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

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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 ($e_\nu < 0$) 57.5 ($e_\nu > 0$)	80.6 ($e_\nu < 0$) 61.3 ($e_\nu > 0$)	126.2 ($e_\nu < 0$) 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 $-1.8\times10^{-14} < e_\nu < 1.8\times10^{-14}$ [6] based on the current and future experiments on elastic neutrino-electron and neutrino-nucleus scattering.

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