Photon Neutrino Interaction in a Charge Neutral Magnetized Medium

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1. Introduction

In the standard model the null electric charge of neutrinos (ν) are protected by the absence of gauge anomaly. However in the extension of standard model neutrinos can have intrinsic charge but we are not considering the same here. We are estimating the induced charge on ν (Dirac neutrino) due to medium effects. As far as their astrophysical application is concern, the rotating dipole field of stars generate an electric field $E_{\|}$ [1]. The neutrinos can interact with this electric field through their induced charge. Thus screening the same. On the other hand, if this is true then the electric field of bare strange star may get screened by in medium charged neutrinos. There may be other astrophysical or cosmological implications of the same but we do not discuss them here.

2. Neutrino Charge

Intuitively as a neutrino moves inside a thermal medium composed of electrons and positrons, they interact with these background particles. The background electrons and positrons themselves have interaction with the electromagnetic fields, and this fact gives rise to an effective coupling of the neutrinos to the photons. Under these circumstance's the neutrinos may acquire an "effective electric charge" through which they interact with the ambient plasma.

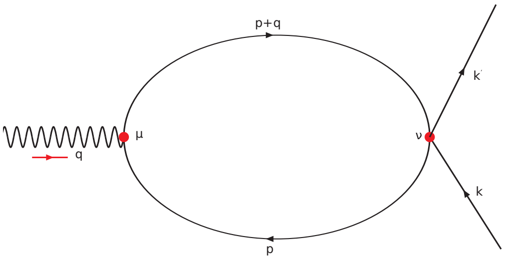

FIG. 1: One-loop diagram for the effective electromagnetic vertex of the neutrino in the limit of infinitely heavy W and Z masses.

The effective charge of the neutrino has been evaluated previously in [2–6]. In this paper we concentrate upon the effective neutrino photon vertex (at zero chemical potential) coming from the vectorial part of the interaction. From there we estimate the effective charge of the neutrino inside a magnetised medium. The effective neutrino photon interaction in the effective Lagrangian becomes possible due to the polarisation tensor $\Pi_{\mu\nu}$, which we have used in this estimates.

For momenta small compared to the masses of the W and Z bosons the leading order expression of the vertex Γ_{ν} in Fermi constant, G_F is given by:

$$\Gamma_{\nu} = -\frac{1}{\sqrt{2}e} G_F \gamma^{\mu}(1-\gamma_5)\left(g_{\rm V}\Pi_{\mu\nu} + g_{\rm A}\Pi^5_{\mu\nu}\right), \quad (1)$$

Where the coupling constants for electron neutrinos,

$$g_{\rm V} = 1 - (1 - 4\sin^2\theta_{\rm W})/2, \quad (2)$$
$$g_{\rm A} = -1 + 1/2 \quad (3)$$

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and for muon and tau neutrino,

$$g_{\rm V} = -(1 - 4\sin^2\theta_{\rm W})/2, \quad (4)$$

$$g_{\rm A} = 1 - 1/2 \quad (5)$$

This vertex is obtained by evaluating the Feynman diagram provided in Fig.[1]. The effective charge of the neutrinos is defined in terms of the vertex function by the following relation [2]:

$$e_{eff} = \frac{1}{2q_0}\bar{u}(q)\Gamma_0(k_0 = 0, \mathbf{k} \to 0)u(q) \quad (6)$$

when,

$$\Gamma_0 = -\left(\frac{G_F g_V}{\sqrt{2}e}\right)\gamma_0(1-\gamma_5)\Pi_L(0, \mathbf{k} \to 0). \quad (7)$$

Finally using the properties of the Dirac spinors, for massive fermions;

$$\begin{aligned} e_{eff} &= -\frac{G_F g_V}{\sqrt{2}e}\Pi_L(0, \mathbf{k} \to 0)\left(1 - \frac{\lambda|k|}{\omega}\right), \quad (8) \\ &= -\frac{G_F g_V}{\sqrt{2}e}(\Pi_L^{(eB)^0} + \Pi_L^{(eB)^2})\left(1 - \frac{\lambda|k|}{\omega}\right). \quad (9) \end{aligned}$$

Where Π_L is the form factor of the longitudinal part of the polarization tensor $\Pi_{\mu\nu}$. The terms $\Pi_L^{(eB)^0}$ and $\Pi_L^{(eB)^2}$ are the magnetic field independent and dependent part of Π_L respectively. The expression of $\Pi_L^{(eB)^0}$ and $\Pi_L^{(eB)^2}$ are obtained as:

$$\begin{aligned} \Pi_L^{(eB)^0} &= -\frac{e^2 m_e^2}{1.68\pi^{\frac{3}{2}}}\left(\frac{T}{m_e}\right)^{\frac{1}{2}} e^{-\frac{\sqrt{2}m_e}{T}}\mathcal{F}(\theta), \quad (10) \\ \Pi_L^{(eB)^2} &= -\frac{e^2 m_e^2}{1.68\pi^{\frac{3}{2}}}\left(\frac{m_e}{T}\right)^{\frac{3}{2}}\left(\frac{eB}{m_e^2}\right)^2 e^{-\frac{\sqrt{2}m_e}{T}} \\ &\times \mathcal{F}(\theta). \quad (11) \end{aligned}$$

Where the term $\mathcal{F}(\theta)$ is an angle dependent factor that may arise due to the rotational symmetry breaking introduced by the external magnetic field.

For ultra-relativistic neutrinos, the effective charge comes out as:

$$\begin{aligned} e_{eff} &= \frac{G_F g_V}{\sqrt{2}e}\frac{e^2 m_e^2}{1.68\pi^{\frac{3}{2}}}\frac{\sqrt{2}m_e}{T}\mathcal{F}(\theta)(1 - \lambda) \\ &\times \left[\left(\frac{T}{m_e}\right)^{\frac{1}{2}} + \left(\frac{m_e}{T}\right)^{\frac{3}{2}}\left(\frac{eB}{m_e^2}\right)^2\right]. \quad (12) \end{aligned}$$

Now, the coulomb force (F_C) experienced by the neutrinos due to this effective charge e_{eff}, in the magnetosphere of a compact star, is $F_C = e_{eff}E_{\|}$, where the electric field $E_{\|}$ is given by[1]:

$$E_{\|} \sim \frac{1}{8\sqrt{3}}(\Omega R_{NS})^{\frac{5}{2}} B\sqrt{\frac{2R_{NS}}{r}}. \quad (13)$$

In eqn. (13), B is the surface magnetic field of the compact object.

The $\nu, \bar{\nu}$ pair production rate due to this electric field via Schwinger mechanism would then be given by [8]:

$$\Gamma_{\gamma\to\nu,\bar{\nu}} = \frac{e_{eff}^2 E_{\|}B}{4\pi^2}\coth\left(\frac{\pi B}{E_{\|}}\right)e^{-\frac{\pi m_\nu^2}{e_{eff}E_{\|}}} \quad (14)$$

For an old compact object like hypothetical strange star, these medium induced neutrino charge stands a chance to screen the electric field ($E_{\|}$) of the star. We would like to explore some of these issues in future.

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