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ONCE MORE ON THE P-ODD ASYMMETRY IN THE ELASTIC SCATTERING OF POLARIZED ELECTRONS ON NUCLEONS

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I. The existence of the weak interaction between electrons and nucleons was estabilished in 1978 when P-odd effects had been observed in the atomic physics experiments with ^{209}Bi [1] and in the deep inelastic scattering of polarized electrons on deuterons [2]. The measurements are in good agreement with the Weinberg-Salam theory [3].

At present the experiments for further studies of the weak $e^- - N$ interaction are planned. In particular, high precision experiments which will measure the P-odd asymmetry arising in the elastic scattering of longitudinally polarized electrons with energy $E \sim 300$-900 MeV on unpolarized nucleons

$$e + N \rightarrow e + N \qquad (1)$$

are under preparation [4,5].

In this note we shall consider the process (1) in the framework of the Weinberg-Salam (W.S.) theory.

The parity violating asymmetry in this process has been discussed previously in a number of papers [6]. However, as the general analysis of the existing data on elastic e-p and e-d scattering performed in refs. [7,8,9] shows, the parametrizations of the electromagnetic nucleon form factors used in these papers [6] are excluded by the data. In this situation a recalculation of the asymmetry using parametrizations of the form factors which give a satisfactory description of the data is necessary. Further on, the experimental data available do not provide a unique description of the electromagnetic and axial-vector nucleon form factors. This may introduce some uncertainties in the numerical predictions for the asymmetry.

Here we calculate the parity violating asymmetry in elastic e-N scattering using form factors [7,9] compatible with the data* and study the above-mentioned ambiguities. We investigate also the sensitivity of the asymmetry on the value of $\sin^2\theta_W$.

II. The parity violating asymmetry in process (1) originates from the interference of the weak and one-photon exchange amplitudes. The effective Hamiltonian which describes the weak interaction of electrons and nucleons in the W.C. theory is:

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*Let us note that the magnitude of the asymmetry obtained here differs from the one calculated in ref. [6] by $\sim 10\%$ already for $E \gtrsim 600$ MeV.

$$\mathcal{H} = \frac{G}{\sqrt{2}} 2 j_\alpha^e j_\alpha^h , \tag{2}$$

where G is the Fermi coupling constant, and the electron j_α^e and hadronic j_α^h neutral currents are given by the expressions:

$$j_\alpha^e = \bar{e}\gamma(g_V + g_A \gamma_5) e,$$

$$g_V = -\frac{1}{2} + 2\sin^2\theta_w , \tag{3}$$

$$g_A = -\frac{1}{2},$$

$$j_\alpha^h = j_\alpha^3 - 2\sin^2\theta_w \, j_\alpha^{em} + j_\alpha^s . \tag{4}$$

In eq.(4) j_α^3 is the third component of the vector V-A current, j_α^{em} is the hadronic electromagnetic current, and j_α^s is an isoscalar current, built up by s, c and other heavier quarks.

The cross section for the scattering of longitudinally polarized electrons on unpolarized nucleons has the form:

$$\left(\frac{d\sigma}{d\Omega}\right)_\lambda = \left(\frac{d\sigma}{d\Omega}\right)_0 (1 + \lambda A_N) , \tag{5}$$

where $\left(\frac{d\sigma}{d\Omega}\right)_0$ is the cross section for unpolarized particles, λ is the longitudinal polarization of the electron, A_N is the P-odd asymmetry. Neglecting the contribution of the s, c and other heavier quarks and using the isospin invariance of strong interactions we obtain the following expression for A_N /6/:

$$A_N = \frac{G}{\sqrt{2}} \cdot \frac{q^2}{2\pi a} [(G_E^N)^2 + (G_M^N)^2 \tau(1 + 2(1+\tau)\,\mathrm{tg}^2\frac{\theta}{2})]^{-1} \times$$

$$\times [2(\frac{E}{M} - \tau)(1+\tau)\cdot \mathrm{tg}^2\frac{\theta}{2} \cdot G_A^{0;N} \cdot G_M^N + 2\tau\,\mathrm{tg}^2\frac{\theta}{2} G_M^{0;N} \cdot G_M^N (1+\tau) + \tag{6}$$

$$+ G_E^{0;N} G_E^N + \tau \cdot G_M^{0;N} \cdot G_M^N] .$$

Here E is the energy of the incoming electron in the lab. system, θ, is the scattering angle, $\tau = \frac{q^2}{4M^2}$ (M is the nucleon mass), $G^N_{E,M}$ are the charge and magnetic form factors of the nucleon. The form factors $G^{0;N}_{E,M}$ are expressed in terms of the electromagnetic and exial-vector nucleon form factors as follows:

$$G^{0;p,n}_{E,M} = \mp\frac{1}{2}(1-2\sin^2\theta_w)(G^p_{E,M} - G^n_{E,M}) + \\ + \sin^2\theta_w(G^p_{E,M} + G^n_{E,M}\cdot) \tag{7}$$

and the form factor $G^{0;p,n}_A$ equals

$$G^{0;p,n}_A = \pm\frac{G_A}{2}(-1+4\sin^2\theta_w). \tag{8}$$

Here G_A is the axial-vector nucleon form factor, measured in the quasielastic processes $\nu_\mu + n \to \mu^- + p$, $\bar{\nu}_\mu + p \to \mu^+ + n$.

So, within the W.S. theory the parity violating asymmetry in the elastic e-N scattering is entirely expressed in terms of the parameter $\sin^2\theta_w$, the electromagnetic form factors and the axial-vector form factor of the nucleon.

III. Up to now no consistent theory of the form factors exists and the description of their q^2-behaviour is achieved mainly by phenomenological parametrizations.

We have calculated the P-odd asymmetry under the following assumptions:

A) Scaling among the form factors exists:

$$\frac{G^p_M(q^2)}{\mu_p} = \frac{G^n_M(q^2)}{\mu_n} = G^p_E(q^2), \tag{9}$$

$$G^n_E(q^2) = 0 \tag{10}$$

and $\frac{G^p_M(q^2)}{\mu_p}$ equals

$$G^p_M(q^2) = \mu_p\left(\frac{a_3}{1+a_1 q^2} + \frac{1-a_3}{1+a_2 q^2}\right). \tag{11}$$

Here a_i are free parameters and $\mu_{p,n}$ are the total magnetic moments of the proton and neutron. As it has been shown in refs. [7,9], eqs. (9)-(11) describe the elastic e-p and e-d scattering data, if

$$a_1 = 0.67\,(\mathrm{GeV/c})^2 ,$$

$$a_2 = 2.23\,(\mathrm{GeV/c})^2 , \qquad (12)$$

$$a_3 = -0.45 ;$$

B) Scaling between the isoscalar and isovector form factors of the nucleon holds [10]:

$$G_M^v(q^2) = \frac{1}{2}\mu_v G_E^v(q^2) ,$$

$$G_M^s(q^2) = \frac{1}{2}\mu_s G_E^s(q^2) , \qquad (13)$$

where $G^v_{M,E}$ and $G^s_{M,E}$ are the isovector and isoscalar form factors, respectively, $\mu_v = \frac{1}{2}(\mu_p - \mu_n)$, $\mu_s = \frac{1}{2}(\mu_p + \mu_n)$.
Using eq. (13) we obtain the following relations between the proton and neutron form factors:

$$G_M^n(q^2) = \mu_n G_n^p(q_E^2) + \frac{\mu_p}{\mu_n}(G_M^p(q^2) - \mu_p G_E^p(q^2)) ,$$

$$G_E^n(q^2) = (G_M^p(q^2) - \mu_p G_E^p(q^2))/\mu_n . \qquad (14)$$

As it has been shown in refs. [7,9], the available data on the elastic scattering of electrons on protons and deuteron can be described if one assumes a form for G_M^p given by eq. (11) and the following expression for G_E^p :

$$G_E^p(q^2) = \frac{b_3}{1 + b_1 q^2} + \frac{1 - b_3}{1 + b_2 q^2} \qquad (15)$$

with

$$a_1 = 0.58\ (\mathrm{GeV/c})^2, \qquad b_1 = 0.37\ (\mathrm{GeV/c})^2,$$

$$a_2 = 2.42\ (\mathrm{GeV/c})^2, \qquad b_2 = 2.50\ (\mathrm{GeV/c})^2, \qquad (16)$$

$$a_3 = -0.33, \qquad b_3 = -0.24 .$$

Note that eqs. (11), (14)-(16) predict a value for $\frac{dG_E^n}{dq^2}\Big|_{q^2=0}$ which has the right sign and is close in magnitude to the value obtained in the scattering [11] of thermal neutrons on atomic electrons: $\frac{dG_E^n}{dq^2}\Big|_{q^2=0} = (0.0195 \pm 0.0003)\,F^2$. Both parametrizations listed above describe the available data nearly with the same confidence level (though in the case B G_E^n differs from zero, its value does not exceed $\simeq 5{,}10^{-3}$ at $q^2 \lesssim 1{,}2$ (GeV(c)^2).

Still less accurate information exists about the axial-vector nucleon form factor. Usually a dipole q^2-behaviour is adopted:

$$G_A(q^2) = \frac{1.24}{(1 + q^2/M_A^2)^2}, \qquad (17)$$

M_A-being a parameter. When calculating the asymmetry A_N we varied the value of M_A from 0.9 to 1 GeV [12]. The value of the asymmetry A_N practically did not change. As it has been pointed out in refs. [12,13] the data can be described also if the following parametrizations for G_A are supposed:

$$G_A(q^2) = \frac{1.24}{1+q_A^2/M_A^2}, \qquad M_A = 0.53\ \mathrm{GeV}, \qquad (18)$$

$$G_A(q^2) = \frac{1.24}{(1+q^2/M_A^2)^3}, \qquad M_A = 1.25\ \mathrm{GeV}. \qquad (19)$$

In the kinematical region considered here the P-odd asymmetry remains insensitive to a change in the parametrization (eqs. (17), (18) or (19)) of the axial-vector for factor.

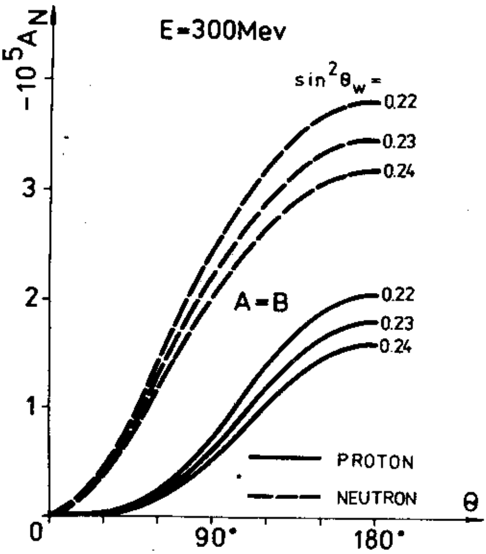

Fig. 1. The asymmetry A_N at $\sin^2\theta_w = 0,22$; 0,23; 0,24 at electron beam energy E = 300 MeV.

IV. We have calculated the asymmetry for the values of $\sin^2\theta_w$ in the interval 0.22 to 0.24. Figs. 1-3 show the values of the asymmetry A_N for both a proton and a neutron for $0 \leq \theta \leq 180°$ at the electron beam energies $E = 300$ MeV, 600 MeV and 3 GeV ($\sin^2\theta_w = 0.22$; 0.23; 0.24). A dipole form - eq. (17) with $M_A = 0.95$ GeV /12/ has been used for $G_A(q^2)$.

We shall first discuss the scattering on a proton target.

As the calculations show at the energies of the initial electron $E \lesssim 900$ MeV the asymmetry A_p is the same for the parametrizations A and B for all values of the scattering angle. (We assume the accuracy of measurements of A_N to be $\simeq 10^{-6}$ /4,5/). As it is seen from Figs. 1 and 2 at $\theta > 100°$ the asymmetry A_p strongly depends on the value of $\sin^2\tilde{\theta}_w$.

At energies $E \gtrsim 1$ GeV the two considered parametrizations A and B at large scattering angles predict different values for A_p. However, at small angles and at high energies the value of the asymmetry does not depend on the type of parametrization for the electromagnetic form factors. For E = 3 GeV this is illustrated in Fig. 3.

When the electron scatters on a neutron the asymmetry A_n is several times bigger than on a proton. However, the dependence of the asymmetry A_n on the parametrization of the form factors in this case appears at lower energies than in the case of e-p scattering. This is illustrated in Figs. 1 - 3.

The performed analysis shows that the measurements of the parity violating asymmetry in the elastic polarized electron-

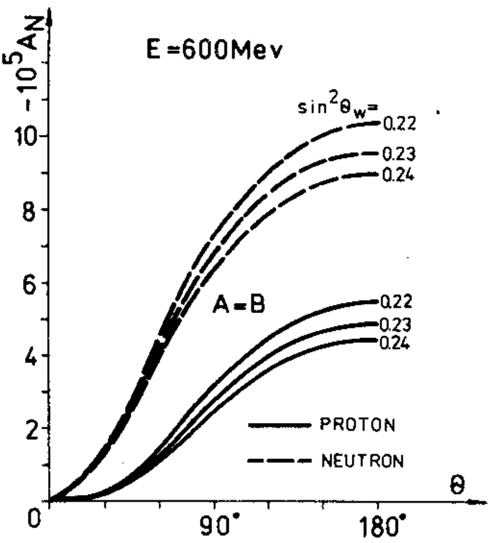

Fig. 2. The asymmetry A_N at $\sin^2\theta_w$ = 0,22; 0,23; 0,24 at electron beam energy E = 600 MeV.

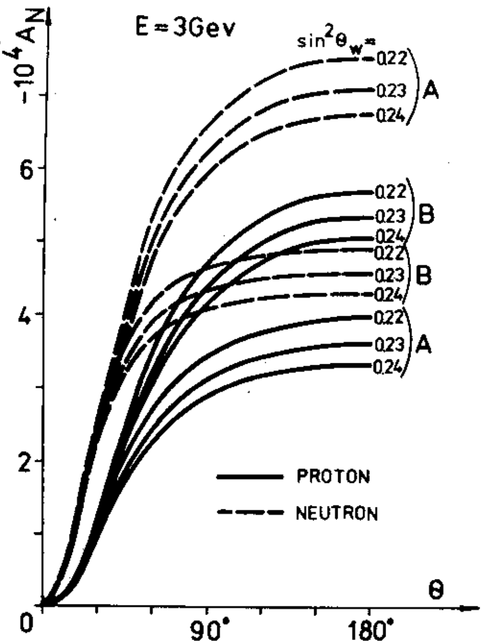

Fig. 3. The asymmetry A_N at $\sin^2\theta_w$ = 0,22; 0,23; 0,24 at electron beam energy E = 3 GeV.

proton scattering at low energies offers an opportunity to obtain new information about the value of $\sin^2\theta_w$. The calculations show that the uncertainties of the nucleon form factors slightly affect the value of the asymmetry in the considered low energy region.

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