Test of the equality of the particle and antiparticle masses in neutron-antineutron oscillations

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Experimental observation of neutron-antineutron oscillations would make it possible to test the equality of the masses of the neutron and the antineutron with an unprecedented accuracy.

The equality of the masses of a particle and its antiparticle which follows from *CPT* invariance has been tested experimentally with an accuracy of only $\Delta m/m \sim 10^{-5}$–10^{-3} (see Ref. 1, for example), except in the case of neutral kaons, for which we have $\Delta m/m \lesssim 10^{-18}$. It has recently been shown[2] that the agreement between the existing experimental data on the decays of neutral kaons and the requirements of CPT symmetry leaves something to be desired: The experimental data deviate from the theory by two standard deviations. A discrepancy of two standard deviations should not, of course, be regarded as evidence of a possible violation of CPT invariance, but it does indicate that it would be desirable to carry out some new and more accurate measurements, and it provokes some speculation. At present, we cannot rule out the possibility of $\Delta m_{K\bar{K}} \sim 10^{-4}\Gamma_S \sim 10^6 s^{-1} \sim 10^{-9}$ eV (Γ_S is the width of the K_S^0 meson). In this letter we wish to point out that an experimental search for neutron-antineutron oscillations might provide a far better upper limit on the difference between the masses of the neutron and the antineutron, $\Delta m_{n\bar{n}}$.

The subject of $n - \bar{n}$ transitions was taken up previously in the pioneering paper by Gell-Mann and Pais,[3] who pointed out that $n - \bar{n}$ transitions, in contrast with $K - \tilde{K}$ transitions, are forbidden by the conservation of baryon charge. The subject of n–$\bar{n}$ oscillations was analyzed in more detail in Ref. 4, but again the conclusion was negative. According to a hypothesis offered subsequently by Sakharov,[5] baryon charge is not conserved, and its nonconservation can, when combined with a breaking of CP symmetry, explain the baryon asymmetry of the universe. This hypothesis was subsequently discussed by Kuz'min,[6] who worked from experimental data on the stability of the proton to set a lower limit on the period of n-n oscillations.

Glashow[7] attracted widespread interest to $n - \bar{n}$ oscillations when he noted that these oscillations are predicted by certain grand unified models. We now have the results of an experimental search at Grenoble for $n - \bar{n}$ oscillations ($\tau_{n\bar{n}} \gtrsim 10^6$ s; Ref. 8), and several other experiments are presently in the stages of planning and preparation. Fidecaro[8] lists eight major $n - \bar{n}$ experiments which are presently being carried out, or which are in planning and preparation stages, and lists in detail recent theoretical papers on $n - \bar{n}$ oscillations. According to Ref. 8, these experiments might detect $n - \bar{n}$ oscillations if the vacuum transition time $\tau_{n\bar{n}}$ is shorter than 10^8–10^9 s.

In all these experiments, a beam of neutrons is moving in a vacuum, in a region with a very weak magnetic field, until it collides with the target, where antineutrons annihilate. The n-$\tilde{n}$ conversion probability is $(t/\tau_{n\tilde{n}})^2$, where t is the transit time in a vacuum. According to Fidecaro,[8] the value of t in these experiments lies in the range 10^{-1}–10^{-2} s. We would like to point out in this connection that n-$\tilde{n}$ oscillations can be detected in these experiments only if the condition $\Delta m_{n\tilde{n}} \lesssim 1/t$ holds. Consequently, the observation of vacuum $n-\tilde{n}$ oscillations would give us an upper limit $\Delta m_{n\tilde{n}} \lesssim 10^1$–$10^2$ s^{-1}, which would correspond to $\Delta m_{n\tilde{n}}/m_n \lesssim 10^{-23}$–$10^{-22}$, five or four orders of magnitude better than the corresponding upper limit on $\Delta m_{K\tilde{K}}$.

If $\Delta m_{n\tilde{n}}$ proved to be greater than $1/t$, then the vacuum conversion of neutrons into antineutrons would be suppressed by a small factor $(t\Delta m_{n\tilde{n}})^{-2}$ and might be unobservably small. A search for n-$\tilde{n}$ oscillations suppressed by a mass difference $\Delta m_{n\tilde{n}} \gtrsim 10$–$100$ s^{-1} would require special experiments, in which the transit time t could be reduced but the neutron flux density maximized.

It is not clear at this point just how useful it will be to search for n-$\tilde{n}$ oscillations through the use of ultracold-neutron traps.[9]

The difference $\Delta m_{n\tilde{n}}$ involved here is so small that it could have no effect of any sort on n-$\tilde{n}$ transitions in nuclei. The observation of two-nucleon annihilation in nuclei, along with the absence or suppression of vacuum n-$\tilde{n}$ oscillations, would therefore indicate $\Delta m_{n\tilde{n}} \neq 0$. The experimental observation of both effects with theoretically consistent conclusions would give us an upper limit on $\Delta m_{n\tilde{n}}$. The absence of both effects experimentally would tell us nothing about $\Delta m_{n\tilde{n}}$, simply giving us an upper limit on the amplitude for n-$\tilde{n}$ transitions. The best lower limit on the two-nucleon annihilation time in nuclei is[10] $\tau_{nn} > 2.4 \times 10^{31}$ yr, in theoretical agreement with a lower limit on $\tau_{n\tilde{n}}$ between 2.7×10^7 and 1.1×10^8 s.

The possibility of a violation of *CPT* invariance due to quantum-gravitational effects is being discussed widely (see Ref. 11, for example). If a nonzero value of $\Delta m_{n\tilde{n}}$ arises from effects which break CPT and C symmetry by a Planckian mass m_{Pl}, then we can expect the following as a highly optimistic upper limit:

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