LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

LA-UR -90-2861

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--90-2861

DE90 016444

TITLE TESTS OF THE WEAK EQUIVALENCE PRINCIPLE FOR ANTIPROTONS AND POSITRONS FROM PARTICLE-ANTIPARTICLE FREQUENCY COMPARISONS

AUTHOR(S) R. J. Hughes, P-15

SUBMITTED TO Workshop on Science at the Kaon Factory, Vancouver, Canada, July 23-28, 1990

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

TESTS OF THE WEAK EQUIVALENCE PRINCIPLE FOR ANTIPROTONS AND POSITRONS FROM PARTICLE-ANTIPARTICLE FREQUENCY COMPARISONS

Richard J. Hughes
University of California,
Los Alamos National Laboratory,
Physics Division P-15,
Los Alamos, NM 87545.

Within the next few years improvements in the precision spectroscopy of single particles or antiparticles in an ion trap[1] will allow a comparison of the influence of gravity on the trapped particles to be made. In particular, the comparison of proton and antiproton cyclotron frequencies, which is used as a test of CPT symmetry for their inertial masses[2], will become sensitive to a violation of the weak equivalence principle by the antiproton in the earth's gravitational field[3]. An experiment to test this fundamental principle of physics for antimatter has yet to be performed[4], although a measurement of the gravitational acceleration of the antiproton is under development[5]. Moreover, in the longer term, it may be possible to compare the frequencies of "sharp" transitions, such as the hyperfine or 1s-2s, in hydrogen and antihydrogen with even higher precision[6], which would provide a test of weak equivalence for the positron[3].

The cyclotron frequency of a charged particle in a magnetic field constitutes a local clock. It is well known that the gravitational red-shift of the rates of two clocks which are separated by some height in a gravitational field results from the coupling of gravity to the energy content of the clocks[7], and that a measurement of the red-shift provides a test of weak equivalence for the clock energy[8]. Therefore, although the cyclotron frequency of a proton in a magnetic field will exhibit the usual red-shift of general relativity in a gravitational field, the antiproton cyclotron frequency would not if it does not obey the weak equivalence principle.

This observation leads to the possibility of testing the equivalence principle for the antiproton by comparing its cyclotron frequency with that of the proton in the same magnetic field and at the same height in the earth's gravitational field. This is because although the cyclotron frequencies of this particle-antiparticle pair would be identical in the absence of gravity (at "infinity"), under the assumption of exact CPT symmetry, they would have different red-shifts between "infinity" and the surface of the earth if the antiparticle violated the weak equivalence principle, and this would produce a non-zero frequency difference. The conventional red-shift between "infinity" and the surface of the earth is $GM_{\oplus}/R_{\oplus}c^2 \sim 6\times10^{-10}$. Therefore, if it is found that the cyclotron frequencies of the proton and antiproton are equal to 1 part in 10^9 in the same magnetic field[2], this result would rule out the possibility that the antiproton experiences a gravitational acceleration which is double (or opposite) that of the proton in the earth's gravitational field[3]. Moreover, if the precision of this frequency comparison can be improved to the 10^{-12} level[1], such an experiment would provide a test of weak equivalence for the antiproton in the earth's gravitational field at the 10^{-3} level[3].

Similar considerations apply to any other pair of CPT-conjugate clock systems. For instance, a comparison of the hyperfine or 1s-2s transition frequencies in hydrogen and antihydrogen could potentially provide a very sensitive test of weak equivalence for the positron[3] in the earth's gravitational field. The 1 Hz natural line-width of the 1s-2s transition in hydrogen offers an eventual precision in this frequency comparison of possibly better than a part in 10^{15}[6], which would translate into a test of weak equivalence for the positron in the earth's gravitational field with a precision of better than a part in 10^6, if this measurement could be achieved in antihydrogen as well. Of course, many technological obstacles need to be overcome before such high precision spectroscopy of antihydrogen becomes possible, not the least of which is antihydrogen production itself, for which three different schemes have been proposed[9]. Other difficulties include the trapping, manipulation and cooling of the antihydrogen, requiring the development of a Lyman-α laser, and the development of appropriate optical frequency standards[6]. We must conclude therefore that these very exciting physics possibilities with antihydrogen are of a much longer term nature than the improvements in the spectroscopy of trapped antiprotons, where the necessary techniques are already in a state of active development[1].

References.

1. D. J. Heinzen and D. J. Wineland, "Laser-Cooled Refrigerator and Detector," NIST Report (1989), to be published in Phys. Rev. A.

2. G. Gabrielse et al., "Progress Report by the Trap Collaboration (PS-196)," CERN/PSCC/89-7/PSCC/M297;
G. Gabrielse et al., Phys. Rev. Lett. 63, 1360 (1989).
G. Gabrielse et al., "A 1000-fold improvement in the measured antiproton mass," Harvard preprint (1990).

3. R. J. Hughes, "Do Positrons and Antiprotons respect the Weak Equivalence Principle?" LA-UR-90-1026, to appear in the proceedings of the Moriond workshop on "New and Exotic Phenomena", Les Arcs, France, January 1990;
R. J. Hughes and M. H. Holzscheiter (in preparation).

4. T. Goldman and M. M. Nieto, Phys. Lett. 112B, 217 (1988);
T. Goldman, R. J. Hughes, and M. M. Nieto, Phys. Lett. 171B, 217 (1988), Sci. Am. 258 No. 3 (March), 48 (1988).

5. N. Beverini et al., "A Measurement of the Gravitational Acceleration of the Antiproton," CERN/PSCC/86-2/P-94 (1986); Los Alamos report LA-UR-86-260 (1986).

6. T. W. Hansch in "The Hydrogen Atom," G. F. Bassani et al. eds., Springer, New York (1989).

7. A. Einstein, Ann. Phys. 35, 898 (1911);
R. H. Dicke in "Relativity, Groups and Topology," C. DeWitt and B. DeWitt, eds. (Gordan and Breach, New York, 1964).

8. K. Nortvedt, Phys. Rev. D11, 245 (1975).

9. H. Poth, Physica Scripta T22, 806 (1988); B. I. Deutsch et al., Hyperf. Inter. 44, 271 (1988); G. Gabrielse et al., Hyperf. Inter. 44, 349 (1988); D. B. Holtkamp, M. H. Holzscheiter, and R. J. Hughes, "Physics with Ultra-Low Energy Antiprotons," Los Alamos report LA-UR-89-3537 (1989), to appear in the proceedings of the "Physics at Fermilab in the 1990's" workshop, Breckenridge, CO., August 1989.