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COOLED ION FREQUENCY STANDARD.(U)
JUN 82 D J WINELAND, F L WALLS   N00014-82-F-0003

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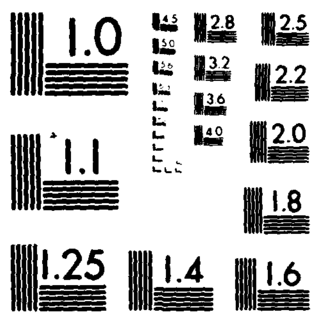

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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 on electromagnetic traps and cooled by radiation pressure to < 1K.

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Summary of Work on

"COOLED ION FREQUENCY STANDARD"

(FY 82)

ONR Contract No. N00014-82-F-0003

Co-Principal Investigators

D. J. Wineland
Frequency & Time Standards Group
524.04
National Bureau of Standards
Boulder, Colorado 80303

FTS: 320-5286
(303) 497-5286

F. L. Walls
Frequency & Time Standards Group
524.04
National Bureau of Standards
Boulder, Colorado 80303

FTS: 320-3207
(303) 497-3207

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 < 1K.

Scientific Problem

Although we have now demonstrated laser cooling to < 0.1K 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 continue studies of 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 of Mg^+, Be^+ and Hg^+ and use the flourescence as a monitor in triple resonance schemes which should allow us to obtain linewidths of less than 0.01 Hz. Such experiments should allow us to study problems generic to all ion frequency standards.

Scientific and Technical Approach

We will continue work to develop better traps for spectroscopic studies. We are completing first tests on a new trap for Be^+ and will soon make improvements. We are developing a separate experiment for $^{201}Hg^+$ ions. This experiment has the goal of realizing a prototype microwave frequency standard with 10^{-15} accuracy. We continue experiments on cloud dynamics. It appears that the largest systematic frequency shift in a frequency standard based on ions stored in a Penning trap will be due to a second order Doppler effect caused by the rotation of the ion cloud. Therefore a detailed study of this rotation is required. A superconducting magnet is now being procured for this purpose.

PROGRESS DURING LAST CONTRACT PERIOD

A. $^{201}Hg^{+}$ studies

1. 194 nm generation. $^{201}Hg^{+}$ has been chosen as a prototype frequency standard because it appears to have the best potential performance of any ion that might conceivably be used in a microwave frequency standard. One of its chief drawbacks is that the coherent 194 nm radiation required for laser cooling/ optical pumping is difficult to produce. Therefore a significant effort has gone into the development of this source. Tunable, narrowband cw radiation at 194 has now been generated by frequency doubling the output of a 514 nm argon ion laser and mixing this output (up to 80 mW at 257 nm) with the output of a 792 nm dye laser in a potassium pentaborate (KB5) crystal. Work now continues to increase the power of this source: it is estimated that several microwatts of 194 nm radiation with bandwidth less than 10 MHz can be produced when all operating conditions are optimized.

2. Hg^{+} trap. Trap design is being studied via the Be^{+} experiments (below). Experiments are now underway to test the injection/

pumping properties of Hg in the trap vacuum system. A high homogeneity electromagnet system has been acquired for initial experiments.

B. Be^+ studies

1. <u>Trap designs</u>. In order to optimize conditions for the Hg^+ experiments, we are studying various trap designs using Be^+ ions where the required radiation (λ = 313 nm) for optical pumping/laser cooling is easier to produce. We are completing experiments on an "open" trap design where the electrodes are made of gold and molybdenum mesh and the light is collected by an ellipsoidal mirror. This trap will then be modified to try to improve storage time and collection efficiency. It appears that the present trap is too open and storage time and residual heating may be a factor of five worse than with the Hg^+ trap used previously.

2. <u>Be^+ precision spectroscopy</u>. We have measured the hyperfine constant A and the nuclear to electronic g factor ratio g_I/g_J with preliminary precisions of about 5×10^{-11} and 5×10^{-9}. This is accomplished by measuring the frequency of two nuclear spin flip hyperfine transitions at "field independent" points-- that is, where the transition frequency becomes independent of magnetic field to first order. Such transitions will form the basis of the $^{201}Hg^+$ frequency standard. We have also measured $g_J(Be^+)$ to about 3 ppm by calibrating the field by measuring the cyclotron frequency of free electrons which are alternately stored in the trap. This experiment is important because it allows a careful check of the wave functions used to calculate $g_J(Be^+)$.

3. Frequency standard. The linewidth (0.05 Hz) and S/N (5-10 per experimental cycle) indicate a stability of $\sigma_y \approx 10^{-11}\tau^{-\frac{1}{2}}$ on the hyperfine transitions we have measured in Be^+. Locking an oscillator to these transitions will be done in FY'83.

C. Theoretical studies

An extensive analysis of laser cooling in Penning traps has been completed and published. We continue to study other possible microwave frequency standard candidates - Hg^+ still seems to be the best choice. In^+ optical structure has been studied for a possible optical frequency standard with inaccuracy less than 10^{-17}. It may be superior to other possibilities because of the (relative) ease of producing the required wavelength (231 nm for laser cooling/optical pumping and 237 nm for the clock transition) and the existence of convenient field independent points. We have calculated and published hyperfine structure frequency shifts due to electric fields. (For example blackbody radiation fields)

D. New apparatus

In addition to the new Be^+ and 194 nm generation apparatus, we are in the process of procuring a high performance superconducting magnet. Experiments with this magnet should improve performance of many experimental operating parameters by about 2 orders of magnitude. (see below)

E. Ion storage publications in preparation or published since May 80

"Precision measurement of the ground state hyperfine constant of $^{25}Mg^{+}$," Wayne M. Itano and D. J. Wineland, Phys. Rev. A24, 1364 (1981).

"Laser cooling of ions stored in harmonic and Penning traps," Wayne M. Itano and D. J. Wineland, Phys. Rev. A25, 35 (1982).

"Shift of $^{2}S_{1/2}$ hyperfine splittings due to blackbody radiation," Wayne M. Itano, L. L. Lewis, and D. J. Wineland, Phys. Rev. A25, 1233 (1982).

"Laser cooled, stored ion experiments at NBS and possible applications to microwave and optical frequency standards" D. J. Wineland, J. C. Bergquist, R. E. Drullinger, H. Hemmati, W. M. Itano, and F. L. Walls, J. de Physique, Colloque C8, suppl. to no. 12, vol. 42, Dec. 1981, p. C8-307.

"Shift of $^{2}S_{1/2}$ hyperfine splittings due to blackbody radiation and its influence on frequency standards" Wayne M. Itano, L. L. Lewis, and D. J. Wineland, J. de Physique, Colloque C8, suppl. to no. 12, vol. 42, Dec. 1981, p. C8-283.

"Prospects for stored ion frequency standards" D. J. Wineland, Proc. 13th Ann. Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Naval Research Laboratory, Washington DC, Dec. 1981.

"Spectroscopy of stored ions" D. J. Wineland, Proc. Conf. on Precision Measurements and Fundamental Constants, Gaithersburg,

10 June 1981. To be published.

"Progress toward a stored ion frequency standard at NBS" Wayne M. Itano, D. J. Wineland, J. C. Bergquist, and F. L. Walls. Proc. Conf. on Precision Measurements and Fundamental Constants, Gaithersburg, 10 June 1981. To be published.

"Laser cooling and double resonance spectroscopy of stored ions" Wayne M. Itano and D. J. Wineland. Laser Spectroscopy V, eds. A. R. W. McKellar, T. Oka, and B. P. Stoicheff (Springer-Verlag, New York, 1981) p. [illegible]

"Spectroscopy of laser cooled Be^+ ions" D. J. Wineland and Wayne M. Itano, Bull. Am. Phys. Soc. [illegible], [illegible] (1982)

"Microwave-optical double resonance spectroscopy of stored atomic ions", Wayne M. Itano, D. J. Wineland, H. Hemmati, J. C. Bergquist, and J. J. Bollinger, Abstracts for the eighth International Conference on Atomic Physics.

"Sum frequency generation of cw 194 nm radiation in potassium pentaborate" H. Hemmati, J. C. Bergquist, and Wayne M. Itano, Proc. Topical meeting on laser techniques for extreme ultraviolet spectroscopy (Am. Inst. of Physics, 1982)

F. Invited talks on ion storage since May 1981.

1. Precision Measurements and Fundamental Constants Conference, Bethesda, MD, June 81.
2. Fifth International Conference on Laser Spectroscopy, Jasper, Canada July 1981.
3. Gordon Conference on Atomic Physics, Wolfboro, NH, July 1981.
4. XXth General Assembly of URSI, Washington, DC Aug. 1981.
5. Univ. of Michigan, Physics Dept. Nov. 1981.
6. Univ. of Virginia, Physics Dept Feb. 1982.
7. Ohio State Univ., Physics Dept. May 1982.

Miscellaneous

A. All FY82 funds will be spent by end of contract year.

B. Other contract support of principal investigators.

David J. Wineland and F. L. Walls

AFOSR [illegible] "Precision Frequency Metrology Using Laser Cooled Ions."

F. L. Walls and [illegible]

NRL [illegible] Development of hydrogen discharge source capable of operation in vacuum

F. L. Walls and David A. Howe

JPL [illegible] Development of UV source for hydrogen masers

F. L. Walls and [illegible]

DPS-JPL [illegible] Consulting on clocks and clock development

F. L. Walls and David A. Howe

NRL [illegible] Development of passive hydrogen maser

C. KEY PERSONNEL (FY83)

Co-Principal Investigators	D. J. Wineland	(40%)
	F. L. Walls	(30%)
Senior Staff Scientists	J. C. Bergquist	(25%)
	W. M. Itano	(25%)
	E. [illegible] (starting June 1/82)	(50%)
Research Associate	H. Hemmati	(40%)
NRC Postdoctoral Research Associate	J. Bollinger (6 months)	(50%)