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SUMMARY OF WORK ON COOLED ION FREQUENCY STANDARD.(U)  
JUN 79 D J WINELAND, F L WALLS

N00014-77-F-0046

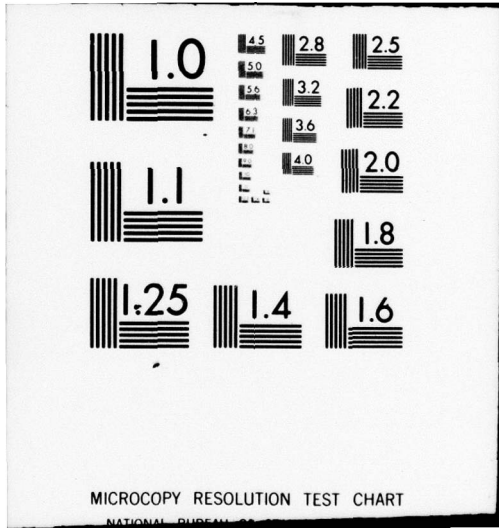
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**SUMMARY OF WORK ON**

**"COOLED ION FREQUENCY STANDARD"**

(FY79)

**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  $< 0.5\text{K}$  we must investigate why the theoretical limit of  $10^{-3}\text{K}$  has not been obtained. We must incorporate this cooling in high-resolution spectroscopy--we propose to observe the resonance fluorescence on Mg II ions as a first step in this direction. Measurements of cooling approaching  $10^{-3}\text{K}$ , isotope shifts,  $^{25}\text{Mg}^+$  h.f.s.,  $g_j$  factors and S/N in optical-double resonance detection with stored ions all appear possible. In addition, we propose to study other interesting ions (e.g.,  $\text{Ba}^+$ ) which may make suitable cooled stored ion frequency standard candidates.

### Scientific and Technical Approach

The search for possible high-resolution spectroscopic candidates in ions has currently centered on those ions which can be stored in electromagnetic traps (Penning traps in our experiments so far) and whose electronic transitions can be accessed by the output or frequency-doubled output of single-mode tunable dye lasers. At this point it is difficult to identify the ultimate candidate for a frequency standard; however,  $\text{Ba}^+$  has very attractive features in this regard.

$\text{Mg}^+$  ions will continue to be studied in the Penning traps as important problems relevant to possible frequency standards can be investigated (see above). Many improvements are possible in the area of trap design, and new traps will be constructed to study  $\text{Ba}^+$  and other ions which appear attractive. The study of  $\text{Ba}^+$  will necessitate the use of a second dye laser (to relax the metastable D states) and possible additional microwave radiation to relax the ground state levels and study their spectroscopy.

Progress during last contract period

We have extended measurements in Mg II ions and have now demonstrated laser cooling to temperatures  $< 0.5$  K. In these measurements the temperature was derived from the Doppler width of the transitions by observing the back-scattered light. This represents a reduction of the second order Doppler effect in a comparable experiment done on room temperature ions of nearly 3 orders of magnitude.

Additional work performed in last contract period:

(1) We have demonstrated that one ion species can be used as a "cooling ion" which can cool simultaneously other trapped ions by coulomb collisions. This greatly increases the choices for ions which may be used as frequency references.

(2) We have demonstrated optical pumping of  $^{25}\text{Mg II}$ . The study of hyperfine structure in this ion will provide a test-bed for ion frequency standards based on optical pumping - double resonance.

(3) We have demonstrated that the magnetron motion in a Penning trap can be laser cooled. In addition this allows for indefinite confinement of ions in a Penning trap.

(4) A theoretical analysis of cooling mechanisms, rates and limits has been performed. (See refs.)

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### Publications (FY79)

1. "Laser Cooling of Atoms," D. J. Wineland and W. M. Itano, Submitted to Phys. Rev. A.
2. "Laser Cooling of Ions Bound to a Penning Trap," R. E. Drullinger and D. J. Wineland" Proc. 4th Int. Conf. Laser Spectroscopy, Rottach-Egern, Tegernsee, Springer-Verlag, June 1979 - Same title by D. J. Wineland and R. E. Drullinger, Proc. 6th Vavilov Conf. Nonlinear Optics, Novosibirsk, Springer, June 1979.
3. "New Possibilities for Frequency Standards Using Laser Cooling and Detection of Stored Ions," F. L. Walls, D. J. Wineland and R. E. Drullinger, Proc. 32nd Ann. Symp. on Frequency Control, Atlantic City, NJ, June 1978 (p. 453).
4. "High Resolution Spectroscopy by Radiative Cooling of Bound Resonant Absorbers," D. J. Wineland, R. E. Drullinger, and F. L. Walls. J. Opt. Soc. Amer. 68, 648 (1978).

### Conference Talks (FY79)

1. "Theoretical Analysis of Laser Cooling of Atoms," D. J. Wineland Wayne M. Itano, and D. J. Larson, Bull. Am. Phys. Soc. 24, 608 (1979).
2. "High Resolution Spectra of Laser Cooled Ions," R. E. Drullinger and D. J. Wineland. Bull. Am. Phys. Soc. 24, 608 (1979).
3. "Laser Cooling of Ions Stored in Penning Traps," D. J. Wineland Bull. Am. Phys. Soc. 24, 634 (1979). (invited talk)
4. "Laser Cooling of Ions Bound to a Penning Trap," R. E. Drullinger and D. J. Wineland, 4th Int. Conf. on Laser Spectroscopy, Rottach-Egern, Tegernsee, June 1979 (invited talk)
5. "Laser Cooling of Ions Bound to a Penning Trap," D. J. Wineland and R. E. Drullinger, Proc. 6th Vavilov Conf. on Nonlinear Spectroscopy, Novosibirsk, June 1979 (invited talk).
6. "Cooling of Resonant Absorbers by Photon Pressure," R. E. Drullinger, D. J. Wineland and F. L. Walls, Bull. Am. Phys. Soc. 24, 132 (1979).

KEY PERSONNEL (FY79)

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