Parametric Dark Detection Of A Single Electron In A Penning Trap

A thesis presented

by

Ching-Hua Tseng

to

The Department of Physics

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

in the subject of

Physics

Harvard University

Cambridge, Massachusetts

February 1995

Abstract

The gyromagnetic ratio measurement of the electron is the most precise comparison between a theory (QED) and an experiment. The leading systematic error is due to the uncertainty of the coupling between the electron and the surrounding trap cavity. To overcome this, the microwave cavity mode structure of a cylindrical geometry trap has been characterized by using parametrically-driven electron oscillators. The coupling between the electron and the radiation field environment of the cavity can now be controlled and measured directly.

The parametric oscillation of a single trapped electron is studied and used to measure enhanced spontaneous emission, an emission rate which is much faster than could be measured before. Hysteresis in this motion provides a 1 bit memory to store information about excitations made with the electron "in the dark". Using this technique, the cyclotron frequency is measured to the precision (1 ppb) needed for a new g factor measurement. A one electron, self-excited oscillator using parametric feedback is examined. The exponential risetime of a parametric excitation is measured, and may provide a sensitive means by which to measure the temperature of the particle.

The cyclotron excitation of one electron is modelled as a driven, damped, anharmonic oscillator at non-zero temperature. The master equation and the associated Q-function are presented. Cyclotron excitations as large as 16.2 eV (n=26,500) were observed. Rates for possible cavity mode sideband cooling of the axial temperature are estimated.

The cyclotron excitation of two electrons is also observed, and the basic features explained using a simple model. Multi-particle plasma interactions can thus be studied in one particle increments.

Contents

Acknowledgments

This work
was
gently
encouraged
by
Professor
Gerald Gabrielse.

Fred Walls at the National Institute of Standards and Technology in Boulder, Colorado collaborated in the construction of the microwave source, and gave valuable advice. Instrument makers Louie DeFeo, Richard Anderson, Emil Hafner, and Harlan Kent constructed much of the apparatus. Jan Ragusa made the paperwork go smoothly. I have had the privilege of interacting with postdoctoral fellows Steve Rolston, Luis Orozco, Ben Brown, Robin Kaiser, Wolfgang Quint, Won Ho Jhe, and Kamal Abdullah. Much of the work would not have been possible without: K. Helmerson, X. Fei, R. Tjoelker, J. Tan, L. Haarsma, J. Wen, A. Khabbaz, D. Phillips, D. Enzer, D. Hall, L. Lapidus, P. Janzen, S. Peil, and C. Levy. I especially acknowledge D. Enzer who worked closely with me during the early struggles with these experiments. Her contributions to improving the microwave system were invaluable. She and L. Lapidus designed and built the pressure regulation system needed to stabilize the superconducting solenoid. The early stages of this work were done at the University of Washington in Seattle.

This work was supported by the National Science Foundation.

Publications during Ph.D. study

1. "A Single Electron In An Orthogonalized Cylindrical Penning Trap", C.H. Tseng, J. Tan, G. Gabrielse, Bull. Am. Phys. Soc. **33**, 931 (1988).

2. "A Superconducting Solenoid System Which Cancels Fluctuations In The Ambient Field", G. Gabrielse, J. Tan, P. Clateman, L.A. Orozco, S.L. Rolston, C.H. Tseng, and R.L. Tjoelker, J. of Mag. Res. **91**, 564 (1991).

3. "Extremely Cold Antiprotons For Mass Measurements and Antihydrogen", G. Gabrielse, W. Jhe, D. Phillips, C. Tseng, L. Haarsma, K. Abdullah, J. Gröbner, H. Kalinowsky, in *Atomic Physics 13, Thirteenth International Conference on Atomic Physics*, (American Institute of Physics, New York), 85 (1993).

4. "Extremely Cold Antiprotons For Antihydrogen Production", G. Gabrielse, W. Jhe, D. Phillips,W. Quint, C. Tseng, L. Haarsma, K. Abdullah, J. Gröbner, H. Kalinowsky, Hyperfine Interactions **76**, 81 (1993).

5. "Portable Trap Carries Particles 5000 Kilometers", C. Tseng and G. Gabrielse, Hyperfine Interactions **76**, 381 (1993).

6. "Parametric Dark Detection With A Single Electron", C.H. Tseng and G. Gabrielse, Bull. Am. Phys. Soc. (April 1994).

7. "One Electron Parametric Oscillator", C.H. Tseng and G. Gabrielse, (festschrift for Prof. Dr. H. Walther), Appl. Phys. B, **60**, 95 (1995).

List of Figures