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ASYMMETRY IN HEATING OF CHARGED LEPTONS AND ANTILEPTONS BY NEUTRINOS IN A STRONGLY MAGNETIZED THERMAL PLASMA

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CONSIDERED PROCESSES

Neutrino-charged lepton scattering (NCLS)

$$\nu_i + l^- \rightarrow \nu_i + l^-$$

Neutrino-charged antilepton scattering (NCAS)

$$\nu_i + l^+ \rightarrow \nu_i + l^+$$

MOTIVATION

-The work described here is motivated by arising asymmetries in parity violating effects in neutrino-induced processes in a strongly magnetized thermal plasma (SMTP).

- The investigation of the asymmetries arising in parity violating effects are of great importance in clarifying new characteristic features of a matter and an antimatter and in observing macroscopic appearance of parity violating and spin effects in a number of phenomena in particle physics, neutrino astrophysics, cosmology, plasma physics and statistical physics.

- Analyses of the asymmetry in heating (AH) of charged leptons and charged antileptons by neutrinos in SMTP enable us to compare the contributions of NCLS and NCAS to the asymmetry of the subsequent explosion of the outer layers of the collapsing stellar core and to advance our understanding of this important astrophysical phenomenon.

- Determination of AH of charged leptons and charged antileptons by neutrinos in SMTP enables us to realize experimental measurement of the parameter $\xi = \sin^2\theta_\omega$

(θ_ω is the Weinberg angle) and to perform the test

of the Standard Model in an external magnetic field.

MAIN PURPOSES

-One of the main purposes of this work is to present an analytic formula for AH of a charged lepton gas and a charged antilepton gas in SMTP with allowance for longitudinal polarizations of charged leptons (charged antileptons) in initial and final states and to demonstrate AH of a matter and antimatter by neutrinos in SMTP in the model of charged leptons and charged antileptons.

-We also want to show that AH is sensitive to neutrino flavor and spin variables of charged leptons (charged antileptons) in initial state.

-Our purpose is also to show the possible astrophysical applications of the obtained results and to show the ways of using asymmetry in heating of charged leptons and charged antileptons by neutrinos.

RELATED PAPERS

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ASSUMPTIONS

-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, Z -is the -boson mass), the 4-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 MF $\mathbf{H}$ vector is directed along the axis Oz.

-We deal with a massless neutrino.

-We use the pseudo-Euclidean metric with signature $(+---)$ and the system of units $k_B=\hbar=c=1,$

where k_B is the Boltzman constant.

DIFFERENTIAL CROSS SECTIONS OF THE PROCESSES

$$\frac{d\sigma_{\mp}}{d\omega' d\Omega'} = \frac{G_F^2 e H \omega'^2}{32\pi^4} \sum_{n,n'=0}^{\infty} \sum_{i} \frac{E_i E_i'}{\left| E_i' p_{zi} - E_i p_{zi}' \right|} f_{\mp} \left(1 - f_{\mp}' \right) Q_{\mp}$$

where $Q_{\mp}$ is the function of a magnetic field strength H, spin variables ζ, ζ' and energies E, E' (or Landau quantum numbers $n = 0,1,\ldots$ $(n' = 0,1,\ldots)$ and z -components of charged lepton (charged antilepton

momenta) of charged leptons (charged antileptons)

in initial and final states, the polar angle of incident

(scattered) neutrino momentum $\vartheta(\vartheta')$,

the difference between the azimuthal angles of

incident neutrino momentum and scattered neutrino

momentum $\alpha - \alpha'$ the angle $\varphi(\tan\varphi = q_y / q_x, q = k - k', k(k')$

is incident (scattered) neutrino momentum and the parameter

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

$\omega\left(\omega'\right)$ is the incident (scattered) neutrino energy, G_F is the Fermi constant, e is the elementary electric charge, $d\Omega'$ is a solid angle element along scattered neutrino momentum,

$$f_{\mp} = f_{l^{\mp}}\left(E, T_{l^{\mp}}\right) = \left\{\exp\left[\left(E \mp \mu\right)/T_{l^{\mp}}\right] + 1\right\}^{-1}$$

is the Fermi-Dirac distribution of charged leptons (charged antileptons) in initial state, E

is the energy of charged leptons (charged antileptons in initial state, μ

is the charged leptons (charged antileptons) chemical potential, $T_{l^{\mp}}$ is the temperature of the matter (charged lepton (charged antilepton) gas) before scattering,

$$f'_{\mp} = f'_{l^{\mp}}\left(E', T'_{l^{\mp}}\right)$$

is the Fermi-Dirac distribution of charged leptons (charged antileptons) in final state, E' is the energy of a charged lepton (charged antilepton) in the final state, $T'_{l^{\mp}}$ is the temperature of the matter (charged lepton (charged antilepton) gas) after scattering.

Here the plus (minus) sign belongs to charged antileptons (charged leptons).

ASYMMETRY IN HEATING OF CHARGED LEPTONS AND CHARGED ANTILEPTONS BY NEUTRINOS

AH of charged leptons (charged antileptons) by neutrinos in SMTP can be determined by the general expression

$$A = \frac{d\sigma_{-} - d\sigma_{+}}{d\sigma_{-} + d\sigma_{+}}$$

or

$$A = \frac{Q_- h_- - Q_+ h_+}{Q_- h_- + Q_+ h_+}$$

where

$$h_- = f_{l-}\left(1 - f'_{l-}\right) = \exp\left[\left(E'_- - \mu\right)/T'_{l-}\right] \Big/ \left\{\left\{\exp\left[\left(E'_- - \mu\right)/T'_{l-}\right] + 1\right\}\left\{\exp\left[\left(E_- - \mu\right)/T_l\right] + 1\right\}\right\}$$

$$h_+ = f_{l+}\left(1 - f'_{l+}\right) = \exp\left[\left(E'_+ + \mu\right)/T'_{l+}\right] \Big/ \left\{\left\{\exp\left[\left(E'_+ + \mu\right)/T'_{l+}\right] + 1\right\}\left\{\exp\left[\left(E_+ + \mu\right)/T_l\right] + 1\right\}\right\}$$

When $E, E' >> m_e$ and $\upsilon = p_z / \sqrt{E^2 - m_l^2} << 1$, $\upsilon' = p'_z / \sqrt{E'^2 - m_l^2} << 1$, in the kinematics $\vartheta' = \pi/2$, $\alpha' = \varphi$ we have for AH

$$A = \frac{H_{1-}\zeta_-\left(I_4^2 - 2I_2I_3\right) + H_{2-}\zeta_+\left(I_3^2 - 2I_2I_4\right) - \left[G_-\zeta\left(1+h_0\right) - G_+\left(1-h_0\right)\right]\left(1+\zeta\zeta'\right)I_2^2}{H_{1+}\zeta_-\left(I_4^2 - 2I_2I_3\right) + H_{2+}\zeta_+\left(I_3^2 - 2I_2I_4\right) - \left[G_-\zeta\left(1-h_0\right) - G_+\left(1+h_0\right)\right]\left(1+\zeta\zeta'\right)I_2^2}$$

where $H_{1\pm} = g_L^2 \pm g_R^2 h_0$, $H_{2\pm} = g_R^2 \pm g_L^2 h_0$, $G_\pm = g_L^2 \pm g_R^2$, $h_0 = h_+ / h_-$,

$\zeta_\pm = \left(1 \pm \zeta\right)\left(1 \pm \zeta'\right)$, $I_1 = I_{n,n'-1}$, $I_2 = I_{n-1,n'}$, $I_3 = I_{n-1,n'-1}$,

$I_4 = I_{nn'}$

are the Laguerre functions,

$$I_{nn'}(x)=\left(n'!/n!\right)^{1/2}e^{-x/2}x^{(n-n')/2}L_{n'}^{n-n'}(x)$$

and $L_{n'}^{n-n'}(x)$ is the Laguerre polynomial.

In the considered kinematics $Q_{\mp}(\vartheta=0)$

does not contain I_1.

When initial charged leptons (charged antileptons)

have a left-hand circular polarization,

we obtain for AH

$$A_{-} = A(\zeta = -1) = \frac{g_L^2 - g_R^2 h_{0L}}{g_L^2 + g_R^2 h_{0L}}$$

where $h_{0L} = h_{+L} / h_{-L}$, $h_{+L} = h_{+}(T'_{e^+} = T'_{e^+_L})$, $h_{-L} = h_{-}(T'_{e^-} = T'_{e^-_L})$.

When initial charged leptons (charged antileptons) have a right-hand circular polarization $(\zeta = +1)$, we obtain for AH

$$A_{+} = A(\zeta = +1) = \frac{g_R^2 - g_L^2 h_{0R}}{g_R^2 + g_L^2 h_{0R}}$$

where $h_{0R} = h_{+R} / h_{-R}\,, \quad h_{+R} = h_{+}(T'_{e^+} = T'_{e^+_R}),\; h_{-R} = h_{-}(T'_{e^-} = T'_{e^-_R})$

NUMERICAL ESTIMATIONS

$$n = 1 \rightarrow n' = 2$$

$$n_0 \sim 10^{30}\, cm^{-3}$$

For these densities

$$\mu \approx 25.68 MeV (n_0 / 10^{33} cm^{-3})(10^{15} G / H) \approx 0.026 MeV.$$

At characteristic temperatures of magnetars $(T \approx 10^{11} K)$

the characteristic energy for charged leptons (charged antileptons) is

$$E_{\pm} \approx 8.5 MeV$$

So, $\mu << E_{\pm}$ and in the considered case the contribution of the charged lepton (charged antilepton) $n_0 \sim 10^{30} cm^{-3}$ can be neglected.

Although for neutron stars $(H \sim 10^{13} G) \mu \approx 2.6 MeV$ but the conditions $E >> m_l, E' >> m'_l$ is not satisfied for the transition of $n = 1 \rightarrow n' = 2$

May be transitions with considerably higher n, n'

could give perceptible contribution to AH in neutron stars.

However, at the densities

$n \sim 10^{33} cm^{-3}$ and $H \sim 10^{15} G (e.g., H \approx 2.15 \times 10^{15} G)$

we have

$$\mu \approx E'_{\pm} \approx 12 MeV$$

and the contribution of the charged lepton (charged antilepton) number densities of this order is essential. If we suppose $T'_{l_L^+} \approx 1.4 \times 10^{11}\, K \approx 12\, MeV$

(for numerical estimations), in the last considered case we obtain

$$A_{-} \approx 0.95$$

for $\nu_l l^{\pm}$ -scatterings. If we suppose

$$T'_{l_R^+} \approx 1.4 \times 10^{11}\, K \approx 12\, MeV$$

and consider the same densities and magnetic field strength, we obtain

$$A_+ \approx -0.42$$

for $\nu_l l^\pm$ -scatterings. For $\nu_l l^\pm$ -scatterings we obtain

$$A_- \approx 0.70 \quad \text{and} \quad A_+ \approx 0.50$$

Analyses show that when neutrinos scatter on their charged partners and charged antipartners having left-hand circular polarizations, NCLS can contribute to the energy balance of the collapsing stellar core more essentially than NCAS

$$d\sigma_{-} = 39 d\sigma_{+}$$

When neutrinos scatter on their charged partners and charged antipartners having right-hand circular polarizations, NCAS can contribute to the energy balance of he collapsing stellar core more essentially than NCLS

$$d\sigma_{+} = 2.5 d\sigma_{-}$$

In case of $\nu_i l^{\pm}$- scatterings NCLS can contribute to the energy balance of the collapsing stellar core more essentially than NCAS.Within the considered kinematics and conditions and in the limiting case of very high temperature, $T >> (eH)^{1/2}, \mu,$ an influence of a medium leads to the constant statistical factors of $1/2$ both for charged leptons and charged antileptons and AH is determined as

$$A = \left(Q_- - Q_+\right) \big/ \left(Q_- + Q_+\right).$$

When initial charged leptons and charged antileptons have left-hand circular polarizations AH is

$$A_- = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

When initial charged leptons and charged antileptons have right-hand circular polarizations AH is

$$A_+ = -\frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

The last two expressions show that in the limiting case of very high temperature

$$A_{-} = -A_{+}$$

and AH is sensitive to neutrino flavor and spin variables of initial charged leptons and charged antileptons. For $\nu_l l^{\pm}$ -scatterings

$$A_{\nu_1 l}(\zeta = \mp) \approx \pm 0.82$$

and for $\nu_i l^{\pm}$ -scatterings $A_{\nu_1 l}(\zeta = \mp) \approx \pm 0.16$

Comparison of AH for $\nu_l l^\pm$- and $\nu_i l^\pm$-scatterings gives

$$A_{\nu_1 l} / A_{\nu_1 l} \approx 5.13$$

In case of $\zeta = -1$ we obtain for $\nu_l l^\pm$ -scatterings

$$d\sigma_- \approx 10 d\sigma_+$$

It means that when neutrinos scatter on their charged partners and charged antipartners having right-hand circular polarizations, NCAS can contribute to the energy balance of the collapsing stellar core more essentially than NCLS.

In case of $\zeta = +1$ we obtain for $\nu_l l^{\pm}$ -scatterings

$$d\sigma_{+} \approx 10 d\sigma_{-}$$

It means that when neutrinos scatter on their charged partners and charged antipartners having right-hand circular polarizations, NCAS can contribute to the energy balance of the collapsing stellar core All these effects could contribute to asymmetry of the subsequent explosion of the outer layers of the collapsing stellar core. more essentially than NCLS.

FUTURE POSSIBLE EXPERIMENT

Another consequence derived for future experiment is that AH of charged leptons and charged antileptons byneutrinos in SMTP enables us to realize experimental determination of the parameter $\xi = \sin^2\theta_w$ (θ_w is the Weinberg angle) and to perform the test of the Standard Model in an external MF. When electron neutrinos scatter at the beam of charged leptons (charged antileptons) having left-hand circular polarization, we obtain for the parameter ξ

$$\xi_{-1,2} = \frac{1 - A_{-} \pm \sqrt{h_{0L}\left(1 - A_{-}^{2}\right)}}{2\left[\left(1 + h_{0L}\right)A_{-} - 1 + h_{0L}\right]}$$

When electron neutrinos scatter at the beam of charged leptons (charged antileptons) having right-hand circular polarization, we obtain for the parameter ξ

$$\xi_{+1,2} = \frac{-h_{0R}\left(1 + A_{+}\right) \pm \sqrt{h_{0R}\left(1 - A_{+}^{2}\right)}}{2\left[\left(1 + h_{0R}\right) A_{+} - 1 + h_{0R}\right]}$$

We choose the roots that satisfy the condition $\xi = \sin^{2}\theta_{w} > 0.$ Experimental value of AH for A_{-} or A_{+} enables us to determine $\sin^{2}\theta_{w}$

from the last two formulae and to compare this value of $\sin^2\theta_w$ with the theoretical one derived from the Standard Model.

CONCLUSIONS

-It is shown that the asymmetry in heating of charged leptons and charged antileptons by neutrinos in a strongly magnetized thermal plasma is sensitive to neutrino flavor and spin variables of initial charged leptons and charged antileptons and it also depends on the charged lepton (charged antilepton) energy and the medium characteristics.

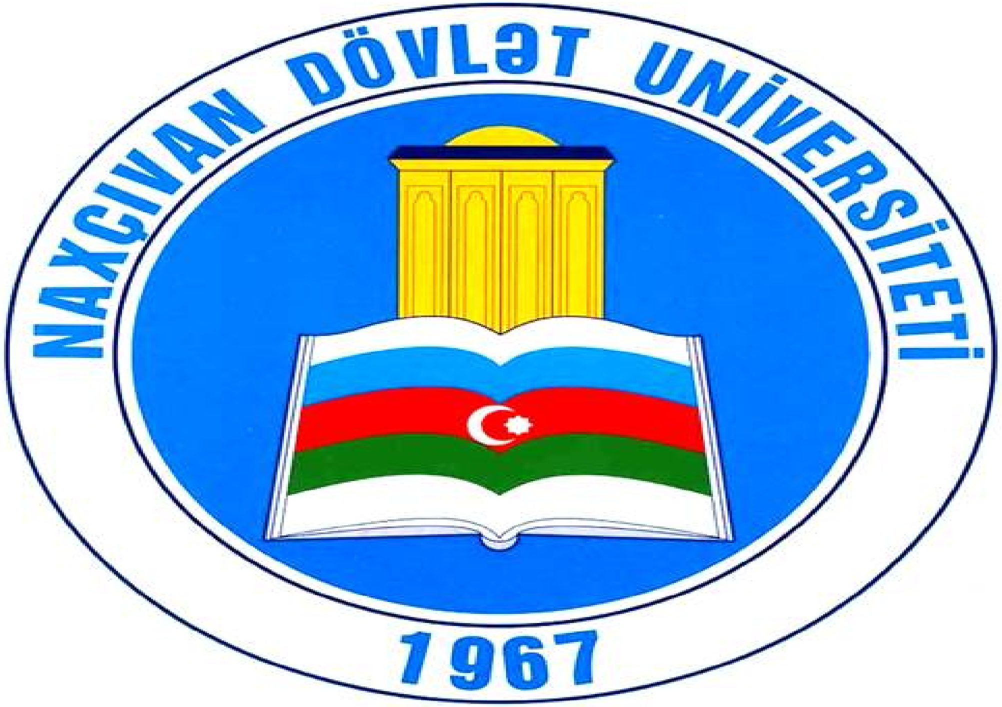
-Analyses of the asymmetry in heating show that the dominant contribution to the asymmetry of the subsequent explosion of the outer layers of the collapsing stellar core is determined with the scattering of neutrinos at their charged partners having a left-hand circular polarization and with the scattering of neutrinos at their charged antipartners having a right-hand circular polarization.

-In principle,the formulae describing neutrino-charged lepton scattering and neutrino-charged antilepton scattering can formally be applied to neutrino-quark (antiquark) scattering.

-The obtained result is evidence for AH of a matter and an antimatter by neutrinos in a strongly magnetized thermal plasma.

The asymmetry in heating of charged leptons and charged antileptons by neutrinos in SMTP enables us to realize experimental determination of the parameter $\xi = \sin^2 \theta_w$

(θ_w is the Weinberg angle) and to perform the test of the Standard Model in an external MF.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