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Study of second-class currents effects on polarization characteristics in quasi-elastic neutrino (anti-neutrino) scattering by nuclei

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Abstract

The differential cross section of quasi-elastic neutrino scattering by nuclei is computed. The numerical analysis of energy dependence of the spin asymmetry, the angular electron-neutrino (eν) correlation and the charge asymmetry coefficients shows that the relative contribution of the second-class current (SCC) tensor form factor can reach some tens of percents in the case of particular values of final nuclei alignment and polarization.

Key Words: Second-class currents, nuclei polarization, neutrino scattering, spin asymmetry and $e\nu$ correlation.

1. Introduction

The most general expressions for the matrix elements of vector currents V_μ and axial - vector currents A_μ between nuclei states p_1 and p_2 are given by the formulae [1]

$$\begin{aligned} \langle p_1 | V_\mu | p_2 \rangle &= \bar{u}(p_1) \left[F_1 \gamma_\mu + F_2 \sigma_{\mu\nu} q_\nu + i F_S q_\mu \right] u(p_2) \\ \langle p_1 | A_\mu | p_2 \rangle &= \bar{u}(p_1) \left[F_A \gamma_\mu + F_T \sigma_{\mu\nu} q_\nu + i F_P q_\mu \right] \gamma_5 u(p_2), \end{aligned} \tag{1}$$

where $q_\mu = (p_1 - p_2)_\mu$ is the 4-momentum transfer to the nucleus, $u(p_1)$, $u(p_2)$ are Dirac spinor amplitudes, F_1, F_A are vector and axial-vector form factors, F_2, F_S, F_T and F_p are respectively weak magnetic, effective scalar, induced and induced pseudo-scalar form factors. All these form factors depend on the square transfer momentum q^2:

$$F_x\left(q_\mu^2\right) = F_x(0)/\left(1+q_\mu^2/(855MeV)^2\right)^2,$$

$$F_p\left(q_\mu^2\right) = 2MF_A(0)/\left(q_\mu^2+m_\pi^2\right)$$

where $x = 1, 2, A, T, S, m_\pi$ and m_π is the pion mass, $F_1(0) = 1.0$, $F_A(0) = -1.23, F_1(0) + 2MF_2(0) = \mu(0) = 4.706$, $F_T(0) = 5\cdot 10^{-3}MeV^{-1}$. We assume the conserved-vector-current hypothesis (CVC) in which case there are no induced scalar currents, and the form factor F_S is zero.

According to S. Weinberg classification [2], based on the G parity transformation (interchanging particles with their anti-particles and rotating the system in isospin space around the T_2 axis), vector and axial-vector currents can be decomposed into first-class currents (FCC) and second-class currents (SCC). F_1, F_2, F_A and F_p are the form factors of the first-class currents and F_S and F_T are the form factors of the second class current.

Issue of second-class currents and their existence are being widely discussed. Some contradictions between different experimental data do not allow a definite solution of this issue. For example, the experimental study of angular distribution of positrons in β decay process of polarized ^{19}Ne nucleus [3] and the study of angular distribution of electron and positron in β decay from polarized ^{12}B and ^{12}N [4, 5], show the existence of SCC whose tensor form factor is of the same order of magnitude as the form factor of weak magnetic interaction. Yet, Morita's data [6] show that the value of tensor form factor is next to zero within the limit of experimental errors, in agreement with the hypothesis of SCC shutting.

An important development has arose in recent years, in which the experimental study of neutrino interactions with nuclei offers opportunity to investigate subtle detail in the structure of the standard model as well as that of the nucleon. Study of neutrino interaction can offer a solid understanding of cross sections in neutrino-induced reactions, particularly with nuclei such as $^{12}\mathrm{C}$, a component of liquid scintillators, and $^{16}\mathrm{O}$, the basic component of water Cerenkov detectors [7].

The present study deals with effects due to the possible existence of SCC in quasi-elastic neutrino (and anti-neutrino) scattering by nuclei and the influence of polarization on the final nuclei on these effects.

2. Differential cross section of quasi-elastic neutrino (anti-neutrino) scattering by nuclei

Second class-currents are difficult to detect without any assumption [8], so we try to extract SCC effects by calculating the differential cross section of neutrino scattering by nuclei.

In first order of perturbation theory, the process of neutrino (anti-neutrino) scattering by nuclei described here can be written as

$$\nu(\tilde{\nu}) + (A,Z) \to (A, Z\pm 1) + \ell^-(\ell^+) \tag{2}$$

with matrix elements expressed as

$$M_{fi} = -\frac{G_F}{\sqrt{2}}\ell_\mu J_\mu, \tag{3}$$

where $G_F \cong 10^{-5}M^{-2}$ is Fermi coupling constant for weak interaction; M is the mass of the nucleus; $\ell_\mu = \bar{u}_2\gamma_\mu(1+\gamma_5)\bar{u}_1$ and $J_\mu = \langle f|\int dx \exp(-iqx)\hat{J}_\mu(x)\,|i\rangle$ are, respectively, leptonic and hadronic currents;

$u_j (j = 1, 2)$ are Dirac spinor amplitudes; $\hat{J}_\mu(x)$ is local current operator of nucleus; $q_\mu = (q, iq_0) \equiv (P_\ell - P_\nu)_\mu$ is the 4-momentum transfer to the nucleus; P_ℓ is the 4-momentum of electron for $\ell = e^-$ (and positron for $\ell = e^+$); P_ν is the 4-momentum of neutrino (anti-neutrino). The initial (final) state of nucleus is determined by the parity π_i (π_f), the spin J_i (J_f), the isotopic spin T_i (T_f) and also by their projections M_i, M_{T_i} (M_f, M_{T_f}).

Using multipole decomposition [1, 9, 10] in a cyclical basis, and with respect to the spin orientation of the final nuclei, we can put the components of the hadronic current into the following forms:

$$J_0 = \sum_{J\geq 0, M'_f} (-i)^J (4\pi(2J+1))^{1/2} \left\langle J_f M'_f \right| \hat{M}_{J0} \left| J_i M_i \right\rangle D^{J_f *}_{M_f M'_f}(\theta*, \varphi*),$$

$$J_3 = \sum_{J\geq 0, M'_f} (-i)^J (4\pi(2J+1))^{1/2} \left\langle J_f M'_f \right| \hat{L}_{J0} \left| J_i M_i \right\rangle D^{J_f *}_{M_f M'_f}(\theta*, \varphi*), \tag{4}$$

$$J_\lambda = -\sum_{J\geq 1, M'_f} (-i)^J (2\pi(2J+1))^{1/2} \left\langle J_f M'_f \right| \lambda \hat{J}^M_{J;-\lambda} + \hat{J}^E_{J;-\lambda} \left| J_i M_i \right\rangle D^{J_f *}_{M_f M'_f}(\theta*, \varphi*), \lambda = \pm 1.$$

Here, $D^{J_f *}_{M_f M'_f}(\theta*, \varphi*)$ is the Wigner D-matrix [11] and $|J_i - J_f| \leq J \leq J_i + J_f$, $\hat{M}_{J0}$, $\hat{L}_{J0}$, $\hat{J}^M_{J;-\lambda}$ and $\hat{J}^E_{J;-\lambda}$ are the coulomb, longitudinal, magnetic and electric multipole operators [1, 9]; $\theta*$ and $\varphi*$ are the angles used in determining the spin orientation of final nuclei [9].

The differential cross section of the process described in equation (2) is given by the following, by taking into account final nuclei spin orientation:

$$\frac{d\sigma}{d\Omega_\ell} = \frac{2J_f+1}{2J_i+1}\frac{E_\ell P_\ell G_F^2}{2\pi}\left\{ \sum_{\substack{L\geq 0\\ even}} f_L^{(f)} P_L(\cos\theta*)\left(v_1 W_1^L + v_2 W_2^L + v_3 W_3^L + v_4 W_4^L + v_5 W_5^L\right) + \right.$$

$$\sum_{\substack{L\geq 1\\ odd}} f_L^{(f)} \left[P_L(\cos\theta*)\left(v_1 \bar{W}_1^L + v_2 \bar{W}_2^L + v_3 \bar{W}_3^L + v_4 \bar{W}_4^L + v_5 \bar{W}_5^L\right) + P_L^1(\cos\theta*)\cos\varphi*\left(v_6 \bar{W}_6^L + \right.\right.$$

$$\left. v_7 \bar{W}_7^L + v_8 \bar{W}_8^L + v_9 \bar{W}_9^L\ \right)\Big] + \sum_{\substack{L\geq 2\\ even}} f_L^{(f)} \left[P_L^1(\cos\theta*)\ \cos\varphi*(v_6 W_6^L + v_7 W_7^L + v_8 W_8^L + v_9 W_9^L) + \right.$$

$$\left. P_L^2(\cos\theta*)\cos 2\varphi* v_{10} W_{10}^L\Big] + \sum_{\substack{L\geq 3\\ odd}} f_L^{(f)} P_L^2(\cos\theta*)\cos 2\varphi* v_{10}\bar{W}_{10}^L \right\} \tag{5}$$

Here, $0 \leq L \leq 2J_f$ and $P_L^m(\cos\theta*)$ are Lagrange functions;

$$f_L^{(f)} = \sum_{M_f} (-1)^{J_f - M_f} [L] \begin{pmatrix} J_f & J_f & L \\ M_f & -M_f & 0 \end{pmatrix} P(M_f)$$

is a Fano tensor [9], where $[x] = \sqrt{2x+1}$ and $P(M_f)$ is the population of magnetic substates; $v_i (i = 1, 2, \cdots, 10)$ are leptonic functions and $W_k^L, \bar{W}_k^L (k = 1, 2, \cdots, 10)$ are hadronic functions.

Leptonic functions are defined by:

$$\begin{aligned}
&v_1 = \tfrac{1}{2}(\ell_1\ell_1^* + \ell_2\ell_2^*) && v_2 = -\tfrac{i}{2}(\ell_1\ell_2^* - \ell_2\ell_1^*) \\
&v_3 = \ell_3\ell_3^* && v_4 = -2Re(\ell_3\ell_0^*), \\
&v_5 = \ell_0\ell_0^* && v_6 = 2Re(\ell_1\ell_3^*) \\
&v_7 = -2Im(\ell_2\ell_3^*) && v_8 = -2Re(\ell_1\ell_0^*) \\
&v_9 = 2Im(\ell_2\ell_0^*) && v_{10} = -\tfrac{1}{2}(\ell_1\ell_1^* - \ell_2\ell_2^*),
\end{aligned} \tag{6}$$

where $\ell_i (i = 0, 1, 2, 3)$ are the components of leptonic currents.

Hadronic functions are given by:

$$\begin{aligned}
W_1^L = -\sum_{J'J} A_{-1;1}^{(L)} \{P_{J'+J}^{+} (F_{EJ}F_{EJ'} + F_{MJ}F_{MJ'} + F_{EJ}^5F_{EJ'}^5 + F_{MJ}^5F_{MJ'}^5) - \\
-P_{J'+J}^{-} (F_{MJ}F_{EJ'} + F_{EJ}F_{MJ'} + F_{EJ}^5F_{MJ'}^5 + F_{MJ}^5F_{EJ'}^5)\}, \\
W_2^L = -\sum_{J'J} A_{-1;1}^{(L)} \{P_{J'+J}^{+} (F_{MJ}^5F_{EJ'} + F_{EJ}F_{MJ'}^5 + F_{MJ}F_{EJ'}^5 + F_{EJ}^5F_{MJ'}) - \\
-P_{J'+J}^{-} (F_{EJ}^5F_{EJ'} + F_{MJ}^5F_{MJ'} + F_{MJ}F_{MJ'}^5 + F_{EJ}F_{EJ'}^5)\}, \\
W_3^L = \sum_{J'J} A_{0,0}^{(L)} P_{J'+J}^{+} (F_{LJ}F_{LJ'} + F_{LJ}^5F_{LJ'}^5), \\
W_4^L = \sum_{J'J} A_{0,0}^{(L)} P_{J'+J}^{+} (F_{LJ}F_{CJ'} + F_{LJ}^5F_{CJ'}^5), \\
W_5^L = \sum_{J'J} A_{0,0}^{(L)} P_{J'+J}^{+} (F_{CJ}F_{CJ'} + F_{CJ}^5F_{CJ'}^5), \\
W_6^L = \sum_{J'J} A_{1;0}^{(L)} P_{J'+J}^{+} (F_{EJ}F_{LJ'} + F_{EJ}^5F_{LJ'}^5 + F_{MJ}F_{LJ'}^5 + F_{MJ}^5F_{LJ'}), \\
W_7^L = \sum_{J'J} A_{1;0}^{(L)} P_{J'+J}^{-} (F_{EJ}F_{LJ'}^5 + F_{EJ}^5F_{LJ'} + F_{MJ}^5F_{LJ'}^5 + F_{MJ}F_{LJ'}), \\
W_8^L = \sum_{J'J} A_{1;0}^{(L)} P_{J'+J}^{+} (F_{EJ}F_{CJ'} + F_{EJ}^5F_{CJ'}^5 + F_{MJ}F_{CJ'}^5 + F_{MJ}^5F_{CJ'}),
\end{aligned} \tag{7}$$

$$W_9^L = \sum_{J'J} A_{1;0}^{(L)} P_{J'+J}^{-} \left(F_{EJ}F_{CJ'}^5 + F_{EJ}^5 F_{CJ'} + F_{MJ}^5 F_{CJ'}^5 + F_{MJ}F_{CJ'}\right),$$

$$W_{10}^L = -\sum_{J'J} A_{1;1}^{(L)} \left\{P_{J'+J}^{+} \left(F_{EJ}F_{EJ'} - F_{MJ}F_{MJ'} + F_{EJ}^5 F_{EJ'}^5 - F_{MJ}^5 F_{MJ'}^5\right) + \right.$$

$$\left. + P_{J'+J}^{-} \left(F_{MJ}F_{EJ'} - F_{EJ}^5 F_{MJ'} + F_{MJ}^5 F_{EJ'}^5 - F_{EJ}F_{MJ'}\right)\right\},$$

$$\bar{W}_3^L = \sum_{J'J} A_{0;0}^{(L)} P_{J'+J}^{-} \left(F_{LJ}F_{LJ'}^5 + F_{LJ}^5 F_{LJ'}\right),$$

$$\bar{W}_4^L = \sum_{J'J} A_{0;0}^{(L)} P_{J'+J}^{-} \left(F_{LJ}F_{CJ'}^5 + F_{LJ}^5 F_{CJ'}\right),$$

$$\bar{W}_5^L = \sum_{J'J} A_{0;0}^{(L)} P_{J'+J}^{-} \left(F_{CJ}F_{CJ'}^5 + F_{CJ}^5 F_{CJ'}\right),$$

$$\bar{W}_{10}^L = -\sum_{J'J} A_{1;1}^{(L)} \left\{P_{J'+J}^{+} \left(F_{MJ}^5 F_{EJ'} + F_{MJ}F_{EJ'}^5 - F_{EJ}^5 F_{MJ'} - F_{EJ}F_{MJ'}^5\right) + \right.$$

$$\left. + P_{J'+J}^{-} \left(F_{EJ}^5 F_{EJ'} + F_{EJ}F_{EJ'}^5 - F_{MJ}F_{MJ'}^5 - F_{MJ}^5 F_{MJ'}\right)\right\},$$

$$\bar{W}_1^L = -W_2^L, \bar{W}_2^L = -W_1^L, \bar{W}_6^L = W_7^L, \bar{W}_7^L = W_6^L,$$

$$\bar{W}_8^L = W_9^L, \bar{W}_9^L = W_8^L$$

Here, F_{CJ}, F_{LJ}, F_{MJ} and F_{EJ} ($F_{CJ}^5, F_{LJ}^5, F_{MJ}^5$ and F_{EJ}^5) are matrix elements of the vector (axial-vector), coulomb, longitudinal, magnetic and electric multipole operators.

The coefficients $A_{m'm}^{(L)}$ and $P_{J'+J}^{\pm}$ are defined by:

$$A_{mm'}^{(L)} = (-1)^{J_i+J_f} [J]\,[J']\,[L] \left(\frac{(L-|M|)!}{(L+|M|)!}\right)^{1/2} \begin{pmatrix} J & J' & L \\ m & m' & M \end{pmatrix} \begin{Bmatrix} J & J' & L \\ J_f & J_f & J_i \end{Bmatrix},$$

$$P_{J'+J}^{+} = \frac{1}{2}(-1)^{\frac{1}{2}(J'-J)} \left(1 + (-1)^{\frac{1}{2}(J'+J)}\right), P_{J'+J}^{-} = \frac{1}{2}(-1)^{\frac{1}{2}(J'-J+1)} \left(1 - (-1)^{\frac{1}{2}(J'+J)}\right).$$

The cross section of the process of neutrino (anti-neutrino) scattering by nuclei (2), taking into account initial nuclei spin orientation, is obtained using formulas (5), (6) and (7) in which W_k^L and $f_L^{(f)}$ are replaced by $W_{k(i)}^L$ and $f_L^{(i)}$ defined as

$$W_{k(i)}^L = \frac{2J_i+1}{2J_f+1}(-1)^{J'+J+L} W_k^L,$$

$$f_L^{(i)} = \sum_{M_f} (-1)^{J_i-M_i} [L] \begin{pmatrix} J_i & J_i & L \\ M_i & -M_i & 0 \end{pmatrix} P(M_i).$$

After summing over the spin states of electron (positron) and, in the case of zero mass neutrino, the leptonic functions are expressed as

$$v_1 = 1 - \beta_\ell C_3, \qquad v_2 = \eta(C_1 - \beta_\ell C_2), \qquad v_3 = 1 + 2\beta_\ell C_3 - \cos\theta, \qquad v_4 = -2(C_1 + \beta_\ell C_2),$$

$$v_5 = 1 + \beta_\ell \cos\theta \qquad v_6 = 2(E_\nu^2 - \beta_\ell^2 E_\ell^2)\frac{\sin\theta}{q^2}, \qquad v_7 = 2\eta\beta_\ell(E_\ell - E_\nu)\frac{\sin\theta}{q} \tag{8}$$

$$v_8 = -2\beta_\ell(E_\ell + E_\nu)\frac{\sin\theta}{q}, \qquad v_9 = 2\eta\beta_\ell \sin\theta, \qquad v_{10} = \frac{\beta_\ell E_\ell E_\nu \sin^2\theta}{q^2}.$$

Here, E_ℓ and E_ν are electron (positron) and neutrino (anti-neutrino) energies; θ is angle between electron (positron) and neutrino (anti-neutrino) momenta; β_ℓ is electron (positron) velocity; $q = |\vec{q}|$ is momentum transferred to nuclei ; η is +1 for neutrino scattering,–1 for anti-neutrino scattering; and C_1, C_2 and C_3 are coefficients given by the relations

$$C_1 = (\beta_\ell E_\ell \cos\theta - E_\nu)/q, \qquad C_2 = (\beta_\ell E_\ell - E_\nu\cos\theta)/q, \qquad C_3 = C_1 C_2.$$

3. The differential scattering quasi-elastic cross section of ^{12}C

Consider the process

$$\nu(\bar{\nu}) +^{12} C \rightarrow^{12} N(^{12}B) + e^-(e^+), \tag{9}$$

for which $J_i = 0 \rightarrow J_f = 1$. The quanta numbers L, J and J' are defined then by

$$0 \le L \le 2J_f \Rightarrow 0 \le L \le 2, \qquad |J_i - J_f| \le J \le J_i + J_f \Rightarrow J = 1, \qquad |J_i - J_f| \le J' \le J_i + J_f \Rightarrow J' = 1.$$

The differential cross section of the process described in equation (9), obtained from (5), is given by

$$\begin{aligned}\frac{d\sigma}{d\Omega_\ell} = \; & \frac{E_\ell^2 G_F^2}{2\pi}\left\{R_0^0 + A\left(P_2(\cos\theta*)R_2^0 + P_2^1(\cos\theta*)\cos\varphi * R_2^1\right.\right.\\ & \left.\left.+P_2^2(\cos\theta*)\cos 2\varphi * R_2^2\right) + P\left(P_1(\cos\theta*)R_1^0 + P_1^1(\cos\theta*)\cos\varphi * R_1^1\right)\right\}\end{aligned} \tag{10}$$

A and P are alignment and polarization coefficients of the final nuclei [12]. Functions R_m^n are given by the relations

$$R_0^0 = v_1 H_1 + v_2 H_2 + v_3 H_3 + v_4 H_4 + v_5 H_5,$$

$$R_2^0 = \frac{1}{2}\left[v_1 H_1 + v_2 H_2 - 2(v_3 H_3 + v_4 H_4 + v_5 H_5)\right]$$

$$R_2^1 = \frac{1}{2\sqrt{6}}(v_6 H_6 + v_8 H_8), \quad R_2^2 = \frac{1}{4} v_{10} H_{10}, \tag{11}$$

$$R_1^0 = -\frac{3}{2}(v_1 H_2 + v_2 H_1), \quad R_1^1 = -\frac{3}{2\sqrt{6}}(v_7 H_6 + v_9 H_8),$$

where

$$H_1 = (F_{M1})^2 + (F_{E1}^5)^2, \quad H_2 = 2F_{M1}F_{E1}^5, \quad H_3 = (F_{L1}^5)^2,$$

$$H_4 = F_{L1}^5 F_{C1}^5, \quad H_5 = (F_{C1}^5)^2, \quad H_6 = F_{L1}^5(F_{E1}^5 + F_{M1}),$$

$$H_8 = F_{C1}^5(F_{E1}^5 + F_{M1}), \quad H_{10} = (F_{E1}^5)^2 - (F_{M1})^2.$$

The matrix elements of the vector magnetic, axial-vector electric, coulomb and longitudinal multipole operators computed in the shell model are

$$F_{M1} = \frac{\psi}{3\sqrt{\pi}}\frac{q}{2M}(F_1 - (F_1 + 2MF_2)(2-y))e^{-y},$$

$$F^5_{E1} = -\frac{\psi}{3\sqrt{\pi}}F_A(2-y)e^{-y},$$

$$F^5_{C1} = -\frac{\sqrt{2}\psi}{3\sqrt{\pi}}\frac{q}{2M}\left[\frac{3}{2}F_A + (W_0F_P + 2\eta MF_T)(1-y)\right]e^{-y}, \tag{12}$$

$$F^5_{L1} = -\frac{\sqrt{2}\psi}{3\sqrt{\pi}}(F_A - \frac{q^2}{2M}F_P)(1-y)e^{-y},$$

where $y = (bq/2)^2$, $b = 1.77$ fm is the oscillator parameter, and $\psi = -0.003$ [1].

4. Spin asymmetry coefficient

Consider the spin asymmetry coefficients defined as

$$A_\nu(E_\nu,\theta) = \frac{d\sigma\left(\vec{S}_N \uparrow\uparrow \vec{P}_\nu\right) - d\sigma\left(\vec{S}_N \uparrow\downarrow \vec{P}_\nu\right)}{d\sigma\left(\vec{S}_N \uparrow\uparrow \vec{P}_\nu\right) + d\sigma\left(\vec{S}_N \uparrow\downarrow \vec{P}_\nu\right)}, \tag{13}$$

where $\vec{S}_N$ is the final nuclei spin and $\vec{P}_\nu$ is the neutrino momentum. Analysis of angular dependence of spin asymmetry shows, for given values of P and A, that the maximum F_T contribution calculated due to ΔA_ν is moving opposite of increasing neutrino energy (see Figures 1(a, b)). This maximum also depends on the angle θ for given values of P and A (see Table).

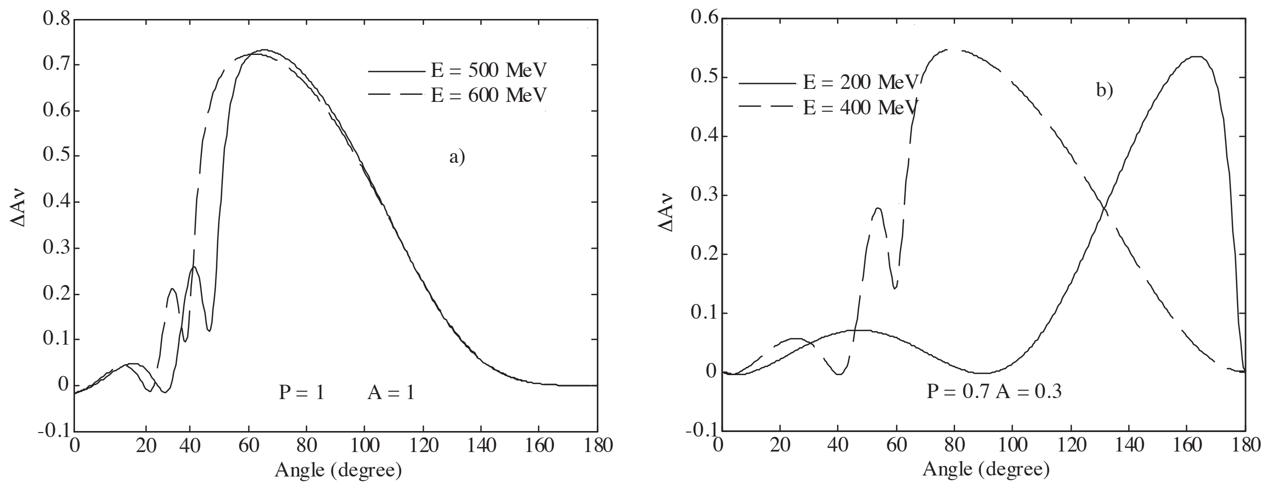

Figure 1. Contribution of SCC to the asymmetry coefficient for different value of the neutrino energy as a function of angle.

Table. Contribution of SCC to spin asymmetry coefficients, with $\Delta A_\nu = A_\nu(F_T = 5\cdot 10^{-3} MeV) - A_\nu(F_T = 0)$.

	$P = 0.7,\ A = 0.3$				$P = 1,\ A = 1$			
E_ν(MeV)	200	200	400	400	500	500	600	600
θ(degree)	47	163	54	80	41.5	66	34	62
ΔA_ν	0.07	0.53	0.27	0.54	0.26	0.73	0.21	0.72

In Figure 2 we show the energy dependence of the contribution D to the SCC, defined as

$$D = \frac{A_v(F_T = 0) - A_v(F_T = 5\cdot 10^{-3} MeV^{-1})}{A_v(F_T = 0)}, \tag{14}$$

relative the asymmetry coefficient for $\theta = 60^\circ$. It seems that the SCC relative contribution is less than 16% for neutrino energy below 300 MeV. This relative contribution can take value in the range of 75% to 92% when neutrino energy is more than 400 MeV.

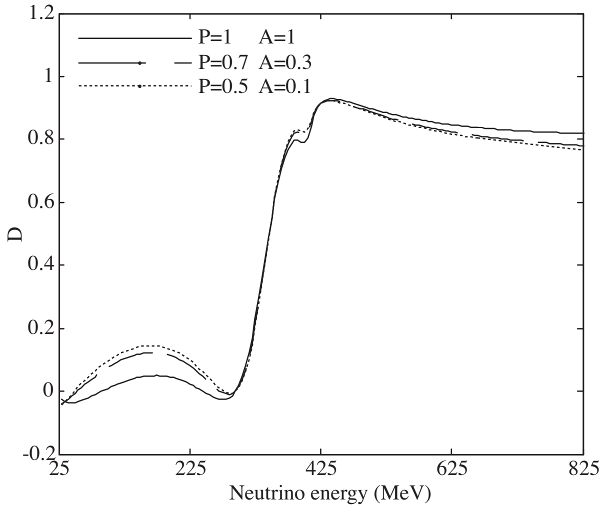

Figure 2. Relative contribution of SCC to the asymmetry coefficient for $\theta = 60^\circ$.

5. Electron-neutrino correlation and charge asymmetry coefficients

The $e\nu$ correlation coefficient is defined by the formula

$$A_{e\nu} = \frac{d\sigma(\theta\approx 0) - d\sigma(\theta\approx\pi)}{d\sigma(\theta\approx 0) + d\sigma(\theta\approx\pi)}. \tag{15}$$

When the final nucleus is oriented in the direction of neutrino and in the ultra relativistic case ($\beta_\ell = 1$), the coefficient $A_{e\nu}$ takes the form

$$A_{e\nu} = \frac{D_1 - D_2}{D_1 + D_2}, \tag{16}$$

with

$$D_1 = 2(1-A)(1-y_1)^2\left((E_\nu - E_\ell)F_T + F_A\right)^2 \exp(-2y_1),$$

$$D_2 = (1 + \tfrac{1}{2}A + \tfrac{3}{2}\eta P)(2 - y_2)^2 \left((E_\nu + E_\ell)F_2 - \eta F_A\right)^2 \exp(-2y_2),$$

$$y_{1,2} = \left(b(E_\nu \mp E_\ell)/2\right)^2 .$$

In the maximum polarization case ($A = P = 1$), $D_1 = 0$, $A_{e\nu} = -1$ and $e\nu$ correlation do not depend on SCC form factor F_T. However, in the case of partial polarization of the final nucleus, the relative contribution of SCC depends on the value of the alignment coefficient A. For example, when $A= 0.1$ and $P = 0.5$ (Figure 3), this value reaches between 1% to 17% in the 80–120 MeV neutrino energy range. When energies E_ν are above 200 MeV the coefficient $A_{e\nu} \cong +1$ and it is no more sensitive to SCC form factor F_T variation.

The charge asymmetry coefficient is defined by the formula

$$B = \frac{d\sigma_\nu - d\sigma_{\tilde{\nu}}}{d\sigma_\nu + d\sigma_{\tilde{\nu}}}, \tag{17}$$

where $d\sigma_\nu$ ($d\sigma_{\tilde{\nu}}$) is the differential cross section for neutrino (anti-neutrino) scattering.

B is determined with respect to the parameter η, which is equal to +1 for neutrino scattering and -1 for anti-neutrino scattering.

The curves (see Figure 4) for which the neutrino energy is in the range of 350 to 423 MeV show that the charge asymmetry coefficient is negative and takes values between –2.6% to –2.5% when $F_T = 0$. But it becomes positive with value between 30% and 60% when $F_T = 5 \times 10^{-3}$ MeV^{-1}. So, in this neutrino energy area, the coefficient B presents only pure SCC effects.

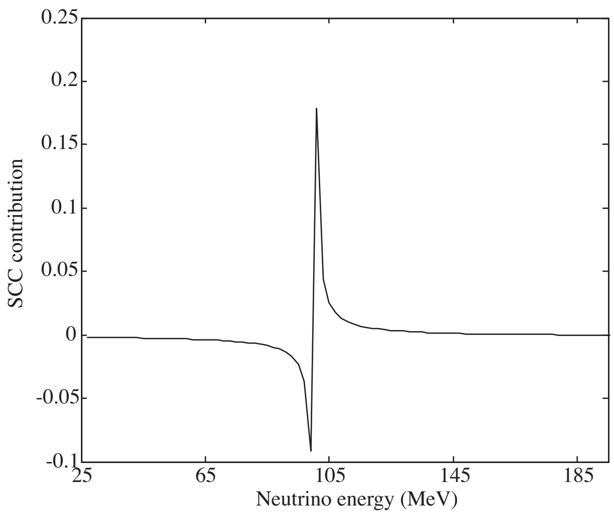

Figure 3. Relative contribution of SCC to the $e\nu$ correlation coefficient.

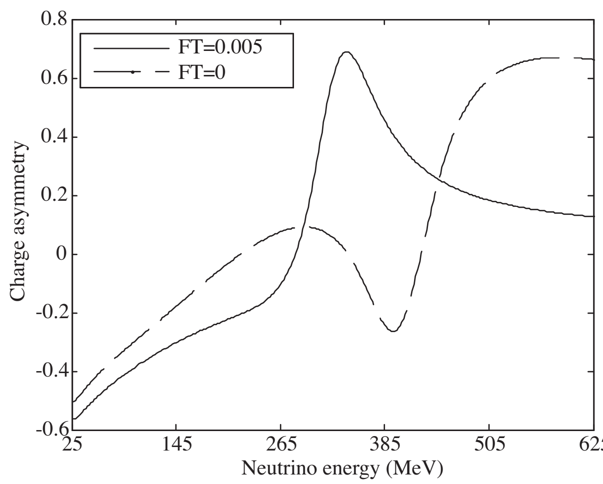

Figure 4. Charge asymmetry coefficient for $P = 0.7$, $A = 0.3$ and $\theta = 60^\circ$ as a function of energy.

6. Conclusion

Theoretical analysis of different characteristics possessed by processes of quasi-elastic neutrino scattering by nuclei has shown that the relative contribution of SCC to spin asymmetry, $e\nu$ correlation and charge asymmetry coefficients for $F_T = 5 \times 10^{-3}$ MeV^{-1}, can reach some tens of percents for particular values of alignment A and polarization P of final (initial) nucleus and that of neutrino (antineutrino) energy.

Therefore, the experimental study of quasi-elastic neutrino (antineutrino) scattering processes can allow more accurate expression of the SCC tensor form factor when the nucleus polarization is taken into account.

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References

[1] T. W. Donnelly, R. D. Peccei, *Phys. Rep.*, **50**, (1975), 1.

[2] S. Weinberg, *Phys. Rev.*, **112**, (1958), 1375.

[3] F. P. Calaprice, S. J. Freedman, W. C. Mead and H. C. Vantine, *Phys. Rev. Lett.*, **35**, (1975), 1566.

[4] K. Sugimoto, I. Tanihata and J. Göring, *Phys. Rev. Lett.*, **34**, (1975), 1533.

[5] T. Minamisono et al. *Phys. Rev. Lett.*, **80**, (1998), 4132.

[6] M. Morita, *Hyperfine Interaction*, **21**, (1985), 143.

[7] P. Vogel, *arXiv: nucl-th/9901027*, **v1**, 12 Jan 1999

[8] B. R. Holstein, www.physics.sc.edu/neutrino/workshop/holstein.pdf, April 2004

[9] T. W. Donnelly, A.S. Raskin, *Ann. Phys.*, **169**, (1986), 247.

[10] I. Aïzenberg, V. Graïner, *Mehanismi vozbujdenia yadr,*Vol. 2 (Atomizdat, Moskva, 1973), p.44 [in Russian].

[11] A. R. Edmonds, *Angular momentum in quantum mechanics*, Princeton University Press, (Princeton, New Jersey, 1957), p.53

[12] E. D. Commins, P. H. Bucksbaum, *Weak interactions of leptons and quarks*, (Energoatomizdat, Moskva, 1987) p. 189 [in Russian].