

Electromagnetic properties of neutrino

Tuesday 30 May 2017 19:10 (20 minutes)

A review of the theory and phenomenology of neutrino electromagnetic properties is presented. A massive neutrino even in the easiest generalization of the Standard Model inevitably has nonzero electromagnetic characteristics, at least nonzero magnetic moment. Although its value, determined by the neutrino mass, is very small, in other BSM theories, as for example the supersymmetric models, much larger values of magnetic moments are predicted.

Derivation of the general structure of the electromagnetic interactions of Dirac and Majorana neutrinos is presented. Then we discuss experimental constraints on neutrino magnetic and electric dipole moments, electric millicharge, charge radius and anapole moments from the terrestrial laboratory experiments. A special credit is done to bounds on neutrino magnetic moments obtained by the reactor (MUNU, TEXONO and GEMMA) and solar (Super-Kamiokande and Borexino) experiments. The effects of neutrino electromagnetic interactions in astrophysical environments are also reviewed. The main manifestation of neutrino electromagnetic interactions, such as: 1) the radiative decay in vacuum, in matter and in a magnetic field, 2) the Cherenkov radiation, 3) the plasmon decay, 4) spin light in matter, 5) spin and spin-flavour precession, 6) neutrino pair production in a strong magnetic field, and the related processes along with their astrophysical phenomenology are also considered.

The best world experimental bounds on neutrino electromagnetic properties are confronted with the predictions of theories beyond the Standard Model. It is shown that studies of neutrino electromagnetic properties provide powerful tools to probe the physics beyond the Standard Model.

References

- [1] C. Guinti and A. Studenikin, "Neutrino electromagnetic interactions: a window to new physics", *Rev. Mod. Phys.*, V.87, 2015, p. 531-591.
- [2] A. Studenikin, "New bounds on neutrino electric millicharge from limits on neutrino magnetic moment", *Europhys. Lett.* 107 (2014) 21001.
- [3] A. Studenikin, I. Tokarev, "Millicharged neutrino with anomalous magnetic moment in rotating magnetized matter", *Nucl. Phys. B* 884 (2014) 396-407.
- [4] K. Kouzakov, A. Studenikin, "Theory of neutrino-atom collisions: the history, present status and BSM physics", *Adv. High Energy Phys.* 2014 (2014) 569409 (16 p.).
- [5] I. Balantsev, A. Studenikin, "From electromagnetic neutrinos to new electromagnetic radiation mechanism in neutrino fluxes", *Int. J. Mod. Phys. A* 30 (2015) 1530044 (10 p) .
- [6] A. Studenikin, Neutrino spin and spin-flavour oscillations in transversally moving or polarized matter, *arXiv: 1610.06563*.

New constraints on neutrino electromagnetic properties will be reviewed in the talk, including our new results on neutrino magnetic moment and millicharge, recently published:

- [2] A. Studenikin, "New bounds on neutrino electric millicharge from limits on neutrino magnetic moment", *Europhys. Lett.* 107 (2014) 21001.
- [3] A. Studenikin, I. Tokarev, "Millicharged neutrino with anomalous magnetic moment in rotating magnetized matter", *Nucl. Phys. B* 884 (2014) 396-407.

I would like to note that a new bound on neutrino millicharge obtained in [2] has been included by «Particle Data Group Collaboration» in the list of the list of neutrino properties in «The Review of Particle Physics 2016» (C. Patrignani et al (Particle Data Group), *Chinese Physics C* 40, No. 10 (2016) 100001).

In my talk I shall also discuss a new effect of the neutrino spin oscillations engendered by interactions with the transversal currents of matter. This effect was proposed by myself several years ago, see details in:

- [6] A. Studenikin, Neutrino spin and spin-flavour oscillations in transversally moving or polarized matter, *arXiv: 1610.06563*.

The existence of this effect and its importance in consideration of neutrino fluxes from supernovae has been shown in a series of papers:

- [7] V. Cirigliano, G. Fuller, A. Vlasenko, Phys. Lett. B 747, 27 (2015);
[8] C. Volpe, Int. J. Mod.Phys. E 24, 1541009 (2015);
[9] A. Kartavtsev, G. Raffelt and H. Vogel, Phys. Rev. D 91, 125020 (2015);
[10] A. Dobrynina, A. Kartavtsev and G. Raffelt, Phys. Rev. D 93 (2016) no.12, 125030.

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Abstract Title

Electromagnetic properties of neutrino

Subject

Neutrinos

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Session Classification: Parallel Session Neutrinos