A Circularly-Polarized Optical Dipole Trap and Other Developments in Laser Trapping of Atoms

by

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Dr. Carl E. Wieman

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The final copy of this thesis has been examined by the signatories, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above mentioned discipline.

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A Circularly-Polarized Optical Dipole Trap and Other Developments in Laser Trapping of Atoms

Thesis directed by Prof. Dr. Carl E. Wieman

Several innovations in laser trapping and cooling of alkali atoms are described. These topics share a common motivation to develop techniques for efficiently manipulating cold atoms. Such advances facilitate sensitive precision measurements such as parity non-conservation and β-decay asymmetry in large trapped samples, even when only small quantities of the desired species are available.

First, a cold, bright beam of Rb atoms is extracted from a magneto-optical trap (MOT) using a very simple technique. This beam has a flux of 5×10^9 atoms/s and a velocity of 14 m/s, and up to 70% of the atoms in the MOT were transferred to the atomic beam. Next, a highly efficient MOT for radioactive atoms is described, in which more than 50% of ^{221}Fr atoms contained in a vapor cell are loaded into a MOT. Measurements were also made of the ^{221}Fr 7 $^2P_{1/2}$ and 7 $^2P_{3/2}$ energies and hyperfine constants. To perform these experiments, two schemes for stabilizing the frequency of the light from a diode laser were developed and are described in detail.

Finally, a new type of trap is described and a powerful cooling technique is demonstrated. The circularly polarized optical dipole trap provides large samples of highly spin-polarized atoms, suitable for many applications. Physical processes that govern the transfer of large numbers of atoms into the trap are described, and spin-polarization is measured to be 98(1)%. In addition, the trap breaks the degeneracy of the atomic spin states much like a magnetic trap does. This allows for RF and microwave cooling via both forced evaporation and a Sisyphus mechanism. Preliminary application of these techniques to the atoms in the circularly polarized dipole trap has

successfully decreased the temperature by a factor of 4 while simultaneously increasing phase space density.

Dedication

To my loving parents,

Allen George Corwin

and

Julie Ann Grastorf Corwin.

Acknowledgements

Many, many people have helped make my graduate school experience a rich and rewarding one. Although it is impossible for me to thank them all, here I attempt to mention those who have had the greatest influence on my research at CU.

I have been very fortunate to learn atom trapping from a master, Carl Wieman. He brings an honest and direct approach to both people and science, which I appreciate. And I thank him for the mentoring me on everything from preparation for oral exams to personal and professional advice on being a good scientist. When he adds this document to his collection, I hope he'll say (as on the day he found the source of some particularly annoying noise) "Superadvisor strikes again!!!"

I have also had the pleasure to work with many talented postdocs. The first was Michelle Stephens, who patiently showed me around JILA and taught me important skills such as tuning a Ti:Sapph laser, making dry film coatings, and drilling holes. Even after she left JILA, her continued support has been very much appreciated. After a couple months on my own, I was very happy to welcome Zheng-Tian Lu to the experiment. Lu always encouraged my complete involvement in the experiment, and inspired me by his example to work efficiently and responsibly, always with the final goal in mind. His love of science is contagious, and I am certain that he is now an excellent advisor for his own students and postdocs at Argonne National Labs.

Simon Kuppens joined the experiment about 1 1/2 years ago. At that time, I was certain that I didn't need a postdoc, much like the eldest VanTrapp daughter in

the Sound of Music who asserted, “I don’t need a governess!” But Simon showed me otherwise. He brought to the experiment a mathematical approach that was crucial to the unraveling of the FORT loading puzzle. In addition, he became a close friend. Once a visitor asked if we always run the experiment with so much laughter, and the answer was... yes! I already miss him since his return to Holland.

The experiment is now in good hands. Kurt Miller has been doing great work on the experiment for over two years. The majority of the evidence for cooling is largely due to his efforts – we wouldn’t even know the FORT temperature without him. As he takes over the experiment, he’ll have excellent help from Stephan Dürr, who only joined the group 6 weeks ago but is already making big contributions. I thank Stephan for his helpful comments on the cooling mechanisms and especially Landau-Zener transitions, and I’m sorry I won’t have a chance to work more with him.

Many other people have contributed directly to the work described in this thesis. The LVIS experiment sprung from an idea of Mike Anderson, followed by an astute observation of Mike Renn. In addition, the DAVLL lock was developed with help from Carter Hand and Ryan Epstein. And Tasha Fairfield contributed to the development of the cavity lock.

The francium experiment would have been impossible without the source and hard work provided by the Berkeley team: Tim Dinneen, Harvey Gould, and Jason Maddi. And prospects for finishing the experiment looked dim until Kurt Vogel rode in on a shining Ar^+ laser (from Jan Hall) and saved the day. Thanks also to JILA for providing us a new Ar^+ laser tube, days before the final francium source arrived. That experiment taught me how close colleagues can become when working on a source with a 1 month decay time; I miss the sense of excitement and camaraderie, but not the sleep deprivation. Several members of the JILA shops made major contributions to the Fr experiment: Dave Alchenberger constructed the vacuum chamber and the high-precision oven manipulator, Hans Rohner built the beautiful glass cell and helped

us coat it, and Terry Brown build the high-speed electronics that made the precise λ-meter measurements possible. John Smedley, a JILA visiting fellow, also worked on experiment construction.

Before the FORT project, I had an opportunity to bridge the gap between the old and new teams on the “Fiber project,” under the supervision of Dana Anderson, Eric Cornell, and Carl Wieman. Elizabeth Donley showed me the ropes, and I passed things on to Eric Abraham, Brian DeMarco, and Dirk Müller. I enjoyed working with Brian and Dirk as new grad students, back when THEY had asked ME questions; it seems the roles are now largely reversed. I also appreciated Eric A.’s guidance at that time, even after I left the project in capable hands to return to the circularly polarized FORT.

The circular FORT project was originally conceived by Dong Hyung Cho, who has continued to participate in the project during his visits to Boulder. He also graciously hosted me at his home institution, Korea University, where the collaboration continued. Timothy Chupp also contributed to the studies of FORT loading while he was a JILA visiting fellow in 1997-98. I appreciate Tim teaching me to take the time to stop and think on the “rare” occasions when we did not immediately understand our experimental results. I also enjoyed working and playing soccer with him. Jake Roberts did a brief stint on the project between the Cs parity violation measurement and the Bose-Einstein Condensation measurement, and his contributions then and throughout the experiment have been very valuable. Neil Claussen has also contributed to both the earliest and most recent stages of the FORT experiment, from modeling the loading of the FORT after its initial observation to providing us with a high-power laser system that he personally constructed (the MOPA).

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Lowell and Travis Andrews also provided a lot of assistance in the labs.

The Wieman-Cornell-Jin "family" provides a wonderful environment in which to do science. Eric Cornell has served as my additional advisor many times, and I appreciate his ideas and his support. Debbie Jin often has helpful insights during group meeting, and I thank her also for a careful reading of this manuscript with many useful suggestions. Other current "family" members who continue to make this a great group include: Brian Anderson, Ian Coddington, Paul Haljan, Heather Lewendowski, Scott Papp, Marco Prevedalli, Malcom Rickard, Peter Schwindt, and Dwight Whitaker. Previous members who have moved on to great things include Anne Curtis, Harold Gauck, Tim Gfroerer, David Hall, Sergio Muniz, and especially Mike Matthews. Jason Ensher deserves special mention, since he and I have been in school together 10 years, both at UB and CU, and he has always both challenged and encouraged me.

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