New distinguishing feature of a matter and an antimatter: asymmetry in the cooling of charged leptons and antileptons by means of neutrino pairs emission in a magnetic field

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The synchrotron emission of neutrino pairs by charged leptons (charged antileptons) in hot dense stellar magnetic fields is investigated in the work. It is shown that a matter and an antimatter are cooled at the expense of neutrino pairs emission asymmetrically. The dominant contribution to the asymmetry of the cooling of the collapsing stellar core is determined with the electron neutrino pairs emission by the electrons (positrons) having a left-hand (right-hand) circular polarization.

1 Introduction

At the neutrino cooling stage a neutron star (NS) cools mainly via neutrino emission from its interiors. In order to analyze the cooling mechanism of a NS it is important to investigate various neutrino reactions in a NS. Here we discuss the neutrino pairs emission by a charged lepton (antilepton) gas in hot dense stellar magnetic fields (e.g., in magnetars [1])

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

where $l^{\pm} = e^{\pm}, \mu^{\pm}, \tau^{\pm}$; $\nu_i = \nu_e, \nu_\mu, \nu_\tau$ and $\widetilde{\nu}_i = \widetilde{\nu}_e, \widetilde{\nu}_\mu, \widetilde{\nu}_\tau$. The considered processes are called the synchrotron emission of neutrino pairs (SEONP) by charged leptons (CL) (charged antileptons (CA)). They are responsible for a significant fraction of the energy loss by CL (CA) in the stellar medium and for the cooling of a NS. The SEONP by CL in a magnetic field (MF) and some aspects of polarization effects arising in these processes were studied by numerous authors [2]-[9]. However, the SEONP by CL in hot stellar MFs with allowance for the longitudinal polarizations (LP) of the initial and final CL has not been investigated completely. The main purpose of this paper is to present an analytic formula for the differential probability (DP) of the SEONP by CL (CA) in a MF with allowance for the LP of the initial and final CL (CA), to analyze polarization effects, to calculate the asymmetry of the cooling (AC) of the CL (charged lepton gas) and CA (charged antilepton gas) having the same polarization states by the emission of neutrino pairs in a MF and to show possible applications of the obtained results. Therefore, here we calculate the dependence of the DP of the SEONP by CL(CA) on the polar and azimuthal angles of the momenta of the emitted neutrinos and antineutrinos in a MF.

2 Differential probability of the processes and asymmetry of cooling of charged leptons and charged antileptons having the same polarization states

In the low-energy approximation of the standard Weinberg-Salam-Glashow model we obtain for the DP per unit of time and per unit of volume

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

The meanings of the above indicated notations can be found in [10]. Let us consider two different types of a gas: the gas consisting of only CL and the gas consisting of only CA. We also assume that these two types of a gas are not mixed and the initial temperatures of both of the gases are equal: $T_{l^-} = T_{l^+} = T$. After neutrino pairs emission by CL and CA the gases will be cooled at the expense of the energy transfer from CL and CA to the neutrino pairs. Analyses show that $Q_- \neq Q_+$ and $dw_- \neq dw_+$, where $Q_-(Q_+)$ and $dw_-(dw_+)$ correspond to the $l^-(l^+)$-processes. So, the gas consisting of only CL and the gas consisting of only CA will be cooled asymmetrically: $T'_{l^-} \neq T'_{l^+}$. Here T'_{l^-} is the temperature of the gas consisting of only CL in the final state and T'_{l^+} is the temperature of the gas consisting of only CA in the final state. The AC of a charged lepton gas and a charged antilepton gas by neutrino pairs emission is explained by asymmetric energy transfer from CL and CA to the neutrino pairs. The AC of a charged lepton gas and a charged antilepton gas by neutrino pairs emission can be determined by the general expression

$$A = \frac{dw_- - dw_+}{dw_- + dw_+}. \quad (3)$$

3 Analyses and numerical estimations

Within the considered kinematics and conditions and in the limiting case of a very high temperature, $T \gg (eH)^{1/2}, \mu$, an influence of a medium leads to the constant statistical factors of 1/2 both for the charged lepton gas and charged antilepton gas and the AC is determined as $A = (Q_- - Q_+)/(Q_- + Q_+)$. Here H is a magnetic field strength and μ is a chemical potential of a charged lepton (antilepton) gas. When initial CL and CA have a left-hand circular polarization, the AC $A_- = A(\zeta = -1) = (g_L^2 - g_R^2)/(g_L^2 + g_R^2)$. Here $g_L = 0.5 + sin^2\theta_w$, $g_R = sin^2\theta_w$ for ν_e-processes, $g_L = -0.5 + sin^2\theta_w$, $g_R = sin^2\theta_w$ for $\nu_\mu(\nu_\tau)-$processes and θ_w is the Weinberg angle. When initial CL and CA have a right-hand circular polarization, the AC is $A_+ = A(\zeta = +1) = -(g_L^2 - g_R^2)/(g_L^2 + g_R^2)$. The expressions for A_- and A_+ show that in the limiting case of a very high temperature $A_- = -A_+$ and the AC is sensitive to a neutrino flavour and spin variables of initial CL and CA. For $e^\pm \longrightarrow e^\pm \nu_e \widetilde{\nu}_e$ processes $A_{e\nu_e\widetilde{\nu}_e}(\zeta = \mp 1) \cong \pm 0.82$ and for $e^\pm \longrightarrow e^\pm \nu_\mu \widetilde{\nu}_\mu$ and $e^\pm \longrightarrow e^\pm \nu_\tau \widetilde{\nu}_\tau$ processes $A_{e\nu_\mu\widetilde{\nu}_\mu}(\zeta = \mp 1) = A_{e\nu_\tau\widetilde{\nu}_\tau}(\zeta = \mp 1) \cong \pm 0.16$. Comparison of the AC for $e^\pm \longrightarrow e^\pm \nu_e \widetilde{\nu}_e$ processes and $e^\pm \longrightarrow e^\pm \nu_\mu \widetilde{\nu}_\mu$ or $e^\pm \longrightarrow e^\pm \nu_\tau \widetilde{\nu}_\tau$ processes gives $A_{e\nu_e\widetilde{\nu}_e}/A_{e\nu_\mu\widetilde{\nu}_\mu} = A_{e\nu_e\widetilde{\nu}_e}/A_{e\nu_\tau\widetilde{\nu}_\tau} \cong 5.13$.

In case of $\zeta = -1$ we obtain for the $e^{\pm} \longrightarrow e^{\pm}\nu_e\widetilde{\nu}_e$ processes $dw_{-} \cong 10dw_{+}$. It means that when electron neutrino pairs are emitted by the electrons and positrons having a left-hand circular polarization, $e^{-} \longrightarrow e^{-}\nu_e\widetilde{\nu}_e$ can contribute to the cooling process of the collapsing stellar core more essentially than $e^{+} \longrightarrow e^{+}\nu_e\widetilde{\nu}_e$. In case of $\zeta = +1$ we obtain for the $e^{\pm} \longrightarrow e^{\pm}\nu_e\widetilde{\nu}_e$ processes $dw_{+} \cong 10dw_{-}$. It means that when electron neutrino pairs are emitted by the electrons and positrons having a right-hand circular polarization, the $e^{+} \longrightarrow e^{+}\nu_e\widetilde{\nu}_e$ process can contribute to the cooling process of the collapsing stellar core more essentially than the $e^{-} \longrightarrow e^{-}\nu_e\widetilde{\nu}_e$ process. In principle, the formulae describing $e^{-} \longrightarrow e^{-}\nu_i\widetilde{\nu}_i$ and $e^{+} \longrightarrow e^{+}\nu_i\widetilde{\nu}_i$ can formally be applied to the $l^{\pm} \longrightarrow l^{\pm}\nu_i\widetilde{\nu}_i$ processes and to the processes of neutrino pairs emission by quarks (antiquarks). So, the obtained result for the AC of an electron gas and a positron gas by neutrino pairs emission is evidence for the AC of a matter and an antimatter by neutrino pairs emission. It is a new distinguishing feature of a matter and antimatter.

4 Conclusions

The obtained result for the AC of CL gas and CA gas by neutrino pairs emission shows that a matter and an antimatter are cooled at the expense of neutrino pairs emission asymmetrically. It is a new distinguishing feature of a matter and antimatter. The dominant contribution to the asymmetry of the cooling of the collapsing stellar core is determined with the electron neutrino pairs emission by the electrons (positrons) having a left-hand (right-hand) circular polarization. All these effects could contribute to the AC of the collapsing stellar core.

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