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G_A/G_V In The Quark Model[1]

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Abstract: It is shown that the naive non-relativistic quark model in the presence of pion emission and absorption, reproduces the usual Goldberger-Treiman relation for the nucleon axial vector coupling constant.

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It is generally held that the non-relativistic quark model (NRQM) predicts a value for the nucleon axial vector coupling

$$G_A/G_V = 5/3 \quad (1)$$

in substantial disagreement with both the experimental value of 1.23 and the current algebra estimate of 1.34 obtained from the Goldberger-Treiman relation

$$G_A/G_V = g_{\pi NN} f_\pi / M_N \quad (2)$$

In (2), f_π=93 MeV, $g_{\pi NN}$ is the πNN coupling constant, $g_{\pi NN}^2/4\pi$=14.6, and M_N is the nucleon mass. The correct statement of the NRQM prediction is, however, not (1) but

$$G_A/G_V = \frac{5}{3}\, g_A/g_V \quad (3)$$

where $g_{A,V}$ are the axial vector and vector couplings of the constituent quarks. While one expects g_A/g_V = 1 for current quarks, the same cannot be said for the constituent quarks, which presumably arise as effective degrees of freedom associated with the breakdown of chiral symmetry. In fact we will show that the constituent value of g_A/g_V is plausibly just such as to ensure the validity of the usual Goldberger-Treiman relation.

Considerable light has been shed recently on the underpinnings of the constituent quark picture and, correspondingly, on the successes of

QCD-inspired potential models[1]. Motivated by the observation that the vacuum gluon energy extracted from QCD sum rules appears to be considerably larger than the volume energy constant of the MIT bag, Shuryak[2] suggested that chiral symmetry breaking in QCD might occur at a scale $\Lambda_\chi \sim 1$ GeV, substantially larger that the deconfinement scale $\Lambda_C \sim 200$ MeV. Such an estimate for Λ_χ is also obtained from an analysis of $K \to 3\pi$ decays using effective chiral Lagrangians[3] and is compatible with the rather large value of m_π^2 when measured on a scale of the light current quark masses. This picture of the QCD vacuum naturally produces an effective theory of constituent quarks coupled to pions and gluons (albeit with, in general, momentum dependent couplings) in the distance regime $1/\Lambda_\chi \lesssim r \lesssim 1/\Lambda_C$ [1]. The notion of pions coupled directly to quarks rather than to baryons is, in fact, more general than suggested by this picture. Pion exchange is believed to play a role in the intermediate range NN interaction; in particular the tensor piece of one pion exchange appears largely responsible for binding the deuteron even in the presence of quark forces[4]. However, to the extent that, to use the language of the bag, the bag surface is not infinitely stiff, one expects antisymmetrization (exchange) effects at internucleon distances such that two nucleon bags either overlap or have surface separations not large compared to the zero point motion of the bag surface. Such exchange effects make the notion of a πNN coupling, at intermediate range, ambiguous, and it is only for large separations, where exchange terms are

exponentially suppressed, that one can define an effective πNN coupling. A πqq coupling, on the other hand, provides a perfectly acceptable framework for incorporating pion exchange at intermediate distance. This is done, for example, in the cloudy bag model[5] which, at least in its surface coupled version, is the natural phenomenological realization of the possibility $\Lambda_\chi \sim \Lambda_C$.

Consider, therefore, an effective πqq coupling with coupling constant $g_{\pi qq}$. The value of $g_{\pi qq}$ must be fixed so as to reproduce the known one pion exchange potential between nucleons at large nucleon separation. One may easily show that

$$g_{\pi qq} = \frac{3}{5} g_{\pi NN} \frac{m}{M_N} \tag{4}$$

where m is the mass of the quark, which we imagine to be its constituent mass. The coupling of the pion to the quarks renormalizes the constituent quark axial coupling. In exactly the usual manner we obtain a quark version of the Goldberger-Treiman relation

$$g_A/g_V = g_{\pi qq} f_\pi / m \tag{5}$$

Substituting (4) into (5) and using (3) we therefore obtain the usual Goldberger-Treiman relation independent of quark mass. (5) is subject to the usual corrections associated with the extrapolation from $q^2=0$ to $q^2 = m_\pi^2$. (2) however, being a consequence of (5) and (4), in this picture, only in the non-relativistic limit, receives also relativistic corrections and corrections due to the d-state content of the nucleon. Both effects lower the value of G_A/G_V, although the latter effect is negligible for d-state probabilities obtained in typical potential model calculations[6].

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