Contribution ID: **649** Type: **Talk**

Electromagnetic neutrino properties: new constraints and new effects

Friday, 31 July 2020 09:00 (15 minutes)

We continue our discussions [1-3] of neutrino electromagnetic properties and give a short introduction to the derivation of the general structure of the electromagnetic form factors of Dirac and Majorana neutrinos. Then we consider experimental constraints on neutrino magnetic and electric dipole moments, electric millicharge, charge radii and anapole moments from the terrestrial laboratory experiments (the bounds obtained by the reactor MUNU, TEXONO and GEMMA experiments and the solar Super-Kamiokande and the recent Borexino experiments). A special credit is done to the recent and most severe constraints on neutrino magnetic moments, millicharge and charge radii [4-8]. The world best reactor [4] and solar [5] neutrino and astrophysical [9,10] bounds on neutrino magnetic moments, as well as bounds on millicharge from the reactor [6] neutrinos fluxes are included in the recent issues of the Review of Particle Physics (see the latest Review: M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98 (2018) 030001). The best astrophysical bound on neutrino millicharge was obtained in [11].
We present results of the recent detailed study [12] of the electromagnetic interactions of massive neutrinos in the theoretical formulation of low-energy elastic neutrino-electron scattering. The formalism of neutrino charge, magnetic, electric, and anapole form factors defined as matrices in the mass basis with account for three-neutrino mixing is presented. Using the derived new expression for a neutrino electromagnetic scattering cross section [13], we further developed studies of neutrino electromagnetic properties using the COHERENT data [7] and obtained [8] new bounds on the neutrino charge radii from the COHERENT experiment. Worthy of note, our paper [8] has been included by the Editors Suggestion to the Phys. Rev. D "Highlights of 2018", and the obtained constraints on the nondiagonal neutrino charge radii has been included by the Particle Data Group to the 2019 upgrade of the Review of Particle Physics.
The main manifestation of neutrino electromagnetic interactions, such as: 1) the radiative decay in vacuum, in matter and in a magnetic field, 2) the neutrino Cherenkov radiation, 3) the plasmon decay to neutrino-antineutrino pair, 4) the neutrino spin light in matter, and 5) the neutrino spin and spin-flavour precession are discussed. Phenomenological consequences of neutrino electromagnetic interactions (including the spin light of neutrino [13]) in astrophysical environments are also reviewed.
The second part of the proposed talk is dedicated to results of our mostly recently performed detailed studies of new effects in neutrino spin, spin-flavour and flavor oscillations under the influence of the transversal matter currents [14] and a constant magnetic field [15, 16], as well as to our newly developed approach to the problem of the neutrino quantum decoherence [17] and also to our recent proposal [18] for an experimental setup to observe coherent elastic neutrino-atom scattering (CEνAS) using electron antineutrinos from tritium decay and a liquid helium target that as we have estimated opens a new frontier in constraining the neutrino magnetic moment.
The discussed in the second part of the talk new results include two new effects that can be summarized as follows:

1) it is shown [14] that neutrino spin and spin-flavor oscillations can be engendered by weak interactions of neutrinos with the medium in the case when there are the transversal matter currents; different possibilities for the resonance amplification of oscillations are discussed, the neutrino Standard Model and non-standard interactions are accounted for;

2) within a new treatment [15] of the neutrino flavor, spin and spin-flavour oscillations in the presence of a constant magnetic field, that is based on the use of the exact neutrino stationary states in the magnetic field, it is shown that there is an interplay of neutrino oscillations on different frequencies; in particular: a) the amplitude of the flavour oscillations νLe↔ νLμ at the vacuum frequency is modulated by the magnetic field frequency μB , and b) the neutrino spin oscillation probability (without change of the neutrino flavour) exhibits the dependence on the neutrino energy and mass square difference Δm2 .

The discovered new phenomena in neutrino oscillations should be accounted for reinterpretation of results of already performed experiments on detection of astrophysical neutrino fluxes produced in astrophysical environments with strong magnetic fields and dense matter. These new neutrino oscillation phenomena are also of interest in view of future experiments on observations of supernova neutrino fluxes with large volume liquid-scintillator and water Chernkov detectors like JUNO and Hyper_Kamiokande, for instance.

Two other new results discussed in the concluding part of the talk are as follows:

3) a new theoretical framework, based on the quantum field theory of open systems applied to neutrinos, has

been developed [17] to describe the neutrino evolution in external environments accounting for the effect of the neutrino quantum decoherence; we have used this approach to consider a new mechanism of the neutrino quantum decoherence engendered by the neutrino radiative decay to photons and dark photons in an astrophysical environment, the corresponding new constraints on the decoherence parameter have been obtained;

4) in [18] we have proposed an experimental setup to observe coherent elastic neutrino-atom scattering (CEνAS) using electron antineutrinos from tritium decay and a liquid helium target and shown that the sensitivity of this apparatus (when using 60 g of tritium) to a possible electron neutrino magnetic moment can be of order about 7×10−13μB at 90% C.L., that is more than one order of magnitude smaller than the current experimental limit.

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 a powerful tool to probe physics beyond the Standard Model.

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Secondary track (number)

08

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Session Classification: Neutrino Physics

Track Classification: 02. Neutrino Physics