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SUMMARY OF WORK ON COOLED ION FREQUENCY STANDARD, FISCAL YEAR 1--ETC(U)
JUN 80 D J WINELAND, F L WALLS

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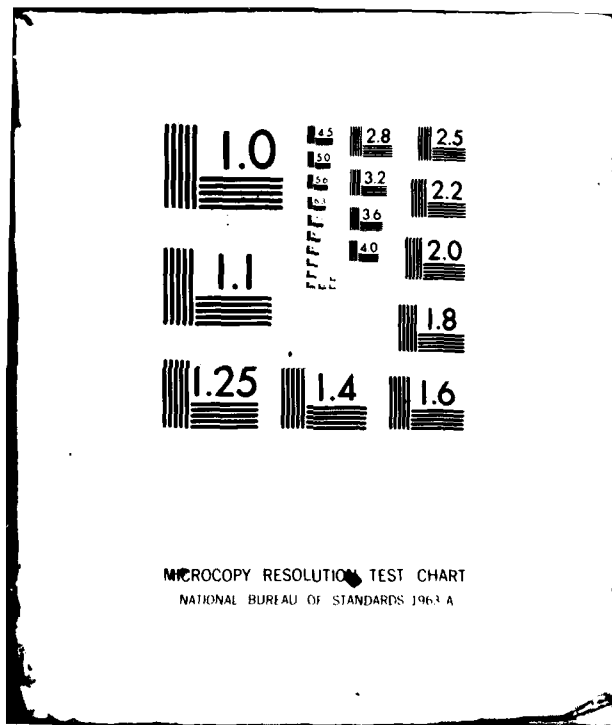
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Summary of Work on
"COOLED ION FREQUENCY STANDARD"
(FY80)

ONR Contract No. N00014-77-F-0046

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Contract Description

The purpose of this work is to develop techniques to overcome the fundamental limits of present frequency standards--the second and residual first-order Doppler shifts. To this end, we study suitable frequency reference transitions in ions which are stored in electromagnetic traps and cooled by radiation pressure to $< 1\text{K}$.

Scientific Problem

Although we have now demonstrated laser cooling to $< 0.5\text{K}$ and have identified some of the causes for the present limit, we will try to approach the theoretical limit of 10^{-3}K . To this end, we will try to isolate a single ion in the trap. In addition, we will try to tailor clouds of modest density that are relatively free of magnetron velocity effects. It should also be possible to observe condensation of the ion cloud into a liquid or solid. We will continue to incorporate the cooling into high resolution spectroscopy and use the fluorescence as a monitor in a triple resonance scheme which should allow us to obtain linewidths of less than 0.1 Hz . Such experiments should allow us to study problems generic to all ion frequency standards.

Scientific and Technical Approach

A special apparatus will be built with improved detection efficiency, so that the fluorescence from a single ion can be observed. This improved detection efficiency will also be beneficial in the double resonance experiments. It may be desirable to use a light ion such as Be^+ and higher magnetic fields, so

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that at a given temperature, the cyclotron and axial amplitudes are much smaller. An experiment on Cd^+ is being set up. The required radiation for pumping and cooling is 214 nm. This radiation can be generated by frequency mixing techniques and will allow a study of the problems associated with frequency generation at the shorter wavelengths, where more attractive ion frequency standard candidates exist. The Ba^+ experimental apparatus will address particular problems of construction, such as obtaining ultimate vacuum and freedom from magnetic perturbations. Dye laser stabilization schemes will be investigated for possible application to optical frequency standards.

Progress During Last Contract Period

1. Optical-Pumping Double Resonance.

- a. We have established mechanisms and rates for optical pumping in $^{24}\text{Mg}^+$ and $^{25}\text{Mg}^+$.
- b. We have realized double resonance schemes where $\sim 10^6$ optical photons can be detected for each microwave photon absorbed. This can be used to give unit detection efficiency even with low collection efficiency.
- c. We have observed relaxation time of > 1 minute in $^{25}\text{Mg}^+$ experiments. This should eventually yield extremely narrow linewidths. At present, we have observed linewidths of 0.2 Hz in a quadruple resonance scheme in $^{25}\text{Mg}^+$. These measurements have a direct bearing on the frequency standard problem.

- d. Have made first high resolution measurements (< 1 ppm) of $^{25}\text{Mg}^+$ hyperfine structure and g_I/g_J ratio (40 ppm).
 - e. Have determined line positions and isotope shifts of Mg isotopes.
- 2. U. V. Source Development. Have generated 214 nm C. W. using frequency mixing techniques. This will be used in spectroscopic experiments on Cd^+ .
 - 3. Cooling Limit Studies. For clouds of ions, lower temperature limit is 0.5K due to magnetron rotation of cloud. For smaller clouds, laser can compress cloud causing higher densities, but temperature limits are still $\sim 0.5\text{K}$. We have observed bistable cloud configurations, which may be condensation effect, since it is expected for our experimental conditions.

Ion Storage Publications (FY80)

- 1. "Laser Cooling of Atoms," D. J. Wineland and W. M. Itano, Phys. Rev. A 20, 1521 (1979).
- 2. D. J. Wineland, "Limitations on Long-Term Stability and Accuracy in Atomic Clocks," Proc. 11th Ann. Precise Time and Time Interval Application and Planning Meeting (Goddard Space Flight Center, Greenbelt, MD.), 1980, NASA Conference Publication 2129.

3. "High Resolution Optical Spectra of Laser Cooled Ions," R. E. Drullinger, D. J. Wineland and J. C. Bergquist. Appl. Phys., to be published.
4. "Double Resonance and Optical Pumping Experiments on Electromagnetically Confined, Laser Cooled Ions," D. J. Wineland, J. C. Bergquist, W. M. Itano, and R. E. Drullinger. Opt. Lett. 5, 245 (1980).
5. "High Resolution RF Spectroscopy of Laser-Cooled $^{25}\text{Mg}^+$ Ions," W. M. Itano, D. J. Wineland, R. E. Drullinger, and J. C. Bergquist. Abstracts for 7th Int. Conf. on Atomic Physics, Boston, MA, August 1980.

Ion Storage Conference Talks (FY80)

1. "Frequency and Time Standards Utilizing Laser Cooled Ions," W. M. Itano and D. J. Wineland, Bull. Am. Phys. Soc. 24, 1185 (1979).
2. "Laser Induced Magnetron Compression (Expansion) of Ions Stored in a Penning Trap," D. J. Wineland, R. E. Drullinger, J. C. Bergquist, and W. M. Itano, Bull. Am. Phys. Soc. 24, 1185 (1979).
3. "Optical Pumping and Double Resonance Experiments on Laser Cooled Ions," D. J. Wineland, J. C. Bergquist, W. M. Itano, and R. E. Drullinger, 11th Int. Conf. on Quantum Electronics, Boston, MA, June 1980.
4. "High Resolution RF Spectroscopy of Laser-Cooled $^{25}\text{Mg}^+$ Ions," W. M. Itano, D. J. Wineland, R. E. Drullinger, and J. C. Bergquist. Abstracts for 7th Int. Conf. on Atomic Physics, Boston, MA, August 1980.

Miscellaneous

All FY80 funds will be spent by end of contract year.

Other contract support of principal investigators:

David J. Wineland:

AFOSR \$100 k "Precision Frequency Metrology Using Laser Cooled Ions."

KEY PERSONNEL (FY80)

Co-Principal Investigators

D. J. Wineland (45%)

F. L. Walls (10%)

Senior Staff Scientists

R. E. Drullinger (10%)

J. C. Bergquist (30%)

Research Associate

W. M. Itano (25%)

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