Plasma induced fermion spin-flip conversion $f_L \longrightarrow f_R + \gamma$

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May 28, 2008

International Seminar *"Quarks-2008"*, Sergiev Posad, Moscow Region, May 23-29, 2008

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Based on the papers:

- Plasma induced neutrino radiative decay instead of neutrino spin light, *Modern Physics Letters A. 2006. V. 21. No. 23. P. 1769-1775;* `arXiv:hep-ph/0606262`.
- Plasma induced fermion spin-flip conversion $f_L \to f_R + \gamma$, *International Journal of Modern Physics A, 2007, V. 22, No. 19, pp. 3211-3227;* `arXiv:hep-ph/0701228`.

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Additional neutrino energy in medium

A left-handed neutrino with the flavor $i = e, \mu, \tau$ acquires in medium the additional energy:

$$W(\nu_i) = \sqrt{2}\, G_{\rm F} \Big[\left(\delta_{ie} - \tfrac{1}{2} + 2\,\sin^2\theta_{\rm W}\right) \left(N_e - \bar{N}_e\right) + \left(\tfrac{1}{2} - 2\,\sin^2\theta_{\rm W}\right) \left(N_p - \bar{N}_p\right) - \tfrac{1}{2} \left(N_n - \bar{N}_n\right) + \sum_{\ell = e,\mu,\tau} \left(1 + \delta_{i\ell}\right) \left(N_{\nu_\ell} - \bar{N}_{\nu_\ell}\right) \Big]$$

$N_e, N_p, N_n, N_{\nu_\ell}$ are the number densities of background electrons, protons, neutrons, and neutrinos;

$\bar{N}_e, \bar{N}_p, \bar{N}_n, \bar{N}_{\nu_\ell}$ are the densities of the antiparticles.

For antineutrinos, one should change the total sign.

This value $W(\nu_i)$ is calculated in the local limit of the weak interaction, when the neutrino energy is not too large.

Additional neutrino energy: the typical case

For a typical astrophysical medium (except for the early Universe and a supernova core): $\bar{N}_e \simeq \bar{N}_p \simeq \bar{N}_n \simeq N_{\nu_\ell} \simeq \bar{N}_{\nu_\ell} \simeq 0$, and $N_p \simeq N_e = Y_e \, N_B, \; N_n \simeq (1 - Y_e) \, N_B$

(N_B is the barion density):

$$W(\nu_e) = \frac{G_{\rm F} \, N_B}{\sqrt{2}} \, (3 \, Y_e - 1) \, , \quad W(\nu_{\mu,\tau}) = - \frac{G_{\rm F} \, N_B}{\sqrt{2}} \, (1 - Y_e) \, .$$

As $Y_e < 1$, it means that $W(\nu_{\mu,\tau}) < 0$ and $W(\bar{\nu}_{\mu,\tau}) > 0$.

$W(\nu_e) > 0$ for $Y_e > 1/3$, and $W(\bar{\nu}_e) > 0$ for $Y_e < 1/3$.

Right-handed Dirac neutrinos (and left-handed antineutrinos), being sterile to weak interactions, do not acquire an additional energy.

Effective mass of the left-handed neutrino

The additional energy W gives an effective mass squared m_L^2 to the left-handed neutrino,

$$m_L^2 = \mathcal{P}^2 = (E + W)^2 - \mathbf{p}^2 = 2\,E\,W + W^2 + m_\nu^2\,,$$

where $\mathcal{P}$ is the neutrino four-momentum in medium, while $(E, \mathbf{p})$ would form the neutrino four-momentum in vacuum,

$$E = \sqrt{\mathbf{p}^2 + m_\nu^2}.$$

Effective mass of the left-handed neutrino

Given a $\nu_L \nu_R \gamma$ interaction, caused by **the neutrino magnetic moment**, the radiative neutrino transition can be considered:

$$\nu_L \to \nu_R + \gamma \, .$$

One can speak about a kinematical possibility for the process due to the **effective mass** of ν_L (not ν_R), **induced by the medium influence.**

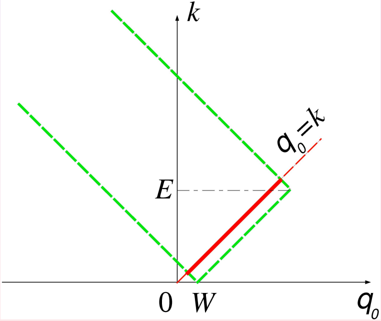
And what about the medium influence on the **photon dispersion properties?**

$SL\nu$ without the photon dispersion in medium

The so-called "spin light of neutrino ($SL\nu$)", was considered in the series of papers by *A. Studenikin et al. (2003-2006, 2008)*, where the photon dispersion in medium was ignored.

$SL\nu$ without the photon dispersion in medium

The region of integration for the width $\Gamma_{\nu_L \to \nu_R}$ with the *fixed initial neutrino energy E* would contain (if a photon did not feel plasma) the vacuum dispersion line $q_0 = k$ (the **red bold** line).

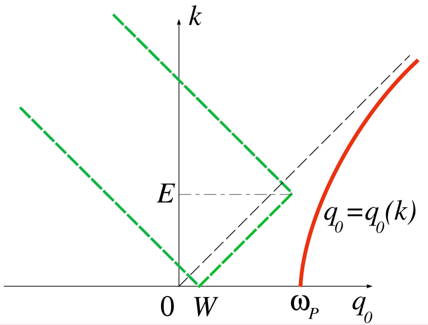


"Spin light of neutrino"?

However, an approach based on a **subtle** effect of the medium influence on the neutrino dispersion, when the **much more significant** influence of the same medium on the photon dispersion is ignored, **has no physical sense!**

The photon dispersion in medium is surely not the vacuum one!

Photon dispersion in plasma changes the kinematics



For the process $\nu_L \to \nu_R \gamma^*$ to be possible, the neutrino energy must exceed a threshold value:

$$E_{\min} \simeq \omega_P \, \frac{\omega_P}{2\,W} \, .$$

Photon dispersion in plasma changes the kinematics

For the interior of a neutron star, the additional energy acquired by a left-handed neutrino in plasma (N_B is the barion density):

$$W \simeq 6 \text{ eV} \left(\frac{N_B}{10^{38} \text{ cm}^{-3}} \right),$$

while the plasmon frequency, defining the photon dispersion:

$$\omega_P \simeq 10^7 \text{ eV} \left(\frac{N_B \, Y_e}{10^{38} \text{ cm}^{-3}} \right)^{1/3}.$$

The threshold neutrino energy in this case:

$$E_{\text{min}} \simeq \frac{\omega_P^2}{2\,W} \simeq 10 \text{ TeV}.$$

$SL\nu$ at ultra-high neutrino energies?

At **ultra-high** neutrino energies the local limit of the weak interaction does not describe comprehensively the additional neutrino energy in plasma, and the **non-local** weak contribution must be taken into account.

In a general case, this non-local term is *identical for both neutrinos and antineutrinos* (the minus sign is essential!)

$$\Delta^{(\mathrm{nloc})} W_i = - \frac{16\, G_{\mathrm{F}}\, E}{3\,\sqrt{2}} \left[\frac{< E_{\nu_i} >}{m_Z^2} \left(N_{\nu_i} + \bar{N}_{\nu_i} \right) + \delta_{ie} \frac{< E_e >}{m_W^2} \left(N_e + \bar{N}_e \right) \right]$$

E is the energy of a neutrino with the flavor i, propagating through plasma, $< E_{\nu_i} >$ and $< E_e >$ are the averaged energies of plasma neutrinos and electrons.

$SL\nu$ at ultra-high neutrino energies?

The non-local term is always negative.

Thus, there arises the window (if exists) in the neutrino energies for the process to be kinematically opened, $E_{\rm min} < E < E_{\rm max}$.

For example, in the solar interior there is no window for the process with electron neutrinos at all.

For the interior of a neutron star where *the window* exists, the mean free path of an ultra-high energy neutrino with respect to the process $\nu_L \to \nu_R \gamma$ is: $L > 10^{19}\,\mathrm{cm}$, to be compared with the neutron star radius $\sim 10^6$ cm.

Thus, the $SL\nu$ effect has no place in real astrophysical situations because of the photon dispersion.

"Spin light of electron"

Similarly to a neutrino, an electron acquires in medium the additional energy depending on its helicity, due to the parity non-conserving weak interaction.

In the series of papers the same authors have extended their approach to the so-called "spin light of electron", $e_L \longrightarrow e_R + \gamma$.

It should be noted however, that just the same mistake of ignoring the photon dispersion in plasma was repeated in those papers.

"Exact solutions" of inexact equations

In two recent papers by *A. Studenikin et al. (e-prints of April, 2008)* there is some progress.
Five unphysical regions of parameters are removed from the analysis, and only one case of an ultra-high neutrino energy is considered.

However:

- an essential threshold effect is not mentioned;
- the non-local weak contribution into the additional neutrino energy in plasma is not taken into account, while it is essential at ultra-high neutrino energies;
- without this non-local weak contribution, the Dirac equation in medium for a neutrino is approximate by definition, thus, the term of an "exact solution" is under question.

Conclusions

- We have shown that an approach based on a **subtle** effect of the medium influence on the neutrino dispersion, when the **much more significant** influence of the same medium on the photon dispersion is ignored, **has no physical sense.**

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- We have shown that an approach based on a **subtle** effect of the medium influence on the neutrino dispersion, when the **much more significant** influence of the same medium on the photon dispersion is ignored, **has no physical sense.**
- With the photon dispersion taken into account, the threshold neutrino energy exists for the process $\nu_L \to \nu_R + \gamma$, which is very large.
- At **ultra-high** neutrino energies, the non-local weak contribution into the additional neutrino energy in plasma **must** be taken into account. There arises the window (if exists) in the neutrino energies for the process to be kinematically opened, $E_{\min} < E < E_{\max}$.

Conclusions (cont'd)

- For the interior of a neutron star, the neutrino mean free path with respect to the process $\nu_L \to \nu_R \gamma$, for the typical neutron star parameters, is $L > 10^{19}\,\mathrm{cm}$, to be compared with the neutron star radius $\sim 10^6$ cm.

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- For the interior of a neutron star, the neutrino mean free path with respect to the process $\nu_L \longrightarrow \nu_R \gamma$, for the typical neutron star parameters, is $L > 10^{19}\ \mathrm{cm}$, to be compared with the neutron star radius $\sim 10^6$ cm.
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- **Thus, the $SL\nu$ effect has no physical sense in real astrophysical situations because of the photon dispersion.**
- In the discovery of the so-called "spin light of electron", $e_L \to e_R + \gamma$, just the same mistake of ignoring the photon dispersion in plasma was repeated.

Thank you for your attention!