Strange Quark Contribution and Polarization Observables in Elastic Electron Deuteron scattering

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Introduction

Parity-violating asymmetries in polarized electron scattering from nucleons and nuclei result from the interference of photon (γ) and Z-exchange. These processes are therefore considered to be ideal for studying the structure of hadrons and in particular to understand the role of sea quarks in the structure of nucleons. A theoretical and experimental study of strange electric $G_E^s(Q^2)$, magnetic $G_M^s(Q^2)$, and axial $G_A^s(Q^2)$ form factors provides thus information about the role of strange sea quarks in the nucleon. Many experimental programs have been started at various electron accelerators to search for the strangeness content of the nucleon through the observation of parity violating asymmetries in the scattering of polarized electrons from proton, deuteron and ^{4}He targets. These experiments are expected to answer questions about the strange form factors of the nucleon and radiative corrections to the axial vector couplings which may also lead to an understanding of anapole moments [1]. In theory, many calculations have been done for the parity-violating helicity-dependent electron asymmetry in the quasi-elastic scattering of polarized electrons off deuterons [2-4]. But there exist very few calculations for the case of elastic electron deuteron scattering.

In this paper we have studied the parity-violating observables in elastic scattering of polarized and unpolarized electrons from unpolarized deuteron targets at electron energies relevant for SAMPLE, PVA4 and G0 experiments [5]. In particular, we have calculated the non-vanishing parity-violating parts of the deuteron vector recoil polarization for the elastic scattering of unpolarized electrons from unpolarized deuterons. In the case of the elastic scattering of polarized electrons from unpolarized deuterons, we have calculated the parity violating helicity-dependent electron asymmetry as well as the parity-violating non vanishing components of the recoil deuteron polarization. The separate contributions due to the γ-Z interference and the odd parity admixture in the deuteron arising from the parity-violating nucleon-nucleon potential have been calculated. The additional contribution due to the strangeness components of the nucleon, including anapole moments and radiative corrections to the weak coupling constants has been evaluated.

Formalism

The general expression for a polarization observable of elastic electron deuteron scattering $e(k_1)+d(d)\rightarrow e(k_2)+d(d')$ including longitudinal electron polarization of degree h but for an unpolarized deuteron target is

$$O_X \frac{d\sigma^{\gamma+Z}}{d\Omega_{k_2}^{lab}} = \sigma_{Mott} S_0\left[A_d^0(X) + hA_{ed}^0(X)\right]$$

with $\sigma_{Mott} = \alpha^2 \cos^2\frac{\theta_e^{lab}}{2} k_2^{lab} \Big/ 4\sin^4\frac{\theta_e^{lab}}{2}\left(k_1^{lab}\right)^3$ as the Mott cross-section in the lab system. The four-momenta of incoming and scattered electrons are denoted by k_1 and k_2, respectively, and the corresponding deuteron four-momenta by $d=\left(E_d,\vec{d}\right)$ and $d'=\left(E_d',\vec{d}'\right)$, respectively. Furthermore, $q_\mu^2 = q_0^2 - \vec{q}^{\,2}$ denotes the squared four-momentum transfer with $q = k_1 - k_2$. The coordinate system chosen is such that the z-axis is taken along the momentum transfer $\vec{q}$, the y-axis along $\vec{k}_1 \times \vec{k}_2$, i.e. perpendicular to the scattering plane, and the x-axis as to form a right-handed system. The observable O_X refers to the various possible polarizations of the final recoiling deuteron including the case of no polarization analysis. It is characterized by a subscript X representing a set of quantum numbers $X = (IM\pm)$ with $I = 0,1,2$ and $0 \le M \le I$. We now list the various observables like differential cross-section and final-state polarization observables calculated here:

(i) Differential cross-section:

$$\frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = \sigma_{Mott} S_0 \left[1 + A^0_d(00+)_{pv} + hA^0_{ed}(00+)_{pv}\right]$$

The unpolarized parity-conserving differential cross-section is given by $\sigma_{Mott} S_0$ with

$$S_0 = \frac{4\pi}{3}\left(\left((C^\gamma_0)^2 + (C^\gamma_0)^2\right)v_L + (M^\gamma_1)^2 v_T\right)$$

where the kinematical functions $v_\alpha(\alpha \in \{L,T,LT,TT\})$ reflecting the virtual photon density matrix are given in detail in ref [6]. The parity-violating contribution by $A^0_d(00+)_{pv}$ and $A^0_{ed}(00+)_{pv}$, are given in ref. [6], with C^c_{LM}, E^c_{LM} and M^c_{LM} denoting charge, electric and magnetic multipoles, respectively.

(ii) Vector recoil polarization:

$$P_x \frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = -\frac{1}{\sqrt{3}}\sigma_{Mott} S_0 \left(A^0_d(11+)_{pv} + hA^0_{ed}(11+)_{pc+pv}\right)$$

$$P_z \frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = \sqrt{\frac{2}{3}}\sigma_{Mott} S_0 \left(A^0_d(10+)_{pv} + hA^0_{ed}(10+)_{pc+pv}\right)$$

Where the asymmetry parameters $A^0_d(11+)_{pv}$, $A^0_d(10+)_{pv}$, $A^0_{ed}(11+)_{pc+pv}$, and $A^0_{ed}(10+)_{pc+pv}$ are given in ref. [6].

(iii) Tensor recoil polarization: The non vanishing components are

$$P_{zz} \frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = \sqrt{\frac{2}{3}}\sigma_{Mott} S_0 \left(A^0_d(20+)_{pc+pv} + hA^0_{ed}(20+)_{pv}\right)$$

$$P_{xx/yy} \frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = \pm\frac{1}{2\sqrt{3}}\sigma_{Mott} S_0 \left(A^0_d(22+)_{pc+pv} + hA^0_{ed}(22+)_{pv}\right) - \frac{1}{2}P_{zz}\frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}}$$

$$P_{zx} \frac{d\sigma^{\gamma+Z}}{d\Omega^{lab}_{k_2}} = -\frac{1}{2\sqrt{3}}\sigma_{Mott} S_0 \left(A^0_d(21+)_{pc+pv} + hA^0_{ed}(21+)_{pv}\right)$$

Where the asymmetry parameters $A^0_d(20+)_{pc+pv}$, $A^0_d(21+)_{pc+pv}$, $A^0_{ed}(20+)_{pv}$, $A^0_{ed}(21+)_{pv}$ and $A^0_{ed}(22+)_{pv}$ are given in ref. [6].

Results

The numerical results calculated like parity-violating observables such as recoil vector polarization of the deuteron P_x and P_z, electron beam asymmetry A, and tensor polarization asymmetry A_{zz}, A_{xy} and A_{yy} of the recoiling deuteron in the scattering of unpolarized and polarized electrons from unpolarized deuterons will be presented. In all these cases, the contributions to the parity-violating observables are dominated by the γ-Z interference term of the Standard Model The uncertainties due to the use of various form factor parameterizations of the electroweak nucleon form factors have also been studied using two different parameterizations taken from literature and are found to be small.. The effects of a nonzero strangeness component in the magnetic form factor as well as the axial vector form factor have been calculated. These effects are found to be important in the backward direction. With present knowledge of G^s_M and G^s_A, the contribution to the asymmetries are in opposite direction. The contribution due to G^s_M being larger than contribution due to G^s_A. It is found that the parity-violating observables are important in the backward directions corresponding to large Q^2 and can be helpful in distinguishing between various models in this region of Q^2. In the region of small Q^2 the parity-violating effects are too small to be measured in the near future.

References

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