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Of Neutrinos and Magnetars

Sushan Konar*
i. Department of Physics & Meteorology, ii. Centre for Theoretical Studies,
Indian Institute of Technology, Kharagpur 721302

Abstract. We discuss the nature of neutrino propagation in presence of the strong magnetic field of *magnetars*.

Keywords : neutrino–propagation: neutron star–magnetic field

Standard Model Neutrinos do not have any mass, charge or anomalous magnetic moment. Even massive neutrinos, beyond standard model, have negligible or zero magnetic moment. Evidently, neutrinos do not couple to photons in vacuum. However, in the presence of a thermal medium and/or an external electro-magnetic field $\nu - \gamma$ interaction can be mediated by W and Z bosons, leading to an effective four-Fermi vertex (Fig.1A). The charged particles, running in the loop, confer their electro-magnetic properties to the neutrinos making the $\nu - \gamma$ processes sensitive to the presence of an external magnetic field. In particular, processes like neutrino Cerenkov radiation ($\nu \rightarrow \nu\gamma$) or plasmon decay ($\gamma \rightarrow \nu\nu$) would be greatly enhanced due to the presence of the strong magnetic field ($\mathcal{B} \sim 10^{15}$ G) of the Magnetars and can strongly influence the space velocity, the cooling history and even the generation of the magnetic field in such objects.

The amplitude of a $\nu - \gamma$ process is proportional to the vertex function Γ_ν which, to leading order in the coupling constant G_F and in the limit of $M_W, M_Z \rightarrow \infty$, is given by

$$\Gamma_\nu = -\frac{1}{\sqrt{2}e} G_F \gamma^\mu (1 - \gamma_5)(g_V \Pi_{\mu\nu} - g_A \Pi^5_{\mu\nu}) \qquad (1)$$

where, $\Pi^5_{\mu\nu}$ and $\Pi_{\mu\nu}$ are the axial-vector–vector coupling (Fig. 1A), and the photon self-energy (Fig. 1B). The dependence of Γ_ν on the magnetic field and the density of the medium enter through the electron propagators (internal lines) of the self-energy and $\nu - \gamma$ coupling diagrams of Fig. 1.

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*e-mail:sushan@cts.iitkgp.ernet.in

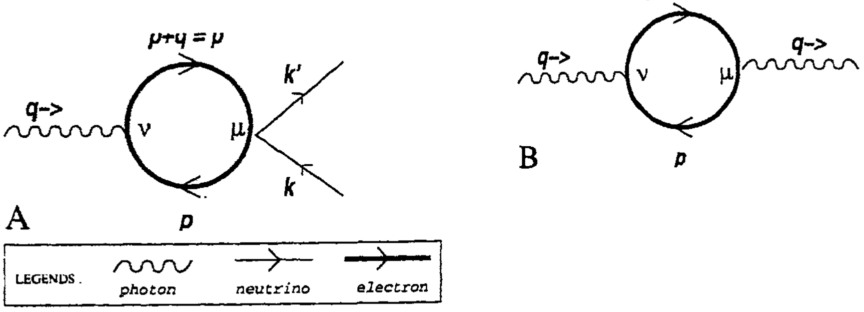

Figure 1. (A) - One-loop diagram for the effective electro-magnetic vertex of the neutrino in the limit of infinitely heavy W and Z masses. (**B**) - One loop diagram for vacuum polarization.

Recently, Bhattacharya, Ganguly & Konar (2002) have shown that, to the first order in the magnetic field strength, the effective charge of the neutrinos is

$$e^{\nu}_{\mathrm{eff}}(\mathcal{B}) \propto \left(\frac{\mathcal{B}}{\mathcal{B}_c}\right) f(m\beta)\cos\theta\, e^{\nu}_{\mathrm{eff}}(\mathcal{B}=0)\,, \quad \mathcal{B}_c \text{ - critical field for electrons} \tag{2}$$

where β is the temperature inverse and θ is the angle between $\mathcal{B}$ and the neutrino 4-momemtum k. Evidently, the $\nu - \mathcal{B}$ interaction is direction dependent which gives rise to asymmetries in neutrino-driven supernova explosion and may result in large pulsar kick velocities (Bhattacharya & Pal, 2000).

The previous investigations have only been concerned with the $\nu - \gamma$ interaction to the linear order in the magnetic field strength. Such results are pertinent for weak-field situations. However, in the context of Magnetars we need the results valid for all orders in the magnetic field strength. In the present work, we calculate the rate of these processes to all orders in the magnetic field strength. Our preliminary results show that the absorptive part of the $\nu - \gamma$ processes, to the lowest order, is enhanced by a factor $\sim \mathcal{B}^2$ (Konar & Das, 2002). Evidently, these effects are important only for strong fields and can be ignored otherwise.

It is understood that with the pre-existing poloidal magnetic field a strong toroidal field can be generated within the supernova due to the differential rotation near the core. The asymmetric neutrino emission would be able to provide the necessary torque required for this rotation and enhance the magnetic field to very large values (Gvozdev & Ognev, 1999). An estimate of such enhancement, based on our result, would be presented in a future communication (Konar, 2003).

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