Pis'ma v ZhETF, vol. 117, iss. 12, pp. 885 – 886

Elastic neutrino-atom scattering as a probe of neutrino millicharge and magnetic moment

G. V. Donchenko, K. A. Kouzakov[1)], *A. I. Studenikin*

Faculty of Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

Submitted 3 April 2023
Resubmitted 25 April 2023
Accepted 4 May 2023

DOI: 10.31857/S1234567823120017, EDN: eumylg

The proposals are discussed in the literature to search for light dark matter particles using liquid and solid-state detectors, which make it possible to achieve sensitivity to low-energy signals down to energies of ∼1 meV (see, for example, [1, 2] and references therein). Such detectors can also be used to study low-energy neutrino scattering, in particular, coherent elastic neutrino-atom scattering (CEνAS) [3].

As is known, nonzero neutrino masses open a door to neutrino electromagnetic interactions [4]. We analyze the sensitivity of CEνAS processes in the case of light atoms to such neutrino electromagnetic characteristics as electric charge e_ν (millicharge) and magnetic moment μ_ν. The results of our calculations of differential cross sections for elastic collisions of tritium neutrinos with the H, ^{2}H, ^{3}He, and ^{4}He atomic targets show that the corresponding experiments can achieve sensitivity to e_ν and μ_ν by orders of magnitude better than the available measurements of elastic neutrino-electron and neutrino-nucleus collisions.

The most promising at the moment is the use of a tritium neutrino source with a superfluid helium-4 detector. Such an experiment is already under preparation, and it can achieve the sensitivity to the neutrino magnetic moment at the level of $\sim (2-4)\times 10^{-13}\mu_B$ (see [5] for details). It is supposed to involve a cylindrical tritium source with an initial activity of at least 10 MCi that will be surrounded by a cylindrically shaped 1-m^3 volume of liquid helium-4 at temperatures as low as few tens of mK. The flux of the tritium $\bar{\nu}_e$ in the liquid helium-4 volume will be at the level of $\sim 10^{13}$–$10^{14}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Within the Standard Model, the expected average number of CEνAS events in the helium-4 detector after a 5-year data-taking is $N^{\mathrm{CE}\nu\mathrm{AS}} = 58.9$. Tables 1 and 2 show the $N^{\mathrm{CE}\nu\mathrm{AS}}$ numbers for different nonzero values of μ_ν and e_ν. It should be noted that the amount of tritium in the upcoming experiment [5] can potentially be increased to reach the activity of 40 MCi. In such a case, the expected number of CEνAS events scales by a factor of approximately 3.3.

Table 1. The average number of expected CEνAS events $N^{\mathrm{CE}\nu\mathrm{AS}}$ in a superfluid He-4 detector after 5 years of data collection depending on the μ_ν value (second row, in units of μ_B)

$N^{\mathrm{CE}\nu\mathrm{AS}}$		
$\mu_\nu = 10^{-13}$	$\mu_\nu = 5\times 10^{-13}$	$\mu_\nu = 10^{-12}$
60.8	80.8	149

Table 2. The same as in Table 1, but depending on the e_ν value (second row, in units of e)

$N^{\mathrm{CE}\nu\mathrm{AS}}$		
$\lvert e_\nu\rvert = 10^{-15}$	$\lvert e_\nu\rvert = 5\times 10^{-15}$	$\lvert e_\nu\rvert = 10^{-14}$
61.4 ($e_\nu < 0$)	80.6 ($e_\nu < 0$)	126.2 ($e_\nu < 0$)
57.5 ($e_\nu > 0$)	61.3 ($e_\nu > 0$)	87.7 ($e_\nu > 0$)

It follows from Table 2 that the e_ν contribution to the CEνAS events in the helium-4 detector can be significant, especially in the $e_\nu < 0$ case, even if the $|e_\nu|$ value does not exceed 10^{-14} in units of e. This should be contrasted with the prospected combined limits $-1.8\times 10^{-14} < e_\nu < 1.8\times 10^{-14}$ [6] based on the current and future experiments on elastic neutrino-electron and neutrino-nucleus scattering.

The study was supported by a grant from the Russian Science Foundation (project # 22-22-00384). G. V. Donchenko acknowledges the support from the National Center for Physics and Mathematics (Sarov, Russia).

This is an excerpt of the article "Elastic neutrino-atom scattering as a probe of neutrino millicharge and magnetic moment". Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364023600982

[1)]e-mail: kouzakov@gmail.com

1. S. M. Griffin, Y. Hochberg, K. Inzani, N. Kurinsky, T. Lin, and T. Chin, Phys. Rev. D **103**, 075002 (2021).
2. B. von Krosigk, K. Eitel, C. Enss, T. Ferber, L. Gastaldo, F. Kahlhoefer, S. Kempf, M. Klute, S. Lindemann, M. Schumann, F. Toschi, and K. Valerius, arXiv:2209.10950 [hep-ex].
3. M. Cadeddu, F. Dordei, C. Giunti, K. Kouzakov, E. Picciau, and A. Studenikin, Phys. Rev. D **100**, 073014 (2019).
4. C. Giunti and A. Studenikin, Rev. Mod. Phys. **87**, 531 (2015).
5. M. Cadeddu, G. Donchenko, F. Dordei, C. Giunti, K. Kouzakov, B. Lubsandorzhiev, A. Studenikin, V. Trofimov, M. Vyalkov, and A. Yukhimchuk, arXiv:2302.05307 [hep-ph].
6. A. Parada, Adv. High Energy Phys. **2020**, 5908904 (2020).