Polarization effects in neutrino pairs production by electrons(positrons) in hot stellar magnetic fields

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Polarization effects in neutrino pairs production by electrons (positrons) in hot stellar magnetic fields with allowance for the longitudinal polarizations of the initial and final electrons (positrons) are investigated. The asymmetry of the cooling in the process of electron neutrino pairs emission by electrons (positrons) is eight (four) times more than that one in the process of muon neutrino pairs emission by electrons (positrons) or in the process of tauon neutrino pairs emission by electrons (positrons).

1 Introduction

We investigate polarization effects in neutrino pairs production by electrons (positrons)

$$e^{\pm} \longrightarrow e^{\pm} + \nu_i + \widetilde{\nu}_i, \tag{1}$$

in hot stellar magnetic fields (e.g., in magnetars [1]) with allowance for the longitudinal polarizations of the initial and final electrons (positrons). Here $\nu_i = \nu_e, \nu_\mu, \nu_\tau$ and $\widetilde{\nu}_i = \widetilde{\nu}_e, \widetilde{\nu}_\mu, \widetilde{\nu}_\tau$. These processes were studied by numerous authors [2]-[9]. We present the analytic formula for the differential probability (DP) of the neutrino pairs emission by electrons (positrons) in hot stellar magnetic fields with allowance for the longitudinal polarizations of the initial and final electrons (positrons). It enables us to analyze the energy loss by electrons (positrons) having the different polarization states by means of neutrino pairs emission in hot stellar magnetic fields with allowance for the longitudinal polarizations of the initial and final electrons (positrons).

2 Differential probability of the processes and asymmetry of cooling of electrons (positrons) having different polarization states

We obtain for the DP per unit of time and per unit of volume

$$dw = (2\pi)^{-7} G_F^2 eH\omega^2\omega'^2 \sum_{\mathrm{n}=1}^{\infty} \sum_{\mathrm{n}'=0}^{\mathrm{n}-1} \sum_{\mathrm{i}} \frac{E_i E_i'}{|E_i' p_{zi} - E_i p_{zi}'|} Q f_e (1 - f_e') d\omega d\omega' d\Omega d\Omega'. \tag{2}$$

The meanings of the above indicated notations can be found in [10]. When electrons (positrons) are in different longitudinal polarization states, the asymmetry of the cooling of an electron (positron) gas by emission of neutrino pairs in a magnetic field can be determined by the general expression

$$A = \frac{dw_R - dw_L}{dw_R + dw_L}, \tag{3}$$

where $dw_R = dw(\zeta = 1, \zeta' = 1)$, $dw_L = dw(\zeta = -1, \zeta' = -1)$. Here $\zeta(\zeta')$ characterizes the orientation of the spin of the initial (final) electrons or positrons and $\zeta, \zeta' = +1(-1)$ corresponds to right-hand (left-hand) helicity.

3 Numerical estimations on asymmetry of cooling of electrons (positrons) having different polarization states

Let us consider two different types of an electron (positron) gas: the gas consisting of only the electrons (positrons) having a left-hand circular polarization and the gas consisting of only the electrons (positrons) having a right-hand circular polarization. We also assume that these two types of an electron (positron) gas are not mixed and the initial temperatures of the both of the gases are equal. After emission of neutrino pairs by electrons (positrons) the gases will be cooled at the expense of the energy transfer from electrons (positrons) to the emitted neutrino pairs. However, the gas consisting of only the electrons (positrons) having a left-hand circular polarization and the gas consisting of only the electrons (positrons) having a right-hand circular polarization will be cooled differently: $T_L \neq T_R$. Here T_L is the temperature of the gas (after neutrino pair emission) consisting of only the electrons (positrons) having a left-hand circular polarization and T_R is the temperature of the gas (after neutrino pair emission) consisting of only the electrons (positrons) having a right-hand circular polarization. Let us consider the case of $\vartheta = 0,\ \vartheta' = \pi/2,\ \alpha' = \varphi$ for numerical estimations, where $\vartheta(\vartheta')$ is the polar angle of the emitted antineutrino (neutrino) momentum, α' is the azimuthal angle of the emitted neutrino momentum, $tg\varphi = q_y/q_x,\ q = k + k',\ k(k')$ is the 4-momentum of the emitted antineutrino (neutrino). If we consider the transition between the following Landau levels $n = 2 \longrightarrow n' = 1$ in magnetars ($H \cong 4.41 \times 10^{15} G$) and the (anti)neutrinos of energy $\omega, \omega' \cong 1 MeV$, we obtain $A_{e^- \nu_e \widetilde{\nu}_e} \cong -0.80$ for the $e^- \longrightarrow e^- \nu_e \widetilde{\nu}_e$ process. Numerical estimations show that for the considered case of the magnetic field strength and the (anti)neutrino energy $A_{e^- \nu_\mu \widetilde{\nu}_\mu} = A_{e^- \nu_\tau \widetilde{\nu}_\tau} \cong -0.10$, i.e. $A_{e^- \nu_e \widetilde{\nu}_e} \cong 8 A_{e^- \nu_\mu \widetilde{\nu}_\mu} \cong 8 A_{e^- \nu_\tau \widetilde{\nu}_\tau}$.

Now we consider the process $e^+ \longrightarrow e^+ \nu_i \widetilde{\nu}_i$ and the case of $\vartheta = 0,\ \vartheta' = \pi/2,\ \alpha' = \varphi$ for numerical estimations of the asymmetry of the cooling. If we consider the transition $n = 2 \longrightarrow n' = 1$ in magnetars ($H \cong 4.41 \times 10^{15} G$) and the (anti)neutrinos of energy $\omega, \omega' \cong 1 MeV$, we obtain $A_{e^+ \nu_e \widetilde{\nu}_e} \cong 0.84$ for the $e^+ \longrightarrow e^+ \nu_e \widetilde{\nu}_e$ process. Numerical estimations show that for the considered case of the magnetic field strength and the (anti)neutrino energy $A_{e^+ \nu_\mu \widetilde{\nu}_\mu} = A_{e^+ \nu_\tau \widetilde{\nu}_\tau} \cong 0.21$, i.e. $A_{e^+ \nu_e \widetilde{\nu}_e} \cong 4 A_{e^+ \nu_\mu \widetilde{\nu}_\mu} \cong 4 A_{e^+ \nu_\tau \widetilde{\nu}_\tau}$.

4 Conclusions

It is shown that the differential probabilities of the considered processes are sensitive to the spin variable of the initial and final electrons (positrons) and to the direction of the emitted neutrino pairs momenta. In general, the gas consisting of only the electrons (positrons) having a left-hand circular polarization and the gas consisting of only the electrons (positrons) having a right-hand circular polarization are cooled at the expense of neutrino pairs emission by the electrons (positrons) in hot stellar magnetic fields asymmetrically. In the cooling process of the electron (positron) gas at the expense of neutrino pairs emission by the electrons (positrons) in hot stellar magnetic fields the dominant role belongs to the electron neutrino pairs emission process compared with the contribution of the muon (tauon) neutrino pairs emission process. The asymmetry of the cooling in the process of electron neutrino pairs emission by electrons is 8 times more than that one in the process of muon neutrino pairs emission by electrons or in the process of tauon neutrino pairs emission by electrons. The asymmetry of cooling in the process of electron neutrino pairs emission by positrons is 4 times more than that one in the process of muon neutrino pairs emission by positrons or in the process of tauon neutrino pairs emission by positrons.

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