FLAVOR SYMMETRY AND THE SPIN OF THE PROTON*

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The analysis of the EMC result on the quark contribution to the spin of the proton has been challenged because of the use of $SU(3)$ flavor symmetry to provide input on the proton wave function from hyperon decays. However, $SU(3)$ symmetry is shown not to be needed to obtain peculiar results about these quark contributions. The analysis without assuming flavor symmetry allows the quark contribution to the proton spin to be large, but only if it is due to the strange quarks, with the nonstrange quark contribution opposite to the spin of the proton.

Recent data from the European Muon Collaboration have been interpreted to suggest that the spin of the proton does not come from the quarks but from some other source[1]. This interpretation has been questioned, both because of the errors in extrapolating[2] to $x = 0$ and because of the use of flavor $SU(3)$ symmetry to relate spin distributions within the proton to weak semileptonic axial vector decays of hyperons. We consider here the use of flavor symmetry.

When the input from hyperon decays is used, the results show an overall inconsistency between the experimental data, the conventional assumptions that the spin of the proton is due primarily to its valence quarks, and the use of $SU(3)$ symmetry to relate the

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couplings of the weak axial-vector current to nucleons and hyperons. However, it is not obvious at this stage that this inconsistency shows that the conventional wisdom about the spin structure of the proton is wrong rather than that the conventional use of flavor $SU(3)$ symmetry in this case is wrong.

The use of flavor $SU(3)$ symmetry to relate the magnetic moments of nucleons and hyperons is known to lead to significant disagreements with experiment. This already implies that differences between the spin structures of nucleons and hyperons which are not understood nor simply explained by QCD may well account for the failure to explain the EMC data. Flavor $SU(3)$ symmetry implies that the wave functions of the proton and the Σ^+ differ only by having a d-quark in the proton replaced replaced by an s quark to make the Σ^+. In the simple constituent quark model where the baryon wave function consists of three valence quarks in a relative s wave, this may be a good approximation. The radial wave functions will be somewhat different because of the higher mass of the strange quark, but this difference may well have a negligible effect on quantities of interest.

When a more complicated baryon wave function is used, containing sea quarks, orbital angular momentum and gluons in addition to s-wave valence quarks, the constraints of $SU(3)$ symmetry become much more severe. The relative amounts of momentum and angular momentum carried by the sea, the valence quarks and the gluons must be exactly the same in the proton and the Σ^+ if $SU(3)$ relations hold. If this is not the case, and one would expect that isn't, then serious questions arise about the validity of conclusions about the spin structure of the proton based on such $SU(3)$ relations.

It is really time to give flavor $SU(3)$ and its associated D/F fudge factors a decent burial and an honorable place in the history of the period when it led us to the realization that the underlying fermion degrees of freedom were fractionally charge colored quarks. Now that we understand this structure, flavor $SU(3)$ becomes irrelevant and misleading. Hadrons are normally not good $SU(3)$ eigenstates, except when a single $SU(3)$ classification is the only one allowed by other conservation laws. This happens accidentally to occur for the ground state baryons in the constituent quark or valence quark models, where the 56 representation of $SU(6)$ with its spin-1/2 $SU(3)$ octet and its spin-3/2 decuplet are the only states allowed by the generalized Pauli principle for a color-singlet three-quark state with a spatially symmetric wave function.

As long as this configuration is a good approximation for a particular kind of phenomenology, it makes sense to use the $SU(6)$ wave function and the value of the D/F ratio determined by $SU(6)$ for couplings to $SU(3)$ octet currents. When this approximation breaks down, it makes no sense to "break $SU(6)$" while keeping $SU(3)$ and readjusting the D/F ratio. The failure of $SU(6)$ implies that the color-singlet three-quark spatially symmetric configuration is not a good approximation, and that other degrees of freedom are needed. But as soon as other degrees of freedom are added, such as orbital excitation or antiquarks, there is mixing of different $SU(3)$ multiplets. This is well known from hadron spectroscopy where there is octet-singlet-decuplet mixing in orbitally excited baryons and octet-singlet mixing in mesons. As soon as non-octet configurations are mixed into the wave function, the D/F ratio for the coupling of any current becomes meaningless.

It is therefore of interest to reexamine the treatment of Brodsky *et al.*[1] to see what conclusions can be drawn from the nucleon data alone, without introducing hyperon data and assuming flavor symmetry. We shall see that the nucleon data are already sufficient to lead to conclusions very different from the conventional picture of the proton. The quark contribution to the proton spin is no longer required to vanish, but it can be appreciable only at the price of having the dominant contribution to the proton spin come from strange quarks.

Brodsky et al write three equations to determine three unknowns, the contributions to the proton spin of the u, d and s quarks, denoted by Δu, Δd and Δs. These are normalized to unity if the contribution is equal to the total spin of the proton. We use here the two equations which depend only on nucleon data. The first equation, eq. (5) of ref. 1 is:

$$\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s = .0.246 \pm 0.026 \pm 0.056 \qquad (1a)$$

where the numbers on the right hand side come from the EMC data, multiplied by a factor of 1.08 from the perturbative QCD corrections introduced later on[1].

This result already shows a peculiarity. The right hand side is much too small. This can be seen explicitly by rewriting eq. (1a):

$$(\Delta u + \Delta d + \Delta s) = \frac{3}{4}(\Delta d + \Delta s) + 0.554 \pm 0.058 \pm 0.126 \qquad (1b)$$

In the conventional valence quark model for the proton, the u quarks are coupled to spin 1 and the projection on the proton spin is greater than the spin of the proton, while the d quark spin is antiparallel to the proton. Eq. (1) is dominated by the u quark contribution because the contributions to electromagnetic cross sections are proportional to the square of the quark charge. If we neglect the d and s contributions to the relation (1) we see that the u quark contribution to the spin of the proton cannot be more than 51%.

This point is sharpened further by introducing the second relation from Brodsky et al, their equation (6)

$$\Delta u - \Delta d = g_A = 1.25 \tag{2}$$

This shows that Δd must be negative and further reduces the right hand side of eq. (1b). This can be seen more quantitatively by rewriting eq. (1) as

$$\frac{1}{9}(\Delta u + \Delta d + \Delta s) + \frac{1}{6}(\Delta u + \Delta d) + \frac{1}{6}(\Delta u - \Delta d) = .0.246 \pm 0.026 \pm 0.056 \tag{3a}$$

and substituting eq. (2) into eq. (3a). This gives a numerical value on the left hand side which almost cancels the right hand side exactly. Multiplying by 6 then gives

$$(\Delta u + \Delta d) = 0.23 \pm 0.16 \pm 0.36 - \frac{2}{3}(\Delta u + \Delta d + \Delta s) \tag{3b}$$

This equation has a solution for any value of the quark contribution $\Delta u + \Delta d + \Delta s$ to the total spin of the proton. However for any appreciable positive value, the contribution $\Delta u + \Delta d$ of the *nonstrange* quarks is seen to be opposite to the total contribution. For example, for $\Delta u + \Delta d + \Delta s = 1$, we find $\Delta u + \Delta d = -0.44$ and $\Delta s = 1.44$, while $\Delta u + \Delta d < 0$ for $\Delta u + \Delta d + \Delta s > 0.36$ and $\Delta u + \Delta d < \Delta s$ for $\Delta u + \Delta d + \Delta s > 0.20$

The solution of ref. 1 that $\Delta u + \Delta d + \Delta s = 0$, $\Delta u + \Delta d = 0.23$ and $\Delta s = -0.23$ appears to be more reasonable than the other solutions allowed if hyperon data and flavor symmetry are not used, since these other solutions have the *strange* quark contribution larger than the nonstrange contribution when the quarks carry more than 20% of the proton spin.

This problem has been further clarified by Ramsey et al[3] who separate the quark contributions into valence and sea quark contributions. The results indicate that the valence quark contributions to the proton spin are roughly what one would expect from naive models, but that this is canceled by the sea contribution.

This can be seen in our formulation by using their notation and defining the sea contributions by their relations:

$$\Delta u^s = \Delta d^s = (1+\epsilon)\Delta s \tag{4}$$

where Δu^s and Δd^s denote the sea quark contributions, Δs is assumed to come entirely from the sea and ϵ is an $SU(3)$-breaking parameter defining the excess of nonstrange quarks in the sea. We can then rewrite eq. (3b) to obtain

$$(\Delta u^v + \Delta d^v) = 0.14 \pm 0.10 \pm 0.22 - (2.4 + 2\epsilon)\Delta s \tag{5}$$

where Δu^v and Δd^v denote the valence quark contributions. The solution of ref. 1 that $\Delta u + \Delta d + \Delta s = 0$, $\Delta u + \Delta d = 0.23$ and $\Delta s = -0.23$ then gives valence quark contributions $\Delta u^v + \Delta d^v = 0.69 + 0.46\epsilon \pm 0.10 \pm 0.22$, thus showing a valence quark contribution somewhat larger than the proton spin but within errors of the equality. This illustrates the point made in ref. 3 that the result of ref. 1 gives the expected result for the valence contribution and that it is the sea contribution which mysteriously cancels it.

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REFERENCES

1. Stanley J. Brodsky, John Ellis and Marek Karliner, Phys. Lett. **206B** (1988) 309; Marek Karliner, these proceedings.

2. F. E. Close and R. G. Roberts, Phys. Rev. Lett. **60** (1988) 1471; F. E. Close, these proceedings.

3. Gordon P. Ramsey, Jian-Wei Qiu, David Richards and Dennis Sivers, Argonne Preprint ANL-HEP-PR-88-16, submitted to Phys. Rev. Lett. Dennis Sivers, these proceedings.