ASYMMETRY IN COOLING OF CHARGED LEPTON GAS IN NEUTRINO PAIR EMISSION BY CHARGED LEPTONS IN HOT STELLAR MAGNETIC FIELDS

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The neutrino pair production by a charged lepton

$$l^- \to l^- + \nu_i + \tilde{\nu}_i \tag{1}$$

plays a significant role in the strongly magnetized stars or in the supernova explosions, where $l^- = e^-, \mu^-, \tau^-$, $\nu_i = \nu_e, \nu_\mu, \nu_\tau$ and $\tilde{\nu}_i = \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$. This process is responsible for a significant fraction of the energy loss by charged leptons in the stellar medium. The main purpose of this work is to present the analytic formula for the differential probability of the neutrino pair emission by charged leptons in hot stellar magnetic fields with allowance for the longitudinal polarizations of the initial and final charged leptons, to calculate the asymmetry in cooling of the charged leptons (charged lepton gas) having a left-hand circular polarization and the charged leptons having a right-hand circular polarization by the neutrino pair emission in hot stellar magnetic fields and to show possible applications of the obtained results.

We use the standard Weinberg-Salam-Glashow electroweak interaction theory. When the momentum transferred is relatively small, $\left|q^2\right| \ll m_W^2, m_Z^2$ (m_W is the $W^\pm$-boson mass, m_Z is the Z-boson mass), the four-fermion approximation of the Weinberg-Salam-Glashow standard model can be used. The gauge of a 4-potential is $A^\mu = (0,0,xH,0)$ and an external magnetic field vector $\mathbf{H}$ is directed along the axis Oz.

The differential probability of the process $l^- \to l^- \nu_i \tilde{\nu}_i$ per unit of time and per unit of volume in a magnetic field can be written as

$$dw = \frac{G_F^2 eH \omega^2 \omega'^2}{(2\pi)^7} \sum_{n,n'=0}^{\infty} \sum_i \frac{E_i E_i'}{\left|E_i' p_{zi} - E_i p_{zi}'\right|} Q_0 f_l (1 - f_l') d\omega d\omega' d\Omega d\Omega', \tag{2}$$

where Q_0 [1] is the function of a magnetic field strength H, spin variables ζ, ζ' and energies E, E' of charged leptons in initial and final states, the polar angle of antineutrino (neutrino) momentum ϑ (ϑ'), the difference between the azimuthal angles of antineutrino momentum and neutrino momentum $\alpha - \alpha'$, the angle φ ($\tan\varphi = q_y / q_x$, $q_\beta = k_\beta - k_\beta'$, $k_\beta\left(k_\beta'\right)$ is the antineutrino (neutrino) 4-momentum, $\beta = 0,1,2,3$) and the parameter

$$x = (1/2eH)\left[\omega^2 \sin^2\vartheta + \omega'^2 \sin^2\vartheta' - 2\omega\omega' \sin\vartheta \sin\vartheta' \cos(\alpha - \alpha')\right], \tag{3}$$

$p_{zi}\left(p_{zi}'\right)$ is the third component of the initial (final) charged lepton momentum which satisfies the equation $p_z = p_z' + k_z + k_z'$, $\omega(\omega')$ is the antineutrino (neutrino) energy, $n(n')$ is the principal quantum number of the charged lepton in the initial (final) state, G_F is the Fermi constant, e is the elementary electric charge, $d\Omega(d\Omega')$ is the solid angle element along the antineutrino (neutrino) momentum, $f_l = f_l(E, T_e)$ is the Fermi-Dirac distribution of charged leptons in the initial state, T_l is the temperature of the matter (charged lepton gas) before scattering, $f_l' = f_l'(E', T_l')$ is the Fermi-Dirac distribution of charged leptons in the final state, T_l' is the temperature of the matter (charged lepton gas) after scattering.

Generally, it is derived from the expressions (2) that the differential probability of the process $l^- \to l^- \nu_i \tilde{\nu}_i$ is sensitive to the spin variables of both initial and final charged leptons.

This could lead to anisotropies and asymmetry in the cooling of the stellar matter (e.g., electron gas). It happens due to asymmetric energy transfer from charged leptons to the emitted neutrino pairs depending on the polarization states of the charged leptons in a magnetic field.

Let us consider two different types of a charged lepton gas: the gas consisting of only the charged leptons having a left-hand circular polarization and the gas consisting of only the charged leptons having a right-hand circular polarization. We also assume that these two types of a charged lepton gas are not mixed and the initial temperatures of the both gases are equal. After emission of neutrino pairs by charged leptons the gases will be cooled at the expense of the energy transfer from charged leptons to the emitted neutrino pairs. However, the gas consisting of only the charged leptons having a left-hand circular polarization and the gas consisting of only the charged leptons 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 charged leptons having a left-hand circular polarization and T_R is the temperature of the gas (after neutrino pair emission) consisting of only the charged leptons having a right-hand circular polarization. Asymmetry in cooling of the two types of a gas consisting of charged leptons having different polarization states in neutrino pair emission by charged leptons in a magnetic field can be determined by the general expression

$$A = \frac{dw_R - dw_L}{dw_R + dw_L} \ , \tag{4}$$

where $dw_R = dw(\zeta = 1, \zeta' = 1)$ and $dw_L = dw(\zeta = -1, \zeta' = -1)$.

If we consider the transition $n = 2 \to n' = 1$ (for numerical estimations) and suppose that antineutrinos and neutrinos are emitted along the magnetic field direction $(\vartheta = 0, \vartheta' = 0)$, for magnetars ($H \simeq 4.41 \times 10^{15} G$) [2] and the neutrinos of energy $\omega' \simeq 1 MeV$ we obtain $A_{l^-\nu_l\tilde{\nu}_l} \simeq -0.91$ for the $l^- \to l^-\nu_l\tilde{\nu}_l$ process and $A_{l^-\nu_i\tilde{\nu}_i} \simeq -0.47$ for the $l^- \to l^-\nu_i\tilde{\nu}_i$ process, where $i \neq l$. If we consider the same transition and suppose that antineutrinos and neutrinos are emitted against the magnetic field direction $(\vartheta = \pi, \vartheta' = \pi)$, for magnetars and the neutrinos of energy $\omega' \simeq 1 MeV$ we obtain $A_{l^-\nu_l\tilde{\nu}_l} \simeq -0.67$ for the $l^- \to l^-\nu_l\tilde{\nu}_l$ process and $A_{l^-\nu_i\tilde{\nu}_i} \simeq -0.18$ for the $l^- \to l^-\nu_i\tilde{\nu}_i$ process, where $i \neq l$. If antineutrinos are emitted along the magnetic field direction $(\vartheta = 0)$ and neutrinos are emitted against the magnetic field direction $(\vartheta' = \pi)$, within the above conditions we obtain $A_{l^-\nu_l\tilde{\nu}_l} \simeq -0.82$ for the $l^- \to l^-\nu_l\tilde{\nu}_l$ process and $A_{l^-\nu_i\tilde{\nu}_i} \simeq -0.16$ for the $l^- \to l^-\nu_i\tilde{\nu}_i$ process, where $i \neq l$.

These estimations enable us to come to the conclusion that within the considered kinematics the charged leptons (charged lepton gas) having a left-hand circular polarization and the charged leptons (charged lepton gas) having a right-hand circular polarization are cooled by emission of neutrino pairs asymmetrically and the asymmetry in cooling is sensitive to the neutrino flavour, the magnetic field strength and the neutrino energy.

The effect of asymmetrical cooling of charged leptons (charged lepton gas) having a left-hand circular polarization and the charged leptons (charged lepton gas) having a right-hand circular polarization could contribute to asymmetry and anisotropy in cooling of the stellar medium. But this is a topic of a separate scientific paper and requires a detailed investigation.

REFERENCES

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