The role of electroweak coupling constants in the deviation from the standard model through the elastic scattering of an electron anti neutrino on electron

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Abstract

In this study, the effective differential cross-section of the electron anti-neutrino scattering on the electron was calculated.The deviation from the standard model of particle physics resulting from the introduction of scalar (S), pseudo scalar (P), and tensor (T) components as well as the vector(V) and axial(A) components simultaneously in the amplitude of the studied scattering was discussed. The research discussed the resilience of the standard model by the expansion of the elastic scattering amplitude of the antineutrino scattering on the electron using the experimental values of the newly obtained electroweak coupling constants from the some relevant experiments with neutrino physics.

Keywords:*elastic scattering , Non Standard Interaction ,standard model, tensor components*

introduction

This study comes as a link in a long chain of standard previous studies [1-4], and another non-standard (NSI) studies [5-8]. This study see also the interaction of the anti-electron neutrino with the electron, where it was included scalar (S), pseudo scalar (P), and tensor (T) components as well as the vector(V) and axial vector (A) components simultaneously in the amplitude of the studied scattering and calculate the resulting corrections. What distinguishes this study from previous studies is the introducing the new experimental constraints on scalar (g_S) pseudo scalar (g_P), and tensor (g_T) coupling constants, according to TEXONO and LSND experiences [9] and its relationship to corrections.

We point out here that the TEXONO experiment was based on the interaction of the anti-electron neutrino with the electron in the field of low energies using different reagents located in Kuo-Sheng Reactor Neutrino Laboratory (KSNL), While LSND experiment was based on the interaction of the anti-electron neutrino with the electron in the field of high energy using the neutrino accelerator. The aim of these two experiments was to find new constraints on the coupling constants of the anti-neutrino's interaction with the electron.

The study of the interaction of the anti-electron neutrino with the electron is important both phenomenological and experimental [10]. This interaction provides a very comfortable channel for testing the standard model of electroweak theory [11-16]. In this research we will deal with reactor neutrinos $\bar{\upsilon}_e$ where the reactors are excellent sources of anti-electron neutrino $\bar{\upsilon}_e$. In our research we show how steadfast the standard model is in front of the expansion of the amplitude of elastic scattering anti-electron neutrino on electron To include scalar (S), pseudo scalar (P), and tensor (T) components, Besides the vector(V) and axial vector (A) components , that the weak V-A theory takes. We also show the role of the experimental values for the coupling constants obtained from two TEXONO, LSND experiments in this deviation.

The importance of research and its objectives:

The importance of this research lies in the method of calculating the total differential cross-section after entering the scalar (S), pseudo scalar (P), and tensor (T) quantities together in the amplitude of elastic scattering electron antineutrino on the electron based on the weak V-A theory,and then determine the amount of deviation obtained from the standard model, and study the relationship between the deviation and the coupling constants.

.Calculate the total differential cross section of the reaction

We express the elastic interaction of the electron neutrino (antielectron neutrino) on the electron by the relationship:

$$e^- + \upsilon_e(\bar{\upsilon}_e) \rightarrow e^{-'} + \upsilon'_e(\bar{\upsilon}'_e) \quad (1)$$

The general formula for the amplitude of elastic scattering of neutrino mass (antineutrino) on the electron is written by the relationship:

$$M = \frac{G_F}{\sqrt{2}} \sum_i g_i \left[\bar{U}_e \hat{O}_i U_e \right] \left[\bar{U}_\upsilon \hat{O}_i (1+\gamma^5) U_\upsilon \right]$$

$$i = V, A, S, P, T \quad (2)$$

Where: $\hat{O}_i$ is a matrix operator that takes the following formulas:

$$\hat{O}_S = I, \hat{O}_P = \gamma^5, \hat{O}_V = \gamma^\mu . \hat{O}_A = \gamma^\mu \gamma^5 .$$

$$\hat{O}_T = \frac{i}{2}(\gamma^\mu \gamma^\upsilon - \gamma^\upsilon \gamma^\mu)$$

g_i: expresses the coupling constants in weak interactions,

G_F : expresses the Fermi constant

We enter the scalar (S), pseudoscalar (P), and tensor (T) components beside the vector (V) and axial vector (A) in the amplitude of the reaction at the same time and we write the phrase of the total amplitude as follows:

$$M^{(V,A,S,P,T)} = M^{(V,A)} + M^{(S,P)} + M^{(T)} + M^{\text{int.}} \quad (3)$$

Where $M^{\text{int.}} = M^{(V,A)}_{(S,P)} + M^{(V,A)}_{(T)}$

expresses the amplitude of Interference limit of (V, A) with (S, P) and (T) respectively.

We write the expression of the total differential cross-section for elastic scattering as follows:

$$d\sigma^{(V,A,S,P,T)} = d\sigma^{(V,A)} + d\sigma^{(S,P)} + d\sigma^{(T)} + d\sigma^{\text{int.}} \quad (4)$$

We also write the general expression of the total matrix element of the studied interaction as follows:

$$\left|M^{(V,A,S,P,T)}\right|^2 =$$
$$\left|M^{(V,A)}\right|^2 + \left|M^{(S,P)}\right|^2 + \left|M^{(T)}\right|^2 + \left|M^{\text{int.}}\right|^2 \quad (5)$$

Where, k, p represents the momentum of the input neutrino and electronwhere k', p' represents the momentum of the output neutrino and electron. E'_e, E_e express the energy of the output and input electron, respectively. E'_υ, E_υ express the energy of the output and input neutrinos, respectively.

We choose the L.S laboratory system to calculate the total differential cross-section of the studied reaction by calculating each term independently in relationship (4).

Calculation of the first term of relationship (4):

We start with the amplitude expression:

$$M^{(V.A)} = \frac{G_F}{\sqrt{2}}\left[\bar{U}_{e'}\gamma_\mu(g_V + g_A\gamma^5)U_e\right]$$
$$\left[\bar{U}_{\upsilon'}\gamma^\mu(1+\gamma^5)U_\upsilon\right]$$

From it we find:

$$M^{(V,A)} = 8G_F^2\begin{bmatrix}(g_V+g_A)^2(p'k')(pk)+\\(g_V-g_A)^2(p'k)(pk')-\\m_e^2(g_V^2-g_A^2)(k'k)\end{bmatrix} \quad (6)$$

Where:

$$(k'p') = (kp) = m_eE_\upsilon \;,\; (k'p) = (kp') = m_e(E_\upsilon - T_e);(k'k) = m_eT_e + m_\upsilon^2 \quad (7)$$

T_e express the kinetic energy of an electron. With substituting (7) in (6), bearing in mind that:

$$y = T_e / E_\upsilon = \frac{E'_e - m_e}{E_\upsilon},$$
$$0 \le y \le y_{\max} = \frac{1}{1+\frac{m_e}{2E_\upsilon}}$$

We find:

$$\left|M^{(V,A)}\right|^2 = 8G_F^2m_e^2E_\upsilon^2\begin{bmatrix}(g_V+g_A)^2+(g_V-g_A)^2(1-y)^2-\\(g_V^2-g_A^2)\frac{m_e}{E_\upsilon}(y-\frac{m_\upsilon^2}{m_e^2})\end{bmatrix} \quad (8)$$

We assume that:

$$\delta = m_\upsilon / E_\upsilon \;,\; \omega = E_\upsilon / m_e \;,\; \sigma_0 = 2G_F^2m_eE_\upsilon/\pi$$

Using the general expression of the differential cross section [17]:

$$\left(\frac{d\sigma}{dy}\right)_{L.S} = \frac{1}{1-\frac{m_\upsilon^2}{E_\upsilon}} \times \left(\frac{|M|^2}{32\pi m_eE_\upsilon}\right) \quad (9)$$

We find:

$$\frac{d\sigma^{(V,A)}}{dy} = \frac{\sigma_0}{1-\delta^2}\begin{bmatrix}(g_V+g_A)^2+(g_V-g_A)^2(1-y)^2-\\(g_V^2-g_A^2)(\frac{y}{\omega}-\delta^2)\end{bmatrix} \quad (10)$$

$$g_V = +\frac{1}{2} + \sin^2\theta_W \;\; g_A = +\frac{1}{2} \quad for \;\; \upsilon_e$$

The upper signIndicate to the electron neutrino and the lower signIndicate to the electron antineutrino.

Calculation of the second term of relationship (4):

In order to calculate our differential cross section $d\sigma^{(S,P)}$ we have:

$$M^{(S,P)} = \frac{G_F}{\sqrt{2}}\left[\overline{U}_{e'}\gamma_\mu(g_S + g_P\gamma^5)U_e\right]\left[\overline{U}_{\upsilon'}(1+\gamma^5)U_\upsilon\right]$$

$$\left|M^{(S,P)}\right|^2 = \left(M^{(S,P)}\right)\left(M^{(S,P)}\right)^* = \frac{G_F^2}{8}Tr\begin{bmatrix}(\hat{p}'+m_e)(g_S+g_p\gamma^5)(p+m_e)\\(g_S-g_p\gamma^5)\end{bmatrix}\times$$

$$.Tr\left[(\hat{k}'+m_\upsilon)(1+\gamma^5)(\hat{k}+m_\upsilon)(1-\gamma^5)\right] = 4G_F^2(kk')\left[(p'p)(g_S^2+g_p^2)+m_e^2(g_S^2-g_p^2)\right]$$

In the last relationship, we substitute the following values:

$$(kk') = m_e E_\upsilon y + m_\upsilon^2 \ :$$

$$(p'p) = m_e E_E = m_e(m_e + E_\upsilon y)$$

We get:

$$\left|M^{(S,P)}\right|^2 = 4G_F^2 m_e E_\upsilon(m_e E_\upsilon y + m_\upsilon^2)\begin{bmatrix}(g_S^2+g_P^2)y+\\ \frac{2g_S^2}{\omega}\end{bmatrix} \quad (11)$$

Using the general expression of differential cross section (9) we find the following relationship:

$$\frac{d\sigma^{(S,P)}}{dy} = \frac{\sigma_0}{1-\delta^2}\frac{\omega\delta^2+y}{2}\begin{bmatrix}(g_S^2+g_P^2)y+\\ \frac{2g_S^2}{\omega}\end{bmatrix} \quad (12)$$

Calculation of the third term of relationship (4):

Using the same method as above, we can write:

$$\left|M^{(T)}\right|^2 = \frac{G_F^2}{8}g_T^2\, Tr\left[(\hat{p}'+m_e)\sigma_{\alpha\beta}(\hat{p}+m_e)\sigma^{\alpha\beta}\right]\times$$

$$Tr\left[(\hat{k}'+m_\upsilon)\sigma_{\mu\upsilon}(1+\gamma^5)(\hat{k}+m_\upsilon)\sigma^{\mu\upsilon}(1-\gamma^5)\right]$$

With the account, we find:

$$\left|M^{T}\right|^2 = 32G_F^2 g_T^2\left\{m_e^2(kk')+2\begin{bmatrix}(p'k')(pk)+\\(p'k)(pk')\end{bmatrix}\right\} \quad (13)$$

Going back to the general expression of the differential cross section (9) we find:

$$\frac{d\sigma^{(T)}}{dy} = 8\sigma_0\left(\frac{1}{1-\delta^2}\right)g_T^2\left[2+2(1-y)^2+\frac{y}{\omega}+\delta^2\right] \quad (14)$$

Calculation of the fourth term from relationship (4):

To calculate the differential cross section $d\sigma^{\text{int}}$ we first compute the corresponding matrix element represented by the following relationship:

$$\left|M^{\text{int}}\right|^2 = 2\,\mathrm{Re}(M^{(V,A)})(M^{(S,P)})^* + 2\,\mathrm{Re}(M^{(V,A)})(M^{(T)})^*$$

After dealing with the necessary procedure, we find:

$$|M^{int.}|^2 = 8G_F^2\{m_e m_\upsilon \begin{bmatrix}(g_V g_S + g_A g_P)(pk) + \\ +(g_V g_S - g_A g_p)(p'k)\end{bmatrix} + +4g_T^2\left[m_e^2(kk') + 2\left((pk)^2 + (p'k)^2\right)\right]\} \quad (15)$$

Using the general expression of the differential cross section in the laboratory system (9) we find:

$$\frac{d\sigma^{int.}}{dy} = \sigma_0 \frac{\delta}{1-\delta^2}\{(g_V g_S + g_A g_P) + [g_V g_S - g_A g_P - 12 g_T(g_V + g_A)(1-y)]\} \quad (16)$$

Now we can write the expression of the differential cross-section of the studied interaction in the final form:

$$\frac{d\sigma_{e\upsilon}^{Total}}{dy} = \frac{\sigma_0}{1-\delta^2}\left\{\begin{matrix}\left[(g_V \pm g_A)^2 + (g_V \mp g_A)^2(1-y)^2 + (g_V^2 - g_A^2)(\frac{y}{\omega} - \delta^2)\right] + \\ + \frac{y+\omega\delta^2}{2}\left[(g_S^2 + g_P^2)y + \frac{2g_S^2}{\omega}\right] + 8g_T^2[2 + 2(1-y)^2 + \frac{y}{\omega} + \delta + \\ + \delta[(g_V g_S + g_A g_P) + (g_V g_S - g_A g_P) - 12 g_T(g_V \mp g_A)](1-y)]\end{matrix}\right\} \quad (17)$$

This relationship becomes within the framework of the standard model as follows:

$$\frac{d\sigma_{e\upsilon}^{Total}}{dy} = \sigma_0\left\{\begin{matrix}\left[(g_V \pm g_A)^2 + (g_V \mp g_A)^2(1-y)^2 + (g_V^2 - g_A^2)\frac{y}{\omega}\right] + \\ + \frac{y}{2}\left[(g_S^2 + g_P^2)y + \frac{2g_S^2}{\omega}\right] + 8g_T^2[2 + 2(1-y)^2 + \frac{y}{\omega}\end{matrix}\right\} \quad (18)$$

Results and discussion:

From the last relationship (18), the deviation from the standard model can be expressed by:

$$\Delta = \sigma_0\left\{\left[\frac{1}{2}(g_S^2 + g_P^2)y^2 + \frac{g_S^2}{\omega}y\right] + 8g_T^2\left[2 + 2(1-y)^2 + \frac{y}{\omega}\right]\right\} \quad (19)$$

To determine this deviation, we consider the energy of the antineutrino (coming from the nuclear reactor), $E_{\bar{\upsilon}} \le 10\,MeV$ this means that $E_{\bar{\upsilon}} \rangle\rangle m_e$ in the field $0 \le y \le 1$. We now choose three values of the variable y in the studied field and compute the expected deviation.

1-For $y \to 0$ as a minimum case, we find that the deviation is given by the following simple relationship:

$$\Delta = 32 g_T^2 \sigma_0 \quad (20)$$

Table (1) shows the deviation values for the lower bound of the y variable using the values of experimental coupling constants [9]:

Table(1): Deviation from the standard model is shown at the lower limits of the variable y

TEXONO Exp.	LSND Exp.
$g_T \leq 0.218$ $\Delta_1^T = 1.81\sigma_0$	$g_T \leq 0.401$ $\Delta_1^L = 5.14\sigma_0$
$\sigma_0 = 0.63\times 10^{-46} cm^2$	

We note from the above table that the deviation is directly proportional to the square of the tensor coupling constant and is not related to other electroweak coupling constants.

2-For $y \to 1$ as the maximum case, we find that the deviation is given by:

$$\Delta = \sigma_0 \left\{ \left[\left(\frac{m_e}{E_\upsilon} + \frac{1}{2}\right) g_S^2 + \frac{g_P^2}{2} \right] + 8 g_T^2 \left(2 + \frac{m_e}{E_\upsilon}\right) \right\} \quad (21)$$

Table (2) shows byusing the values of experimental coupling constants [9] the corrective limit for each case .

Table (2): Deviation from the standard model is shown at the maximum limits of the variable y

	TEXONO	LSND
a)	$g_p = 0, g_S \leq 0.112, g_T \leq 0.238$ $\Delta_2^T = 0.936\sigma_0$	$g_p = 0, g_S \leq 0.88, g_T \leq 0.401$ $\Delta_2^L = 3.065\sigma_0$
b)	$g_S = 0, g_p \leq 0.314, g_T \leq 0.238$ $\Delta_2^T = 0.979\sigma_0$	$g_S = 0, g_p \leq 0.642, g_T \leq 0.401$ $\Delta_2^L = 2.845\ \sigma_0$
c)	$g_p = g_S \leq 0.100, g_T \leq 0.238$ $\Delta_2^T = 0.939\sigma_0$	$g_p = g_S \leq 0.375, g_T \leq 0.401$ $\Delta_2^L = 2.786\sigma_0$
$\sigma_0 = 0.63\times 10^{-46} cm^2$		

We note from table (2) the following:

a)The deviation values for each case are not neglected, but are related to the values of the electroweak coupling constants. This deviation is magnified by increasing the values of the coupling constants and vice versa.

b)The deviation values are not related to the first-degree coupling constants, but related to the second-degree coupling constants and this is agree with relationship (21).

c)The contribution of the Tensor corrective limit to the deviation from the standard model is much greater than the contribution of the scalar and pseudo-scalar limits.

3-For $y = 1/2$ as the median state between the minimum boundary state and the maximum boundary state of the variable y, we find that the deviation is given by:

$$\Delta = \sigma_0 \left[\frac{g_S^2 + g_P^2}{8} + \frac{m_e}{E_{\bar{\upsilon}}} \frac{g_S^2}{2} + 4g_T^2 (5 + \frac{m_e}{E_{\bar{\upsilon}}}) \right] \quad (22)$$

After performing the calculations, we arrange them in Table (3):

Table (3): Deviation from the standard model at the middle limits of the variable y

	TEXONO Exp.		LSND Exp.	
الحالة	البيانات التجريبية	الانحراف (Δ_3^T)	البيانات التجريبية	الانحراف (Δ_3^L)
(a)	$g_p = 0, g_S \le 0.112,$ $g_T \le 0.238$	$1.146\sigma_0$	$g_p = 0, g_S \le 0.88,$ $g_T \le 0.401$	$3.251\sigma_0$
(b)	$g_S = 0, g_p \le 0.314,$ $g_T \le 0.238$	$1.156\sigma_0$	$g_S = 0, g_p \le 0.642,$ $g_T \le 0.401$	$3.313\sigma_0$
(c)	$g_p = g_S \le 0.100,$ $g_T \le 0.238$	$1.147\sigma_0$	$g_p = g_S \le 0.375,$ $g_T \le 0.401$	$3.288\sigma_0$
$\sigma_0 = 0.63 \times 10^{-46} cm^2$				

We notice from the previous table (3) that the deviation from the standard model in the three modes (a), (b), (c) according to the values of the TEXONO experiment rounded to two decimal numbers is the same and equal to $1.15\sigma_0$.We also note that this deviation from the standard model in the three modes (a), (b), (c) according to LSND experiment rounded to one decimal number is equal to $3.3\sigma_0$.

We conclude the following result:

The deviation from the standard model according to the LSND experiment is almost three times the deviation according to the TEXONO experiment for the same energy, and this is due to the influence of the electroweak coupling constants.

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