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SPIN CORRELATIONS IN NEUTRINO AND ANTINEUTRINO SCATTERING BY ELECTRONS

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INTEREST has risen recently in the possibility of an experimental observation of weak neutrino-lepton interaction of the type $(e\nu)(\overline{\nu}e)$, predicted by Feynman and Gell-Mann[1]. They noted that the scattering of a neutrino and antineutrino by an electron can be observed by searching for recoil electrons in targets bombarded with neutrinos (antineutrinos). If the neutrino is capable of being scattered by an electron, then the recoil electrons may be polarized. The appearance of spin polarization of the recoil electrons is connected with the helicity properties of the neutrino.

In the present work, continuing earlier investigations[2,3], we calculated the cross sections for νe and $\overline{\nu}e$ scattering in the V-A variant of the weak four-fermion interaction with allowance for the polarization of the target electron and the recoil electron. The analysis was made within the framework of the theory of the four-component Dirac neutrino[2-9], with two different kinds of neutrinos (ν_R, ν_L) and two different antineutrinos ($\overline{\nu}_R$, $\overline{\nu}_L$), having right-hand and left-hand polarizations.

The total cross sections of the scattering processes

$$\nu + e \to \nu' + e', \quad \bar{\nu} + e \to \bar{\nu}' + e'$$

with allowance for the longitudinal polarization of the recoil electron, are given by the following formulas (in the laboratory frame)

$$\sigma_{e\nu}(s_\nu, s_{\nu'}, s_{e'}, \omega) = \frac{1}{4}\sigma_0(1 + s_\nu s_{\nu'})\left(\frac{\omega^2}{2\omega+1} + \frac{1}{4}s_\nu s_{e'} f_1(\omega)\right),$$

$$\sigma_{e\bar{\nu}}(s_{\bar{\nu}}, s_{\bar{\nu}'}, s_{e'}, \omega) = \frac{1}{4}\sigma_0(1 + s_{\bar{\nu}} s_{\bar{\nu}'})\left(\frac{\omega}{6}\left(1 - \frac{1}{(2\omega+1)^3}\right) - \frac{1}{4}s_{\bar{\nu}} s_{e'} f_2(\omega)\right), \quad (1)$$

where

$$f_1(\omega) = 4(2\omega+1)^{-3}(4\omega^4 + 12\omega^3 + 13\omega^2 + 6\omega + 1) - 2\left(1 + \frac{1}{\omega}\right)\ln(2\omega+1),$$

$$f_2(\omega) = (2\omega+1)^{-3}\left(\frac{16}{3}\omega^4 + 40\omega^3 + 84\omega^2 + \frac{220}{3}\omega + 28 + \frac{4}{\omega}\right) - 2\left(1 + \frac{1+2\omega}{\omega^2}\right)\ln(2\omega+1),$$

$$\sigma_0 = \frac{2G^2 m_0^2}{\pi\hbar^4}, \quad \omega = \frac{E_q}{m_0 c^2}, \quad q = \nu, \bar{\nu}. \quad (2)$$

E_q—energy of the initial neutrino (antineutrino); m_0—rest mass of the electron; $s_i = \pm 1$, ($i = e'$, ν, $\overline{\nu}$, ν', and $\overline{\nu}'$)—eigenvalue of the projection operator $\sigma_i \cdot p_i/p_i$[2,3,10], which determines the helicity of the recoil electron, neutrino, and antineutrino before and after scattering.

The degree of longitudinal polarization of the recoil electrons, defined as the ratio of the difference of the cross sections to their sum at $s_{e'} = 1$ and $s_{e'} = -1$, is

$$P_{e'}^{\nu e}(\omega) = s_\nu \frac{2\omega+1}{4\omega^2} f_1(\omega),$$

$$P_{e'}^{\bar{\nu}e}(\omega) = -s_{\bar{\nu}} \frac{3}{2\omega(E^{\bar{\nu}e}(1-(2\omega+1)^{-3})} f_2(\omega). \quad (3)$$

It follows from (3) that at the high limit of the neutrino energy ($\omega \gg 1$) the recoil electrons produced in νe scattering will have the same helicity as the incident neutrino ($P_{e'}^{\nu e} \cong s_\nu$), whereas the recoil electrons from $\overline{\nu}e$ scattering will have an helicity which is opposite that of the incident antineutrinos ($P_{e'}^{\overline{\nu}e}$ − $s_{\overline{\nu}}$). Thus, for $\omega = 100$ ($E_\nu = 15$ MeV) we have $P_{e'}^{\nu e} \cong 0.97\, s_\nu$ and $P_{e'}^{\overline{\nu}e} \cong 0.90\, s_{\overline{\nu}}$. When left-polarized neutrinos (or right-polarized antineutrinos) of high energy

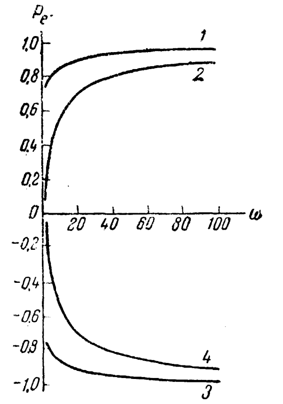

FIG. 1. Dependence of $P_{e'}$ on the energy ω of the initial neutrino and antineutrino: 1 – for right-polarized incident neutrinos (ν_R), 2 – for left-polarized antineutrinos ($\bar{\nu}_L$), 3 – for left-polarized neutrinos (ν_L), 4 – for right-polarized antineutrinos ($\bar{\nu}_R$).

are scattered by electrons, the resultant recoil electrons will be completely left-polarized, while scattering of right-polarized neutrinos (left-polarized antineutrinos) of high energy will result in completely right-polarized recoil electrons.

The figure shows the dependence of $P_{e'}$ on the energy of the incident neutrino and antineutrino, as calculated from (3).

The expressions obtained for the total scattering cross sections of the neutrinos and antineutrinos by a polarized electron at rest are:

$$\sigma_{e\nu}(s_e, s_\nu, s_{\nu'}, \omega) = \frac{1}{2}\sigma_0 \frac{\omega^2}{2\omega+1}(1 + s_\nu s_{\nu'})(1 - s_\nu (s_e \mathbf{k}_\nu{}^0)),$$

$$\sigma_{e\bar{\nu}}(s_e, s_{\bar{\nu}}, s_{\bar{\nu}'}, \omega) = \frac{1}{2}\sigma_0 \frac{\omega}{6}\left(1 - \frac{1}{(2\omega+1)^3}\right) \times (1 + s_{\bar{\nu}} s_{\bar{\nu}'})(1 + a(\omega) s_{\bar{\nu}} (s_e \mathbf{k}_\nu{}^0)),$$

$$a(\omega) = 8\omega^2(\omega+1)/[(2\omega+1)^3 - 1], \qquad (4)$$

where $\mathbf{s}_e$—electron-target spin vector, $\mathbf{p}_q = \hbar \mathbf{k}_q$—neutrino ($q = \nu$) or antineutrino ($q = \bar{\nu}$) momentum, and $\mathbf{k}_q^0 = \mathbf{k}_q / k_q$.

We see from (4) that when the target electron is polarized in the same direction as the incident neutrino beam ($\mathbf{s}_e \parallel \mathbf{k}_\nu{}^0$), the scattering cross section of the right-polarized neutrinos (ν_R; $s_\nu = 1$) vanishes, whereas the scattering cross section of the left-polarized neutrinos (ν_L; $s_\nu = -1$) differs from zero and assumes a maximum value.

On the other hand, when an antineutrino of high energy ($\omega \gg 1$) is scattered by an electron which is polarized in the direction of the incident antineutrino beam, the scattering cross section of the left-polarized antineutrinos ($\bar{\nu}_L$; $s_{\bar{\nu}} = -1$) vanishes, whereas the cross section for the scattering of right-polarized antineutrinos ($\bar{\nu}_R$, $s_{\bar{\nu}} = 1$) differs from zero and has a maximum. If the target electron is polarized in a direction opposite that of the incident neutrino (antineutrino) beam, we obtain the opposite result. The results obtained show that a study of the spin correlations in neutrino (antineutrino) electron scatterings would make it possible, on the one hand, to resolve the problem of the existence of direct neutrino-electron interaction and, on the other hand, to check the predictions of the theory of the four-component neutrino[2-9], relative to the helicities of the two neutrinos and two antineutrinos.

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