Three-quark currents and baryon spin

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The question how baryon spin J is made up from quark spin Σ, quark orbital angular momentum L_q, gluon spin Δg, and gluon orbital angular momentum L_g, as in

$$J = \frac{1}{2}\Sigma + L_q + \Delta g + L_g,$$

is one of the central issues in strong interaction physics. In the constituent quark model with only one-quark currents, one obtains for example for the proton spin, $J = \frac{1}{2}\Sigma = \frac{1}{2}$, i.e., the proton spin is the sum of the constituent quark spins with $\Sigma = 1$ and nothing else. However, experimentally it is known that only about 1/3 of the proton spin comes from quarks [1]. The disagreement between the quark model result and experiment came as a surprise because the same model accurately described the related proton and neutron magnetic moments.

Using a broken SU(6) spin-flavor symmetry based parametrization of quantum chromodynamics, we find that the failure of the quark model to describe the quark contribution to proton spin correctly, is due to the neglect of three-quark terms in the axial current [2]. We show that the novel three-quark axial currents largely cancel the contribution of the one-quark axial current so that Σ is reduced from the additive quark model result $\Sigma_p = 1$ to $\Sigma_p = 0.35(12)$ [2] consistent with the empirical value [1]. We also calculate the Δ^+ spin [2] and find that the previously uncalculated three-quark currents increase the quark spin contribution to the Δ^+ spin from the additive quark model value $\Sigma_{\Delta^+} = 3$ to $\Sigma_{\Delta^+} = 3.93(22)$.

Because the gluon spin Δg and gluon orbital angular momentum L_g contributions to baryon spin are presumably small [1,3], quark orbital angular momentum L_q must provide the remainder according to $J \approx \frac{1}{2}\Sigma + L_q$. This suggests a positive quark orbital angular momentum contribution to proton spin and a negative L_q contribution to the Δ^+ spin. We investigate whether this finding may be understood in terms of the different geometric shapes of proton and Δ^+ as revealed by their intrinsic quadrupole moments, $Q_0(p) \approx -Q_0(\Delta^+)$, which were found to be nearly equal in magnitude but opposite in sign [4].

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