Neutrino radiation in matter

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● **A. Grigoriev, A. Lokhov, A. Studenikin, A. Ternov**

"Spin light in neutrino transition between different mass states in matter"

New mechanism of electromagnetic radiation by neutrino in matter

SLν

$$\nu \rightarrow \nu + \gamma$$

$$\mu_\nu \neq 0! \qquad \longleftrightarrow \qquad m_\nu \neq 0$$

Recent review of neutrino electromagnetic properties

see: C. Giunti, A. Studenikin, Phys.Atom.Nucl. 72, 2151 (2009)

$$m_i = m_f$$

Spin Light of Neutrino in matter (gamma-rays for relativistic neutrinos $\omega \sim 1/3 \, E_\nu$)

A.Lobanov, A.Studenikin, **Phys.Lett.B**; **564** (2003) 27; **601** (2004) 171

A.Studenikin, A.Ternov, **Phys.Lett.B 608** (2005) 107

A.Grigoriev, A.Studenikin, A.Ternov, **Phys.Lett.B 622** (2005) 199

Neutrino radiative decay in vacuum

$$\nu_i \rightarrow \nu_j + \gamma$$

$$m_i \qquad m_j$$

was also considered before:

S. Petcov, Nucl. Phys. 25 (1977) 641
G. Zatsepin, A. Smirnov, Nucl. Phys. 28 (1978) 6
A. De Rujula and S. L. Glashow, Phys. Rev. Lett. 45 (1980) 942
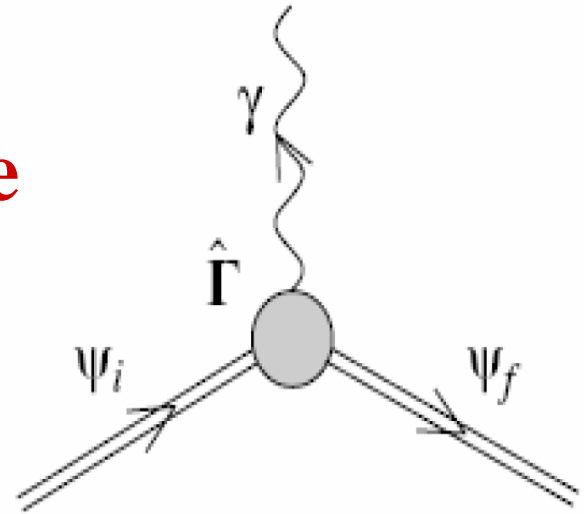P. Pal, L. Wolfenstein, Phys.Rev.D 25 (1982) 766
C. Giunti, C.W. Kim, W.P. Lam, Phys.Rev.D 43 (1991) 164

$$\nu_i \rightarrow \nu_j + \gamma$$

$$m_i \neq m_j$$

$$SL\nu$$

Neutrinos weak interaction with matter is taking into account: we use exact wave functions for the initial and final neutrinos in presence of matter

- γ **is coupled to *neutrinos* by transition magnetic moment** μ_ν

- **high density of matter** $n \sim 10^{37} \div 10^{40} \ cm^{-3}$

  (neutron stars)

- **relativistic neutrinos**

Modified Dirac Equation

$$\left\{ i\gamma_\mu \partial^\mu - \frac{1}{2}\gamma_\mu(1+\gamma^5)f^\mu - m \right\}\Psi(x) = 0.$$

$$f^\mu = \frac{G_F}{\sqrt{2}}(n_n, 0, 0, 0)$$

for unpolarized and matter at rest

neutrino energy spectrum

$$E_\varepsilon = \varepsilon\sqrt{(p - s\alpha m)^2 + m^2} + \alpha m$$

neutrino momentum

matter density parameter

$$\alpha = \frac{1}{2\sqrt{2}}G_F\frac{n_n}{m}$$

S *is neutrino helicity*

$\varepsilon = \pm 1$ *defines positive and negative energy solutions*

n_n *is neutron number density*

A. Studenikin, A. Ternov Phys.Lett. B 60 (2005) 107

A. Studenikin, J.Phys. A:Math.Theor. 41 (2008) 16402

Total rate

$$\nu_i \rightarrow \nu_j + \gamma$$

$$SL\nu$$

$$m_i \qquad m_j$$

Parameters:
$$\frac{\alpha m_i}{p_i}, \quad \frac{m_i}{p_i}, \quad \frac{m_i^2 - m_f^2}{p_i^2}$$

matter density parameter
$$\alpha = \frac{1}{2\sqrt{2}} G_F \frac{n_n}{m}$$

$$\frac{1}{2\sqrt{2}} \tilde{G}_F n \sim 1 \; eV$$

for

$$n = 10^{37} \; cm^{-3}$$

🔴 **Ultrahigh density**

$$\Gamma = 4\mu^2 \alpha^3 m_i^3 \left[1 + \frac{3}{2} \frac{m_i^2 - m_f^2}{\alpha m_i p_i} + \frac{p_i}{\alpha m_i} \right]$$

$$\frac{\alpha m_i}{p_i} \gg 1, \quad \frac{m_i}{p_i} \ll 1, \quad \frac{m_f}{p_i} \ll 1, \quad \frac{m_i^2 - m_f^2}{p_i^2} \ll 1$$

🔴 **High density**

$$\Gamma = 4\mu^2 \alpha^2 m_i^2 p_i \left(1 + \frac{\alpha m_i}{p_i} + \frac{m_i^2 - m_f^2}{\alpha m_i p_i} + \frac{3}{2} \frac{m_i^2 - m_f^2}{p_i^2} \right)$$

$$\frac{m_i}{p_i} \ll \alpha \ll \frac{p_i}{m_i}$$

🔴 **Low density**

$$\Gamma = 1.87 \cdot \mu^2 p_i^3 \left(\frac{m_i^2 - m_f^2}{p_i^2} \right)^3$$

$$\frac{\alpha m_i}{p_i} \ll \frac{m_i^2}{p_i^2}$$

Conclusions

SLν

- The theory of spin light of neutrino in matter is now generalized for the case of neutrino transition between two different mass states (originally *SLv* was considered for the case of equal masses of neutrino in initial and final states)

- The rate of the process provided by the transition magnetic moment is of the same order as provided by the diagonal one

- The energy spectrum of *SLv* for the case of relativistic neutrino moving in dense matter span up to the range peculiar for gamma-rays

- In the case of ultra-relativistic neutrino energies and high densities of matter (astrophysical applications) the neutrino mass difference gives subdominant effect

- In the case of low neutrino energies and low densities of matter in the leading order our result is in agreement with

  A. De Rujula and S. L. Glashow; G. Zatsepin, A.Smirnov; S. Petcov; P. Pal, L. Wolfenstein

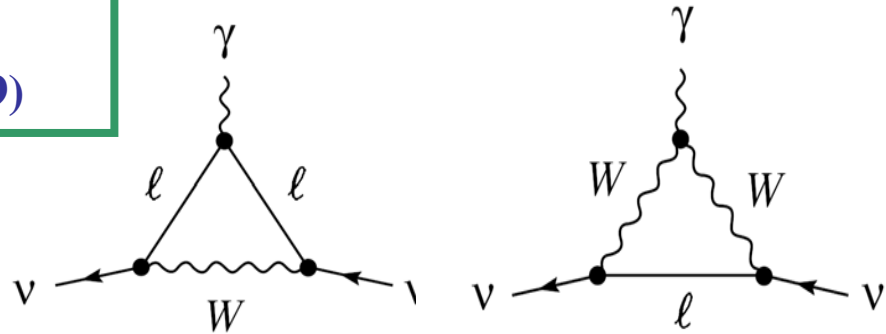- The rate of *SLv* is determined by the value of neutrino effective magnetic (transition) moment

Neutrino magnetic moment

SLν

Recent review of neutrino electromagnetic properties see:

C. Giunti, A. Studenikin,
Phys.Atom.Nucl. 72, 2151 (2009)

$\boxed{U_{ij}}$ **- mixing matrix**

Theory SM with massive neutrino

$$\mu_{ij}^{D} = \frac{eG_F m_i}{8\sqrt{2}\pi^2}\left(1+\frac{m_j}{m_i}\right)\sum_{l=e,\mu,\tau} U_{1l}U_{2l}F(r_l)$$

$$\mu_{ii}^{D} \approx 3.2\times10^{-19}\left(\frac{m_i}{1\,eV}\right)\mu_B$$

K. Fujikawa and R. E. Shrock, Phys. Rev. Lett. 45, 963 (1980)

Experiment

$$\mu_\nu \leq 3.2\times10^{-11}\mu_B$$

GEMMA collaboration

A.G. Beda *et al.*, in *Particle Physics on the Eve of LHC*, Ed. by A. Studenikin (World Sci., Singapore, 2009), p. 112, arXiv:0906.1926

It is possible to have $\boxed{\tau = \dfrac{1}{\Gamma_{SL\nu}} \ll}$ **age of the Universe ?**

For ultra-relativistic ν
with momentum $p \sim 10^{20} eV$
and magnetic moment $\mu \sim 10^{-10} \mu_B$
in very dense matter $n \sim 10^{40} cm^{-3}$
from $\boxed{\Gamma_{SL\nu} = 4\mu^2 \alpha^2 m_\nu^2 p}$

$\boxed{p \gg m_{plasmon}}$

recently also discussed by A.Kuznetsov, N.Mikheev, 2006

A.Lobanov, A.Studenikin, PLB 2003; PLB 2004
A.Grigoriev, A.Studenikin,   PLB 2005
A.Grigoriev, A.Studenikin, A.Ternov,   PLB 2005

$$\alpha m_\nu = \frac{1}{2\sqrt{2}} G_F n \left(1 + \sin^2\theta_W\right)$$

it follows that $\boxed{\tau = \dfrac{1}{\Gamma_{SL\nu}} = 1.5 \times 10^{-8} s}$