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A new experimental approach to search for free neutron-antineutron oscillations based on coherent neutron and antineutron mirror reflection

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An observation of neutron-antineutron oscillations, which violate both baryon and baryon-lepton conservation, would constitute a scientific discovery of fundamental importance to physics and cosmology. A stringent upper bound on its transition rate would make an important contribution to our understanding of the baryon asymmetry of the Universe by eliminating the postsphaleron baryogenesis scenario in the light quark sector.

We show [1-5] that one can design an experiment using slow neutrons that in principle can reach the required sensitivity of 10^10 s in the oscillation time, an improvement of 10^4 in the oscillation probability relative to the existing limit for free neutrons. The improved statistical accuracy needed to reach this sensitivity can be achieved by allowing both the neutron and antineutron components of the developing superposition state to coherently reflect from mirrors.

We present a quantitative analysis of this scenario and show that, for sufficiently small transverse momenta neutrons/antineutrons and for certain choices of nuclei for the neutron/antineutron guide material, the relative phase shift of the neutron and antineutron components upon reflection and the antineutron annihilation rate can be small enough to maintain sufficient coherence to benefit from the greater phase space acceptance the mirror provides.

The values of the antineutron-nucleus scattering lengths, and in particular their imaginary parts, are needed to evaluate the feasibility of using neutron and antineutron mirrors to search for neutron-antineutron oscillations as well to evaluate the resulting experimental sensitivity. We analyze existing experimental and theoretical constraints on these values with emphasis on low-A nuclei and use the results to suggest materials for the neutron-antineutron guide and to evaluate the systematic uncertainties in estimating the neutron-antineutron oscillation time.

As examples, we discuss scenarios for future neutron-antineutron oscillation experiments at the European Spallation Source or the Institut Laue-Langevin. We show that for the lengths of neutron/antineutron guides and the cold neutron spectra, which can be considered presently at these facilities, the theoretical uncertainties associated with the interaction of antineutrons with the guide walls are negligible, and the gain in sensitivity compared to the existing bounds can be large.

Even better gain factors of up to 10^4 can be hypothetically obtained with longer neutron/antineutron guides and/or softer neutron spectra from dedicated sources of very cold neutrons.

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