Strange nucleon form factors: Solitonic approach to $G^s_M$, $G^s_E$, $G^p_A$ and $G^n_A$ and comparison with world data

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Abstract. We summarize the results of the chiral quark-soliton model ($\chi$QSM) concerning basically all form factors necessary to interpret the present data of the parity-violating electron scattering experiments SAMPLE, HAPPEX, A4 and G0. The results particularly focus on the recently measured asymmetries and the detailed data for various combinations of $G^s_M$, $G^s_E$, $G^p_A$ and $G^n_A$ at $Q^2 = 0.1\text{GeV}^2$. The calculations yield positive strange magnetic and electric form factors and a negative axial vector one, all being rather small. The results are very close to the combined experimental world data from parity-violating electron scattering and elastic $\nu p$ and $\bar{\nu} p$ scattering.

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1 Introduction

The strange quark contribution to the distributions of charge and magnetization in the nucleon has been a very important issue well over decades, since it provides a vital clue in understanding the structure of the nucleon and in particular in probing the quark sea. There are some indications of about 4% contribution to the momentum sum rule of deep inelastic lepton scattering, of roughly 15% to the spin of the nucleon extracted from polarized deep inelastic scattering, or of up to 30% contribution to the mass of the nucleon, where all these numbers show rather large uncertainties. Recently, the strangeness content of the nucleon has been studied particularly intensively since parity-violating electron scattering (PVES) has demonstrated to provide an essential tool for probing the sea of $s\bar{s}$ pairs in the vector channel \cite{1}. In fact, various PVES experiments have been already conducted from which the strange vector form factors can be extracted \cite{2–12}. The results from the SAMPLE, HAPPEX, PVA4, and G0 Collaborations have shown evidence for a non-vanishing strange quark contribution to the structure of the nucleon. In particular, evidence was found that the strange magnetic moment of the proton is positive \cite{11}, suggesting that the strange quarks reduce the proton’s magnetic moment. This is an unexpected and surprising finding, since a majority of theoretical studies favors a negative value. One of the models, which yield a positive strange magnetic moment of the proton, is the chiral quark soliton model ($\chi$QSM). It will be used in the present paper to investigate the form factors $G^s_M$, $G^s_E$, $G^p_A$ and $G^n_A$ and to compare them with world data.

Using the $\chi$QSM the present authors have recently investigated the set of six electromagnetic form factors ($G^s_{E,M}$) and three axial-vector ones ($G^{u,d,s}_A$) \cite{13–16}. The results show a good agreement with the data of the SAMPLE, HAPPEX, A4 and G0 experiments. This includes parity-violating asymmetries (PVA) which have been measured by the G0 experiment over a range of momentum transfers in the forward direction \cite{12}. We even predicted the PVAs of the future G0 experiment at backward angles \cite{17}. In the present contribution we perform more detailed comparison including the most recent data of the HAPPEX experiment on He-4 and the results of the PVAs combined with elastic $\nu p$ and $\bar{\nu} p$ scattering.

2 Chiral quark soliton model

The $\chi$QSM has been used several times to calculate strange properties of the nucleon and of hyperons. It is
an effective relativistic quark theory based on the instanton degrees of freedom of the QCD vacuum and has been derived from QCD in the large-N_c limit. In the end it turns out to be the simplest possible quark theory which allows for spontaneously broken chiral symmetry. It results in an effective chiral action for valence and sea quarks both moving in a static self-consistent Goldstone background field [18–20]. For this model it is absolutely natural to have strange quark contributions to the nucleon. The χQSM has very successfully been applied to mass splittings of hyperons, to electromagnetic and axial-vector form factors [18] of the baryon octet and decuplet and to forward and generalized parton distributions of the nucleon. With one set of four parameters, unchanged for years, it reproduces all appropriate observables of light baryons with an accuracy of (10–30)%.

Also the combined data G^p_E(0) ± 0.010 measured at Q^2 = 1.0 GeV^2, where in addition to the usual linear combinations of electric and magnetic form factors the measurements of parity violation on He-4 allowed an extraction of G^M_E. The experimental situation is by far the best at Q^2 = 0.1 GeV^2, including the HAPPEX data on He-4 of 2004. The figure is taken from ref. [11]. The numbers indicate the references of theoretical calculations. The χQSM is given by [13].

\[ \tilde{G}_A^p = -(1 + R_A^1)G_A^{s}(Q^2) + R_A^0 + G_A^s, \]  
\[ \tilde{G}_A^M = 3(1 + R_A^1)G_A^{s}(Q^2) + R_A^0 + G_A^s, \]  
\[ \tilde{G}_A^p = G_A^s = -\frac{1}{2}G_A^{NC}, \]  

with the values for the electro-weak radiative corrections [21]:

\[ R_A^1 = -0.41 \pm 0.24, \quad R_A^0 = 0.06 \pm 0.14. \]

3 Electron and neutrino scattering data

The experimental situation is by far the best at Q^2 = 0.1 GeV^2, where in addition to the usual linear combinations of electric and magnetic form factors the measurements of parity violation on He-4 allowed an extraction of G^s_E. The experimental results of the HAPPEX Collaboration are G^p_E = -0.038 ± 0.042 ± 0.010 measured at Q^2 = 0.091 GeV^2 [10] and, more recently, G^s_E = -0.002 ± 0.017 at Q^2 = 0.1 GeV^2 [23].

Also the combined data G^M_E = -0.006 ± 0.016 [23] are consistent with zero. Experimental evidence from

![Fig. 1](image1.png)  
**Fig. 1.** The world data on the strange form factors G^M_M and G^E_E at Q^2 = 0.1 GeV^2 including the HAPPEX data on He-4 of 2004. The figure is taken from ref. [11]. The numbers indicate the references of theoretical calculations. The χQSM is given by [13].

![Fig. 2](image2.png)  
**Fig. 2.** The world data on the strange form factors G^M_M and G^E_E at Q^2 = 0.1 GeV^2 including the HAPPEX data on He-4 of 2004 and of 2005 (preliminary). The numbers indicate the references of theoretical calculations. The figure is taken from ref. [23]. The χQSM is given by [13].