

**Quenched narrow-line laser cooling of ^{40}Ca with
application to an optical clock based on ultracold
neutral Ca atoms**

by

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Quenched narrow-line laser cooling of ^{40}Ca with application to an optical clock based
on ultracold neutral Ca atoms

Thesis directed by Dr. Leo Hollberg

I describe a novel method of laser cooling that utilizes extremely narrow (< 1 kHz natural linewidth) atomic transitions to cool and trap neutral atoms. To effectively cool using these narrow lines we introduce quenching of the excited state to speed up the decay process of the long-lived excited states. This allows rapid cooling of the atoms before they can escape the trap. In this dissertation, methods of quenched narrow-line laser cooling are explored through simulations and experiments using ^{40}Ca atoms, reducing atomic temperatures from ~ 2 mK, accessible through standard Doppler-cooling methods, to $10 \mu\text{K}$, in three dimensions. Further cooling is performed in one dimension, producing distributions in the hundreds of nanokelvin range. The impetus for the development of second-stage cooling of calcium lies with our concurrent development of an optical frequency standard based on the narrow $^1S_0 \rightarrow ^3P_1$ intercombination line at 657 nm (456 THz) in neutral ^{40}Ca . Compared to the present microwave-based standards, an optical transition used as the basis for an atomic frequency standard has the potential to improve the stability by over 3 orders of magnitude. Absolute frequency measurements that we have performed of the Ca 456 THz transition relative to the Cs primary standard show that the accuracy of the present system is limited due to frequency shifts caused by the residual velocity (~ 70 cm/s) of the Doppler cooled calcium atoms. The use of micokelvin temperature atoms achieved with quenched narrow-line cooling can potentially increase the accuracy of the standard by more than an order of magnitude, and opens the way for the other improvements to the standard, such as clock spectroscopy performed on atoms that have been loaded into an optical lattice.

Dedication

I would like to dedicate this dissertation to
my parents,

Chris and Rhys Curtis

who have always seemed to believe
that I could accomplish anything,
as long as I tried hard enough.

It seems that they were right.

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