PROPERTIES OF MATTER VERSUS THOSE OF ANTIMATTER AS A TEST OF CPT INVARIANCE

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The general principles of relativistic field theory require invariance under the combined transformation CPT. The simplest way of testing CPT invariance is to compare the mass, the lifetime, and the magnetic moment of a particle, and of its antiparticle. In this contribution, some prospects for the improvement of the limits¹ derived from various particle-antiparticle systems are presented, updating an earlier paper.²

ANTIPROTON MASS

Two experiments^{3,4} that are under way at LEAR aim at the determination of the mass of the *free* antiproton with very high precision ($\leq 10^{-9}$), the achievement of which would be a big step forward. Previously the mass of the *bound* antiproton was deduced from X-ray energies of antiprotonic atoms. Using crystal spectrometers or Ge solid-state detectors, the line positions can be measured with an accuracy of better than 1 ppm. It was pointed out by Decker and Pilkuhn that, at this level, novel binding effects (hadronic Lamb shift) should show up.⁵ Previously, these effects would have been buried under unknown contributions from residual electrons attached to the antiprotonic atoms. However, it now seems possible to produce 'naked' antiprotonic atoms where electrons are stripped off.⁶ A measurement of the mass of the *bound* antiproton with high accuracy would therefore provide new information in addition to CPT tests.

ANTIPROTON LIFETIME

The best limit for the lifetime of the antiproton comes from the measurement at ICE, which gave a value of 10^6 s.⁷ As worked out previously,² an improvement up to the level of 10^{13} s should be possible.

MAGNETIC MOMENT OF THE ANTIPROTON

The magnetic moment of the antiproton was newly determined from the fine structure splitting of X-ray transitions in $\bar{p}$ -Pb.⁸ The accuracy was improved by a factor of > 2 and is now at 3×10^{-3} . Again one expects binding effects to alter the magnetic moment of the bound antiproton with respect to a free one.⁵ These contributions may reach the level of 10^{-3} . Difficulties in the measurement of the fine structure splitting in antiprotonic atoms arise mainly from the unknown contribution of higher X-ray transitions hidden beneath the X-ray line under consideration. This problem can be overcome by influencing the atomic cascade in such a way that the de-excitation proceeds mainly through circular transitions (for instance by stripping off the electrons⁶). The measurement of the splitting with a solid-state detector should be possible to an

ultimate precision of 0.5 eV, which would allow a determination of the magnetic moment to 4×10^{-4} , choosing a heavy target. With a crystal spectrometer one may even approach 5×10^{-5} .

The measurement of the hyperfine structure in antihydrogen has, in principle, an enormous potential for achieving high accuracy in the determination of the antiproton magnetic moment. For hydrogen, this quantity is one of the best measured values in physics. The precision to which it can be determined in antihydrogen depends very much on the production rate of antihydrogen and its velocity.

ANTINEUTRON MASS

The antineutron mass was deduced in a pre-LEAR bubble chamber experiment, with an accuracy of 42 ppm,⁹ by analysing the kinematics of the charge-exchange reaction $p\bar{p} \rightarrow n\bar{n}$. This accuracy is based on 20,000 zero-prong reactions producing a sample of 59 events surviving various cuts. As stated by the authors,⁹ the error is purely statistical. It is probably justified to assume that this accuracy can be further improved until it is comparable to that of the neutron (2.9 ppm) in a counter experiment at an antiproton storage ring.

ANTINEUTRON LIFETIME

The measurement of this lifetime has not yet been attempted as it requires very slow antineutrons. Low-energy antineutrons are created in the antiproton source of antiproton accumulators, and they can be produced in the charge-exchange reaction $\bar{p}p \rightarrow \bar{n}n$, where the momentum of the incoming antiproton is above 1 GeV/c. It is not inconceivable that antineutrons could be trapped in a magnetic storage device. In contrast to the neutron, decaying antineutrons can probably be more easily detected owing to the outgoing antiproton and its subsequent annihilation. This could allow the antineutron lifetime to be determined directly from the exponential decay. One would thus be free from normalization problems. An accuracy of at least 1% should be achievable.

MAGNETIC MOMENT OF THE ANTINEUTRON

The magnetic moment of the neutron is known with an accuracy of 0.28 ppm.¹ There is no corresponding experimental information for the antineutron. Polarized antineutrons can possibly be produced through polarization transfer in the charge-exchange reaction, as the theory predicts large polarization effects. Given enough analysing power for antineutron-induced reactions, the magnetic moment of the antineutron can be determined by measuring the spin precession of polarized antineutrons in a magnetic field. Here again the achievable precision depends very much on the intensity of the polarized antineutrons.

LEVEL ENERGIES IN ANTIHYDROGEN

The hydrogen and antihydrogen atoms form a conjugate system, but one which is distinguished from other particle-antiparticle systems by the fact that it is composed of elementary particles which are also existing in free space. So any measurement of the properties of antihydrogen is intimately related to the measurement of the properties of antiprotons and positrons, and whilst some of their properties are very well determined (e.g. the positron magnetic moment), others could be much improved. Therefore the measurement of a few level energies in antihydrogen, if done precisely, would provide a great deal of information on the validity of particle-antiparticle symmetries. If there would be any CPT violation at all observed in the electron-positron or the proton-antiproton system, it should also show up in hydrogen-antihydrogen. The spectroscopy of antihydrogen is discussed in detail at this Workshop by R. Neumann.

CONCLUSIONS

The availability of intense antiproton beams provides excellent possibilities for measuring the properties of antiparticle systems very precisely. So far, these possibilities have been exploited only partially, namely for the determination of the magnetic moment and the mass of the *bound* antiproton. In the immediate future we expect to make important progress by measuring the mass of the *free* antiproton. However, it would also be desirable to improve the measurement of the mass and the magnetic moment for *bound* antiprotons, in order to detect binding effects. Apart from this, even moderately precise measurements of the magnetic moment and the lifetime of the antineutron would be of interest as there exist no experimental data. Antihydrogen is a composed particle-antiparticle system which carries all the information on the antiproton and positron. The study of this system is certainly rewarding.

Apart from the experimental possibilities for measuring the properties of antiparticles very precisely, and consequently for testing invariance, it is somewhat disturbing that we have no satisfactory theoretical interconnection between the various limits for the CPT invariance tests.

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