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Moments of the spin structure functions g_1^p and g_1^d for $0.05 < Q^2 < 3.0$ GeV^2

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ABSTRACT

The spin structure functions g_1 for the proton and the deuteron have been measured over a wide kinematic range in x and Q^2 using 1.6 and 5.7 GeV longitudinally polarized electrons incident upon polarized NH_3 and ND_3 targets at Jefferson Lab. Scattered electrons were detected in the CEBAF Large Acceptance Spectrometer, for $0.05 < Q^2 < 5\ \text{GeV}^2$ and $W < 3$ GeV. The first moments of g_1 for the proton and deuteron are presented – both have a negative slope at low Q^2, as predicted by the extended Gerasimov–Drell–Hearn sum rule. The first extraction of the generalized forward spin polarizability of the proton γ_0^p is also reported. This quantity shows strong Q^2 dependence at low Q^2. Our analysis of the Q^2 evolution of the first moment of g_1 shows agreement in leading order with Heavy Baryon Chiral Perturbation Theory. However, a significant discrepancy is observed between the γ_0^p data and Chiral Perturbation calculations for γ_0^p, even at the lowest Q^2.

Fundamental to our understanding of nuclear matter is a complete picture of the spin structure of the nucleon. The spin of the nucleon arises from the spin and orbital angular momenta of both the quarks and gluons. One way to access the quark spins in lepton scattering is through measurements of the spin structure functions g_1 and g_2 [1], which are not well known at low momentum transfer to the target nucleon ($Q^2 < 2\ \text{GeV}^2$). At larger momentum transfer, $g_1(x, Q^2) = \frac{1}{2}\Sigma e_i^2 \Delta q_i(x)$ (in the parton picture), where $\Delta q_i/q_i$ is the net helicity of quarks of flavor i in the direction of the (longitudinally polarized) nucleon spin, q_i is the probability of finding a quark of flavor i with momentum fraction x, and e_i is the quark charge. (The Bjorken scaling variable $x = \frac{Q^2}{2M\nu}$ in the lab frame, M is the nucleon mass and ν is the energy transferred from the electron to the target nucleon.) At sufficiently small Q^2, g_1 and its moments can be more economically described by hadronic degrees of freedom and effective low-energy approximations to QCD, like Chiral Perturbation Theory (χPT).

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There is particular interest in the first moment of g_1, $\Gamma_1(Q^2) = \int_0^{x_0} g_1(x, Q^2)\,dx$, which is related to the fraction of the nucleon spin carried by quark spins. The upper limit of the integral, x_0, corresponds to pion production threshold. This limit excludes elastic scattering, which otherwise dominates the low Q^2 behavior of the integral. Γ_1 is constrained as $Q^2 \to 0$ by the Gerasimov–Drell–Hearn (GDH) sum rule [2,3] to be $-\frac{\kappa^2}{8M^2}Q^2$, where κ is the anomalous magnetic moment of the nucleon. At high Q^2, Γ_1 has been measured in deep inelastic scattering (DIS) experiments at SLAC [4,5], CERN [6–8] and DESY [9]. Ji and Osborne [10] have shown that the GDH sum rule can be generalized to all Q^2 via

$$\Gamma_1(Q^2) = \frac{Q^2}{8} S_1(\nu = 0, Q^2) - \Gamma_1^{\text{el}}(Q^2), \tag{1}$$

where $S_1(\nu, Q^2)$ is the spin-dependent virtual photon Compton amplitude and Γ_1^{el} is the contribution to the integral from elastic scattering. At high Q^2, S_1 can be calculated using the operator product expansion (OPE). By comparing the OPE twist series with Γ_1, one can extract higher twist parameters [11–15], which are sensitive to quark–gluon and quark–quark correlations in the nucleon at moderate Q^2. Lattice QCD calculations may eventually