Neutrinos become less and less mysterious

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The authors of a study published in *Physical Review D* have shown that coherent neutrino scattering with nuclei provides a novel way to measure the neutrino charge radii. This interaction was theoretically predicted more than 40 years ago, but the difficulty of measuring the very small nuclear recoil inhibited its experimental observation until 2017 by the COHERENT experiment.

Using the COHERENT data, the authors of this paper were able to put bounds on the neutrino charge radii, and, for the first time, bounds on the neutrino transition charge radii, which are quantities beyond the standard model of particle physics.

Neutrinos are widely believed to be neutral particles, but in reality, they could have a very small electrical charge, and it is very likely that they have charge radii. Indeed, in the standard model, neutrinos have very small charge radii of the order of 10^{-33} square centimeters.

Until now, the neutrino charge radii have been searched in elastic neutrino-electron scattering experiments. For small energy transfer, both the standard model cross section and the effect of the neutrino charge radii in the case of elastic neutrino-electron scattering turn out to be smaller by a factor of the order of the nuclear mass divided by the electron mass with respect to the case of coherent elastic neutrino nucleus scattering. Therefore, in terms of data collection, coherent elastic neutrino-nucleus scattering experiments have a greater potential for investigating the neutrino charge radii than measurements of neutrino-electron scattering.

In the fundamental theory of electromagnetic neutrino interactions, the neutrino charge radii are defined for massive neutrinos. However, the effects of neutrino oscillations can be neglected for experiments with a short distance between the neutrino source and detector, as in the setup of the COHERENT experiment. In this case, the effective charge radius of a flavor neutrino is relevant, where "flavor" means electron, muon or tau neutrinos. Since in the ultra-relativistic limit, the charge form factor conserves the neutrino helicity as the standard model weak interactions, the contribution of the neutrino charge radius to the elastic scattering of neutrinos with a charged particle adds coherently to the standard model weak interactions and can be expressed through the shift in the weak mixing angle, also known as the Weinberg angle.

This prescription takes into account the contributions to neutrino interactions of the charge radii of the three flavor neutrinos. These are the only charge radii that exist in the standard model, because the generation lepton numbers are conserved. However, in theories beyond the standard model, neutrinos can have transition charge radii that change the neutrino flavor. For example, in massive neutrino theories, the charge radii are defined in the mass basis of the physically propagating neutrinos, so that even if the matrix of the neutrino charge radii is diagonal in the mass basis, transition charge radii are generated by the mixing, a quantum mechanical phenomenon which implies that a neutrino created with a specific lepton family number can later be measured to have a different lepton family number.

The authors obtained limits on the diagonal charge radii and on the transition charge radii from analyses of the time-integrated COHERENT energy spectrum and the time-dependent COHERENT data taking into account the uncertainty of the neutron distributions in caesium and iodine (the target material of the experiment), parameterized by the corresponding nuclear root mean square radii. The authors have shown that the time information of the COHERENT data restricts the allowed

ranges of the charge radii, especially that of muon neutrinos which turned out to be in the range -8×10^{-32} to 11×10^{-32} square centimeters at a 90 percent confidence level.

These results show promising prospects for current and upcoming neutrino-nucleus scattering experiments.

More information: M. Cadeddu et al. Neutrino charge radii from COHERENT elastic neutrino-nucleus scattering, *Physical Review D* (2018). DOI: 10.1103/PhysRevD.98.113010

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