Spin light of neutrino in matter: a new type of electromagnetic radiation

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Abstract

A short review of the properties of the spin light of neutrino ($SL\nu$) in matter, supplied with some historical notes on the discussed subject, is given. It is shown that consideration of the $SL\nu$ in matter in hep-ph/0605114 is based on erroneous calculations which ignore the fact that the energy-momentum conservation law can not be violated for this process. An attempt to rename the $SL\nu$ in matter, undertaken in hep-ph/0606262, is groundless.

In a series of our papers [1] - [11], we have proposed and studied in detail a new type of electromagnetic radiation that can be emitted by a massive neutrino with nonzero magnetic moment moving in background matter. We have termed this radiation the "spin light of neutrino" ($SL\nu$) [1]. At first we have developed the quasi-classical theory of this radiation on the basis of the generalized Bargmann-Michel-Telegdi equation that we have derived [12], [4] for description of the neutrino spin evolution in the presence of matter. As it was clear from the very beginning [1], the $SL\nu$ is a quantum phenomenon by its nature. Therefore, we later on considered the $SL\nu$ on a solid base of the modified Dirac equation for the neutrino wave function in matter and elaborated [6] - [11] the quantum theory of this radiation.

The main results of the performed studies [1] - [11] of the $SL\nu$ in matter enable us to summarize the properties of this process as follows [9]:

1) a neutrino with nonzero mass and magnetic moment can emit spin light when moving in dense matter;

2) in general, $SL\nu$ in matter is due to the dependence of the neutrino dispersion relation in matter on the neutrino helicity;

3) the $SL\nu$ radiation rate and power depend on the neutrino magnetic moment and energy, and also on the matter density;

4) the matter density parameter, which depends on the type of neutrino and matter composition, can be negative; therefore the types of initial and final neutrino (and antineutrino) states, conversion between which effectively produces the $SL\nu$ radiation, are determined by the matter composition;

5) the $SL\nu$ in matter leads to the neutrino-spin polarization effect; depending on the type of the initial neutrino (or antineutrino) and matter composition the negative-helicity relativistic neutrino (the left-handed neutrino ν_L) is converted to the positive-helicity neutrino (the right-handed neutrino ν_R) or vice versa;

6) the obtained expressions for the $SL\nu$ radiation rate and power exhibit non-trivial dependence on the density of matter and on the initial neutrino energy; the $SL\nu$ radiation rate and power are proportional to the neutrino magnetic moment squared which is, in general, a small

value and also on the neutrino energy, that is why the radiation discussed can be effectively produced only in the case of ultra-relativistic neutrinos;

7) for a wide range of matter densities the radiation is beamed along the neutrino momentum, however the actual shape of the radiation spatial distribution may vary from projector-like to cap-like, depending on the neutrino momentum-to-mass ratio and the matter density;

8) in a wide range of matter densities the $SL\nu$ radiation is characterized by total circular polarization;

9) the emitted photon energy is also essentially dependent on the neutrino energy and matter density; in particular, in the most interesting for possible astrophysical and cosmology applications case of ultra-high energy neutrinos, the average energy of the $SL\nu$ photons is one third of the neutrino momentum.

Considering the listed above properties of the $SL\nu$ in matter, we argue that this radiation may be produced by high-energy neutrinos propagating in different astrophysical and cosmological environments.

Here we should like to mention that the considered $SL\nu$ is indeed a new type of electromagnetic radiation of neutrino that can be emitted by neutrino and that has never been considered before. As it was mentioned in our first paper on this subject [1], the proposed mechanism of radiation is totally different from many other known processes characterized by the same signature, $\nu \to \nu + \gamma$, as one of the $SL\nu$, for instance:

i) the photon radiation by massless neutrino ($\nu_i \to \nu_j + \gamma,\ i = j$) due to the vacuum polarization loop diagram in presence of an external magnetic field [13, 14];

ii) the photon radiation by massive neutrino with non-vanishing magnetic moment in constant magnetic and electromagnetic wave fields [15, 16];

iii) the Cherenkov radiation due to the non-vanishing neutrino magnetic moment in homogeneous and infinitely extended medium which is only possible if the speed of neutrino is larger than the speed of light in medium [17, 18];

iv) the transition radiation due to non-vanishing neutrino magnetic moment which would be produced when the neutrino crosses the interface of two media with different refractive indices [19, 20];

v) the Cherenkov radiation by massless neutrino due to its induced charge in medium [21];

vi) the Cherenkov radiation by massive and massless neutrino in magnetized medium [22,23];

vii) the neutrino radiative decay ($\nu_i \to \nu_j + \gamma,\ i \neq j$) in external fields and medium or in vacuum [24–28].

Thus, that the proposed and studied in our papers [1] - [11] mechanism of electromagnetic radiation generated by the neutrino magnetic moment which occurs due to electroweak interaction of a neutrino with the background environment has never been considered before. It should be emphasized that the spin light of neutrino can not be described as the Cherenkov radiation, because the $SL\nu$ is produced even in the case when modification of the photon dispersion relation by the environment can be neglected.

Note that possible influence of medium on emitted photons was also discussed in our papers [7, 9]. It was shown [7, 9] that for the most interesting case of high-energy neutrinos the matter influence on the photon dispersion can be neglected. In addition, here it should be noted that, as it is well known (see, for instance, [29] and [30]), plasma is transparent for electromagnetic radiation on frequencies greater than the plasmon frequency. In [1] - [11], we have shown from the energy-momentum conservation law that a relativistic neutrino can emit the $SL\nu$ photons with characteristic energy equals to a reasonable fraction of neutrino energy. So that if neutrino energy much exceeds the plasmon frequency then the plasma influence on photons can be neglected [7, 9].

The phenomenon of $SL\nu$ in matter has attracted attention of another authors. In the preprint hep-ph/0605114 (V 1 of May 10, 2006) [31], it has been claimed that there is "no neutrino spin light because of photon dispersion in medium". In our remark [32] (hep-ph/0606011,

V 1 of June 1, 2006) to this statement, we have explained why the mentioned above conclusion of [31] is wrong. As it follows from the consideration undertaken in [31], the mentioned above false statement is based on uncorrect evaluation of the $SL\nu$ photon energy in which the authors of [31] ignore the momentum conservation law. It is obvious that the fundamental law of the energy-momentum conservation can not be violated in any process, including the $SL\nu$ in matter.

The same authors have further continued their studies on the $SL\nu$ in matter. Recently, without any reference to the first their preprint [31] and our remark [32] the authors of [31] have issued the second preprint hep-ph/0606262 (V 1 of June 25, 2006) and published the exactly identical paper [33] entitled "Plasma induced neutrino radiative decay instead of neutrino spin light". In these new studies [33], the authors have undertaken an attempt to consider, as it is written in [33], " the conversion of a neutrino with a magnetic moment... caused by the additional Wolfenstein energy acquired by a left-handed neutrino in medium, with an accurate account of the photon dispersion in medium". Obviously, it is the $SL\nu$ in matter that is considered in [33] with addition account for the photon dispersion in medium.

As it follows from the title of the paper [33], the authors try to allege that inclusion of the photon medium dispersion in the $SL\nu$ effect sufficiently changes the nature of this phenomena, so that the new title instead of the "spin light of neutrino" is needed. However, as it is clear from the studies of [33], the authors deals with the same phenomenon that was first introduced and studied in detail in our papers [1] - [11] and then was also discussed in their first preprint [31], where there have been no word said about the need to rename the spin light of neutrino. The fact is that the "new effect" introduced in [33] appears, as the authors say themselves in [33], due to 1) the neutrino magnetic moment interaction with photons, 2) the additional energy acquired by neutrino in matter. This is just exactly the same mechanism that one of the $SL\nu$ in matter [1] - [11].

We should like to mention that the introduced and used in our papers [1] - [11] term "spin light of neutrino" has a famous precursor of the same physics nature. Indeed, the $SL\nu$ in matter is an example of a more general sort of radiation previously termed "spin light" [34], which is just radiation of an intrinsic magnetic moment of an electron associated with its spin. In the case of the "synchrotron radiation" (i.e. the radiation of a relativistic charged particle in an external magnetic field), its dependence on the electron spin orientation was studied both theoretically [34] and also experimentally in the Budker INP (Novosibirsk) [35]. As a result of these studies, it has become clear that the synchrotron radiation can be considered as if it consists of the radiation of an electron charge itself and the one of an intrinsic magnetic moment of an electron. The latter is just what was called the "spin light".

In connection with the attempt [33] to rename the $SL\nu$ in matter to "plasma induced neutrino radiative decay", we should like to remind that the proposed in [33] term "decay" has been already used for designation of various transitions between different types of neutrinos with emission of photons (or plasmons) [23–28], the processes of quite different nature that one considered in [33].

Although the obtained in [33] final expression for the total width of the considered process in the most interesting limiting case of ultra-high neutrino energies gives exactly the result that have been obtained previously in our papers [7] - [10] (for some reason this fact is not pointed out in [33]), it is not clear how this result was obtained in [33]. The fact is that the studies of the process in [33] are based on the ill-defined expression for the process matrix element squared. The expression for the matrix element squared given by formula (18) of [33] is not positively-defined. One may wonder how this result, as the authors wrote in [33] while explaining the derivation of formula (18), "can by obtained by the standard way".

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