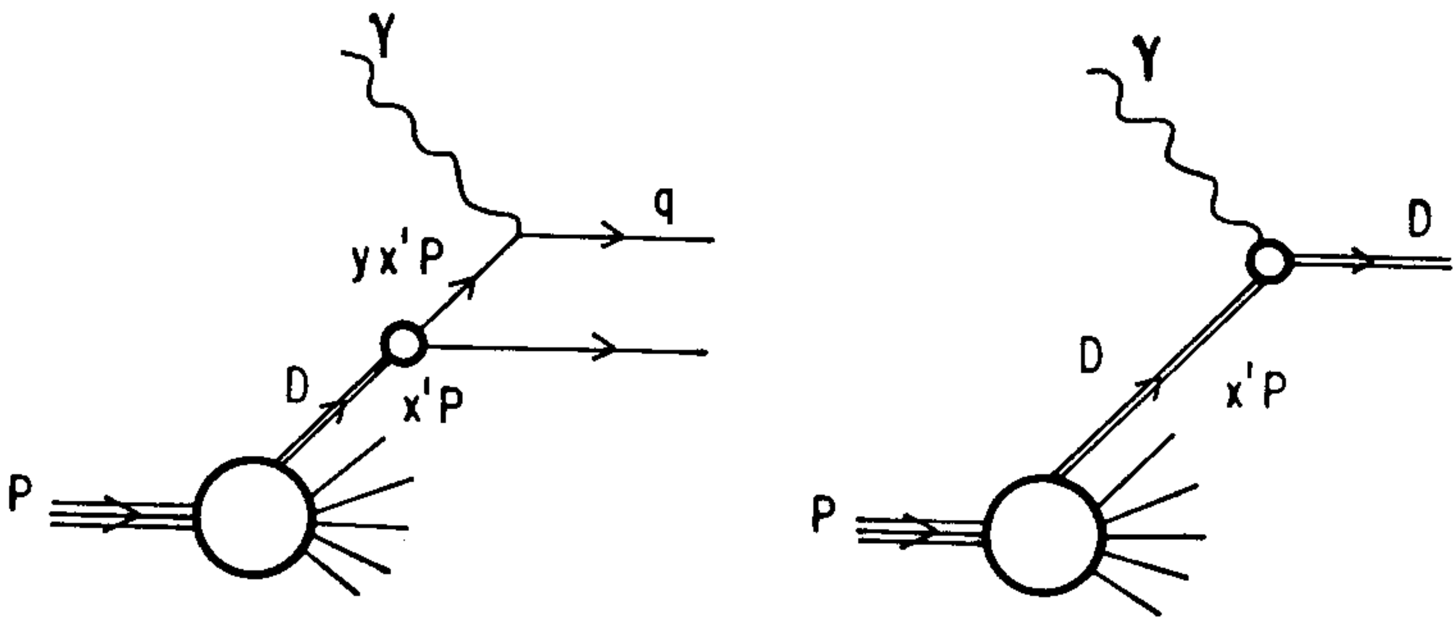

Figure 1

Figure Caption - Elastic and inelastic scattering of the virtual photon on a diquark constituent.

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