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Our ATRAP team has managed to simultaneously accumulate cold antiprotons and cold positrons. Cold antihydrogen is produced when antiprotoris are repeatedly driven into collisions with cold positrons within a nested Penning trap. Efficient antihydrogen production takes place during many cyoles of positron cooling of antiprotons. A first measurement of a distribution of antihydrogen states is made using a preionizing electric field between separated production and detection regions. Surviving antihydrogen is stripped in an ionization well that captures and stores the free antiproton for background-free detection. A background-free observation of cold antihydrogen atoms was made using field ionization followed by antiproton storage, a detection method that provided the first experimental information about antihydrogen atomic states. More antihydrogen atoms can be field ionized in an hour than all the antimatter atoms that have been previously reported, and the production rate per incident high energy antiproton is higher than ever observed. The high rate and the high Rydberg states suggest that the antihydrogen is formed via three-body recombination.

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Final Report

on

Antiprotons and Cold Antihydrogen

In 2004, we report substantial progress on "Antiprotons and Cold Antihydrogen" project funded by AFOSR. Listed below are the publications funded by AFOSR support. The topics indicate new discoveries and progress.

"Strongly Magnetized Antihydrogen and Its Field Ionization"
D. Vrinceanu, B.E. Granger, R. Parrott, H. R. Sadeghpour, L. Cederbaum, A. Mody, J. N. Tan and G. Gabrielse
Phys. Rev. Lett. **92**, 133402 (2004).

"G. Gabrielse, et al. reply" (A reply to a Comment discusses comparing our measured field ionization spectra to theory)
G. Gabrielse, *et al.*
Phys. Rev. Lett. **92**, 149304 (2004).

"Aperture Method to Determine the Density and Geometry of Anti-Particle Plasmas", P. Oxley, N. S.Bowden, R. Parrott, A. Speck, C. Storry, J.N. Tan, M. Wessels, G. Gabrielse, D. Grzonka, W. Oelert, G. Schepers, T. Sefzick, J. Walz, H. Pittner, T.W. Haensch and E. A. Hessels
Phys. Lett. B **595**, 60 (2004).

"First Measurement of the Velocity of Slow Antihydrogen Atoms",
G. Gabrielse, A. Speck and C.H. Storry, D. Le Sage, N. Guise, D. Grzonka, W. Oelert, G. Schepers, T. Sefzick, H. Pittner, J. Walz, T.W. Haensch, D. Comeau, E.A. Hessels
Phys. Rev. Lett. **93**, 073401 (2004).

"First Evidence for Atoms of Antihydrogen Too Deeply Bound to be Guiding Center Atoms",
G. Gabrielse, A. Speck, C.H. Storry, D. Le Sage, N. Guise, D. Grzonka, W. Oelert, G. Schepers, T. Sefzick, H. Pittner, J. Walz, T.W. Haensch, D. Comeau, E.A. Hessels
Submitted for publication.

"Laser-Controlled Production of Rydberg Positronium"
A. Speck, C.H. Storry, E. Hessels and G. Gabrielse
Phys. Lett. B **597**, 257 (2004).

"Single-Particle Self-excited Oscillator (includes application to measuring antiproton spin flips)
B. D'Urso, R. Van Handel, B. Odom and G. Gabrielse
Phys. Rev. Lett. (in press).

"First Laser-Controlled Antihdyrogen Production"
C.H. Storry, A. Speck, D. Le Sage, N. Guise, G. Gabrielse, D. Grozonka, W. Oelert, G. Scheppers, T. Sefzick, J. Walz, H. Pittner, M. Herrmann, T.W. Haensch, E.A. Hessels and D. Comeau
Phys. Rev. Lett. (in press).

Review paper: "Atoms Made Entirely of Antimatter: Two Methods Produce Slow Antihydrogen"

G. Gabrielse
Advances in Atomic, Molecular and Optical Physics **50** (2004).

Invited Talks

There were a large number of outside lectures on AFOSR supported research during 2004.

Jan. 13 Atomic and Molecular Interactions Group (AMIG) of the Institute of Physics, Dublin City University (invited speaker)
Feb. 3 CERN SPSC (antihydrogen progress lecture)
Feb. 11 University of Michigan (physics colloquium)
Feb. 12 University of Michigan (atomic, molecular and optical physics seminar)
Feb. 12 University of Michigan (science and religion lecture)
Mar. 2 University of Uppsala, Sweden (Lecture on attracting students to science and teaching science so they love it)
Mar. 3 University of Uppsala, Sweden (physics seminar)
Mar. 4 Umeå University, Sweden (physics colloquium)
Mar. 4 Umeå University, Sweden (atomic physics seminar)
Mar. 9 Göteborg University, Sweden (physics colloquium)
Mar. 9 Göteborg University, Sweden (Lecture on attracting students to science and teaching science so they love it)
Mar. 10 Manne Sigbahn Laboratory, Stockholm (physics colloquium)
Mar. 11 University of Stockholm, Sweden (Alba Nova colloquium)
Mar. 12 Uppsala University, Sweden (physics colloquium)
Apr. 19 14th American Physical Society Topical Conference on Atomic Processes in Plasmas (APiP), Santa Fe, NM (the plenary lecture)
Apr. 22 Pluecker Lecture I, University of Bonn (physics colloquium)
Apr. 23 Pluecker Lecture II, University of Bonn (special audience lecture)
May 7 KVA Seminar, Groningen, The Netherlands
May 10 Free University of Amsterdam (physics colloquium)
May 13 Eindhoven University (physics colloquium)
May 14 Nijmegen Univeristy (physics colloquium)
May 15 US National Academy of Sciences CAMOS (invited lecture)
May 17 Aachen University (physics colloquium)
May 18 Johannes Gutenberg University and Max Planck Institute for Polymer Research, Mainz, Germany (physics colloquium)
May 24 University of Nottingham, UK (physics colloquium)
May 26 University of Sussex, UK (physics colloquium)

May 28 University of Liverpool, UK (particle physics seminar)
July 27 XIX International Conference on Atomic Physics, Rio de Janeiro (invited speaker)
Aug. 25 Laser Spectroscopy Conference, Novosibirsk, Russia (invited speaker)
Oct. 14 Calvin College (physics colloquium)
Nov. 16 Guelph-Waterloo Physics Institute, Guelph, Ontario (distinguished scientist lecture)
Nov. 19 Ohio University (physics colloquium)
Dec. 2 California Institute of Technology (physics colloquium)
Dec. 3 California State University, Long Beach (physics colloquium)
Dec. 9 Wesleyan University (physics colloquium)
Dec. 16 Brookhaven National Laboratory (particle physics seminar)

New Discoveries, Inventions, Patents: None

Honors/Awards:

George Ledlie Prize, Harvard University, 2004. The Ledlie Prize is awarded approximately every two years to "the person at the University who has by research, discovery or otherwise made the most valuable contribution to science, or in any way for the benefit of mankind."

Some quotations from http://www.hno.harvard.edu/gazette/2004/04.22/03-ledlie.html are listed below:

"He received the award for his 'stunning' scientific accomplishment of creating antimatter, according to Provost Steven Hyman."

"As the head of an international team of physicists at CERN [European Organization for Nuclear Research], Professor Gabrielse developed the techniques to accumulate antiprotons at energies more than 10^{10} times lower than previously realized," Hyman said. These techniques allow for extremely accurate measurements of the properties of matter and antimatter."

"Gerald Gabrielse's achievements in pushing back the frontiers of knowledge are nothing less than extraordinary," said Harvard President Lawrence H. Summers. "His work not only throws light on some of the fundamental questions about the nature of matter, but has also led to several technological advances in other fields, such as medicine."

"In recommending Gabrielse for the award, FAS Dean William C. Kirby explained that the goal of his experiments is to "ultimately help to solve puzzles about antimatter's presence in the universe. The spin-off technology associated with this work has been a benefit in its own right, helping advance nuclear magnetic resonance, and magnetic resonance imaging techniques."