"Anapole" moment of leptons and quarks as a source of parity violating interaction between leptons and hadrons

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We show that within the framework of single-photon mechanism "anapole" moments of an electron or quarks may lead to a p-violating asymmetry in the inelastic scattering of longitudinally-polarized electrons by unpolarized nucleons and deuterons. Experimental methods are considered for discriminating predictions by unified theories of the weak and electromagnetic interactions of the Weinberg model type from predictions by a model with "anapole" moments.

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1. A P-violating asymmetry in the inelastic scattering of longitudinally-polarized electrons by unpolarized protons and deuterons has been experimentally demonstrated recently.[1] The asymmetry should be determined by interference of the P-conserving amplitude of the one-photon mechanism and P-violating amplitude of the weak mechanism. Normally, in this case the weak mechanism is assumed to depend on the interaction between weak neutral electron currents and hadrons. The experimental values of asymmetry agree with predictions by Weinberg's unified theory of weak and electromagnetic interactions[2] and fail to agree with predictions of vector-like theories.

In this paper we consider the case where P-violating effects in the scattering of polarized leptons may be also due to "anapole" moments of an electron or quarks. Even in 1957 Zel'dovich showed[3] that for spin $\frac{1}{2}$ particles there exists a unique P-violating characteristic–the anapole moment–which does not contradict the CP-invarican be shown that the scattering asymmetry of longitudinally-polarized electrons by unpolarized hadrons is a linear function of the "anapole" moment. Therefore, using the results of Ref. 1, we may evaluate not only the absolute values of "anapole" moments of the electron and quarks, but also their sign. We shall use the following expression for the electromagnetic electron current:

$$l_\mu = e\bar{u}(k_2)\left[\gamma_\mu + \frac{a_e}{m_e^2}(\gamma_\mu k^2 + 2m_e k_\mu)\gamma_5\right]u(k_1), \quad k = k_1 - k_2, \tag{1}$$

where a_e is the "anapole" moment of the electron in e/m_e^2 units. Thus, the asymmetry of inelastic scattering of longitudinally-polarized electrons by an unpolarized hadronic target is determined by the following formula:

$$A(e) = \frac{\sigma^{(+)} - \sigma^{(-)}}{\sigma^{(+)} + \sigma^{(-)}} = 4a_e \frac{(-k^2)}{m_e^2}, \tag{2}$$

where $\sigma^{(\pm)} \equiv d^2\sigma/d\Omega_e d\epsilon_2$ is the inelastic scattering cross section of the electron with helicity $\pm\frac{1}{2}$, calculated in the 1-photon approximation (ϵ_2 is the energy of scattered electron). Clearly, the asymmetry depends only on the square of the transmitted momentum and is independent of transmitted energy. The experimental values of asymmetry are

$$A_d = (9.5 \pm 1.6)\cdot 10^{-5} k^2/\text{GeV}^2, \quad A_p = (9.7 \pm 1.7)\cdot 10^{-5} k^2/\text{GeV}^2 \tag{3}$$

and are independent of target, thus yielding $a_e = 6\times 10^{-12}$. If we assume that the "anapole" moment depends on the weak interaction, a "natural" value of a_e may be derived from dimensional considerations, $a_e \approx Gm_e^2 = 2\times 10^{-12}$ (G is weak interaction constant), i.e., close to the experimental value of a_e.

Weak interaction should also lead to "anapole" moments of quarks which, in turn, will cause P-violating effects in eN-scattering. In this case the asymmetry of highly-inelastic scattering of polarized electrons by unpolarized nucleons may be analyzed within the framework of the quark-parton model. For the sake of simplicity we shall take into consideration contributions only from the valence quarks, and we obtain the following:

$$\begin{aligned} A_p &= -6\frac{k^2}{M^2}\frac{2a_u u(x) - a_d d(x)}{4u(x) + d(x)}\frac{1-(1-y)^2}{1+(1-y)^2}, \\ A_n &= -6\frac{k^2}{M^2}\frac{2a_u d(x) - a_d u(x)}{4d(x) + u(x)}\frac{1-(1-y)^2}{1+(1-y)^2}, \end{aligned} \tag{4}$$

where a_u and a_d are "anapole" moments of u- and d-quarks (in e/M^2 units, where M is the nucleon mass), $u(x)$ and $d(x)$ are the distribution functions of u- and d-quarks,

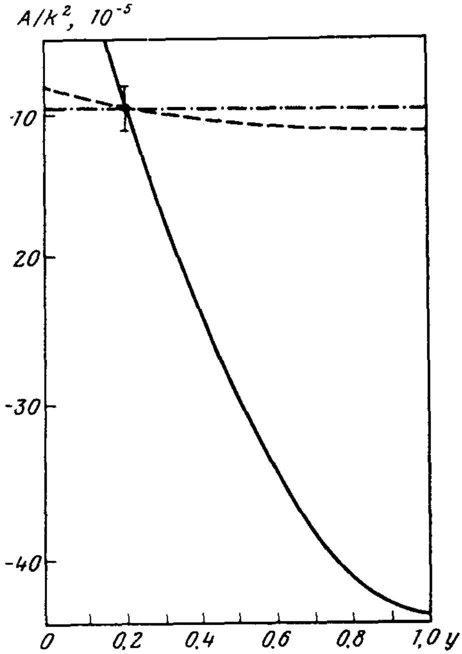

FIG. 1. y—dependence of asymmetry A_d ——- - - ——Weinberg model; ·······——"anapole" moment of electron; —– – "anapole" moment of quarks.

respectively, in a proton as a function of longitudinal momenta, $x = -k^2/2\nu$, $\nu = M(\epsilon_1 - \epsilon_2)$, $y = 1 - \epsilon_2/\epsilon_1$, ϵ_1 is energy of the original electron (in the laboratory system).

The asymmetry of deeply-inelastic scattering of longitudinally-polarized electrons by deuterons is independent in our approximation of the structure functions:

$$A_d = -\frac{6}{5}\frac{k^2}{M^2}(2a_u - a_d)\frac{1-(1-y)^2}{1+(1-y)^2}, \quad \overline{A}_d = -\frac{3}{5}\frac{k^2}{M^2}(2a_u - a_d), \tag{5}$$

where $\overline{A}_d$ is the asymmetry integrated over the energy transfer y. Using the experimental value of A_d, we get $2a_u - a_d = (-3.2 \pm 0.5)\times 10^{-4}$. One more equation may be obtained for a_u and a_d using the experimental value of A_p. Using the ratio $u(x)/d(x)$—found when analyzing results from deeply-inelastic scattering of unpolarized electrons by nucleons[4]—we get $2a_u - 0.25a_d \neq (2.8 \pm 0.8)\times 10^{-4}$, i.e., $a_u = -1.4\times 10^{-4}$, $a_d = 0.5\times 10^{-4}$. The resultant values of a_u and a_d can now be used to predict the value of scattering asymmetry of polarized electrons by neutrons under the conditions of Ref. 1: $A_n = 9\times 10^{-5} k^2/\text{GeV}^2$.

Thus, the measured values of scattering asymmetry of polarized electrons may be used to determine the "anapole" moments of the electron and quarks. In this connection a question arises concerning how to choose in practice between alternative explanations of the origin of P-violating effects occuring during the scattering of electrons by hadrons? Figure 1 clearly shows that the y-dependence of $A_d^{(W)}$ in the Weinberg model differs substantially from the y-dependence expected in a model with the "anapole" moments of quarks; while with the present degree of accuracy in measuring the y-dependence, $A_d^{(W)}$ and $A_d^{(e)}$ are indistinguishable. However, models with "anapole" moments of the electron and quarks which lead to identical values of asymmetry for e^-d-scattering should lead to different magnitudes of P-violating effects in atoms; specifically, only the "anapole" moment of the electron gives rise to P-violating effects in atoms which are comparable to P-violating effects predicted in the Weinberg model.

[1]C.Y. Prescott, W.B. Atwood, R.L.A. Cottrell *et al.*, Preprint SLAC-PUB-2148, 1978.
[2]S. Weinberg, Phys. Rev. Lett. **19**, 1264 (1967).
[3]Ya. B. Zel'dovich, Zh. Eksp. Teor. Fiz. **33**, 1531 (1957) [Sov. Phys. JETP **6**, 1184 (1958)].
[4]R.C. McElhaney and S.F. Tuan, Nucl. Phys. B **72**, 487 (1974).