## ON THE INSTANTON INDUCED NUCLEON STRANGENESS

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We report on a calculation of the instanton contribution to the proton strangeness in the MIT bag enriched by the presence of a dilute instanton liquid. We express the proton matrix elements of strange-quark operators (in various Lorentz channels) in terms of a model valence nucleon state and interactions producing quark-antiquark fluctuations on top of that valence state. Only the scalar channel is found to be affected by the interaction induced by the random instanton liquid.

## 1 Introduction

More recent measurements of the strange axial vector form factor in the $\nu p$ and $\bar{\nu} p$ elastic [1] and $\mu p$ polarized deep inelastic scattering [2] support an early observation [3] of the large scalar strangeness of the proton – comparable scalar matrix elements $\langle N|\bar{q}q|N\rangle$ of the $u$-, $d$-, and $s$-quark matrix elements, respectively, [4]:

$$\langle N|\bar{u}u\;;\bar{d}d\;;\bar{s}s|N\rangle \simeq 3.5\;;2.8\;;1.4\ \ . \tag{1}$$

This unexpectedly large *scalar strangeness* is in accordance with the *quark condensates* in the QCD vacuum. A QCD sum-rule analysis [5] shows that the vacuum expectation value of $\bar{s}s$ is actually approximately as large as for non-strange light ($q = u, d$) quarks, $\langle 0|\bar{s}s|0\rangle = (0.8 \pm 0.1)\langle 0|\bar{q}q|0\rangle$. The hadronic and the vacuum scalar strangeness are connected via the (naive) bag-model relation [6], $\langle N|\bar{s}s|N\rangle = -\langle 0|\bar{s}s|0\rangle V$ . This stimulated us, in Refs. [7], [8], to provide a framework that would allow one to calculate various strange proton matrix elements for various quark models and flavour-mixing interactions $\mathcal{L}_I$.
We are interested in the values of the nucleon matrix element $\langle N| : \bar{s}\Gamma s : |N\rangle$, where the bilinear $\bar{s}\Gamma s$ might represent the scalar, pseudoscalar, vector, axial vector or tensor strange current densities ($\Gamma = 1, \gamma_5, \gamma_\mu,\ \gamma_\mu\gamma_5, \sigma_{\mu\nu}$). Taking matrix elements of the normal ordered operators excludes a contribution coming from the QCD vacuum condensate.

## 2 Instanton-induced strangeness in the MIT bag model

Some investigators[9,10,11,12] have suggested the instantons as the most important non-perturbative configurations of the gluon fields. It is also an important candidate for the *strangeness inducing interaction* $\mathcal{L}_I$, generating the strange nucleon matrix elements of some operators. *E.g.* the calculation [13] in the context of the NJL model found that large strange-pair components were present in the nucleon only if a very strong instanton-induced interaction $\mathcal{L}_{inst}$ was included in low-energy dynamics.

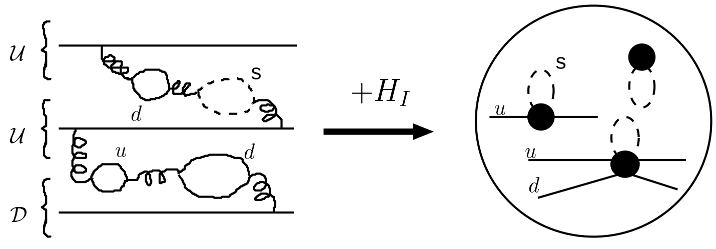
We used the vacuum-averaged version of the instanton-induced interaction $\mathcal{L}_{inst}$ derived [14] in the instanton-liquid approach. Here we write only schematically:

$$\mathcal{L}_{inst} = \mathcal{L}_1 + \mathcal{L}_2 + \mathcal{L}_3, \qquad \mathcal{L}_k = -n \left( \tfrac{4\pi^2}{3}\rho^3 \right)^k c_k \prod_{i=u,d,s} \mathcal{F}_i \left[ (\bar{q}^i_R \lambda q^i_L)^{k-factors} \right], \tag{2}$$

where $n$ is the instanton density and $\mathcal{F}_i$'s are the characteristic factors. *E.g.*, $\mathcal{F}_u \equiv [m_u\rho - \frac{2\pi^2}{3}\rho^3 \langle 0|\overline{q}q|0\rangle]^{-1}$,composed of the current light quark mass and the average instanton size $\rho \simeq \frac{1}{3}$ fm [15,10,11]. This interaction is actually the same as the well-known one of Shifman, Vainshtein and Zakharov although we utilised much simpler equivalent Nowak's [16]expressions obtained by Fierzing.

In order to employ this interaction in conjunction with for *e.g.* MIT bag model of the proton we used the following picture. The MIT-bag hadrons are viewed as bubbles having perturbative QCD interior. Such hadron bags are immersed in the physical QCD vacuum, permeated by the instanton liquid. Allowing the droplets of the instanton liquid to penetrate into the bag interior with small but nonvanishing probability leads to "a foggy bag". Such presence of a dilute instanton liquid corresponds to switching on the interaction (2), as displayed on the figure:

$|N_0\rangle = |\mathcal{UUD}\rangle \qquad\qquad |N\rangle = |N_0\rangle + |\delta N\rangle$




$\langle N_0| : \bar{s}s : |N_0\rangle = 0 \qquad\qquad \langle N| : \bar{s}s : |N\rangle \neq 0$

The potentially nonvanishing strange matrix elements $\langle N| : \overline{s}\Gamma s : |N\rangle$ arise on account of introducing the full nucleon (proton) state $|N\rangle = |N_0\rangle + |\delta N\rangle$.

In Refs. [7,8] we employed the method of sources to obtain $|\delta N\rangle$ as the response of $|N_0\rangle$ to the external probe which is the source of a strange current. In this way we avoided the need for the explicit form of $|\delta N\rangle$. The final result is that required matrix elements are given by [8]

$$\begin{aligned} \langle N| : \overline{s}\Gamma s : |N\rangle \; &= \; i \int_{-\infty}^{+\infty} dt' \, \langle N_0|\hat{T} : \langle \overline{s}\Gamma s(t_0)\rangle : : L_I(t') : |N_0\rangle \\ - \; \frac{1}{2} \int_{-\infty}^{+\infty} dt' &\int_{-\infty}^{+\infty} dt'' \, \langle N_0|\hat{T} : \langle \overline{s}\Gamma s(t_0)\rangle : : L_I(t') : : L_I(t'') : |N_0\rangle \; . \end{aligned} \tag{3}$$

This formula can now be applied to any mean field type hadron model and arbitrary strangeness inducing interaction $L_I$.

## 3 Results and conclusions

The sum over quark modes, appearing after field contractions in the (3), should naturally run up only to some typical hadron-physics low-energy cut-off $\Lambda \sim 0.6 - 1$ GeV. In the case of the MIT bag model this means that the sum encompasses four lowest-lying strange quark states. In the evaluation of the strange matrix elements we have used the average instanton size $\rho$=1/600 MeV$^{-1}$ and the depleted instanton density $n = 2.66 \cdot 10^7$ MeV$^4$. This gave the result [7]

$$\langle N| : \bar{s}s : |N\rangle = 0.058 \tag{4}$$

for the *scalar* strangeness, and it turned out that strange matrix elements of pseudoscalar ($\bar{s}\gamma_5 s$), vector ($\bar{s}\gamma_\mu s$) and axial vector ($\bar{s}\gamma_\mu\gamma_5 s$) operators vanish. To make a sensible comparison of the value (4) for the scalar strangeness with (1) it is necessary also to take into account the strangeness induced by the difference between the perturbative vacuum inside and the non-perturbative one outside the bag. As discussed by Donoghue and Nappi [6], $\langle N|\bar{s}s|N\rangle_{\rm bag} = 4.36$ , which thus dominates the summed scalar strangeness

$$\langle N|\bar{s}s|N\rangle = 4.42\ . \tag{5}$$

The scalar strangeness is special because of non-vanishing scalar $\bar{q}q$ condensates of the QCD vacuum. This explains why it is larger than vector, axial or other kinds of strangeness.

These results are also consistent with the most recent measurements of the strange vector form factors at low momentum transfer, $Q^2 \lesssim 1$ GeV. The experimental strange magnetic form factor of the nucleon at $Q^2 = 0.1$ (GeV/c)$^2$, $G_M^s = 0.23 \pm 0.37 \pm 0.15 \pm 0.19\,\mu_N$ , obtained at MIT/Bates [17] is consistent with the absence of strange quarks, but the error bars are large. However, the results and conclusions of our approach, that channels other than the scalar one should not be appreciably affected by strange quarks, seems to get support especially from the most recent and very precise TJNAF (JLab) measurement [18] yielding the small strange vector form factors at $Q^2 = 0.48$ (GeV/c)$^2$, $G_E^s + 0.39 G_M^s = 0.023 \pm 0.034 \pm 0.022 \pm 0.026\,\mu_N$.

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