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ДУБНА

E2 - 9395

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Submitted to ЯФ

At present when neutral currents in neutrino reactions are experimentally observed it is crucial to test the existence of weak neutral currents of the charged particles. As is well-known, such currents arise in a natural way in certain class of gauge theories of weak and electromagnetic interactions and lead to P-violating effects in lepton and lepton-hadron processes.

Recently many papers [1,2,3] have appeared in which various possibilities of examining these currents in e^+e^- collisions have been discussed.

In this paper we consider the P-violating effects in the annihilation of longitudinally polarized electrons and positrons into a pair of baryon and antibaryon

$$e^+e^- \longrightarrow B\bar{B}\,, \tag{1}$$

where $B = (p,\ n,\ \Lambda^0,\ \Sigma$ and so on). Numerical estimates of the discussed effects are obtained for the process $e^+e^- \to p\bar{p}$ in the Weinberg model at typical for the next generation of e^+e^- machine energy of the leptonic beam $E = 14$ GeV /4/ . Earlier /2/ this reaction was considered when the initial electron-positron pair was transversely polarized. However, the specification of the weak neutral-current effects in this case is complicated by the higher order electromagnetic diagrams.

In the latest papers /5/ the possibility of obtaining longitudinally polarized beams is discussed. The advantages of observing neutral-current effects with such beams have already been emphasized in ref. /3/ .

For the Hamiltonian of weak interactions of the charged leptons with hadrons we take the following expression:

$$\mathcal{H}^0 = \frac{G}{\sqrt{2}} j_\mu^0 \mathcal{J}_\mu^0 .$$

Here

$$j_\mu^0 = \bar{e} \gamma_\mu (c_V + c_A \gamma_5) e,$$

G is the weak coupling constant, c_V and c_A are parameters and $\mathcal{J}_\mu^0$ is the hadronic neutral current.

Such an effective neutral-current Hamiltonian arises in the Weinberg model /6/ in which a massive neutral vector boson is supposed to couple the leptons and hadrons. The parameters c_V and c_A equal:

$$c_V = 1 - 4\sin^2\theta_W , \qquad c_A = 1,$$

where $\sin^2\theta_W$ is the Weinberg parameter and $\mathcal{J}_\mu^0$ has the structure:

$$\mathcal{J}_\mu^0 = \mathcal{J}_\mu^3 - 2\sin^2\theta_W \mathcal{J}_\mu^{em}. \tag{2}$$

In this expression $\mathcal{J}_\mu^3$ is the third component of the usual V-A current and $\mathcal{J}_\mu^{em}$ is the electromagnetic hadronic current.

The matrix element for process (1) in one photon approximation and in the lowest order in G is

$$\langle B\bar{B}|S|e^+e^-\rangle = \frac{i(2\pi)^3}{(2\pi)^2}\left(\frac{m^2}{\kappa_{+0}\kappa_{-0}}\right)^{\frac{1}{2}} \frac{e^2}{q^2}\Big[\bar{u}(-\kappa_+)\gamma_\mu u(\kappa_-) . \tag{3}$$

$$\cdot \langle p_+p_-|\mathcal{J}_\mu^{em}|0\rangle - \rho\, \bar{u}(-\kappa_+)\gamma_\mu(c_V + c_A\gamma_5)u(\kappa_-)\langle p_+p_-|\mathcal{J}_\mu^0|0\rangle .$$

Here κ_- and κ_+ are the momenta of the electron and positron respectively, p_- and p_+ are the momenta of the final hadrons, $q_\mu = \kappa_{-\mu} + \kappa_{+\mu}$ and

$$\rho = \frac{G}{\sqrt{2}} \frac{q^2}{4\pi\alpha} , \qquad \alpha = \frac{e^2}{4\pi} = \frac{1}{137}$$

The matrix elements for the hadronic currents are:

$$\langle p_+p_-|\mathcal{J}_\mu^{em}|0\rangle = \frac{1}{(2\pi)^3}\left(\frac{M^2}{p_{+0}p_{-0}}\right)^{\frac{1}{2}} \bar{u}(p_-)\Big[\gamma_\mu G_M + i P_\mu \frac{F_2}{2M}\Big] u(-p_+), \tag{4}$$

$$\langle p_+p_-|\mathcal{J}_\mu^0|0\rangle = \frac{1}{(2\pi)^3}\left(\frac{M^2}{p_{+0}p_{-0}}\right)^{\frac{1}{2}} \bar{u}(p_-)\Big[\gamma_\mu g_V^0 + i P_\mu \frac{f_V^0}{2M} + \tag{5}$$

$$+ \gamma_\mu\gamma_5 g_A^0 + i q_\mu \gamma_5 \frac{h_A^0}{2M}\Big] u(-p_+),$$

where $P_\mu = p_{-\mu} - p_{+\mu}$. In writing (5) we have assumed that $\mathcal{J}_\mu^0$ is a first class current. Note that the electromagnetic form factors G_M and F_2 , as well as the form factors g_V^0, f_V^0, g_A^0 and h_A^0 of the weak neutral current which enter (4) and (5) are complex functions of q^2 .

The density matrices for the longitudinally polarized electron and positron equal, respectively:

$$\rho(\kappa_-) = \frac{1}{2}(1 - \lambda_-\gamma_5)\,\frac{\hat{\kappa}_- + im}{2im}, \tag{6}$$

$$\rho(-\kappa_+) = \frac{1}{2}(1 + \lambda_+\gamma_5)\,\frac{-\hat{\kappa}_+ + im}{2im},$$

where λ_- and λ_+ are the longitudinal polarisations of e^- and e^+ . From eqs. (3)-(6) for the differential cross section of process (1) when the hadron B leaves with helicity h we obtain (in the center-of-mass frame and in the limit m =0):

$$\frac{d\sigma}{d(\cos\theta)} = (d\sigma)_0 \Big\{ 1 - \lambda_+\lambda_- +$$

$$+(1-\lambda_+\lambda_-)h\frac{2\rho}{A_0}\left[c_V(1+\cos^2\theta)\left(1-\frac{M^2}{2E^2}\right)\mathrm{Re}\,G_M g_A^{0*}+\right.$$

$$\left.+2c_A\cos\theta\,\mathrm{Re}\,G_M g_V^{0*}\right]-$$

$$-\frac{\lambda_+-\lambda_-}{A_0}h\left[2\cos\theta\left(|G_M|^2-2\rho c_V\,\mathrm{Re}\,G_M g_V^{0*}\right)-\right.$$

$$\left.-2\rho c_A(1+\cos^2\theta)\,\mathrm{Re}\,G_M g_A^{0*}\right]- \qquad (7)$$

$$-(\lambda_+-\lambda_-)\frac{2\rho}{A_0}\left[c_A\left((1+\cos^2\theta)\,\mathrm{Re}\,G_M g_V^{0*}-\right.\right.$$

$$\left.\left.-\frac{4M^2}{q^2}\sin^2\theta\,\mathrm{Re}\,G_E g_E^*\right)+2c_V\cos\theta\,\mathrm{Re}\,G_M g_A^{0*}\right]\Big\}.$$

In eq. (7) we have used the notations:

$$(d\sigma)_0=\frac{\pi}{16}\frac{\alpha^2}{E^2}\left(1-\frac{M^2}{2E^2}\right)\left[(1+\cos^2\theta)|G_M|^2-\frac{4M^2}{q^2}\sin^2\theta|G_E|^2-\right.$$

$$-2\rho\left(c_V\left((1+\cos^2\theta)\,\mathrm{Re}\,G_M g_V^{0*}-\frac{4M^2}{q^2}\sin^2\theta\,\mathrm{Re}\,G_E g_E^*\right)+\right.$$

$$\left.\left.+2c_A\cos\theta\left(1-\frac{M^2}{2E^2}\right)\mathrm{Re}\,G_M g_A^{0*}\right)\right]\equiv$$

$$\equiv\frac{\pi}{16}\frac{\alpha^2}{E^2}\left(1-\frac{M^2}{2E^2}\right)A_0,$$

E **is the leptonic energy,** θ **- the scattering angle and**

$$g_E=g_V^0-\left(1+\frac{q^2}{4M^2}\right)f_V^0.$$

Using (7) let us discuss the possibilities for testing the weak interactions in process (1).

1. An unambiguous indication of weak neutral currents in (1) is the presence of the parity violating asymmetry $A_{\lambda_+\lambda_-}$ **in the summed over** h **differential cross section (7):**

$$A_{\lambda_+\lambda_-}=\frac{\left(\frac{d\sigma}{d\Omega}\right)_{\lambda_+\lambda_-}-\left(\frac{d\sigma}{d\Omega}\right)_{-\lambda_+,-\lambda_-}}{\left(\frac{d\sigma}{d\Omega}\right)_{\lambda_+\lambda_-}+\left(\frac{d\sigma}{d\Omega}\right)_{-\lambda_+,-\lambda_-}}. \qquad (8)$$

Retaining only the linear in ρ **terms we obtain:**

$$A_{\lambda_+\lambda_-}=-\frac{\lambda_+-\lambda_-}{1-\lambda_+\lambda_-}\frac{2\rho}{a_0}\left[c_A\left((1+\cos^2\theta)\,\mathrm{Re}\,G_M g_V^{0*}-\right.\right. \qquad (9)$$

$$\left.\left.-\frac{4M^2}{q^2}\sin^2\theta\,\mathrm{Re}\,G_E g_E^*\right)+2c_V\cos\theta\,\mathrm{Re}\,G_M g_A^{0*}\right],$$

where

$$a_0=(1+\cos^2\theta)|G_M|^2-\frac{4M^2}{q^2}\sin^2\theta|G_E|^2.$$

We shall estimate the asymmetry $A_{\lambda_+\lambda_-}$ **which occurs in the process** $e^+e^-\to p\bar{p}$ **using the Weinberg model** [6]**. According to (2) and keeping in mind the CVC relations, for the form factors entering Eq. (5) we obtain:**

$$g_V^0=G_M^V-2\sin^2\theta_W G_M^p,\qquad G_M^V=\frac{1}{2}\left(G_M^p-G_M^n\right)$$

$$f_V^0=F_2^V-2\sin^2\theta_W F_2^p,\qquad F_2^V=\frac{1}{2}\left(F_2^p-F_2^n\right)$$

$$g_A^0=\frac{1}{2}g_A\qquad\qquad h_A^0=\frac{1}{2}h_A.$$

The form factors g_A **and** h_A **characterize the matrix element of the weak axial-vector current** $\langle p\bar{n}|A_\mu^{1+i2}|0\rangle$ **. The available data are inadequate to provide the** q^2 **dependence of**

the electromagnetic and weak form factors for $q^2 < 0$. In accord with this we shall assume /2,6/ that they all have the same q^2 -behaviour normalized to their experimental values near $q^2 = 0$. We have:

$$\frac{G_M^p(q^2)}{G_M^p(0)} = \frac{G_M^n(q^2)}{G_M^n(q^2)} = \frac{G_E^p(q^2)}{G_E^p(0)} = \frac{G_E^n(q^2)}{G_E^n(0)} = \frac{g_A(q^2)}{g_A(0)} = \mathcal{F}(q^2) \tag{10}$$

$$G_M^p(0) = 2,79, \qquad G_M^n(0) = -1,91,$$

$$G_E^p(0) = 1, \qquad G_E^n(0) = 0, \qquad g_A(0) = 1,2.$$

Then for the weak neutral form factors we obtain:

$$g_V^0(q^2) = (2,35 - 5,58 \sin^2\theta_W)\, \mathcal{F}(q^2),$$

$$g_E(q^2) = \left(\tfrac{1}{2} - 2\sin^2\theta_W\right) \mathcal{F}(q^2),$$

$$g_A^0(q^2) = 0,6\, \mathcal{F}(q^2).$$

In fig.1 the asymmetry $A_{\lambda_+\lambda_-}$ is plotted against $z = \cos\theta$ for different values of $\sin^2\theta_W = 0,2, 0,4, 0,6$ and at lepton energy E = 14 GeV. For the polarizations of e^+ and e^- we have assumed $\lambda_+ = -\lambda_- = 0.9$ (the maximum experimentally attainable polarization). As is clear from the figures drawn, if the values of $\sin^2\theta_W$ are in the range allowed by experiment /7/ , then the asymmetry effect could be as large as 8% and for the "favourite" value /8/ $\sin^2\theta_W = 0.40$ it does not surpass 2%.

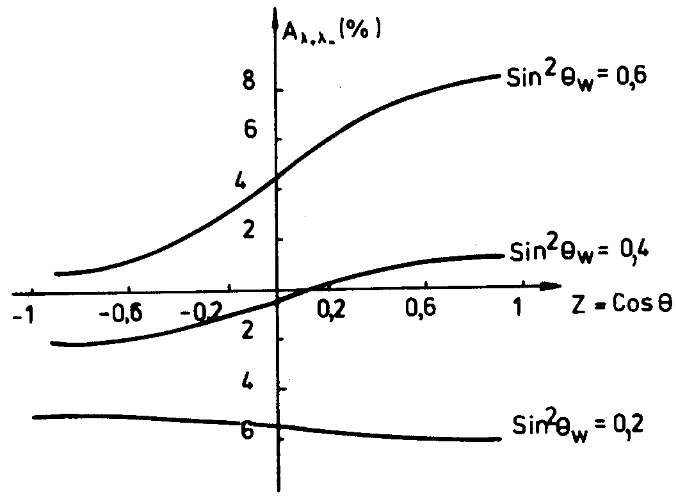

Fig. 1. The asymmetry $A_{\lambda_+\lambda_-}$ as a function of $z = \cos\theta$ with $\lambda_+ = -\lambda_- = 0.9$ for various values of $\sin^2\theta_W$ at E=14 GeV.

2. If in Eqs. (8) and (9) we get $\lambda_+ = 0$ (or $\lambda_- = 0$) we obtain the P-violating asymmetry A_λ when only one of the initial leptonic beams is longitudinally polarised and the other is either unpolarized or transversely polarised. Since the analytic expression for A_λ differs from that of $A_{\lambda_+\lambda_-}$ only by the replacement of the factor $-\frac{\lambda_+ - \lambda_-}{1-\lambda_+\lambda_-}$ in Eq.(9) by λ — the longitudinal polarization of the electron (or the positron), the numerical values of A_λ calculated at $\lambda = 0.9$ approximately equal those obtained for $A_{\lambda_+\lambda_-}$. In general, the asymmetry $A_{\lambda_+\lambda_-}$ is greater than A_λ.

3. A nonzero value of the parameter η:

$$\eta = P(\lambda_+ \lambda_-) + P(-\lambda_+, -\lambda_-) = \tag{11}$$

$$= \frac{4\rho}{a_0}\Big[c_V(1+\cos^2\theta)\Big(1-\frac{M^2}{2E^2}\Big) Re\, G_M g_A^{0*} + 2c_A \cos\theta\, Re\, G_M g_V^{0*} -$$

$$- \frac{2\cos\theta\, |G_M|^2}{a_0} \frac{(\lambda_+ - \lambda_-)^2}{(1-\lambda_+\lambda_-)^2} \Big(c_A\big((1+\cos^2\theta)\, Re\, G_M g_V^{0*} -$$

$$- \frac{4M^2}{q^2}\sin^2\theta\, Re\, G_E g_E^{*}\big) + 2c_V \cos\theta\, Re\, G_M g_A^{0*}\Big)\Big]$$

is an alternative method for searching for P-violation when both the electron and positron beams are longitudinally polarised and the helicity $P(\lambda_+, \lambda_-)$ of B is detected, too.

4. If the initial leptons are unpolarised, an evidence for the presence of neutral currents would be the nonzero longitudinal polarisation of the final hadron B :

$$h_B = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{h=+1} - \left(\frac{d\sigma}{d\Omega}\right)_{h=-1}}{\left(\frac{d\sigma}{d\Omega}\right)_{h=+1} + \left(\frac{d\sigma}{d\Omega}\right)_{h=-1}} = \tag{12}$$

$$= \frac{2\rho}{a_0}\left[c_V(1+\cos^2\theta) Re\, G_M g_A^{0*} + 2c_A\cos\theta\, Re\, G_M g_V^{0*}\right].$$

Note that expression (12) coincides up to linear in ρ terms with the expression contained in ref. /2/.

In figs. 2 and 3 the numerical values of η and h_B obtained for the process $e^+e^- \to p\bar{p}$ in terms of the Weinberg model are presented. In the calculations of η and h_B we have assumed the same q^2-behaviour – Eq.(10) for the form factors, which we have used earlier in order to estimate the asymmetry $A_{\lambda_+\lambda_-}$. The values of η and h_B are plotted against $x = \cos\theta$ at E=14 GeV for $\sin^2\theta_W = 0.2$; 0.4; 0.6. As one can see from the figures, if $\sin^2\theta_W = 0.40$ the parameter η amounts up to 3.4%.

5. Let us consider the process:

$$e^+e^- \to \Lambda^0 \bar{\Lambda}^0, \tag{13}$$

which is very convenient for detection of the polarization of the Λ^0 by the angular distribution of its decay products.

Process (13) is of a special interest also for investigation of the isotopic structure of the neutral hadronic current.

If in accord with Weinberg-Salam class models we assume that J_μ^0 is composed of isovector and isoscalar pieces, the general structure of the neutral hadronic current can be written in the form /9/ :

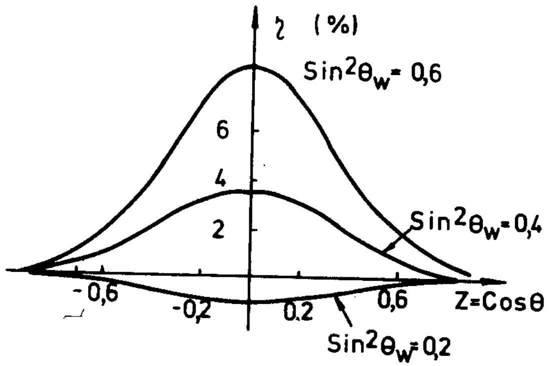

Fig.2. Parameter η as a function of $z = \cos\theta$ with $\lambda_+ = -\lambda_- = 0.9$ for various values of $\sin^2\theta_W$ at E=14 GeV.

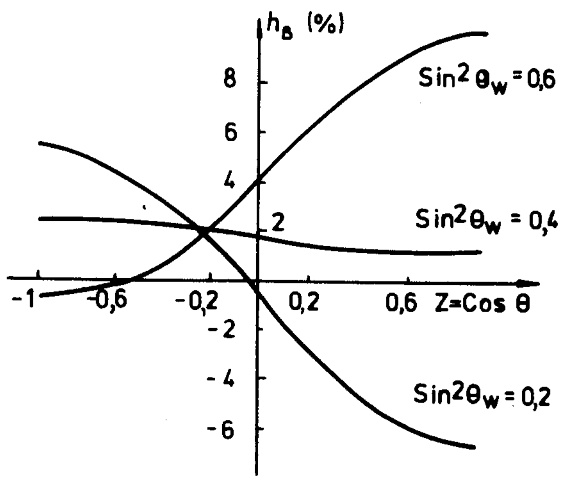

Fig.3. Helicity h_B as a function of $z = \cos\theta$ for various values of $\sin^2\theta_W$ at E= 14 GeV.

$$\mathcal{J}^0_\mu = v^3_\mu + a^3_\mu + v^0_\mu + a^0_\mu . \qquad (14)$$

In Eq. (14) by v^3_μ and a^3_μ we denote the vector and axial vector pieces of the isovector current and by v^0_μ and a^0_μ those of the isoscalar current. Since Λ^0 has isospin I=0 the hadronic matrix element (5) is characterized solely by the isoscalar pieces v^0_μ and a^0_μ. A special interest represents the "new" component, the axial-vector isoscalar a^0_μ, which may appear in $\mathcal{J}^0_\mu$ and which does not enter the electromagnetic and charge-changing currents.

An evidence for the presence of this component will be the nonzero value of the sum:

$$h_B(\theta) + h_B(\pi-\theta) = \frac{4\rho}{a_0}\, c_V (1+\cos^2\theta)\left(1-\frac{M^2}{2E^2}\right) \mathrm{Re}\, G_M\, g_A^{0*}$$

or

$$\eta(\theta) + \eta(\pi-\theta) = \frac{4\rho}{a_0}\, 2c_V\, \mathrm{Re}\, G_M\, g_A^{0*} \left[1 + \cos^2\theta \left(1 - \frac{(\lambda_+ - \lambda_-)^2}{(1-\lambda_+\lambda_-)^2}\, \frac{4|G_M|^2}{a_0}\right)\right].$$

Also an alternative way to isolate the term a^0_μ is to look for the quantities η or h_B at angle $\theta = \frac{\pi}{2}$ where only the proportional to g_A^0 part can contribute:

$$\eta\left(\frac{\pi}{2}\right) = 2 h_B\left(\frac{\pi}{2}\right) = \frac{4\rho}{a_0}\, c_V\, \mathrm{Re}\, G_M\, g_A^{0*} .$$

The analysis performed shows that the study of the exclusive two particle process $e^+e^- \to B\bar{B}$ in the colliding beam experiments with longitudinally polarized initial leptons with E > 10 GeV is very suitable for examining possible P-violating effects. This is of special importance for justification of the unified theories for weak and electromagnetic interactions. The discussed effects estimated in terms of the Weinberg model for $e^+e^- \to p\bar{p}$ amount up to 8% at E=14 GeV.

In conclusion the author is pleased to thank S.M.Bilenky, N.A.Dadajan and S.Petkov for the helpfull discussions on the considered problems.

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Received by Publishing Department
on December 18, 1975.