Neutrino helicity effects on the effective cross-section of the pair annihilation $e^- e^+ \to \upsilon_i \bar{\upsilon}_i \ (i = e, \mu, \tau)$ in a very hot stellar medium

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Abstract:

In this study, the effective differential cross-section of the lepton interactions $e^- e^+ \to \upsilon_i \bar{\upsilon}_i \ (i = e, \mu, \tau)$ usually obtained in very hot stars was calculated, taking into account the influence of weak currents, and the effect of electromagnetic form factors of neutrino on differential cross sections. The effects of neutrino helicity and antineutrino helicity, and Polarizing effects of the electron and positron on the effective cross-sections in the center mass system were studied. The relationship of these cross-sections with the energy of center mass system was indicated.

Keywords: hot stars, helicity, Generation of neutrinos and antineutrino pairs.

Introduction:

Interactions $e^- e^+ \to \upsilon_i \bar{\upsilon}_i \ (i = e, \mu, \tau)$ usually occur in the hot star medium [1-3] and are generated by pairs of neutrinos and antineutrinos. These pairs move freely in the star medium because of their weak interactions with these medium and when they leave they carry large energy into outer space [4,5]. Because of their abundance, they contribute to cooling the star that they have left. Therefore the detection of these pairs is an early warning system to indicate the near collapse of the star and the phenomenon of supernova.

The neutrino helicity plays an important role in the production of neutron pairs [5] $(\nu_i\bar{\nu}_i)$; $i = e$, μ , τ . For example, the helicity was studied in references [6-8] and its vibration mechanism was developed in reference [9,10].

In this paper, emphasis was placed on the importance of neutrino helicity and the polarizing effects of electrons and positrons in the study of scattering cross-section reactions $e^-e^+ \to \nu_i\bar{\nu}_i$; $i = e$, μ , τ which occur in hot stellar circles.

The importance of research and its aim:

The importance of this research is the role that such lepton interactions play in cosmological studies. The aim of this study is to study the effect of neutrino and antineutrino-helicity on the effective differential cross-section of lepton interactions $e^-e^+ \to \upsilon_i\,\bar{\upsilon}_i\ (i = e, \mu, \tau)$ taking into account the effects of the neutral current, the charged current and the electromagnetic current in the reaction Hamiltonian..

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The effective differential cross-section of the interaction: $e^-e^+ \to \upsilon_i\,\bar{\upsilon}_i\ (i = e, \mu, \tau)$

The reaction amplitude consists of three components reflected by the Feynman diagrams shown in Figure (1):

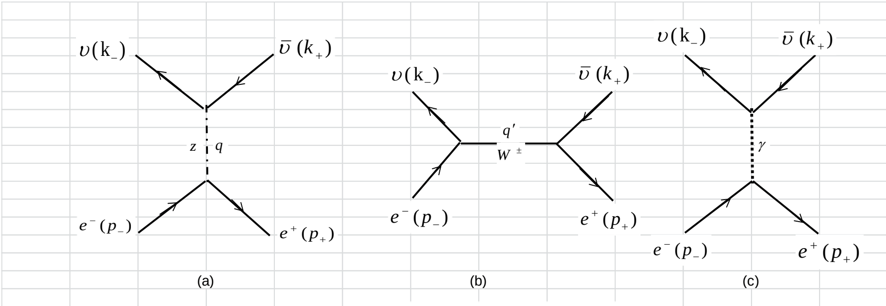

Figure (1): Feynman diagrams accompanying the interactions

$$e^-(p_-)e^+(p_+)\rightarrow\upsilon_i(k_-)\bar{\upsilon}_i(k_+)\ ,\ i=e\,,\mu,\tau\,.$$

(a) and (b) represent weak influences and (c) represents the electromagnetic effects

The three compounds make up the total amplitude relationship:

$$M^{total}=M_Z+M_W+M_\gamma \qquad (1)$$

Without entering the details ,the total amplitude of interaction:

$e^-e^+\rightarrow\upsilon_i\,\bar{\upsilon}_i\ \ (i=e\,,\mu,\tau)$ can be expressed by the equation:

$$M^{total}=\frac{G_F}{\sqrt{2}}(\bar{u}_\upsilon\gamma_\alpha u_{\bar{\upsilon}})[\bar{u}_{e^+}\gamma_\beta(C_V+C_A\gamma^5)u_{e^-}]$$
$$-\frac{G_F}{\sqrt{2}}(\bar{u}_\upsilon|C_{2\upsilon}|u_{e^-})(\bar{u}_{e^+}\frac{\hat{P}}{2m_e}u_{e^-}) \qquad (2)$$

$$C_V = (1-\eta_-)\,g_V + \frac{4\sqrt{2}\,\pi\alpha}{q^2 G_F}(f_{m\upsilon} - \eta_- g_{1\upsilon})\ ;$$

Where:

$$C_A = (1-\eta_-)g_A\ ;|C_{2\upsilon}| = \frac{4\sqrt{2}\,\pi\alpha}{q^2 G_F}\left|f_{2\upsilon} - i\,\eta_-\,g_{2\upsilon}\right|$$

$$g_V = \frac{g_{Ve}}{1 - s/m_z^2 - i\,\Gamma_z/m_z} + \frac{1}{1 - t/m_w^2 - i\,\Gamma_w/m_w}\ ,$$

$$g_A = \frac{g_{Ae}}{1 - s/m_z^2 - i\,\Gamma_z/m_z} + \frac{1}{1 - t/m_w^2 - i\,\Gamma_w/m_w}$$

g_{Ae} , g_{Ve} express the coupling constants of weak interactions expressed as :

$$g_{Ve} = -\frac{1}{2} + 2\sin^2\theta_w\ \ ;\ g_{Ae} = -\frac{1}{2}\quad for\ \ \upsilon_\mu\ ,\ \upsilon_\tau$$

$$g_{Ve} = +\frac{1}{2} + 2\sin^2\theta_w\ \ ;\ g_{Ae} = +\frac{1}{2}\quad for\ \ \upsilon_e$$

$$q^2 = (p_- + p_+)^2 = (k_- + k_+)^2 = S\ ,$$
$$q'^2 = (p_- - k_-)^2 = (k_+ - p_+)^2 = t$$

$$\hat{P} \equiv \not{P} = P^\mu \gamma^\mu\ ;\ P^\mu = (k_- + k_+)^\mu\ ,\ \alpha = \frac{e^2}{4\pi} \cong \frac{1}{137}\ ,$$
$$\hat{o}_\alpha = \gamma_\alpha (1 + \gamma^5)\ ,$$

$f_{m\upsilon} = f_{1\upsilon} + \frac{m_\upsilon}{m_e} f_{2\upsilon}$ .Here $g_{2\upsilon}, f_{2\upsilon}, g_{1\upsilon}, f_{1\upsilon}$ express the: Dirac, anapole, magnetic and electric electromagnetic form factors of neutrino. Γ_w , Γ_z are the total widths of W and Z boson respectively.$\bar{u}_{e^+} = \bar{u}(p_+, s_+)$; $u_{e^-} = u(p_-, s_-)$, $\bar{u}_{\upsilon} = \bar{u}(k_-, \eta_-)$; $u_{\bar{\upsilon}} = u(k_+, \eta_+)$ indicate the Dirac spinors : momentum and helicity for neutrino or antineutrino or momentum and spin for electron or positron.We choose the center mass system c.m.s to calculate the matrix element $\left|M^{total}\right|^2$ through the relationship: $\left|M^{total}\right|^2 = M^{total}(M^{total})^*$.Substituting the result in the general phrase of the effective cross-section in the center mass system:

$$\left(\frac{d\sigma}{d\Omega}\right)_{c.m.s} = \frac{k}{64\pi^2 s\, p}\left|M^{total}\right|^2$$

. We obtain the total effective differential cross-section :

$$\left(\frac{d\sigma^{total}}{d\Omega}\right)_{c.m} = \frac{G_F^2 E^2}{64\pi^2}\left\{\frac{(1-\eta_-\eta_+)}{4}[(1-s_-s_+)(1+\eta_-s_-)(C_V - \eta_- C_A)^2 + \right.$$
$$+ (1-\eta_-s_+)(1-\eta_-s_+)(C_V + \eta_- C_A)^2 +$$
$$+ \frac{2m_e^2}{E^2}(C_V^2 - C_A^2)](1+\eta_-s_-\cos\theta)(1-\eta_-s_+\cos\theta) +$$
$$+ \left(\frac{1+\eta_-\eta_+}{2}\right)\left(\frac{f_{2\upsilon}^2 + g_{2\upsilon}^2}{Q_s^2}\right)[(1+s_-s_+)\cos^2\theta +$$
$$\left. + (1-s_-s_+)\frac{E^2}{m_e^2}\sin^2\theta] \right\} \qquad (3)$$

Where: $Q_s = G_F.\mathrm{s}/4\pi\sqrt{2}.\alpha$, $\sqrt{s} = 2E_{c.m}$,
$|p_-| = |p_+| = p$; $|k_-| = |k_+| = k$

Results and discussion:

Now to see the effect of helicity and spin on the effective differential cross section, we suppose that the electron is left-polarized e_L^-, and that means positron is right-polarized e_R^+. Note that the helicity of neutrino is left υ_L and the helicity of antineutrino is right $\bar{\upsilon}_R$ according to experimental data. By applying this to the equation (3) we find:

$$(\frac{d\sigma^{total}}{d\Omega})_{c.m} = \frac{G_F^2 E^2}{64\pi^2}[2(C_V + C_A)^2 + 2(C_V - C_A)^2 + \frac{m_e^2}{E^2}(C_V^2 - C_A^2)](1+\cos\theta)^2$$

We note here clearly the disappearance of the second term of the differential cross-section relation (3) related to the electrostatic form factors $f_{2\upsilon}$, $g_{2\upsilon}$ of neutrino, and the survival of the Dirac and anapole coefficients, though not visible in the differential cross-section, but present through the coefficient C_V .

Let us look at the effect of two factors $f_{1\upsilon}$, $g_{1\upsilon}$ in the differential cross-section by their effect on the constant C_V. We know that $m_e \rangle\rangle m_{\upsilon_e}$, $\Gamma_W \langle\langle m_W$ and $\Gamma_Z \langle\langle m_Z$ [8]. Thus, we can write C_V and C_A as follows:

$$C_V = \frac{2g_{Ve}}{1 - S/m_z^2} + \frac{2}{1 - S/m_w^2} + (f_{1\upsilon} + g_{1\upsilon})\frac{4\pi\sqrt{2}\,\alpha}{G_F S} \quad ;$$

$$C_A = \frac{2g_{Ae}}{1 - S/m_z^2} + \frac{2}{1 - S/m_w^2}$$

The amount $(f_{1\upsilon} + g_{1\upsilon})$ according to references [12,11] is of the order [np] cm2. It is very small compared to the first term whatever the values of the mixing constant $Sin^2\theta_w$. We conclude that the neutrino helicity as an experiential reality completely eliminates the role of electromagnetic form factors of neutrino in the effective differential cross-section, whether the electron and the positron are polarized or not . It seems like the weak interaction of neutrinos in the stellar medium in which the pairs of neutrino and neutrinos form, Is the dominant factor. This facilitates the release of neutrino pairs from the hot star medium, which carries energy into the outer medium. This speeds up the process of cooling the star down to its death.Now let us look at the effect of the ratio $\frac{m_e^2}{E^2}$ on the differential cross-section when E take its value from the energy interval $[89-94GeV]$ according to the reference [13] .We write the relationship (3) as follows:

$$(\frac{d\sigma^{total}}{d\Omega_\upsilon})_{c.m} = \sigma_0\,(1+\cos\theta)^2$$ .Where:

$$\sigma_0 = \frac{G_F^2 E^2}{64\,\pi^2}[2\,(C_V + C_A)^2 + 2(C_V - C_A)^2 + \frac{m_e^2}{E^2}(C_V^2 - C_A^2)]$$

After calculating: $(C_V^2 - C_A^2)$, $(C_V - C_A)^2$, $(C_V + C_A)^2$ and substituting them in σ_0, we find that they are of the order [np] cm2 relative to $\frac{m_e^2}{E^2}$. Thus, the effect of this term can be neglected in the expression σ_0 which is then reduced to the following:

$$\sigma_0 = \frac{G_F^2 E^2}{32\,\pi^2}[\,(C_V + C_A)^2 + (C_V - C_A)^2\,] = \frac{G_F^2 E^2}{16\pi^2}[C_V^2 + C_A^2]$$

. Therefore, the cross-section expression becomes: $(\frac{d\sigma^{total}}{d\Omega_\upsilon})_{c.m} = \frac{G_F^2 E^2}{16\pi^2}(C_V^2 + C_A^2)(1+\cos\theta)^2$

We know that $d\Omega_\upsilon = 2\pi \sin\theta \; d\theta$. By integrating the last equation, we get the total cross-section in the center mass system:

$\sigma^{total} = \frac{G_F^2 S}{16\pi}(C_V^2 + C_A^2)$. This relationship shows the linear proportion between the cross section of generation neutrino pairs and the square of energy of center mass system. Hence the importance of these neutrino pairs in the cooling of the ultra-hot star medium by carrying energy from the star to the outer sphere as we mentioned earlier.Returning to equation (3) and conducting the integration, we get neutrinos pairs $(\upsilon_L \;, \upsilon_R)$ being generated in the total cross-section of the interaction $e^- e^+ \to \nu_i \bar{\nu}_i \;;\; i = e \;,\; \mu \;,\; \tau$ which is expressed as follows:

$$\sigma^{total} = (\frac{1-\eta_- \eta_+}{2})\sigma_+ + (\frac{1+\eta_- \eta_+}{2})\sigma_= \qquad (4)$$

Where: $\sigma_+ = \sigma_+^{SM} + \sigma_+^{EM} + \sigma_+^{INT}$, $\sigma_- = \sigma_-^{EM}$

Assuming that: $S \langle\langle\, m_W^2$, $S \langle\langle\, m_Z^2$ (This is possible in the very hot stellar medium) we can write:

$$\sigma_+^{SM} = \frac{G_F^2 E^2}{8\pi}(1 - \frac{s_- s_+}{3})[(1-s_-)(1+s_+)(g_{Ve} \pm g_{Ae})^2 + (1-s_+)(1+s_-)(g_{Ve} \mp g_{Ae})^2 + \frac{2m_e^2}{E^2}(g_{Ve}^2 - g_{Ae}^2)] \qquad (5)$$

$$\sigma_{+}^{EM} = \frac{\pi\alpha^2}{8E^2}(1-\frac{s_{-}s_{+}}{3})(1-s_{-}s_{+}+\frac{m_e^2}{E^2})(f_{1\upsilon}+g_{1\upsilon})^2 \quad (6)$$

$$\sigma_{-}^{EM} = \frac{\pi\alpha^2}{24E^2}[(1+s_{-}s_{+})+2(1-s_{-}s_{+})\frac{E^2}{m_e^2}](f_{2\upsilon}^2+g_{2\upsilon}^2) \quad (7)$$

$$\sigma^{INT} = \frac{G_F^2E^2}{8\pi}\{(1-\frac{s_{-}s_{+}}{3})[(1-s_{-})(1+s_{+})(g_{Ve}+g_{Ae})+(1+s_{-})(1-s_{+})(g_{Ve}-g_{Ae})+ \frac{2m_e^2 g_{Ve}}{E^2}]\frac{(f_{1\upsilon}+g_{1\upsilon})}{Q_S}+\frac{2m_e^2}{E^2}g_1^0(1+s_{-}s_{+})[2(g_{Ve}+g_{Ae})+\frac{f_{1\upsilon}+g_{1\upsilon}}{Q_s} \quad (8)$$

Where:

$$g_1^0 \rightarrow 1 \; for \; e^-e^+ \rightarrow \upsilon_e\bar{\upsilon}_e \;, \; g_1^0 \rightarrow 0 \; for \; e^-e^+ \rightarrow \upsilon_{\mu,\tau}\bar{\upsilon}_{\mu,\tau}$$

$$Q_s = \frac{G_F\, S}{4\pi\sqrt{2}\,\alpha} \;\; ; \;\; S = 4E^2$$

If we return to the main equation (4) to know the effect of neutrino helicity on it, it is enough to consider the neutrino being left- handed υ_L and the antineutrino right- handed $\bar{\upsilon}_R$, and that the spin of neutrino is linked linearly with its momentum until the second term disappears forever because $(1+\eta_{-}\eta_{+})=0$, and equation (4) becomes:

$\sigma^{total} = (\frac{1-\eta_{-}\eta_{+}}{2})\sigma_{+}$. If the helicity is equal $\eta_{\mp} = \mp\frac{1}{2}$ the second term loses a quarter of its value in this case. Now let us study all the possibilities of the pairs (electron - positron) due to their helicity effects: In the case of equal helicity of electron with a helicity of positron, we find for pairs $(e^-_{L,R}, e^+_{L,R})$ the following cross-sections:

$$\sigma_+^{SM}(e^-_{L,R}, e^+_{L,R}) = \frac{G_F^2 m_e^2}{6\pi}(g_{Ve}^2 - g_{Ae}^2) \tag{9}$$

$$\sigma_+^{EM}(e^-_{L,R}, e^+_{L,R}) = \frac{\pi\alpha^2 m_e^2}{12E^4}(f_{1\upsilon} + g_{1\upsilon})^2 \tag{10}$$

$$\sigma_-^{EM}(e^-_{L,R}, e^+_{L,R}) = \frac{\pi\alpha^2}{12E^2}(f_{2\upsilon}^2 + g_{2\upsilon}^2) \tag{11}$$

$$\sigma_+^{INT}(e^-_{L,R}, e^+_{L,R}) = \frac{G_F^2 m_e^2}{2\pi}[2\delta_1^0(g_{Ve} + g_{Ae}) + (\delta_1^0 + \frac{g_{Ve}}{3})(\frac{f_{1\upsilon} + g_{1\upsilon}}{Q_S})] \tag{12}$$

In the case of opposite electron and positron helicity, we find the following cross-sections for the pairs $(e^-_{L,R}, e^+_{R,L})$:

$$\sigma_+^{SM}(e^-_{L,R}, e^+_{R,L}) = \frac{G_F^2 E^2}{3\pi}[2(g_{Ve} \pm g_{Ae})^2 + \frac{m_e^2}{E^2}(g_{Ve}^2 - g_{Ae}^2)] \tag{13}$$

$$\sigma_+^{EM}(e^-_{L,R}, e^+_{R,L}) = \frac{\pi\alpha^2}{6E^2}(2 + \frac{m_e^2}{E^2})(f_{1\upsilon} + g_{1\upsilon})^2 \tag{14}$$

$$\sigma_+^{INT}(e^-_{L,R}, e^+_{R,L}) = \frac{G_F^2 E^2}{3\pi}[2(g_{Ve} \pm g_{Ae}) + \frac{m_e^2}{E^2} g_{Ve}](\frac{f_{1\upsilon} + g_{1\upsilon}}{Q_S}) \tag{15}$$

$$\sigma_{-}^{EM}(e_{L,R}^{-},e_{R,L}^{+})=\frac{\pi\alpha^{2}}{6m_{e}^{2}}(f_{2\upsilon}^{2}+g_{2\upsilon}^{2}) \qquad (16)$$

The upper sign goes back to the case (e_L^-, e_R^+) and the lower sign returns to the case (e_R^-, e_L^+). By comparing cross sections for pairs $(e_{L,R}^-, e_{L,R}^+)$ with cross-sections for pairs $(e_{L,R}^-, e_{R,L}^+)$ in the case of high energies which prevail among the stars, we note that the result of the situation $s_- s_+ = -1$ accompanying the pairs $(e_{L,R}^-, e_{R,L}^+)$ not equal to the result of the situation $s_- s_+ = 1$ accompanying the pairs $(e_{L,R}^-, e_{L,R}^+)$ but is above it.

This study suggests that neutrinos propagate in medium (material and electromagnetic fields) under the influence of specific bonds that lead to a flip in their helicity as is the case with flavor oscillation of neutrino stimulated by electromagnetic fields and material currents. These correlation s, however small, remain an interesting subject that may change our current understanding of the helicity of neutrinos in dense and hot media, and may cause the failed simulation of the supernova to become a successful one.

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