NBSIR 83-2793

Technical Activities 1983
Center for Basic Standards

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Basic Standards
Washington, DC 20234

November 1983

Final

Issued January 1984

Prepared for:
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CENTER FOR BASIC STANDARDS

Karl G. Kessler, Director

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Part II Page

INTRODUCTION

This book is Part II of the 1983 Annual Report of the Center for Basic Standards and contains a summary of the technical activities of the Center for the period October 1, 1982 to September 30, 1983. The Center is one of the five resources and operating units in the National Measurement Laboratory.

The summary of activities is organized in six sections, one for the technical activities of the Quantum Metrology Group, and one each for the five divisions of the Center. Each division or group tells its own story in its own way. In general, there is an overview followed by a series of short reports on current projects. Then the publications, invited talks, committee participation and professional interactions during the year are listed.

More information about particular work may be desired. To obtain this, the reader should address the individual scientists or their division, c/o Center for Basic Standards, B160 Physics Building, National Bureau of Standards, Washington, D.C. 20234.

QUANTUM METROLOGY GROUP

SUMMARY OF ACTIVITIES

FISCAL YEAR 1983

I. OVERVIEW

In the period of 1979 to 1982 there had been a general contraction of the activities and staff of the Quantum Metrology Group. It is a pleasure to report that this trend was significantly reversed during the past year. Two full-time staff people have been added to the group and three guest workers were in residence. Since no entirely new programs were begun, expansion and acceleration of existing programs in precision x-ray and γ-ray wavelength measurements and inner shell physics occurred. In addition the important measurement of a Si crystal lattice spacing was revived.

Efforts in the area of precision x-ray and γ-ray wavelengths have been concentrated on bringing into operation a four-meter Dumond curved crystal spectrometer. Basil Duval, a guest worker from Culham Laboratory and Oxford University, and Ernie Kessler were the primary contributors to this effort. Firm plans to move a precision double flat crystal spectrometer to the Institut Laue-Langevin (ILL), Grenoble, France, have been made and the instrument should be in place and operational by late November 1983. This activity has been discussed a number of times over the past 4 years but only during the past year have funds and staff made this venture possible. Geoff Greene, a new staff member, will be the resident NBS scientist for the first year of operation. During installation and initial operation, Ernie Kessler and Richard Deslattes will also be at ILL. Precision measurement of high energy gamma-rays (>2 MeV) is the purpose of moving this facility to ILL.

A manuscript with Kansas State University and Brookhaven National Laboratory on the 1s Lamb shift measurement from $C\ell^{+15}$ is nearing completion. Data concerning the 1s Lamb shift of Ar^{+17} recoil ions have been recorded at Gesellschaft für Schwerionenforschung (GSI) and are being analyzed. Richard Deslattes, Paul Cowan and Robert LaVilla contribute to this effort.

The major thrust in the area of inner shell physics has been the preparation of a beamline to be installed at the National Synchrotron Light Source (NSLS). The vacuum envelope has been completely tested, the mirror manipulators are installed, and the monochromator testing is almost complete. Shipment of the beamline to NSLS should occur before the end of 1983. The beamline is primarily the work of Paul Cowan, Terry Jach, Al Henins, Ernie Kessler and Sean Brennan. The first experiments will use the tunable monochromatized synchrotron light as a probe of the inner shell region of atomic and molecular species. Brennan, the second new staff person, has had extensive experience at the Stanford Synchrotron Radiation Laboratory (SSRL) before joining the beamline effort during the spring of 1983. His interest in solid state studies using synchrotron radiation is a natural extension of the presently planned studies of atomic and molecular systems.

Position sensitive detectors of the backgammon type have been studied by Jochen Barth, a guest worker from the University of Hamburg, and Basil Duval. With the aid of Gabe Luther a number of new detectors were built with some improvements in linearity and resolution.

Spectra from chlorine and chlorine molecules were studied by Rupert Perera, a guest worker from Virginia Polytechnic Institute and State University, and Robert LaVilla using a curved crystal spectrometer and position sensitive detector. Information related to multi-vacancies and molecular binding is derived from this data.

The NBS measurement of the lattice spacing of a Si crystal was published in 1976 and was unchallenged until 1982 when a measurement at PTB differed by 1.8 ppm from the NBS value. After interchange of Si crystal samples, an unexplained difference close to 1.8 ppm still remains. In order to understand this difference the x-ray interferometer facility has been brought back into operation in a manner which will permit a definitive test of the 1976 result and an entirely new measurement if it is necessary. Richard Deslattes is the driving force behind this effort just as he was in 1976 with Geoff Greene, Al Henins, and Mary Cutkosky making significant contributions. An automated crystal lattice comparison facility is also nearing completion. This facility (primarily the work of Al Henins) will permit more accurate comparison of NBS and PTB crystal samples as well as more accurate comparison of various crystals in use at NBS.

Finally in early August, Richard Deslattes, the group leader, took up residence at the University of Heidelberg as a von Humboldt fellow. In addition to his studies at Heidelberg, he will collaborate on high Z one-electron measurements at GSI and in the high energy γ-ray measurements at ILL. Also in August, Jim Snyder moved to NBS Boulder for a year under the auspices of the NBS Gaithersburg-NBS Boulder exchange program. He will be closely associated with John Hall of the Quantum Physics Division.

II. TECHNICAL ACTIVITIES

1. Optical Physics
   J. Snyder

Objectives

This program is concerned chiefly with experimental laser spectroscopy and the development of related technology.

Current Activities

The principal investigator (Snyder) is currently a Visiting Fellow at JILA, Boulder, for a period of one year ending September 1984. As a result, some of the activities of this program will be suspended until his return.

The collaboration with the West German national standards laboratory (Physikalisch-Technische Bundesanstalt) (PTB) continued this year with a second visit of one month by Snyder to Braunschweig, Germany. The joint experiment is intended to investigate the potential of the narrow calcium intercombination line at 657 nm as a possible future optical frequency standard, as well as to develop the combined spectroscopic techniques of merged laser-atomic beams and time-domain Ramsey excitation. The dye laser linewidth has been reduced to about 1 kHz during the past year and is expected to be further reduced to the region of a few hundred hertz. The major effort at the present time is to develop efficient high-frequency laser modulators capable of generating the required frequency shift of ∿2 GHz. In addition a new collaboration has been initiated with Bordé at the University of Paris to model the proposed use of multiple pulse (∿40 pulses) Ramsey excitation to reduce fringe complexity and width.

The Fizeau wavemeter project is essentially dormant at NBS at the present time. The original instrument continues in full-time routine use in the Temperature and Pressure Measurements and Standards Division (Rosasco). The University of Maryland Fizeau Wavemeter is currently being modified by the introduction of single-mode fiber input coupler. It is hoped that the fiber (which will replace the pinhole used as a spatial filter) will alleviate some problems due to pulsed laser damage of the pinhole substrate.

The wire-wrap prototype of the Frequency Meter, although functional, had insufficient noise margin and insufficient speed due to stray capacitance of the wire-wrap pins. A second, printed-circuit prototype was designed using the new NBS computer-aided-design (CAD) facility. This board is currently being built at a commercial firm. Further work on the Mossbauer-drive lambda meter awaits completion of the Frequency Meter electronics.

A new collaboration with a group at the University of Rochester was begun to develop interferometers for characterizing the mode structure of pulsed amplified spontaneous emission (ASE) sources.

Accomplishments

The second round of experiments on calcium at the PTB had limited success due to the limitations of the high-frequency phase modulator. However, the new optical cavity was built and tested successfully, and the modulation and detection electronics were completed.

An invited paper on the calcium experiment was presented at the Sixth International Conference on Laser Spectroscopy.

The NBS Fizeau Wavemeter has been temperature stabilized. This appears to have significantly reduced short-term drift of the instrument's calibration.

A printed-circuit board prototype of the Frequency Meter was designed.

A high-finesse Fizeau interferometer for spectral analysis of pulsed lasers and other light sources was developed and is in use at the University of Rochester.

A second firm, under license from NTIS, is now advertising the Fizeau Wavemeter.

Future Plans

The PTB collaboration will continue. The next experiments, possibly in summer 1984, require an efficient high-frequency modulator to produce the necessary 2 GHz shift of the laser frequency. In addition, it will eventually be very useful to operate with a supersonic or perhaps even a decelerated calcium beam.

The use of a single-mode fiber input coupler for the Fizeau Wavemeter will be investigated in detail.

The new Frequency Meter prototype will be tested and de-bugged. When fully functional, it will be tested in operation with the JILA lambda-meter, and later with the Mossbauer-drive lambda-meter.

2. Gravity
G. Luther (3/4)

Objectives

Our present objectives are two-fold and only indirectly related. They are, first to exploit the unique capabilities of the apparatus used to measure the Newtonian Gravitational Constant and second, to study the general limits of physical measurements.

Accomplishments

A paper was prepared and delivered to the Third Meeting of the Marcel Grossman Conference on the Recent Developments of General Relativity (to be published) on "The Redetermination of the Newtonian Gravitational Constant at NBS".

A study was made to determine if the present apparatus could be made to yield data regarding the test of the equivalence of active gravitational mass and inertial mass. All precision measurements of the Etvös type equate the passive gravitational mass to the inertial mass. Only one experiment performed by L.B. Kreuzer in the late 1960's has been performed to specifically test this equivalence. It was determined that a significant contribution could be made with relatively little effort and expense, and a preliminary measurement was performed using some bronze masses already on hand. The results were encouraging enough (a paper describing this measurement is being prepared) so that a set of alumina masses were ordered and obtained. The sphericity and homogeneity of these were measured and determined to be sufficient unto the task.

Several quartz and tungsten fibers were tested and discarded for various reasons. At present, the small-mass system is suspended on a tungsten fiber of about 10 microns diameter which shows considerable promise.

In line with the objective "to study the general limits of physical measurements", an autocollimator has been designed and built which is capable of resolving rotations as small as a nanoradian. The advantages of this instrument are, in part, its small size (it is approximately the size of a "Big Mac"), its light weight (it may be made to weigh less than a pound), and its low power dissipation (less than 1/8 watt). A paper describing this autocollimator has been submitted to the Review of Scientific Instruments.

Current Activities and Future Plans

The system is now being prepared for what is hoped will be the final series of big G measurements. A gain of a factor of 2 in precision is anticipated. The configuration will also be suitable for the determination of the equivalence principle as mentioned above with only a slight change in the measurement regimen. It is also hoped it will be possible to perform a measurement of the radial dependence of big G. The anticipated precision of the measurement of the radial dependence of big G should be sufficient to discriminate among several theories now current.

3. Synchrotron Radiation

P. Cowan (3/4), S. Brennan, T. Jach (1/2), A. Henins (1/4), M. Cutkosky (1/3), E. Kessler (1/4), G. Greene (GW)

Objectives

Quantum Metrology Group activities in synchrotron radiation research can be classified in two ways. First experimental facilities are being constructed to allow synchrotron radiation to be used in experiments which are extensions of those performed by the Group in-house. Secondly, new experiments are being designed which virtually require the special characteristics of synchrotron radiation. The best example of the latter activity is the recently published study of threshold excitation of Ar Kβ and its satellites. This experiment would be virtually impossible without the intense beam of a monochromatic x-ray photons available at synchrotron. Work will be directed toward studies similar to this initial experiment and to developing other novel experiments using synchrotron radiation.

Current Activities

Presently the principal activity in this area is to construct, test, and install an UHV soft x-ray beamline at the National Synchrotron Light Source. In addition members of the Group are collaborating on experiments in-house and performed at other synchrotron radiation facilities.

The x-ray ring at the National Synchrotron Light Source (NSLS) has not been completed due to a series of problems at that facility. This necessarily has delayed the installation of the UHV soft x-ray beamline. Instead the beamline has been assembled at NBS for testing and computer interfacing. This work is largely completed although some testing and refining of the instrument will continue at NBS until the NSLS staff are ready to allow final beamline installation at Brookhaven.

Despite the unavoidable delay of initial beamline operation, careful study has been directed towards "second generation" instrumentation to replace or enhance the original equipment. This work has produced a novel scheme for photon energy analysis by reflectivity modulation using x-ray mirrors. This work has been submitted for publication and is expected to be useful in certain future synchrotron radiation experiments. In addition studies of solid state (PIN) detectors as x-ray detectors has continued. The Group's development of "backgammon" position sensitive proportional detectors will have application at synchrotrons as well. Initial designs of curved crystal secondary spectrometers have also been completed.

Preliminary experiments have been performed, both in the lab and at other synchrotron radiation facilities, which may lead to new areas of research. This disparate work generally involves studies of solid surfaces using x-rays at glancing incidence angles. For example laboratory studies have been initiated at NBS by Cowan and Jach toward using the x-ray evenescent wave effect to study surface chemical shifts. X-ray surface scattering experiments have been conducted by Brennan at SSRL in association with Eisenberger et al. from Exxon Research Laboratories. Also, the theoretical ground work has been laid for several other novel experiments using x-rays at glancing incidence. This area is largely unexplored and is rich in potential applications ranging from the fundamentals of x-ray optics to surface and interface characterization.

Accomplishments

Construction and assembly of beamline hardware is complete.

Beamline UHV control system is installed and programmed.

A description of photon energy analysis by reflectivity modulation has been presented at the Third National Conference on Synchrotron Research Instrumentation and a manuscript has been submitted to Nuclear Instruments and Methods for publication.

Results of experiments on the Ar Kβ spectrum have appeared in print and a subsequent paper with theorist Ken Dyall has been submitted for publication.

Surface x-ray scattering experiments have been completed and results are analyzed for publication.

Future Plans

The major task of the coming year should be the installation, commissioning, and characterization of the UHV soft x-ray beamline at NSLS. However, it presently appears that installation cannot begin before January 1984. Assuming installation in early 1984, experiments on x-ray fluorescence and scattering from gases should resume by summer 1984. Preliminary laboratory experiments and equipment development will continue with the aim toward eventually expanding the range of synchrotron experiments. In the event that initial beamline operations at NSLS are delayed further, consideration must be given to expanding our experimental programs at other synchrotron radiation facilities.

4. X-ray Spectroscopy/Position-Sensitive Detector
R. LaVilla (3/4), R. Perera (GW), J. Barth (GW), B. Duval (GW-1/2)

Objective

The objective is to study the limits of a single particle interpretation of x-ray emission and absorption processes to help support the application of x-ray spectra in elucidating the electronic structure of matter. In the recent past we have studied the manifestations of many-body effects in the x-ray spectra of atoms, molecules and solids, with particular attention to the excitation and decay of multi-vacancy configurations and the dynamics of a core hole. Since count rates are often low, state of the art instrumentation for acceptable signal-to-noise ratio are necessary for experimental measurements of these effects.

Current Activities

(1) Vacuum Double Crystal Spectrometer

Following the wavelength measurements of argon $K\alpha_{1,2}$ and potassium $K\alpha_{1,2}$ from $KC\ell$, the encoder on the precision axis was discovered to have slipped. After repairing the encoder to spindle axis coupling, a highly efficient scheme was implemented to automate the axis calibration and the axis was recalibrated with a precision of $\sim$1 ppm. Then the argon $K\alpha_{1,2}$ and potassium $K\alpha_{1,2}$ emission lines were remeasured. These lines serve as calibration wavelengths for the one-electron chlorine and argon spectra. Data was also collected on the argon $K\beta_{1,3}$ emission line before disassembling the instrument to modify the axis drives.

(2) Curved Crystal Spectrometer

The assembly and initial operation of a highly efficient flexible curved crystal spectrometer was completed. The instrument uses a 1/2 meter bent crystal coupled to a position-sensitive detector of the "backgammon" type and a conventional demountable x-ray tube. By operating the instrument in an enclosed helium atmosphere, measurements down to the chlorine K-edge region (2830 eV) can be obtained. The instrument is currently being used to study the excitation and radiative decay of multi-vacancy configurations in the chlorine $K\beta$ region by monitoring the fluorescence and K absorption spectra from gaseous methyl chloride ($CH_3C\ell$) and vinyl chloride ($CH_2CHC\ell$) by taking advantage of the near coincidence between characteristic emission lines and core absorption edges of different elements. The quasi-monochromatic character of the exciting radiation permits the specification of the nature of the initial excited state of the specimen. The high efficiency of the instrument enables the acquisition of emission and absorption spectra with high statistical quality.

(3) Position-Sensitive Detector

Development work on the position-sensitive detector has proceeded with a study of its performance characteristics as a function of different design parameters and modes of operation. A better understanding of the detector has evolved, however there is a need for quieter preamps to take full advantage of these detectors.

Accomplishments

A highly efficient curved crystal spectrometer has been assembled, tested, and used for initial measurements. A manuscript of the Cℓ Kβ spectra of $CH_3C\ell$ and $CH_2CHC\ell$ obtained at resonant excitation near the Cℓ K threshold has been prepared.

The Ru L_3 "white line" absorption feature has been measured from ruthenium metal and ruthenium dioxide. The Ru Lα and Lβ emission spectra have been obtained at the resonant excitation of the Ru L_3 "white line".

A paper on the position-sensitive detector work was presented at the Third National Conference on Synchrotron Radiation Instrumentation at Brookhaven National Laboratory. This paper will be included in the Conference proceedings published by Nuclear Instruments and Methods.

Future Plans

The axis drives for the vacuum double crystal spectrometer will be modified to improve the efficiency of operation. Upon satisfactory operation, when the spectrometer is back in operation, the Krypton $K\alpha_{1,2}$ and some Xenon L series lines will be measured.

The Ta emission spectrum in the region of the Ta L_3 "white line" absorption feature will be recorded following resonant excitation.

5. X-ray-Optical Interferometry/Lattice Spacing Comparison
R. Deslattes (3/4), G. Greene (3/4), A. Henins (3/4),
M. Cutkosky (2/3)

Objective

We intend to redetermine the silicon (220) crystal lattice plane spacing with improved accuracy and so to resolve the discrepancy between the values as obtained at NBS and more recently at the Physikalisch-Technische Bundesanstalt (PTB). The lattice spacing of perfect single crystal silicon in absolute units is an experimental quantity of great importance for a variety of reasons. It is an important input into the least squares adjustment of the fundamental constants. The most accurate determination of the Avogadro constant and all absolute wavelengths in the x-ray and γ-ray region are tied directly to this quantity. Much work in exotic atomic spectroscopy relies on this quantity.

The value of the silicon lattice spacing with a quoted accuracy of about 0.1 ppm as published by PTB is 1.8 ppm smaller than the earlier NBS value. The difference is considerably larger than what is expected from sample to sample variation in silicon. An interchange of samples and intercomparison at both laboratories explains only about 0.1 ppm of this discrepancy. In view of the importance of this quantity every effort should be made to resolve this apparent discrepancy.

Current Activities

Two instruments are being constructed to address the silicon lattice spacing question. The first consists of significant modifications to the x-ray/optical interferometer (XROI) apparatus earlier used by this group to directly measure the silicon lattice spacing in terms of both Lamb dip and iodine stabilized He-Ne lasers. The second is a new two-crystal single axis goniometer for measuring the saml1 differences between lattice spacings of different crystals (Δd apparatus).

The XROI instrument uses the linear translation stage and crystal of the earlier measurements. By using the same single crystal silicon interferometer the lattice spacing determination can be directly compared with the previous NBS measurements. The important difference is the present apparatus consists of the installation of four independent beam polarization encoded angle interferometers which will be employed to accurately characterize the translation path (curvature) of the moving "ear" with respect to the stationary "ears". This will allow unambigous determination of any Abbé sine errors present. Additional improvements include a more robust and agile position locking servo-loop, improved acoustical and vibration isolation, and a fully automated micro-computer control of all aspects of data collection. In this way we hope to provide a definitive determination of the lattice spacing of our Si crystal. Most of our efforts have gone into bringing this instrument on line.

The Δd-apparatus is an entirely new device which should be capable of comparing the lattice spacings of crystals having nearly the same spacing to parts in 10^8 or better. By providing direct comparison between samples it will be possible to ascertain with a great deal of confidence if sample to sample variation is responsible for some of the NBS and PTB discrepancy. Ultimately one would compare the actual artifacts used in both XROI measurements. This apparatus will also be used to transfer lattice spacing information to crystals used in wavelength measurements. The device is under full microcomputer control during data collection.

Accomplishments

The new XROI apparatus has been assembled and is now capable of taking data. The new four-beam path curvature interferometer has been installed. A PDP-11/23 controlled CAMAC system has been commissioned and is currently controlling all facets of the experiment. A new frequency offset locked laser system has been installed. The entire XROI laboratory has been refurbished to give better acoustical and vibrational isolation.

Fabrication of most of the Δd-instrument and its assembly has been completed. A novel electronic fringe counting interferometer for angle measurement is nearing completion. Connections to the PDP-11/23-CAMAC system for computer control is underway.

Future Plans

We hope in the near future to complete our XROI measurements and make lattice comparisons between the NBS and PTB silicon samples. Based on that experience we hope to continue the XROI/Δd program to provide an order of magnitude improvement in determination of the lattice spacing ($\sim 10^{-8}$) and its dissemination to other crystals. Such carefully characterized crystals will then be employed in our group's efforts to extend the accuracy of γ-ray standards, in the determination of a new collection of fundamental constants, and in the accurate determination of highly ionized atomic spectra.

6. Precision X-ray and γ-ray Wavelength Measurements
E. Kessler (3/4), B. Duval (GW-1/2), R. Deslattes (1/4),
R. LaVilla (1/4), P. Cowan (1/4), G. Luther (1/4), G. Greene (1/4)

Objectives

The objective of this project is accurate wavelength standards in the 20 keV to 5 MeV region. The standards are related to visible wavelengths and the Rydberg, R_∞, through the x-ray/optical interferometry measurement of the lattice spacing of a silicon crystal. X-rays, γ-rays and absorption edges have been measured with an accuracy of a few ppm, 0.1 to 1 ppm, and 15 ppm respectively. The wavelength standards are used for testing state-of-the-art relativistic atomic calculations, calibrating curved crystal spectrometers and Ge detectors and in critical absorption measurements.

Precision γ-ray measurements have the potential of contributing to the fundamental constants. By combining wavelength measurements of capture γ-ray cascades with mass spectroscopy measurements of the associated mass differences, a mass-wavelength conversion factor can be obtained.

Current Activities

The four-meter Dumond curved crystal spectrometer has been extensively tested and modified during the past year. This instrument is located in the Radiation Physics Building and uses x-rays produced by bombardment of targets with electrons from a 4 MeV Van de Graaff. The uniformity of the crystal bend was tested by diffracting x-rays from small areas of the crystal. Because significant non-uniformity of bend was detected, an optical testing facility was established. This facility uses a laser to illuminate the x-ray source slit and the bent crystal along with a detector to receive the light reflected from the surface of the bent crystal. Very accurate characterization of the crystal bend was achieved and improper focussing was detected. Other modifications to this instrument were improved electronic resolution on the detector motion, a more stable x-ray slit mounting, improved x-ray intensity monitors, and more efficient software to control the spectrometer. Because the Van de Graaff has been plagued with electron source problems for the past eight months, no usable x-ray data has been recorded. Measurements of satellite lines associated with high Z K series x-rays and $K\alpha_{1,2}$ and $K\beta_{1,3}$ lines from elements with $Z > 92$ await an operational Van de Graaff. Preparation of a precision double flat crystal spectrometer for shipment and installation at Institut Laue-Langevin (ILL), Grenoble, France, was a major undertaking. Many electronic components were replaced with more reliable modules, interconnecting cables were remade, and computer software programs were modified. Packing for shipment was done with great care in order to insure that the instrument could be made operational shortly after arrival. The spectrometer will be shipped in early October and should be operational by mid-November. Precision γ-ray wavelength measurements in the 2 MeV to 5 MeV region is the goal of moving the spectrometer to ILL. Sources in this energy region are short-lived neutron capture sources which require the source to reside in the reactor during measurement. The scientific interest in these measurements are accurate γ-ray standards for calibration of Ge detectors, a measurement of the wavelength-mass conversion factor by combining γ-ray cascade measurements with a mass difference measurement, and improved resolution of complex nuclear spectra.

Accurate wavelength measurements of highly ionized atoms are theoretically interesting because a number of terms scale as some power of Z. Although the spectra are very weak, and subject to large Doppler shifts, successful measurements have been made with fixed curved crystals and position sensitive detectors. Measurements on the Lyman α spectrum of $C\ell^{+16}$ were made at the tandum accelerator at Brookhaven National Laboratory in collaboration with Kansas State University. This work tests the Lamb shift to $\sim$ 10 percent. Measurements on the Lyman α spectrum of recoil Ar^{+17} ions were made at GSI in collaboration with Dr. Heinrich Beyer. Analysis of this data is continuing. The precision measurements on Ar $K\alpha_{1,2}$ and K $K\alpha_{1,2}$ using the vacuum crystal spectrometer discussed under 4 above, served as the calibration lines for these one-electron measurements.

A multi-configuration Dirac Fock computer code was acquired from Oxford University and installed on the NBS computer. After an initial learning period, extensive calculations were made over a wide range of Z (13 to 98) in order to compare experimental and theoretical data. A book chapter on precision experimental x-ray measurements and comparison of experimental and theoretical data was written and submitted for publication.

Accomplishments

A manuscript on precision mid-to-high Z x-ray measurements and their comparison with theoretical calculations was published.

The curved crystal spectrometer has been significantly improved and will be used to make x-ray measurements as soon as the Van de Graaff becomes operational.

A major new measurement facility was established at ILL which provides the ability to make precision γ-ray measurements at energies >2 MeV.

Data on one-electron spectra from highly ionized species has been acquired and the analysis is nearing completion.

State-of-the-art theoretical calculations for many-electron atoms have been installed on the NBS computer and used to make extensive theoretical calculations for comparison with experimental data. A book chapter comparing experimental and theoretical x-ray data has been submitted for publication.

Future Plans

Precision measurement of hypersatellite lines (double K vacancies) from heavy elements will be made using the four-meter curved crystal spectrometer. This instrument will also be used for measurements of $K\alpha_{1,2}$ and $K\beta_{1,3}$ for elements with $Z > 92$ to test theoretical calculations in this important region.

After initial measurements high energy measurements using Ta, a hydrogen sample will be prepared to measure the n-p capture γ-ray at 2.2 MeV. This is an important measurement from which the mass of the neutron can be derived.

Additional data analysis and measurements on one-electron spectra for high Z atoms are planned.

INVITED TALKS

Quantum Metrology Group - 520.06

G.G. Luther, "Gravity and Levity in the Peoples' Republic of China", October 6, 1982, Center for Absolute Physical Quantities' Colloquium, NBS, Gaithersburg, Maryland.

J.J. Snyder, "Longitudinal Ramsey Fringe Spectroscopy: A Potential Optical Frequency Standard?", October 15, 1982, Physics Department Colloquium, Stanford University, Stanford, California.

E.G. Kessler, Jr., "Utilization of MeV Van de Graaff Electrons to Produce Characteristic X-rays for Precision Measurements", November 8-10, 1982, Conference on the Application of Accelerators in Research and Industry, North Texas State University, Denton, Texas.

R.D. Deslattes, "Thoughts Old and New on Connecting Visible and Gamma-ray Secondary Standards", March 2, 1983, Center for Absolute Physical Quantities' Colloquium, NBS, Gaithersburg, Maryland.

G.G. Luther, "Measurement of Big 'G' at the National Bureau of Standards", April 18, 1983, Physics Department Colloquium, North Carolina State University, Raleigh, North Carolina.

R.D. Deslattes, "Normal Atoms, Stripped Atoms, and Exotic Atoms", April 28, 1983, Physics Department Colloquium, Polytechnic Institute of New York, Brooklyn, New York.

J.J. Snyder, "Longitudinal Ramsey Fringe Spectroscopy in a Calcium Beam", June 28 - July 1, 1983, Sixth International Conference on Laser Spectroscopy, Interlaken, Switzerland.

P.L. Cowan, "Photon Energy Analysis by Reflectivity Modulation", September 12-14, 1983, Third National Conference on Synchrotron Radiation Instrumentation, Brookhaven National Laboratory, Upton, New York.

J. Barth, "Position Sensitive X-ray Detector", September 12-14, 1983, Third National Conference on Synchrotron Radiation Instrumentation, Brookhaven National Laboratory, Upton, New York.

R.D. Deslattes, "Present Difficulties and Future Possibilities of Absolute Gamma-ray Measurements", September 20, 1983, Physics Department Colloquium, Schweizerisches Institut für Nuklearforschung (SIN), Villigen, Switzerland.

PUBLICATIONS

Quantum Metrology Group - 520.06

E.G. Kessler, Jr., R.D. Deslattes, D. Girard, W. Schwitz, L. Jacobs, and O. Renner, "Mid-to-High-Z Precision X-ray Measurements", Phys. Rev. A 26, 2696-2706 (1982).

R.D. Deslattes, R.E. LaVilla, P.L. Cowan, and A. Henins, "Threshold Studies of A Multivacancy Process in the Kβ Region of Argon", Phys. Rev. A 27, 923-933 (1983).

P.L. Cowan, J.B. Hastings, T. Jach, and J.P. Kirkland, "A UHV Compatible Two-Crystal Monochromator for Synchrotron Radiation", Nucl. Instru. and Meth. 208, 349-353 (1983).

A. Henins, E.G. Kessler, Jr., and P.L. Cowan, "Flexure Pivot Mirror Support", Nucl. Instru. and Meth. 208, 287-289 (1983).

Richard D. Deslattes, "X-ray Fluorescence Spectroscopy", Nucl. Instru. and Meth. 208, 655-658 (1983).

Terrence Jach and P.L. Cowan, "Pin Diodes as Detectors in the Energy Region 500 eV - 10 keV", Nucl. Instru. and Meth. 208, 423-425 (1983).

E.G. Kessler, Jr. and R.D. Deslattes, "Utilization of MeV Van de Graaff Electrons to Produce Characteristic X-rays for Precision Measurements", IEEE Trans. on Nucl. Sci. NS-30, 991-995 (1983).

Gabriel G. Luther, "Redetermination of the Newtonian Gravitational Constant 'G'", Proc. Third Marcel Grossman Meeting on the Recent Developments of General Relativity held in Shanghai, China, August 30 - September 3, 1982.

J.J. Snyder, J. Helmcke, and D. Zevgolis, "Longitudinal Ramsey Fringe Spectroscopy in a Calcium Beam", Proc. 6th Internat. Conf. on Laser Spectroscopy held in Interlaken, Switzerland, June 27 - July 1, 1983.

Richard D. Deslattes and Ernest G. Kessler, Jr., "Experimental Estimation of Inner Vacancy Level Energies for Comparison with Theory", Atomic Inner-Shell Physics (to be published).

G.L. Greene, "Trapping of Low Energy Neutrons, Proc. Workshop on Spectroscopic Applications of Slow Atomic Beams held at NBS, Gaithersburg, Md., April 14-15, 1983.

J.J. Snyder, J. Helmcke, and D. Zevgolid, "Longitudinal Ramsey Fringe Spectroscopy in a Calcium Beam", Applied Physics B (to be published).

J.J. Snyder, J. Helmcke, M. Glaser, and D. Zevgolis, "Longitudinal Ramsey Fringe Spectroscopy in an Atomic Beam", Proc. 6th Internat. Conf. on Laser Spectroscopy held in Interlaken, Switzerland, June 27 - July 1, 1983.

Gabriel G. Luther, Richard D. Deslattes, and William R. Towler, "Single Axis Photoelectronic Autocollimator", Review of Scientific Instruments (to be published).

P.L. Cowan, "Photon Energy Analysis by Reflectivity Modulation", Proc. Third National Conference on Synchrotron Radiation Instrumentation held at Brookhaven National Laboratory, Upton, New York, September 12-14, 1983. (to be published).

B.P. Duval, J. Barth, R.D. Deslattes, A. Henins, and G.G. Luther, "Position Sensitive X-ray Detector", Proc. Third National Conference on Synchrotron Radiation Instrumentation held at Brookhaven National Laboratory, Upton, New York, September 12-14, 1983 (to be published).

SEMINARS FOR STAFF AND GUESTS

Quantum Metrology Group - 520.06

C. Mande, Nagpur University, Department of Physics, Nagpur, India - CAPQ Colloquium, "Chemical Effects in X-ray Absorption Spectra", October 5, 1982.

S. Brennan, EXXON Research and Engineering, San Francisco, California - CAPQ Colloquium, "Surface EXAFS and Surface Bragg Scattering - An Overview", October 13, 1982.

J. Arthur, Massachusetts Institute of Technology, Department of Physics, Cambridge, Massachusetts - CAPQ Colloquium, "Testing Quantum Mechanics with a Neutron Interferometer", October 15, 1982.

G.L. Greene, Yale University, Department of Physics, New Haven, Connecticut - CAPQ Colloquium, "Neutron Optical Activity", October 20, 1982.

R. Powers, California Institute of Technology, Department of Physics, Pasadena, California - CAPQ Colloquium, "Two Recent Applications of Hadronic Atoms: Measurement of the Sigma Minus Magnetic Moment; Study of the Pion-Nucleus Optical Potential", November 15, 1982.

TECHNICAL ACTIVITIES

ELECTRICITY DIVISION, 521

FISCAL YEAR 1983

Overview

The Electricity Division (ED) concerns itself with the fundamental electrical quantities such as current, voltage, and impedance at dc and low frequencies (to roughly 100 kHz) over many orders of magnitude and at the highest possible levels of accuracy. Its primary mission is to provide the central basis for a reliable and consistent system of electrical measurement throughout the U.S., including the Nation's scientific community as well as industry and commerce; and to ensure that the U.S. system is consistent with those of other countries and the internationally accepted system.

The justification for all of the ED's work comes directly from the Bureau's Organic Act, as amended, and is in its prime mission areas, that is, the areas of responsibility for which the Bureau was originally founded in 1901. The major technical problems which benefit from the ED's work include fundamental physical theory; electrical power revenue metering, transmission, and distribution; industrial process control; quality control in the manufacture of electronic components and products; testing and maintenance of electronic systems, which includes the civilian side of defense and aerospace; and national defense requirements directly under the Department of Defense. End user groups include scientists in universities; electric power utilities, both public and private; electric equipment manufacturers; process engineers who design, build, and use industrial process control systems; manufacturers of electronic components and consumer products; high technology civilian companies and government agencies involved with communications, computers, aerospace, transportation, health, and defense; and finally the armed services.

It is probably not an overstatement to say that the Nation's electric power system, the cost-effective manufacture of reliable consumer goods, the economic production of industrial materials, and a viable national defense would not be possible without adequate electrical measurements; and that the basis for all such measurements within the U.S. is the fundamental electrical units the ED maintains and disseminates through its calibrations and MAP's; the measurement methods and instrumentation it develops; and the tests and calibrations of instruments and apparatus it performs. For example, each year on the order of one thousand calibrations are carried out on primary electrical standards that belong to some of the Nation's most important corporations, utilities, and government organizations, including Hewlett-Packard, General Motors, IBM, General Electric, Pacific Gas and Electric, American Electric Power, the TVA, and FAA, and the DoD.

To fulfill its responsibilities, the ED carries out work in eight principal areas with the objectives as indicated:

1. Realize the SI definitions of basic electrical measurement units such as the ampere, volt, ohm, and farad, thereby ensuring that the U.S. legal electrical units are consistent with the internationally accepted system.

2. Develop and maintain U.S. legal or national reference standards for the basic electrical units and related quantities, thus providing a central basis for the U.S. system of electrical measurement.

3. Disseminate the basic electrical measurement units to users within the U.S. via a variety of measurement and calibration services, and develop new means for doing so, thereby ensuring the traceability of electrical measurements made thoughout the country to national reference standards.

4. Develop new methodologies and the required instrumentation and standards which will lead to advances in the state-of-the-art of electrical measurement, thus ensuring the availability to the technical community of adequate measurement techniques.

5. Determine fundamental physical constants closely related to the electrical units in order to provide the scientific community the means to test basic physical theory.

6. Carry out international comparisons of the basic electrical units, thus ensuring that the U.S. system of electrical measurement is consistent with those of other countries.

7. Participate in voluntary national and international standardizing activities related to the electrical units, and the fundamental physical constants, in order to eliminate and prevent non-tariff barriers to trade, and to contribute to internationally acceptable data compilations.

8. Provide training for personnel active in the field of electrical measurements and standards, including the generation of tutorial written material, thereby elevating the overall level of competence in the field.

The objectives, current activities, FY 83 accomplishments, and future plans of the various projects underway within the ED which contribute to these principal areas are described in detail in the following Project Reports. Highlights, categorized according to these eight principal areas of work, include:

1. Realize SI Units. Construction of the entire room temperature version of the new ampere balance to determine the ratio of the NBS

as-maintained ampere to the SI ampere to an accuracy of 0.1 ppm by equating electrical and mechanical work has been essentially completed. Tests of the apparatus and preliminary measurements are expected to be underway early in FY 84. The redetermination of the NBS as-maintained farad and ohm in terms of their respective SI units via the NBS calculable capacitor has also progressed and a tie between the NBS bank of 10 pF capacitors and 1 ohm resistors used to maintain the NBS farad and ohm should be completed to an accuracy of 0.1 ppm early in FY 84.

2. Develop and Maintain U.S. Reference Standards. Extensive investigations of the quantized Hall resistance in GaAs-AlGaAs heterostructures were carried out, including measurements as a function of device temperature and current, as part of the ED's effort to develop the quantum Hall effect into a reproducible, highly accurate (e.g., 0.01-0.02 ppm), and easily used resistance standard based on fundamental physical constants. A precision approaching 0.01 ppm was achieved and an accuracy in terms of the NBS ohm of 0.05 ppm. New, non-linear phenomena were discovered and described in a paper to appear in Physical Review Letters.

3. Dissemination. Electrical calibration services including MAP's were generally provided in a timely way and without serious problems. Measureable improvements in turnaround time were achieved in most areas except ac-dc transfer standards for which a scheduling system was instituted. On the order of 1000 calibration reports were issued and over 200 individual clients served; 22 MAP's were conducted and calibration income totled $430 K. The reevaluation of NBS primary, secondary, and working standards and measuring systems for ac current and voltage begun in July 1981 was nearly completed. A replacement for the Maxwell-Wien bridge used to calibrate standard inductors for the last 35 years has been constructed and is being tested. Automated measurement systems for calibrating 10 and 100 ohm resistance standards and resistance standards from 100 to 10 kohm have essentially been completed. A new transport standard of dc voltage using unsaturated standard cells has been developed and is under test. The operating instructions for the dc voltage MAP have undergone major revision.

4. New Methods, Instruments, and Standards. A prototype, improved 10 pF fused silica capacitance standard with significantly reduced voltage dependence has been developed in conjunction with the development of an automated capacitance bridge. If the early promise of the standard is fulfilled, it could ease the difficulty of realizing the SI farad and ohm via the NBS calculable capacitor. It may also lead to improved maintenance of the NBS farad and ohm.

5. Fundamental Constants. Since the quantum Hall effect can also be used to determine the fine-structure constant α, the work described above under areas (1) and (2) relating to the realization of the SI

ohm and determining the quantized Hall resistance directly impacts the determination of α via the Hall effect. Construction of the apparatus for the new determination of the proton gyromagnetic ratio also progressed well during FY 83. The precision solenoid and straightedge are now installed, the detector coils required to measure its dimensions are wound, and the solenoid cooling system is operational. Preliminary dimensional measurements of the solenoid should be underway sometime during the first half of FY 84. Two new Precision Measurement Grants were awarded, one for the theoretical study of quantum nondemolition experiments, the other for the development of a cryogenic hydrogen maser.

6. International Comparisons. An international comparison of one ohm and 10 kohm resistance standards was carried out with the National Research Council, Canada. Measurements were begun on the three NBS one-ohm resistors to be used in the international comparison of resistance standards to be conducted by and at the International Bureau of Weights and Measures (BIPM) during the winter of 1983-1984. Plans have been made to carry out an international comparison of one-ohm resistance standards with the Australian national standards laboratory (CSIRO Division of Applied Physics) in the first half of 1984. The three NBS travelling capacitors circulating between national standards laboratories under BIPM auspices were returned to NBS for remeasurement and subsequent reshipment to East Germany.

7. Standardization. The ED contributed to and actively participated in the 16th Session of the Consultative Committee on Electricity, held at the International Bureau of Weights and Measures in March 1983. At this meeting, plans were made to improve the international standardization of electrical measurements by internationally adopting in 1986 a new value of 2e/h for volt maintenance purposes, and a value of the quantum Hall resistance for maintaing the ohm. The draft standard, Recommended Practice for Eddy Current Conductivity Measurements, prepared for ASTM Committee E7, Nondestructive Testing, and which spells out how eddy current NDT measurements using currently available commercial instruments should be carried out and how the instruments should be calibrated, was approved.

8. Training. In collaboration with the National Conference of Standards Laboratories, two well attended and well received seminars on electrical measurement assurance programs were given, one in Fullerton California, the other in Peabody Massachussetts. A highly successful workshop on the laser cooling and trapping of neutral atoms was held at NBS in collaboration with the Office of Naval Research. Three tutorial NBS Technical Notes were published: Testing to Quantify the Effects of Handling of Gas Dielectric Capacitors; Transportable 1000 pF Standard for the NBS capacitance Measurement Assurance Program; and the Practical Uses of AC-DC Transfer Instruments. Three foreign guest workers (two from the PRC, one from Egypt) were trained in various aspects of electrical measurement. Under AID auspices, assistance

was provided the National Institute for Standards, Egypt, in selecting new equipment to upgrade their capabilities in basic electrical measurements and standards.

In summary, the Electricity Division has once again met its principal electrical unit maintenance and dissemination responsibilities and at the same time made good progress on a number of important research projects. This should continue in FY 84.

DISSEMINATION SERVICES: SUPPORT AND OPERATION INCLUDING MAP DEVELOPMENT

(N. B. Belecki, C. B. Childers, R. F. Dziuba, W. G. Eicke, R. C. Fronk, J. R. Hastings, C. R. Levy, R. E. Long, T. P. Moore, D. D. Prather, J. E. Sims, S. B. Tillett, A. R. Wise; F. L. Hermach, E. S. Williams)

Objectives

The overall objective of this project is to enable all measurements of electrical quantities performed in the United States to be made in terms of the U.S. legal electrical units at the required levels of accuracy. The legal units are provided to the user community via reimbursable calibration and MAP services listed in NBS Special Publication 250 and its appendices. The timeliness and adequacy of these services must be ensured by research and development work on new measurement techniques, standards, and apparatus, since the quality of both MAP and calibration services ultimately depends on the basic metrology competence of the NBS.

The outputs of this project are used directly by the metrology community - the major standards laboratories of industry, government, and the academic community - and indirectly through them by industry for the quality control and maintenance of electronic products, for the control of manufacturing processes in basic industry, for the support of research and development aimed at the improvement of instrumentation and in response to Federal and state regulatory requirements, such as those for traceability of voltage measurements used for the establishment of local power and energy standards and watt-hour meter testing by power companies. In large measure, the pre-eminence of the U. S. in high-technology areas, such as electronics, avionics, communications, aircraft, and space vehicles, has been made possible by our country's sophisticated measurement capability, reflected in automatic test equipment (ATE) systems and high-quality electronic instrumentation. Likewise, advances and progress in these areas have been rapid because they have not been limited by measurement constraints, such as the nonavailability of electrical instruments of adequate accuracy. This condition can only occur if NBS maintains a strong R&D program to ensure the availability of adequate electrical standards for the instrumentation industry.

Current Activities

The measurement services offered by NBS in the electrical area include the calibration of primary standards of alternating current and voltage, impedance at audio frequencies, direct voltage, and resistance at direct current, as well as MAP services for capacitance, dc voltage, and dc resistance. Some measurements are also done on ac ratio standards of the highest accuracy. In FY83, 22 MAP transfers and approximately 973 calibrations of basic standards were performed, as detailed at the end of this project description, for a total income of about $430K for the year.

As in past years, efforts have been made to reduce calibration turnround time. In the ac-dc difference area, scheduling of calibrations has been made more realistic by making more conservative estimates of test times. While a large queue exists for those wanting service in this area, scheduling is running more smoothly than in the past. Overtime and additional manpower will be used to minimize the queue until automated measurement systems are implemented. In the other areas, turnaround times have been measurably improved.

The majority of NBS calibration clientele is represented by the National Conference of Standards Laboratories (NCSL), which is a major source of information for planning future calibration activities, as well as a mechanism (through its technical committees) for disseminating NBS electrical metrology information. The military and its defense systems contractors and the instrumentation community are the heaviest users of electrical calibration services and it is from them that the most stringent measurement requirements arise.

Measurement services support activities fall into two broad categories: the development of improved measurement methods and standards (including MAP development work), and the automation of the measurement systems used to perform both calibrations and MAP activities. Work in the former category is directed toward improvement of the processes by which the ohm is maintained and scaled and of both ac and dc voltage and current measurement and dissemination techniques. In the automation area, objectives are to complete automation of the systems used for ac-dc difference measurements on thermal voltage and current converters (ac V&I), resistance measurements through 100 teraohms, and standard cell calibrations.

Accomplishments

AC Current and Voltage

The re-evaluation of NBS primary, secondary, and working standards and measuring systems in the ac current and voltage area begun in July 1981 has been nearly completed. This effort was undertaken by F. L. Hermach, under contract. In this re-evaluation, a set of multijunction thermal converters has been established as the new NBS primary standard; they have ac-dc differences of only a few tenths of a ppm with an uncertainty of 0.5 ppm. The reference (secondary) and working standards have been re-evaluated by comparison to the primary standards, and by bootstrapping techniques over the voltage, current, and frequency ranges beyond those directly accessible via the primary standards. A detailed comparison of the redetermined values of ac-dc differences of the working standards with the previously-determined values shows generally excellent agreement, except over a limited range of current. Further measurements have been made covering half of this range and show good agreement with the data taken earlier in the re-evaluation. The differences, however, are well within our customary calibration uncertainty. In the very worse case, a few customer calibrations at really low frequencies (20 Hz) were done with a quoted uncertainty of 50 ppm using a reference whose value was in error by 35 ppm or so. (The transfer uncertainty is small - no more than 5 ppm.) Follow-up measurements over the second half of the range are scheduled shortly.

The re-evaluation measurements cover a broader range than those upon which past values of NBS standards are based. (The values in the case above resulted from extrapolation of data taken over a more limited range.) The range has been extended to 16 A and 50 kHz for the current standards and to 600 V and 100 kHZ for the voltage standards. A detailed report describing this work has been written for NBS use; a condensed version is planned for publication. This work was supported in part by the DoD Calibration Coordination Group (CCG). [Hermach (under contract), Hastings, Williams (under contract), Childers, Krishnamurthy (student)]

E. S. Williams, under a contract supported by the CCG, has begun an investigation of solid-state thermoelements directed toward the development of a secondary or transport standard capable of 10 to 50 ppm accuracies. Measurement circuitry and an automated ac-dc comparison system have been developed for comparing these newer thermoelements, with their tenfold-higher output emf's, to conventional vacuum thermoelements. The new devices form the basis for ac voltage measurement accuracies of commercial voltmeters that are within an order of magnitude of NBS calibration uncertainties. [Williams (under contract), Hastings]

Impedance

A replacement for the Maxwell-Wien bridge, used for calibrating standard inductors for the past thirty-five years, has been constructed and is being tested. The new bridge is an offshoot of the Division's eddy-current conductivity work and is based on the use of inductive voltage dividers to eliminate the need for switched resistors and capacitors. It uses two fixed resistors to establish ratios and one of four fixed resistors to establish the amplitude of the resistive component of the inductors it measures. The new bridge has a frequency range of 100 Hz to 100 kHz and a low-end inductance limit of 100 microhenries because of current limitations. Testing is expected to be completed in about six months. Its use will enable the uncertainties of inductance calibrations to be reduced by about an order of magnitude, or from 200 ppm to 20 ppm over the most frequently used magnitude/frequency combinations. [Free, Levy]

Resistance

The design of a standard printed circuit relay-control board has been completed and put into use. This board is used to control low-thermal relays used in critical applications in the automation of resistance measurement systems by S-100-based microcomputers. [Dziuba, Wisniewski (student)]

A commercial direct-current-comparator bridge has been modified to permit high-accuracy automatic comparisons of nominally-equal resistors in the range from 100 ohms to 10 kohms. The modifications include improved shielding of leads, replacement of open terminals with shielded terminations, and the replacement of the photocell amplifier with one with an isolated output. A microcomputer controls the current reversal, detector balancing, and the determination of the sensitivity of the bridge. A computer program collects and processes the data. [Dziuba, Wisniewski (student), Poneleit (student)]

A guarded series/parallel (Hamon) resistance transfer standard for scaling from 100 ohms to 10 kohms has been designed and constructed. The guarding feature suppresses errors due to leakage currents through the insulated supports of the resistors and the mineral oil in which the standard is immersed (in the event of breakdown or contamination). The standard has been used to verify the assigned values of the NBS 10 kohm standards relative to the legal ohm to better than 0.05 ppm. [Dziuba, Campbell (student)]

A direct-reading ratio set for comparing resistors of nominally equal values in the range from 100 ohms to 10 kohms has been modified to improve its resolution by two orders of magnitude (to 0.01 ppm). In addition, a guard circuit has been installed to reduce errors caused by leakage currents to negligible levels, and the instrument tested and calibrated. [Dziuba, Rice (student)]

A special series/parallel resistance transfer standard was constructed to be used in the chain of measurements for the calibration of quantized Hall-resistance standards in terms of the legal ohm. Using three measurement systems simultaneously (the one-ohm system, a dc-current-comparator resistance bridge, and a modified direct-reading ratio set), the intercomparison can now be performed in four hours without moving any critical resistance standards. Measurements using this transfer standard verified the discrepancy of the order of 0.8 ppm between the as-maintained unit of resistance and that derived from quantized Hall resistance experiments using the accepted value of the fine-structure constant. [Dziuba]

Modifications were made to the automated one-ohm measurement system to enable it to compare resistors in auxiliary baths at any temperature to the NBS primary reference group of resistors maintained at 25 degrees C. These included interfacing a thermometer bridge for measuring platinum thermometer resistances to the microcomputer. The system is currently being used to monitor three one-ohm standards at 20 degrees C for use in a multi-national intercomparison at the BIPM in the first part of 1984. [Dziuba, Fronk, Poneleit (student)]

The measurement system used to calibrate customers' standard resistors at the 10 kohm level has been improved to reduce errors due to leakage currents and decrease the measurement time required to perform a calibration. [Dziuba, Wisniewski (student), Prather]

Automation of the dc current-comparator potentiometer for the calibration of 10 and 100-ohm resistance standards will be completed by the end of FY83. The system will be tested and put into operation early in FY84.

A communications link to permit automatic transfer of data between the microcomputers in the resistance laboratory and the central minicomputer has been completed. This eliminated the need for transferring data by hand (speeding the calibration process) and permits experiments to be controlled and data gathered by microcomputer, while reserving the central minicomputer for complex data analyses and report production. [Dziuba, Fronk]

Voltage

A new transport standard of dc voltage has been developed and is under test. The standard is based on the use of unsaturated standard cells in a temperature-controlled enclosure. The premise behind its use is that, although unsaturated cells drift with time, they are considerably more robust than saturated cells with respect to temperature and mechanical disturbances. Environmental testing is currently underway. [Eicke]

Two seminars on dc voltage MAP techniques were given. The first was in Fullerton, CA in January, and the second in Peabody, MA in September. Despite the recent economic slump, both were well-enrolled and many requests were received for the course material by those not able to attend. [Eicke, Belecki, Croarkin (CAM), Vecchia (CAM), Eberhard (CAM), Belanger (OPMS), McCoubrey (CBS)]

New power supplies were designed for the VTP saturated cell enclosures. These new supplies are more reliable and useable than the original design proved to be. Prototype models have been built and tested, printed circuit boards fabricated, and production versions are now under construction. [Eicke, Long]

The operating instructions for the Volt Transfer Program, the dc voltage MAP service, have undergone major revision. They now include information on how to use digital meters for standard cell measurements, more distinct instructions regarding data submission, and complete explanations of all aspects of the reports issued after each transfer. [Sims]

Calibrations of Zener-diode-based voltage standards are now being done on a new automated system based on a desktop computer. The system is self-calibrating and can measure any arbitrary voltage less than 10.6 volts relative to a local group of standard cells with an uncertainty of the order of 0.2 - 0.4 ppm. The system generates ten voltages, each approximating that of a saturated standard cell, in series, and uses a precision digital voltmeter to compare each of them to cells in the local standard using a ten by four block design. The resulting calibrated cumulative voltages are used to calibrate the DVM, and the closest voltage is used as a reference to measure each Zener-based standard with the DVM measuring the difference emf. This system affords a fourfold improvement in accuracy and a considerable reduction in turnaround time relative to the old, manual system. [Field]

Future Plans

AC Current and Voltage

After the completion of some check measurements, the new values of ac-dc difference of the working standards used in NBS calibrations will be substituted for presently-used values. (For the most part, only slight changes are necessary.) Reductions of the uncertainty estimates for the calibrations, however, will require further tests and the implementation of the various quality control procedures recommended by F. L. Hermach. The reduced uncertainties will depend in more detail than the previous estimates on the current and voltage as well as the frequency.

The automated ac-dc comparison system developed in the investigation of solid-state thermoelements has been redesigned to be compatible with IEEE standard 488. The redesigned system, now based on a desktop computer, is being tested and will be used in the coming year to evaluate these new thermoelements. The development of a secondary standard, based on these new devices and suitable for field use, will be undertaken. Efforts will be made to obtain devices that are more readily useable under adverse environmental conditions than are conventional vacuum thermoelements.

The revised measurement system will also be used as the basis for a new automated system to handle the calibration workload. The new system will be computer based and IEEE 488 compatible as well. A prototype version is expected to be ready for testing by the end of FY84.

Longer-range plans are for the completion of the automated system, and the development of an ac voltage MAP service to support instrument manufacturers and the major standards laboratories of the DoD and their high-technology suppliers.

Impedance

The major effort over the coming year will be to complete testing of the new inductance bridge and implement its use for calibrating standard inductors on a routine basis. Documentation of its use is also expected to be finished by the end of the year. An investigation of the possibilty of using the bridge to calibrate resistance standards in the audio frequency range will be started. Such a service would require considerable effort in determining the frequency response of at least one resistor and using it as an ac-dc transfer device to characterize the bridge. This effort is expected to continue for several years.

An improved system for ensuring the quality of capacitor and inductive voltage divider calibrations will be developed and tested in the next year. The present systems are separate and rely largely on check standards and analyses of workload historical data to ensure a high level of quality. While the system will quickly flag irregularities, it is vulnerable to errors caused by slight, long-term drifts in transformer ratios. Current techniques for calibrating these ratios are cumbersome at best and do not lend themselves to frequent use. It is hoped that a technique can be developed to enable the ready calibration of a few representative ratios. This would be coupled with a scheme for easy intercomparison of the ratios of the Type II capacitance bridge with those of the inductive voltage divider set-up. At present, only a general idea of how to approach this exists. Work will begin in FY 84 to develop and perfect a technique that can be used on a regular basis.

Resistance

Work will begin on the development of an automated, unbalanced bridge system for intercomparison of nominally-equal standard resistors in the range from 100 ohms to 1 megohm. This would include the design and construction of interfacing circuitry and a switching module for the system. The system will be controlled by an S-100-based microcomputer which will pass data to the central minicomputer for reduction and analysis. Considerable work on the development of software systems to control switching and measurements and reduce the final data will be required. The entire project will require three to four years for completion.

An improved capacitive discharge system for the calibration of resistors in the range from 100 gigaohms to 100 teraohms will be completed in the coming year. The system will run under computer control and enable resistors to be tested at arbitrary voltages up to 1000 volts with accuracies of 0.1% or better. It is planned to reinstate the calibration services for resistors of nominal value of a teraohm or higher as soon as the system is thoroughly tested.

Voltage

Effort in the dc voltage area will primarily be devoted to automating several measurement systems in the Volt Facility and on documentation. The measurements required for calibrations of customers' standard cells, those required to do environmental testing of standards, and those required to monitor the laboratory environment are slated for automation. A prototype system to do regular calibrations, based on the IEEE 488 Interface Standard and the use of a desktop computer, will be finished in the next FY and testing of it will be well under way. Implementation will probably occur early in FY85. The remaining systems, including a new system to replace the current volt MAP measurement system, will follow shortly thereafter. The computers controlling these systems will be networked with the central computer using a desktop computer as an interface.

The new transport standard developed during the past year will undergo extensive testing. If it proves successful, several copies will be made and pressed into service.

Completion of the documentation of quality-control procedures throughout the voltage lab will be finished by the year's end.

Two more voltage MAP seminars will be given. The first is scheduled for early spring in Dallas and the second for late summer, probably in the Midwest.

Electricity Division Calibration Workload Summary for FY 83

SP-250 - 3.1 Resistance Measurements

397 Standard Resistors and Shunts
5 MAP Transfers
(12 companies)

3.2 Precision Apparatus

26 Inductive Voltage Dividers
2 Hamon Devices

3.3 Impedance Measurements

171 Standard Inductors
172 Standard Capacitors
1 MAP Transfer
(1 company)

3.4 DC Voltage Measurements

121 Standard Cell Enclosures
(484 cells)
16 MAP Transfers
(28 companies)
32 Unsaturated Cells
10 Zener-diode Based Standards

3.5 Electrical Instruments (AC-DC)

44 Standard Thermal Converter Instruments
(813 points)

Estimated FY83 Billing $430,000

JOSEPHSON VOLTAGE STANDARDS
(R. F. Dziuba, B. F. Field, J. Toots)

Objectives

The objectives of this project are to maintain the NBS or U.S. Legal Volt via the ac Josephson effect in superconductors to an accuracy of a few parts in 100 million, and to improve the maintenance and dissemination of the unit of dc voltage for the U.S. through the development of voltage standards based on the ac Josephson effect.

More specifically, the objectives are (i) to periodically maintain the U.S. Legal Volt using the assigned value $2e/h = 483593.420\ GHz/V_{NBS}$ for the Josephson frequency-voltage ratio; (ii) to simplify and to improve the maintenance of the NBS Volt to an accuracy of one part in 100 million or better by developing an all cryogenic voltage standard to replace the current part room temperature standard; (iii) to investigate zero-current-bias arrays of Josephson tunnel junctions as a means of producing significantly larger quantized voltages (100 mV or greater). This could measurably improve the accuracy and ease with which the U.S. Legal Volt could be maintained as well as pave the way for the wide-spread use of Josephson voltage standards in industry; (iv) to develop Josephson junctions from high transition temperature superconducting materials for use in voltage standards which can be operated with a mechanical refrigerator rather than with liquid helium. Again, this could lead to the greater use of Josephson voltage standards in industry; and (v) to develop reliable Josephson junctions which are impervious to the effects of room-temperature aging and thermal cycling between liquid helium and room temperatures. These junctions are primarily for use in the commercial 1 ppm Josephson effect voltage standards developed for the Calibration Coordination Group (CCG) of the DoD and KSRI (Korean Standards Research Institute) but could be offered as an SRM if sufficient interest existed and the production yield was sufficiently high. Currently, the goal is to prepare adequate samples for our own in-house use and for the remaining three instruments and to test, calibrate and deliver them.

Current Activities

With the departure to private industry early in FY83 of the project's senior Josephson device researcher, the effort in FY83 was limited to Objectives (i) and (v). Objective (i), although a continuing activity since early in 1972, requires a surprisingly large amount of work - - equipment must constantly be tested, repaired, and calibrated. Because of this Objective's critical importance to electrical measurements throughout the U.S. and the equipment's high degree of complexity, maintenance of the U.S. Legal Volt via the Josephson effect must still be done by highly skilled, knowledgeable, and dedicated professionals.

(It should be noted that all customer standard cells are calibrated in terms of NBS working standards which in turn are calibrated in terms of reference cells maintained via the Josephson effect. These latter cells constitute the U.S. Legal Volt.)

Niobium-based tunnel junctions with lead counter electrodes and having the requisite characteristics are being fabricated for the 1 ppm voltage standards. These standards are then being tested, repaired, and calibrated as required to bring them into specification.

Accomplishments

A joint proposal with the Electromagnetic Technology Division, NEL, for collaborative work on Josephson junction arrays [Objective (iii)] was submitted to the NBS Director and subsequently funded. However, progress will necessarily be limited until a replacement for the above mentioned senior researcher is found. Active recruiting is underway.

In FY83 there were six comparisons of the Josephson voltage standard against NBS reference groups of saturated standard cells. The results of these measurements indicate that primary reference groups NBS-13 and NBS-17 are drifting at the rates of -0.15 ppm/month and -0.03 ppm/month respectively.

A 1 ppm voltage standard has been under test during the past year. Problems with fabricating usable Nb-Pb junctions for the standards have been solved to the point where several junctions are on hand for installation in the remaining instruments. A serious construction fault was discovered in one of the voltage standard potentiometers that produces an unacceptable error. All the remaining potentiometers were tested and found not to have this fault. An extra potentiometer will be substituted for the faulty one.

The glow discharge oxidation process used to produce Nb-Pb junctions has been studied. By varying the process parameters, for example, direct and indirect exposure time to the discharge, oxygen pressure, etc., a set of process parameters has been found such that junction yield has improved significantly, i.e., to the point where almost every evaporation run of six devices now produces at least one usable device.

Future Plans

Maintenance of the U.S. Legal Volt via the ac Josephson effect will continue. Replacement cells with a lower drift rate are being sought for reference group NBS-13. The enclosure was designed for smaller NBS type cells, thus replacements must be specially made.

Two commercial voltage standards have been delivered, the remaining three will be tested, brought into specification, and delivered during FY84. Production of Nb-Pb junctions will continue for use in the 1 ppm voltage standards and the all-cryogenic system. Fabrication process parameters will be investigated to improve the yield of devices, thus reducing the amount of electrical testing required.

It is expected that the replacement Josephson device research scientist will be hired and on board no later than mid-FY84. On this basis, one can expect significant progress towards the completion of the all-cryogenic voltage standard [Objective (ii)] since it is very nearly finished - - testing and modest modifications should be all that are required to bring it to the point where it can be used on a routine basis. One can also expect the collaborative research effort on Josephson junction arrays [Objective (iii)] to be well underway by the end of FY84. However, this is a difficult technical problem likely to require several years of creative research to solve (if in fact it can be solved). Thus, immediate results are not anticipated.

REALIZATION OF THE SI AMPERE

(P. T. Olsen, W. D. Phillips, E. R. Williams, V. E. Bower)

Objectives

The objective of this research is to measure the NBS as-maintained ampere in terms of the SI units of mass, length, and time to an accuracy of at least one or two parts in ten million, or nearly two orders of magnitude better than has ever been previously achieved. Determination of the SI ampere has been periodically undertaken by NBS since its founding. This responsibility was given to NBS in its Organic Act.

Although the most modern scientific tools available at a given epoch have been applied to the ampere realization experiment, there has not been a significant decrease in uncertainty in its measurement (presently about 5 to 10 ppm) since the turn of the century. Continuing improvements in the measurements of other fundamental constants have permitted calculations which indicate that there are possible errors in the present ampere determinations or in the measurements of these other constants. A recently suggested method of directly measuring the NBS ampere in terms of the SI unit by equating electrical and mechanical energy could reduce its uncertainty by at least a factor of 50. Such an improvement would (1) lead to greater consistency between the SI and as-maintained systems of electrical units; (2) help to resolve the present discrepancies in the fundamental constants; and (3) provide a means for monitoring the kilogram. There is even the possibility that the new technique could lead to an artifact-independent definition of the kilogram and the mole.

Current Activities

Traditional absolute ampere experiments have measured the force between current-carrying coils whose dimensions have been carefully determined. This latter determination, along with uncertainties about current distributions within the conductors, has been the major limitation in accuracy. The new approach avoids dimensional measurement by comparing the mechanical and electrical work done as one coil is moved in the field produced by another coil. The experiment is performed in two parts. First, the electrical work is determined from a measurement of the voltage induced in one coil while it moves with respect to the other, current-carrying, coil for a measured time interval. Then the mechanical work is determined from the force, as measured by static weighing, between the coils when both carry current and from the distance traversed. Since only a velocity and displacement need be measured, the difficulties of determining the dimensions of current carrying coils are avoided. Because of this, multilayer windings and superconductors may be used which allows large forces and induced voltages.

Accomplishments

Our plan for determining the NBS ampere in terms of the SI ampere has three phases. The first phase, completed in early FY 82, involved assembling and making measurements with a relatively small scale working model to evaluate the general method described above. It was surprisingly successful considering the crudity of the apparatus, yielding a statistical measurement uncertainty of about 2 ppm. The systematic uncertainties were not seriously evaluated, however, because of the unfavorable Pellat balance (rotational) geometry used.

Phase II involves more sophisticated apparatus in a highly favorable linear geometry. Construction of this apparatus and its assembly and partial testing was completed in FY 83; evaluation of the complete system will begin in early FY 84. Figure 1 schematically represents the essential components. To date, most of the evaluation has been performed on the balance wheel A. A sensitivity of some tens of micrograms has been demonstrated. The vertical position of the scale pan hanging from spider E is read by a laser interferometer and the position maintained

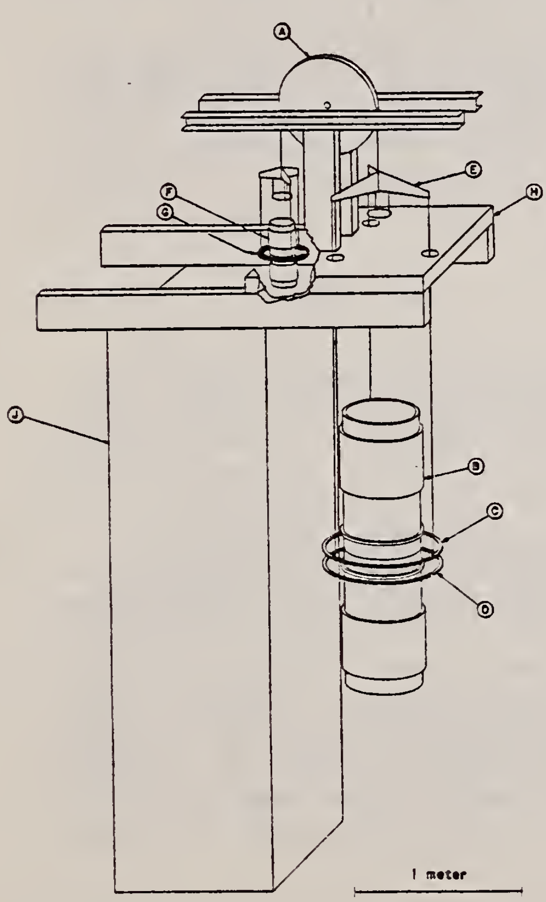


Fig. 1. A: Balance wheel; B: main magnetic field generating coil; C: moveable coil; D: reference coil; E: balance support spider; F: servo magnetic field generating coil; G: servo moveable coil; H: marble slab; J: stone pier.

through a computer controlled servo loop. The correction forces are applied by a force coil G and magnetic field generating coil F. A computer controlled hydraulic weight lifter deposits and removes masses from the scale pans as appropriate.

A temperature controlled oil bath (not shown) houses the main magnetic field generating coil B. The suspended coils C and D (the latter serving as a fixed reference) are wound on specially made epoxy impregnated fiber glass cloth forms. A thermal isolation cabinet (not shown) encloses these coils. A similar cabinet encloses the servo coils and balance.

A dedicated tabletop computer has been programmed to perform all servo operations of the balance. A larger mini-computer (PDP-11/60) has been programmed to make all essential measurements to instruct the tabletop computer which part of the servo operation it must perform.

The apparatus for Phase III is similar to that for Phase II except that the room temperature magnet B will be replaced by a superconducting magnet. This will increase the force and voltage to the kilogram and volt level respectively, and should enable the ultimate 0.1 ppm accuracy to be achieved. The superconducting magnet is on site and was tested during the FY. It was found that a modification in construction will be necessary to reduce its liquid helium consumption to an acceptable level.

Future Plans

As noted above, the apparatus for Phase II is completely constructed and assembled. The principal subassemblies have been evaluated and appear to behave satisfactorily. The next step is to evaluate the entire system in operation. Undoubtedly, this will require some parameter changes in the software of the servo programs.

It is expected that preliminary but meaningful measurements will be made during the winter and spring of 1983 - 1984. Further, unless major changes are required, it should be possible to evaluate some systematic effects during this period so that by the end of FY 84 the NBS ampere experiment can yield a publishable result with a 2-3 ppm uncertainty.

If all goes as planned, we will convert to Phase III in early to mid FY 85 and begin to evaluate thoroughly all possible sources of systematic error and accumulate the best possible data.

REALIZATION OF THE SI VOLT

(F. K. Harris, L. H. Lee)

Objectives

The objective of this project is to realize the SI volt directly by force measurements in terms of the base SI mechanical units of length, mass, and time interval, and the assigned SI magnetic constant.

The present volt assignment is derived from absolute ohm and ampere determinations and is uncertain to the same extent as the latter (5 ppm or more). However, a direct volt determination should be free from some of the systematic errors of past ampere determinations. Furthermore, there is no conversion of electrical energy to heat, which may have affected dimensional results and balance operation in past ampere determinations. Thus it is hoped that a direct determination of the volt may reduce the uncertainty in its assigned value.

Current Activities

Our volt balance consists of a vertically aligned coaxial-cylinder electrode system with the low-voltage electrode in the annular space between an inner and outer high-voltage electrode, and suspended from the balance beam. The vertical electrical force on this suspended electrode is compared by substitution to the mechanical force produced by a known mass. The relation between electrical and mechanical forces,

$$E^2 \frac{\partial C}{\partial z} = 2mg,$$

requires that capacitance be measured against vertical electrode displacement; and the high-voltage electrode system is mounted on a carriage which can be moved vertically on three guide rails, position being determined using a laser interferometer.

It has been shown that horizontal electrical forces which are present if the system is not truly symmetrical about a vertical axis may translate into a quasi-vertical force if the knife-edges of the balance beam are not in a horizontal plane. Thus it is extremely important that the electrode system be accurately symmetrical (within a few micrometers) about an axis that is vertical (within a few seconds of arc); the carriage movement of the high-voltage electrode system must also be vertical within the same constraint. Thus this year's activities have been centered on the development of techniques to accomplish these objectives.

Accomplishments

As previously noted, lateral motion of the balance's base-plate as the carriage is moved vertically to change electrode position, is a source of uncertainty in the determination of $\partial C/\partial z$. Parallel alignment of the rails on which the carriage moves, and centering of the hydraulic pusher and its bearings with respect to the guide rails, have reduced this lateral motion below the 1 μm level over a carriage traverse of 70 mm. Next the fixed electrodes were assembled on the carriage and adjusted to be vertical and centered. Also their profiles were studied using a non-contacting capacitance probe with a resolution of approximately 0.1 μm. The intermediate electrode, suspended from the balance-beam in the annular space between the fixed electrodes, is now being similarly studied.

Future Plans

The next step will be the determination of $\partial C/\partial z$, preliminary to force measurements at the 1 g level. This will complete the first phase of our volt determination. The center of gravity of the suspended electrode system will require to be lowered before force measurements can be carried out at higher levels. This is because the centering force of gravity acting on the pendulous electrode structure must be greater than the lateral electrical force resulting from departure of the electrode from its coaxial position.

REALIZATION OF THE SI FARAD AND OHM

(J. Q. Shields, R. D. Cutkosky, L. H. Lee)

Objectives

The objectives of this project are to build, maintain, and operate equipment for calibrating the NBS standards of capacitance and resistance in terms of their SI definitions to an accuracy of 1 or 2 parts in 100 million, and to assure the compatibility of these standards with those of other countries. Accurate realizations of the farad and ohm are required to assure the compatibility of instruments (via resistance, inductance, and capacitance calibrations) that are manufactured within the U.S., and for the determination of certain fundamental constants.

The absolute farad and ohm measurements make use of a calculable capacitor and a series of bridges for comparing capacitors and resistors. The result of the measurement sequence is an absolute calibration of the NBS reference standards of capacitance and resistance that is accurate to a few parts in 10^8. These measurements can also be considered as fundamental constants measurements, with applications to questions concerning the adequacy of quantum electrodynamic theory and to the determinations of more exotic constants. For example, a reliable value of the ratio of the NBS ohm to the SI ohm is required in order to obtain a value for the fine-structure constant from a measurement of the proton gyromagnetic ratio and 2e/h as measured via the Josephson effect; and from a measurement of the quantized Hall resistance in a two dimensional electron gas. It is also necessary for the new NBS absolute ampere experiment.

Current Activities

The equipment was completed a number of years ago and is among the best in the world; a value for the NBS farad and ohm in terms of the SI farad and ohm accurate to a few parts in 10^8 was obtained in 1974. Work is presently concentrated on the preparation of this equipment for a new determination of the absolute farad and ohm with slightly improved accuracy. Other current activities include maintenance of the NBS unit of capacitance at the 10 pF level, and participation in international comparisons of capacitance and resistance standards.

Accomplishments

Three capacitors of NBS construction have been circulating for many years between the major national standards laboratories under BIPM auspices. The capacitors were returned to NBS this past year following measurements in Canada, France, and Italy. They continue to exhibit excellent stability while being shipped via commercial carrier. After remeasurement, they were sent to the ASMW, German Democratic Republic.

The laser previously used with the calculable capacitor is being replaced by a new stabilized, helium-neon laser having much better stability. The new laser in combination with an acousto-optic modulator for eliminating the effects of reflected light from the interferometer should significantly reduce the uncertainty in the basic length measurement required for the realization of the SI farad and ohm.

Much of the recent effort to improve the absolute farad and ohm measuring system has been concentrated on that part of the system which compares the NBS unit of capacitance with the NBS unit of resistance. The problem of frequent equipment failures in this area appears to have been reduced to a tolerable level as a result of equipment replacement and modification and the provision for backup equipment.

Measurements of the stabilities of components used in the measuring system have provided a sound basis for determining acceptable time-lags between calibration and use of components. The better than excepted stabilities found for capacitor voltage dependencies is especially significant in view of the time-consuming nature of voltage dependence measurements.

Future Plans

New absolute farad and ohm measurements are in progress. Present thinking is that these measurements should be made on a regular basis during the next few years so as to determine the drift rates of the NBS reference capacitors and resistors. Efforts to upgrade the existing apparatus will continue. An international comparison of resistance standards at BIPM is scheduled for FY 84. Also planned is a direct comparison with Australia of one ohm standards calibrated in terms of each laboratory's calculable capacitor. This comparison should provide a good test of the overall reliability of each laboratory's measurement chain.

QUANTIZED HALL RESISTANCE

(M. E. Cage, R. F. Dziuba, and B. F. Field)

Objectives

To develop the quantum Hall effect in semiconductors to the point where it can be used (1) to determine the fine-structure constant α to the unprecedented accuracy of a few parts in 100 million, thereby allowing the unequivocal testing of quantum electrodynamic (QED) theory; and (2) to establish a reproducible resistance standard of the same accuracy.

The quantum Hall effect has the potential of providing the most accurate QED-independent value of the fine-structure constant as well as an SI or absolute resistance standard based on fundamental constants of nature rather than the present resistance artifacts. It would thus permit definitive tests of QED as well as allow NBS to continually maintain the U.S. unit of resistance to very high accuracy in SI units, rather than at multi-year intervals via the very difficult calculable cross-capacitor experiment.

Current Activities

The method for achieving these goals involves measurements of the Hall resistance, R_H, of metal-oxide-semiconductor field effect transistors (MOSFETs) and of GaAs-AlGaAs heterojunctions at liquid helium temperatures in large magnetic fields. The Hall resistance (the ratio between the Hall voltage and sample current I) is given by

$$R_H = \frac{V_H}{I} = \frac{\mu_0 c}{2\alpha i} \simeq \frac{25{,}812.8}{i} \ \Omega, \qquad (1)$$

where μ_0 is the permeability of vacuum (defined to be $4\pi \times 10^{-7}$ H/m), c is the speed of light in vacuum, and i is an exact quantum integer. Currently we are (1) acquiring and building new apparatus to be used in a second generation measurement system for this project, (2) continuing the collaboration with R. J. Wagner of the Naval Research Laboratory (NRL) in studies of MOSFET devices using the 15 T superconducting magnet at the NRL high Magnetic Field Facility, and (3) performing quantum Hall effect experiments on GaAs heterojunction samples using an 8 T magnet installed in a shielded room at NBS.

Accomplishments

We have demonstrated in a series of experiments that GaAs heterojunction devices can be used as resistance standards. The shape of the i=4 (6,453.2 ohm) Hall steps of device GaAs(7) was measured to high precision and found to be flat to within 0.02 ppm. Furthermore, measurements of R_H have a day-to-day reproducibility on the order of 0.01 ppm and are apparently limited by the stability of the wire-wound reference resistors. There would seem to be little doubt that the quantum Hall effect can eventually be used to maintain the U.S. unit of resistance.

The temperature dependence of R_H was measured for GaAs(7), and as Fig. 1 shows, the value of R_H changed by 20 ppm between 1.1 K and

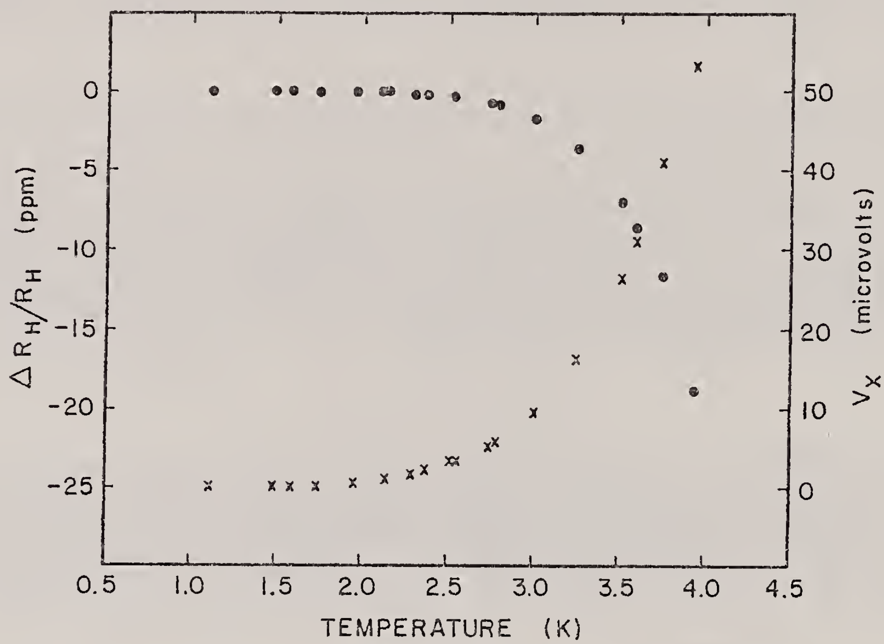


Fig. 1. Although R_H (filled circles in the figure) is temperature dependent, we can reduce the temperature sufficiently to introduce less than a 0.01 ppm error, an accuracy which is required if the device is to be used as a resistance standard. V_x (the voltage drop along the channel, plotted with crosses) can be used as a quality factor to determine the inaccuracy of R_H. These data were obtained at 25 μA.

and 4.0 K. The temperature-dependent error appears to be less than 0.01 ppm for this device when cooled to 1.1 K. Temperature dependences will have to be determined for every device which is proposed as a resistance standard. A paper reporting this work will be prepared in early FY 84 and submitted to Physical Review B.

We also studied the current dependence of GaAs devices and observed dynamic non-linear behavior resulting from catastrophic breakdown of the dissipationless current flow (see Fig. 2) at high currents (corresponding to a three-dimensional current density of 40,000 A/cm^2). We demonstrated that this breakdown is spacially localized and observed transient switching on a microsecond time scale among a discrete set of distinct dissipation states. A paper describing this work and which includes a proposed macroscopic

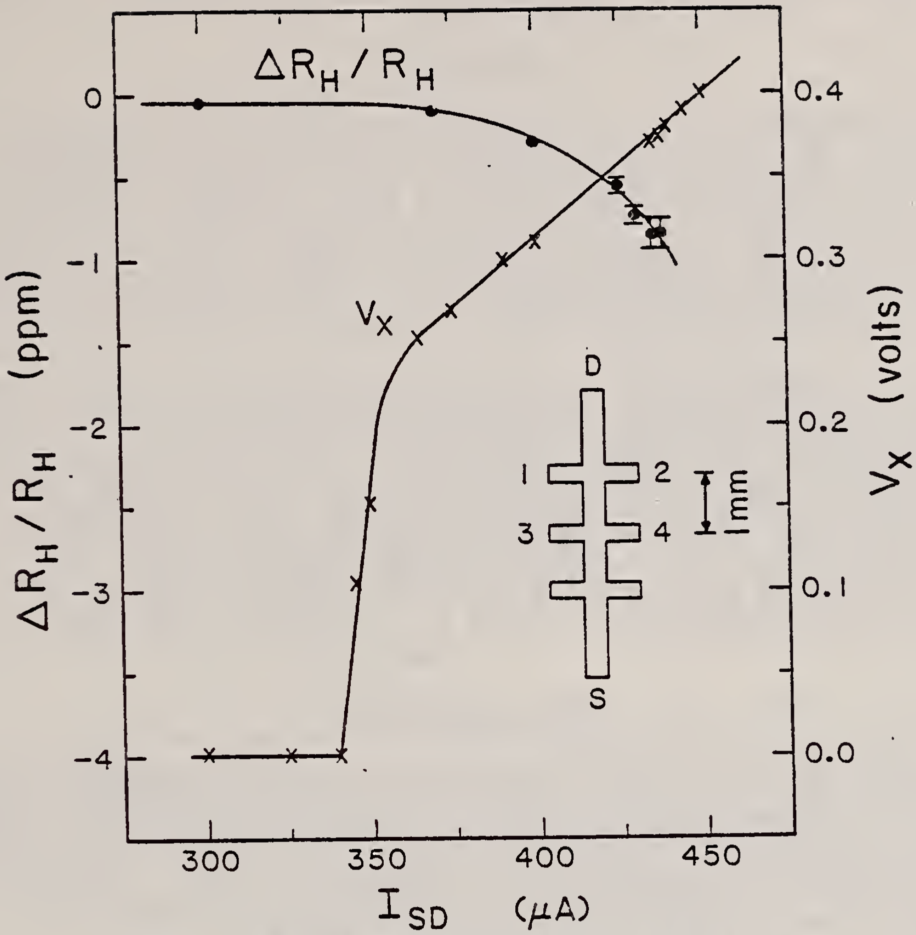


Fig. 2 Current dependence of $\Delta R_H/R_H \equiv [R_H(I_{SD})/R_H(25\ \mu A) - 1]$ and V_x for the i=4 step of GaAs(7) at 1.1 K. The solid lines are meant to guide the eye. Also shown are the source, drain, and four potential probes. Each device is 4.6 mm long and 0.38 mm wide.

picture which accounts for the novel phenomena observed will appear in Physical Review Letters (10 October 1983).

We now believe we have an explanation for the 0.8 ppm discrepancy between the values of R_H that we obtained at Bell Labs and those obtained at the Naval Research Laboratory and at NBS. Part of the discrepancy can likely be accounted for by the temperature dependencies of the Hall steps which were only measured at 4.2 K at Bell Labs. Also, the Bell Labs results were based on i=2 (12,906.4 ohm) Hall steps while the other measurements at NBS and NRL used i=4 steps. Part of the discrepancy may thus be due to errors in the calibration step-up from 6453.2 ohms to 12,906.4 ohms.

Future Plans

Providing Bell Labs can locate the samples used in our early measurements there, we will attempt to verify that the 0.8 ppm discrepancy problem has indeed been resolved by carrying out new measurements near 1 K. In the meantime, we will continue to determine the value of R_H in terms of the NBS as-maintained ohm. To this end, we have devoted many months work to identifying systematic errors in the quantum Hall effect measurement system. No errors larger than 0.02 ppm have been found. We did discover, however, that the room temperature current comparator bridge may have a systematic error as large as 0.25 ppm when used to intercompare 6,453.2 ohm and 10 kohm resistors. We plan to bypass this bridge using four different methods. The first, already completed, uses a Kelvin-Varley divider to measure the 6.4532 kohm/10 kohm ratio with an estimated uncertainty of 0.13 ppm. The result is a value of R_H that is 0.27 ppm larger than that obtained using the current comparator. The second method will use a Hamon device to step-up from 100 ohm to 6,453.2 ohm with an expected uncertainty of 0.01 - 0.02 ppm. These measurements are ready to commence. The third method will employ a Hamon step-up from 1 ohm to 6,453.2 ohm, while the fourth will use a cryogenic current comparator bridge for a 0.01 ppm step-up from 1 ohm to 100 ohm, 1 kohm, 6,453.2 ohm and 10 kohm. However, the determination of R_H in SI units will have to await the results of the redetermination of the NBS ohm in SI units currently underway using a calculable cross-capacitor.

The 15 T magnet system and its associated ^3He refrigerator ordered at the end of FY 82 should be delivered, installed, and tested in FY 84. This magnet will enable us to investigate the geometry dependence of Si MOSFET devices at NBS. We also plan to continue temperature and current dependence measurements and to further verify that the value of R_H can be device-independent under the proper conditions. A new automated measurement system which should be ready to use during FY 84 will greatly reduce the tedium of data collection.

GAMMA-P AND THE FINE-STRUCTURE CONSTANT

(P. T. Olsen, W. D. Phillips, E. R. Williams, Song Junshou, G. R. Jones)

Objectives

To carry out an improved determination of the gyromagnetic ratio of protons in H_2O, γ_p', to an accuracy of a few parts in 100 million, thereby obtaining a value of the fine structure constant, α, to an accuracy of 0.02 - 0.03 ppm. This will extend the precision with which quantum electrodynamics (QED), the Josephson effect, and the quantum Hall effect, can be tested. It will also provide an alternate means to monitor and maintain the NBS units of voltage and current.

The present approach to redetermining α is based on improving the inductive dimensional measurement method developed in our laboratory for determining the pitch and diameter variations of a precision solenoid and used to carry out a 0.2 ppm experiment reported in 1979. The NPL in England and the VNIIM in the USSR have reported values of γ_p' that are in complete disagreement with our 1979 result (10-15 standard deviation discrepancies). The Chinese value obtained at NIM, Beijing, agrees with our value. We expect a new determination of γ_p' will resolve this major disagreement.

Current Activities

The gyromagnetic ratio of the proton is defined as the ratio of the angular precession frequency ω_p' of a proton in a magnetic field B to the magnitude of the field, ω_p'/B (the prime indicates the proton is in a spherical, pure, H_2O sample). The precession frequency is measured by standard nuclear magnetic resonance methods. The magnetic field is calculated from the measured physical dimensions of a single-layer solenoid, wound on a precision-ground quartz form, with a known (in terms of NBS standards) electric current in the turns of wire. The location of each turn of the solenoid is found by an inductive pick-up probe and a laser interferometer which locates the position of the probe. We are constructing a new solenoid and measuring apparatus that will reduce the sources of error in the previous experiment. This new experiment will have the following improvements: (i) a reduced sensitivity to the diameter of the solenoid; (ii) improved axial symmetry of the inductive pick-up probe; (iii) an improved straightedge used to guide the probe; (iv) an improved laser measuring system that will allow measurement of all six degrees of freedom of the probe; (v) increased S/N ratio for the NMR signal; (vi) improved temperature control; (vii) improved calibrations of our length and electrical standards; and (viii) capability for a direct measurement of all the susceptibility corrections. These advances should produce an order of magnitude improvement in our previous determination. The new quantum Hall effect, which provides an independent value of α, provides additional incentive for completing the γ_p' measurement in the near future.

Accomplishments

We have installed the solenoid and straightedge; the detector coils are all wound; the cooling system is operational, controls the solenoid temperature to 0.1 °C, and the temperature can be reliably read to 0.01°C. Provisions have been made to control the temperature to 0.01 °C if necessary, but the system as it presently operates should be adeuqate for a 0.01 ppm experiment. We are changing the automation system so that the laser for the absolute ampere and γ_p' experiments are operated by separate computers. This will allow us to run and debug the two experiments simultaneously. This has delayed automating the γ_p' experiment, but all the required equipment is now on hand.

The new pick-up coils have 0.01 $\mu m/\sqrt{Hz}$ resolution limit (due to amplifier and resistive noise) for the diameter and pitch measurements. This is a factor of 5 to 10 improvement over the last experiment. However, it does not include the noise, not yet evaluated, due to mechanical vibrations. A new method to operate two inductive pick-up probes simultaneously has been developed and the digital electronics built. This will allow us to have the entire interferometer in vacuum.

Future Plans

Our goal to have a preliminary but publishable value of γ_p' and α by June of 1984 is unchanged. However, we have made several changes in the design for automating this experiment and must realize those changes in the next four months in order to meet this timetable. Dimensional measurements must be in progress by January 1984. The perliminary results should yield a value of γ_p' accurate to about 0.1 ppm, (0.05 ppm value of α). It will be very important to have our measurements coincide with those of the quantum Hall resistance and the calculable capacitor experiment so that we can eliminate the question of drift in the electrical units. The present discrepancy between the old γ_p' results and some preliminary quantum Hall results heightens the need for a 0.1 ppm value of γ_p' as soon as possible.

ADVANCED IMPEDANCE-MEASUREMENTS RESEARCH
(R. D. Cutkosky, L. H. Lee)

Objective

To design, build, and test components and subassemblies for a family of portable, stand-alone, automatic impedance bridges with IEEE 488 bus compatibility. A prototype working capacitance bridge has been the focus of the work for the last several years.

A significant number of important electrical measurement problems are encountered in the course of providing measurement services, conducting exploratory research, determining fundamental constants, and realizing the SI definitions of the electrical units. Yet, although important, the problems are often too specialized to attract commercial development of appropriate instrumentation. The purpose of this project is to help solve these problems by working closely with the personnel of other projects involved in these activities.

Current Activities and Accomplishments

The prototype automatic capacitance bridge was completed during FY 83. It has the following specifications: frequency range: 20 Hz to 20000 Hz; capacitance range: 1200 pF maximum, in three ranges - 0-12 pF, 0-120 pF, and 0-1200 pF; conductance range: 9300 pS maximum, in the highest range; voltage range: up to 90 volts, dependent upon range and frequency (1 volt max. at 20 Hz); resolution: up to one part in 100 million, dependent upon frequency and voltage; stability: not yet determined, but evidently close to one part in 10 million per year; accuracy: this will be studied in the coming year, but should be better than 1 ppm over its entire range.

The bridge is a stand-alone instrument that can be controlled from the front panel to select and measure one of up to 16 capacitors connected to its input terminals at any frequency and voltage within its range. The result is displayed on the front panel in standard decimal format. Optionally, the bridge can be controlled remotely via its IEEE 488 bus interface. This would be the expected mode of operation, since the remote computer or desk calculator could then be used to store the data and apply the necessary calibration corrections. Part of the program residing in the read-only memory of the bridge is devoted to the generation of the internal look-up table that is accessed by the bridge during its normal operation. This internal calibration program is in turn controlled over the 488 bus by a program now running on a desk calculator. The look-up table for a bridge can be generated with this system in about six hours of nearly hands-off operation. The system will allow a new bridge containing this feature to be placed in operation very quickly, and will provide a means for re-aligning a bridge after routine servicing.

The internal capacitance standard gave some cause for concern last year, but a preliminary model was installed early this year so that the work on the rest of the bridge could proceed. The capacitor has never been temperature cycled to improve it's stability, but it is now drifting about one part in ten million per year. It is expected that future models will be better. A stand-alone capacitance standard is also being constructed. It will be some time before anything can be said about it.

Future Plans

Plans are being made to design equipment for performing an automatic external calibration of the bridge under computer control. This will yield a set of calibration tables indexed with frequency that could be placed in the desk calculator controlling the bridge in a calibration environment. The equipment needed for such a process are two or more programmable inductive dividers, sets of defining transformers and coaxial star junctions, and a few capacitance and conductance standards of an appropriate value. Some minor modification to the bridge internal program may be required to achieve the result required. It should be noted that beyond the process outlined above, which involves purely ratio measurements, though complex ratios, it is also necessary to have access to standards of capacitance and conductance, that are known as a function of frequency, to obtain a complete calibration of the bridge. Such standards are not presently available, and will have to be provided by another source.

Other work that will be carried out next year includes continuing the production of drawings, wiring diagrams, and assembly instructions for the bridge. If more bridges are constructed, a great deal of time will be spent seeing that these instructions are complete and correct.

NEW DC VOLTAGE METROLOGY

(B. F. Field)

Objectives

The objective of this project is to improve the ten volt voltage maintenance process so that a laboratory can reliably maintain a unit of voltage and traceability to NBS at the ten volt level. This includes (a) developing new voltage standards based on rugged solid-state devices, and (b) developing measuring instruments and methodologies to take advantage of the new standards.

Although the latest voltage references on the market provide stability approaching primary standards (approximately 0.5 ppm/yr), several problems remain. Shipping of the standards requires careful coordination between the shipper and receiver because of the requirement to maintain the unit under power (with limited battery life). Highest accuracy is obtainable only at the six to ten volt level, a voltage not particularly suitable for calibration with standard cells.

We will develop a measurement system to characterize voltage reference devices (e.g., Zener diodes) at the six to ten volt level. Since NBS does not manufacture reference devices, we will establish liaison with industrial companies and characterize presently available devices. In addition we will design an easily transportable 10 V standard with good short term predictability (0.5 ppm over several weeks). This standard will be used in a program to disseminate the volt directly to the user at the ten volt level at reduced cost as compared to standard cell calibrations.

Current Activities

We are using the recently developed automated measuring system to continue evaluation of a number of reference devices (components) and complete voltage standards (instruments). In particular, we are studying the effects of extraneous ac, long term stability, short term predictability, and the effects of cycling power and temperature regulation on and off. This information will be used to help design the transportable 10 V standard.

The measurement system presently uses a special scanner switch. We are in the process of developing an improved scanner that may be easily replicated for use by other laboratories. This scanner is expected to produce thermal emf errors less than 50 nV and would be useful for many other electrical measurements. Other laboratories will thus be able to duplicate our measuring system, permitting them to make more accurate measurements between one and ten volts (up to 5 times more accurate than present instrumentation).

We are working on the design of a 10 V transportable standard. Our purpose is to develop a convenient standard that can be turned off and shipped to another standards laboratory by commercial carrier with a transfer accuracy of 0.5 ppm or better. A group of reference devices are currently under test to determine their sensitivity to power cycling on and off and their response to wide temperature fluctuations. Additionally, we are considering a burn-in procedure to minimize voltage hystersis on power cycling.

Accomplishments

An automated measuring system to measure voltage references in the range of 1 - 10 volts has been completed. An error analysis which included performing a series of experiments and developing models to evaluate systematic measurement errors was completed during the past year. Some of the digital voltmeter (DVM) errors (zero offset and gain) are determined and corrected during voltage measurements, while others (linearity, leakage resistance, ac effects from DVM noise) were found to be small enough (< 0.1 ppm) to be neglected. A sensitive loop closure experiment was designed in which three different measurements are made on a given reference with the measurements ideally summing to zero. This study found that the measurement system has an accuracy of 0.2 ppm (3 standard deviation estimate) when comparing a properly isolated Zener-diode-based reference to a standard cell.

Extraneous alternating currents, some generated by the reference under test, continue to be the largest single source of error. We have concluded that each new type of voltage standard must be checked to determine what effect normal and common mode noise have on the dc output of the unit.

A special NBS designed low-level switch is used in the measurement system. We have constructed a first attempt prototype card that can be used in a commercially available scanner. This card should be reasonably inexpensive, less than $50 per switch point, and can be readily duplicated. Figure 1 compares thermal emf errors for two commercial cards presently available, and our prototype card.

As a result of our on-going study of reference devices and standards, we have identified several weak areas.

1. Many of the standards exhibit a dc shift when a small amount of noise is applied at the output (i.e., noise from a DVM input).

2. Some reference devices appear to have much poorer dynamic resistance than manufacturers specifications. Several stages of preregulation are required for good short term stability.

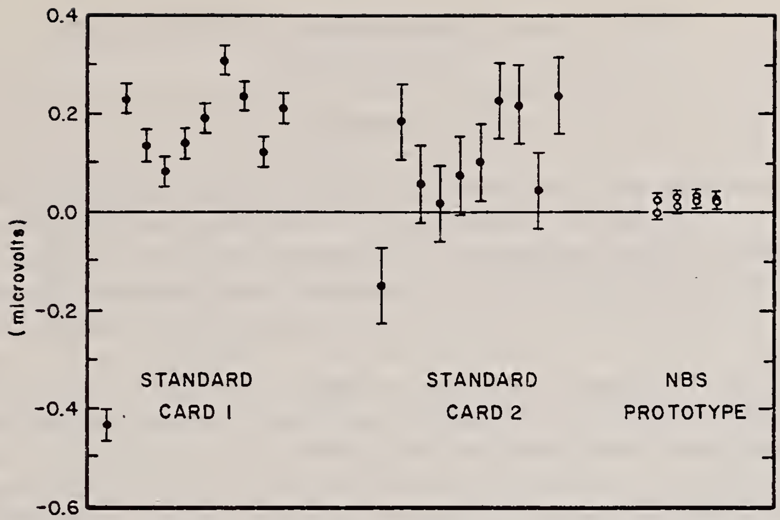


Figure 1

3. Most transportable standards need to be shipped under power for best transfer accuracy. Battery life limits the shipping distance and ease of shipping.

4. Some reference devices are more stable if they are kept "turned off" with only short term application of power during infrequent measurements.

5. An extensive testing and selection process appears necessary to select reference devices with desired noise levels and stability.

A commercial voltage standard has been subjected to a long term test. The data (Fig. 2) shows that if a correction were made for the long term drift of the standard, an accuracy of 0.4 ppm could be realized in the laboratory. The test was terminated when the standard failed, badly overheating the internal reference (105 °C).

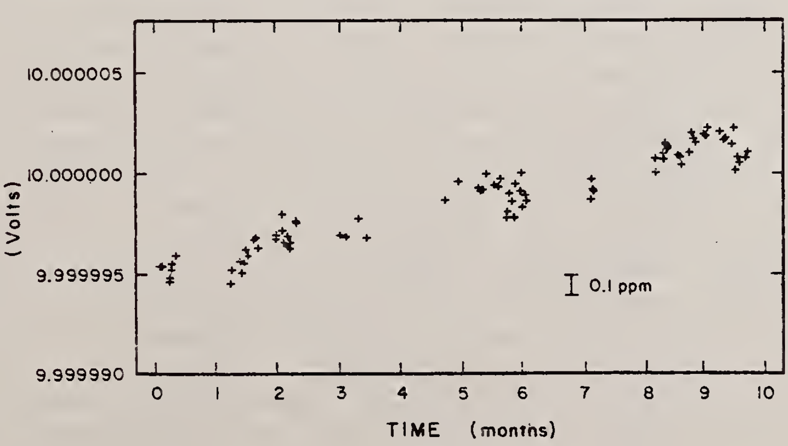


Figure 2

Future Plans

We intend to continue testing available reference devices; long term tests will continue to help estimate their ultimate stability. Effects of power cycling, temperature, and humidity will be studied to allow selection of a suitable device for the transportable standard.

The design of the transportable standard should be completed in FY 84, including a highly regulated and isolated current source, an enclosure with appropriate thermal packaging, and possibly a temperature regulation circuit. Construction of a prototype will begin, to be followed by an evaluation of its shipping characteristics. Once the transportable standard has been completed, we will consider disseminating the volt at the ten volt level. This should increase the ultimate accuracy available to the end user by eliminating the error associated with scaling the volt at the user's laboratory.

EDDY-CURRENT NONDESTRUCTIVE EVALUATION
(G. M. Free)

Objectives

The eddy-current project has two principal objectives: the development of a calibration service for electrical conductivity standards in the range 1%-100% IACS (International Annealed Copper Standard); and the production of electrical conductivity standards which will become NBS Standard Reference Materials.

Eddy-current testing of metal components based on the change in impedance of a pick-up or test coil placed on the component is prevalent in industry. The primary uses are in the measurement of material properties and in the detection of flaws. The tests have such applications as the sorting of metals, the measurement of cladding thickness, and the sizing of defects. Despite the large number of applications, adequate standards for the calibration of eddy-current instruments do not exist. The development of standard reference materials and a calibration service for electrical conductivity standards will meet the need for accurate calibration of conductivity test systems.

Current Activities

The electrical conductivity calibration service and the calibration of electrical conductivity standard reference materials have as a common factor the instrumentation developed to measure electrical conductivity. This instrumentation consists of a direct-current or dc measuring system by which the dc conductivity of metal samples is determined. These metal samples then become the primary conductivity standards at NBS. Using an eddy-current bridge developed at NBS that is based on a new concept in eddy-current measurement, comparison is made between the primary conductivity standards and either customer samples or SRM's to determine their electrical conductivity.

The dc measurement system has been modified so that four-point measurements can be made on small samples. The feasibility of using the four-point measurement technique in conjunction with the relationships between conductivity, sample resistance, and sample thickness developed by Van der Pauw has been tested. Although accurate measurement of resistance can be made, thermal emf's are a major source of error. To eliminate this problem, a new temperature controlled oil bath has been purchased and is now being tested for temperature stability. The four-point measurement approach should improve the dc measurement by an order of magnitude since resistivity is a function of sample thickness instead of sample cross-sectional area, and the thickness of the sample can be measured extremely accuratey over a small area. Also, since the samples are small, optical techniques can be used in machining, thus significantly improving the dimensional tolerances of the samples.

Development work on the eddy-current bridge used to determine the impedance of the test coil is focussed on simplifying the measurement and increasing the frequency range of the bridge. In the typical Maxwell inductance bridge, two sets of balances must be made: the primary circuit balance (which determines the value of R and L of the inductor), and the ground circuit balance (which reduces the error due to stray capacitance). To simplify the measurement either the ground circuit can be eliminated or the number of balances between the two circuits can be reduced. Both approaches are being tested but at present elimination of the ground circuit is not possible. The current method is to match components in the primary and ground circuits and to use common inductive dividers to drive the components. Using this scheme the measurement has been greatly simplified. The main circuit is balanced, a slight adjustment at the highest detector sensitivity is made to the ground circuit, and then a final balance is made of the main circuit. In most cases three circuit adjustments are all that are necessary to obtain final balance.

To increase the frequency range of the bridge it was necessary to use new broadband operational amplifiers in the ground network; it now covers the range 100 Hz to 100 kHz. The final configuration of the ground circuit to obtain minimum noise and drift and high phase accuracy over this range is being completed.

Accomplishments

The following was accomplished during FY 83: (1) The dc measurement circuit was modified to make measurements of resistance at the 10 micro-ohm level. (2) A holder for small metal samples was constructed and the feasibility of making measurements using Van der Pauw's relationship was tested. The major sources of error in this technique were determined and steps are being taken to eliminate them. (3) The frequency range of the eddy current bridge was extended to cover the range 100 Hz to 100 kHz. (4) Measurements using the eddy-current bridge have been simplified so that in most cases three adjustments of circuit parameters are all that are necessary to achieve final balance at the highest sensitivity. (5) A new sample holder has been constructed which allows the test coil to metal-separation distance to be varied by increments of less than 0.1 micrometers. (6) A new calibration scheme has been devised which incorporates the capabilities of the new sample holder so that it is now possible to reduce lift-off error to the ppm level. (7) The effects of coil heating have been significantly reduced. (Once the lift-off error is minimized, it is possible to determine the drift rate of the coil due to heating. By interspersing measurements of the standard with those of the unknown, corrections can be made to the measurements to reduce this error.) (8) A method has been devised to determine the frequency error in the calibration of the test coil. This has not been tested as yet. (9) A document on the measurement of electrical conductivity by the eddy-current method written for ASTM has passed the

ASTM main committee ballot and will be published in either the 1984 or 1985 ASTM book of standards. (10) Documentation of the dc and eddy current measurement systems has been completed in draft form for possible publication as a NBS Technical Note.

Future Plans

Plans for FY 84 include: (1) Calibration of all primary standards using the new dc method. (2) Determination of temperature coefficients of the primary standards over a broader range of temperature, i.e., 15-30 °C. (3) Calibration of new SRM's at the 100% and 1% IACS levels. (4) Completion and publication of the above mentioned documentation and announcement of the calibration service for eddy current conductivity standards. (5) Determination of those ferromagnetic materials for which SRM's would have the greatest impact. (6) Initial design of an eddy-current bridge for the calibration of ferromagnetic materials.

LASER COOLING AND TRAPPING OF NEUTRAL ATOMS

(W. D. Phillips, J. V. Prodan, J. J. Metcalf)

Objectives

The fundamental objectives of this project are to decelerate, cool, and possibly confine (trap) neutral atoms using tuneable lasers.

The motivation for this work is that cooling and trapping provide solutions to the problems of 2nd order Doppler effect, transit time effects, and other motional effects which limit the performance of ultra-high resolution spectroscopy. This work is complementary to the trapped ion cooling work of the Time and Frequency Division. Both projects are directed to improved spectroscopic resolution, but neutral atoms present different opportunities, such as studies of atoms in electric fields. These could test theories of the Stark effect or provide a new determination of the fine-structure constant from Stark splittings. Spectroscopy of very cold neutral atoms also has possible applications in microwave and optical frequency standards, and in atomic theory and fundamental constants.

Current Activities

Atoms which interact with light that is resonant with an atomic transition experience forces which can decelerate, deflect, or confine the atoms. In our initial experiments we have opposed a beam of sodium atoms with a resonant laser beam. Atoms absorb and re-radiate photons from the laser beam, with about 30,000 absorptions needed to bring thermal velocity atoms to rest. A key problem is that atoms which absorb several hundred photons will decelerate enough to be Doppler shifted out of resonance with the laser. In addition, after several absorptions, atoms may be optically pumped to states which are inaccessible to further excitation by the laser. Both of these problems are solved using a spatially varying magnetic field. This field causes a spatially varying Zeeman shift which compensates the Doppler shift, and also allows optical pumping to be avoided when the laser is circularly polarized. Using these techniques, sodium atoms have been decelerated to velocities as low as 40 m/s.

During the past year we have improved the performance of the atomic beam deceleration procedure by providing better vacuum conditions, increased laser power, and improved laser beam optics to optimize the cooling process. In addition, we have recently used another technique for avoiding the Doppler shift problem -- rapidly scanning the cooling laser frequency to stay in tune with the atoms as they decelerate. This method was suggested a number of years ago but has never before been successfully used.

Angular divergence of the atomic beam as it decelerates is a process which limits the achievable density of slow atoms. We have constructed a magnetic hexapole lens to re-focus the diverging atomic beam, and preliminary results indicate that a substantial gain in density is possible at the lowest velocities.

Using our improved techniques for modest decelerations (about a factor of two) we have obtained cooled atomic beams with velocity spreads as small as 2% and with densities per unit velocity more than 20 times higher than is achieved in a thermal beam.

We have developed a numerical computer model of the cooling process which yields results in good quantitative agreement with experiments, and which we hope will be helpful in further experiment design.

A well received workshop on laser cooling and trapping of neutral atoms was held which stimulated a number of new ideas, and the proceedings published as NBS Spec. Publ. 653, Laser Cooled and Trapped Atoms.

Future Plans

We will continue to study the basic cooling process, with a view to better understanding its limitations and how to optimize it. In particular, we will be attempting to achieve lower final velocities, narrower velocity distributions, and higher densities. We will be continuing with the studies of magnetic refocussing and we will be investigating the effects of our detection process on the final atomic velocity distribution.

Recent theoretical developments in the field of laser trapping of atoms indicate that stable trapping of sodium atoms for periods as long as ten seconds should be possible. While the energy of atoms in such traps is still lower than the lowest energies we have obtained, we will be considering techniques to decelerate the atoms as they enter the trap, with an ultimate goal of trapping and further cooling the atoms.

We are also considering the deceleration of a beam of atoms having a narrow visible transition as a possible candidate for an optical frequency standard. At present, calcium seems to be a likely first candidate, since the observation of the red intercombination line yields the narrowest observed feature in the visible spectrum, and the width is limited by the second order Doppler effect. Cooling calcium as we have cooled sodium should virtually eliminate the second order Doppler width.

FRACTIONAL CHARGE ELECTROMETER

(G. R. Jones, E. R. Williams)

Objectives

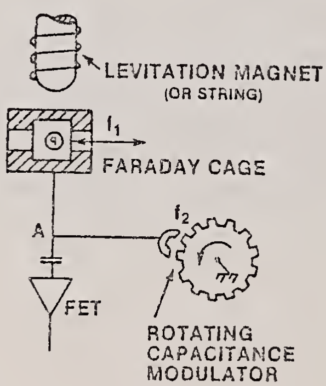
To construct a device capable of measuring the net electric charge on a small test mass (a sphere with a diameter of approximately 6 mm) to an accuracy of one tenth of an electron charge. This instrument shall be used in a search for stable fractional charges.

Previous attempts to detect stable fractional charges have led to null results except for the Stanford experiment. The majority of these tests measure the response of a magnetically suspended test mass to an applied electric field, i.e., a force measurement. The test masses are typically small steel or niobium spheres with diameters of less than 0.3 mm. Due to the nature of this experimental technique, spurious effects, such as the patch effect, can mimic fractional charges. The method discussed here would avoid many of these "artificial" signals by making a direct measurement of the net electrical charge on the test mass. This will be accomplished by placing the sphere within a Faraday cage and measuring the image charge induced on the outer surface of the cage through the use of a modulating capacitor. From Gauss' Law it is apparent that theoretically only the net charge of the sphere, and not the charge distribution or orientation of the sphere, is important. Because this method of detecting fractional charges is fundamentally different from previous attempts it should be able to resolve the apparent conflict between the Stanford results and those of other experimental groups. Furthermore, this method allows far more massive objects to be examined than in earlier tests.

Current Activities

At present the first apparatus capable of effectively testing the Faraday cage/modulating capacitor system is being fabricated in the NBS shops. The means by which the capacitance modulation is achieved is depicted schematically in the figure. A 10 cm disk, with 300 teeth in

QUARK ELECTROMETER



$V_A \approx q \sin(2\pi f_1 t) / [C_0 + C_1 \sin(2\pi f_2 t)]$

$f_1 \approx 1$ to 100 Hz

$f_2 =$ Rotation freq. x no. of teeth ≈ 100 kHz

If $q = e$ and $C_0 \approx C_1 \approx 10$ pF, then $V_A \approx 10^{8}\ V_{pp}$

$C_0 =$ Average capacitance at A

$C_1 =$ Peak modulation capacitance

a pattern similar to that of a gear, is spun at rotational frequencies of up to 20000 rpm. A small probe with a complimentary tooth pattern is placed approximately 10 micrometers from the rim of the disk. As the disk rotates the gap between the disk and the probe varies due to the patterns, the result being a periodically varying capacitance with an average value of approximately 10 pF.

In the initial tests of the apparatus the test sphere will be suspended within the Faraday cage by means of a quartz fiber. However, the height of the sphere within the Faraday cage can be adjusted to test for false signals due to the supporting fiber. Further, the test mass will be periodically shielded from the Faraday cage by a second, grounded cage rotating with the capacitor disk. By thus "removing" the test sphere from the measurement Faraday cage, that part of the output signal of the device due to the charge of the sphere can be separated from the part due to noise sources within the electronics. The deisgn of the equipment is such as to allow the inclusion of a magnetic suspension system to levitate the sphere at a later date.

The entire apparatus is placed within a vacuum chamber to reduce the transfer rate of charges between the test mass and the surrounding environment. Magnetic and electrical shields are also being made to fit around the capacitor and the Faraday cage.

Accomplishments

Preliminary experiments at atmospheric pressure and with minimal shielding were encouraging in that sensitivities of a few 100 $e/\sqrt{Hz}$ were obtainable. However, due to the rapid transfer of charge to and from the test sphere it was obvious that a shielded and vacuum enclosed system was necessary to continue the experiments to achieve the optimal geometry and measuring techniques required for this test.

A variety of different methods of producing the modulated capacitance were examined with a motor driven flutted wheel being chosen as the best method by which sufficient modulation (50%) of a small capacitance could be accomplished. (The motor is mounted outside the vacuum system and drives the wheel through a ferrofluidic rotating feedthrough capable of spinning at 30000 rpm.) A full scale model of the 10 cm diameter disk (without the teeth) has been successfully rotated at 20000 rpm using a 1.9 cm diameter ceramic rod as the spindle. To mount the ceramic rod between a bearing and the motor, aluminum caps (which reduce the diameter of the resulting shaft from 1.9 cm to 0.64 cm) were heat shrunk to the ends of the rod. Due to misalignment between the motor at one end of the rod and the bearing at the other end, the 0.64 cm diameter aluminum shaft eventually snapped. This problem will be eliminated through the use of steel end caps, bearings at each end of the rod, and a flexible coupling between the motor shaft and the rod.

Future Plans

Once the equipment is completed, various geometries involving the measuring Faraday cage, grounded shielding cage, and capacitance disk will be examined to determine the system which produces the best sensitivity. After this preliminary examination, test spheres of different materials and sizes will be measured. Further, the innermost shield around the disk and cage is of 6 cm thick copper which will allow the system to be cooled to liquid nitrogen temperatures. This cooling may be necessary to freeze any thin electrically charged films which could be on the surface of the capacitor, and hence be a source of noise.

If the necessary sensitivity can be achieved, this method will greatly increase the total amount of matter examined for fractional charges. (At present, the total mass studied in all experiments is less than a gram.)

FUNDAMENTAL CONSTANTS DATA CENTER
(B. N. Taylor)

Objectives

The principal objectives of this project are to provide an international information center within the U.S. for work in the general area of precision measurement and fundamental constants, to analyze the consistency of measured values of the fundamental constants that are obtained from different experiments, and to obtain sets of recommended values of these constants for international use.

The close relationships that exist between the fundamental constants and precision measurements, basic measurement units such as the ampere, volt, and ohm, fundamental physics, and state-of-the-art measurement technology, makes the subject a natural one for NBS involvement. One of the purposes of this project is to provide assistance and guidance in the general area of precision measurement and fundamental constants to both NBS staff and university scientists, in particular, to advise them on the potential impact of the various experiments they are considering carrying out and to keep them informed of related work currently underway in various laboratories throughout the world.

Self-consistent sets of "best values" of the fundamental constants, obtained by means of least-squares adjustments, are required for a variety of purposes in science and technology, for example, in accurate calculations of the energy levels of atoms that are of importance in nuclear fusion, or for critical comparison of theoretical calculations with experiment. Furthermore, as the basic invariants of nature, they can be expected to form the basis for a system of reproducible, artifact-independent measurement units. Such a system is the ultimate long-range goal of metrology.

Current Activities

Current activities in the precision measurement-fundamental constants (PMFC) field include (1) keeping apprised of and maintaining a complete reprint collection of the latest accomplishments throughout the world in PMFC; (2) carrying out new least-squares adjustments of the fundamental constants to obtain sets of recommended values; (3) participating in the work of national and international groups (for example, the CODATA task Group on Fundamental Constants and the NAS/NRC Advisory Committee on Fundamental Constants); (4) publishing the quarterly "Preprints on Precision Measurement and Fundamental Constants" (PPMFC) for the OSRD (this publication lists preprints as well as reprints of PMFC papers); (5) attending and organizing national and international conferences on PMFC, visiting laboratories carrying out work in this field, and giving talks on the present status of the fundamental constants; and (6) answering inquiries from both within and without NBS relating to the PMFC field.

Accomplishments

Accomplishments in FY 82 include:

(i) Publication of four quarterly issues of PPMFC and continued maintenance of the Data Center's PMFC reprint file.

(ii) Completion, in collaboration with W. D. Phillips of the Electricity Division, of all the editorial and proofreading work for the Proceedings of the Second International Conference on Precision Measurement and Fundamental Constants (held at NBS 1981 June 8-12), to be published as a hard-bound volume under the title NBS Special Publication 617, Precision Measurement and Fundamental Constants II. Uncontrollable production problems have delayed publication but the volume should be available by the end of 1983 or in early 1984.

(iii) Participation in the work of the NAS/NRC Advisory Committee on Fundamental Constants, in particular, the writing and editing of a report documenting the importance of the PMFC field to physics and the need for continued, strong support of research in this field. The report has now been published under the title Research Concerning Metrology and Fundamental Constants.

(iv) Presentation of three talks related to the fundamental constants: The Boston Chapter of the IEEE Society on Instrumentation and Measurement (20th anniversary meeting); the APS January 1983 General Meeting; the International Bureau of Weights and Measures; and the NBS Research Advisory Committee's (RAC) Seminar "New Directions in Fundamental Constants."

(v) Representing NBS at the 16th Session of the Consultative Committee on Electricity and participating in discussions of measurements of 2e/h in SI units and determining the fine-structure constant from the quantum Hall effect; meeting with the NBS RAC and providing input to their deliberations on PMFC work at NBS; visiting several laboratories in France carrying out PMFC related work (LCIE, BIPM, Thomson-CSF); reviewing four papers for Physical Review Letters in the PMFC area; and answering a number of telephone and written inquiries relating to PMFC and providing assistance to Wineland and colleagues (NBS/Boulder) on m_p/m_e via ion cyclotron resonance, Hughes (Yale) on μ_μ/μ_p from the muonium hyperfine splitting, Sapirstein (Cornell) on α^{-1} from the muonium hyperfine splitting, Barker (Auckland) and Greene (NBS) on $N_A h/c$, and Berquist (NBS/Boulder) on m_p/m_e via laser spectroscopy.

(vi) The main effort during FY 83 was directed towards completing the 1983 Least-Squares Adjustment of the Fundamental Constants (LSAFC83). While considerable progress was made in this direction, the task is yet to be completed (it is about one quarter finished). Unfortunately, administrative burdens during this period were especially heavy, thus preventing the progress hoped for. Nevertheless, it is expected that the LSAFC83 will be completed by mid-1984.

Future Plans

The following is planned for FY 84: (i) continue overseeing the publication of PMFC-II (it should be out in early 1984 at the latest); (ii) publish as usual the quarterly PPMFC; (iii) respond to inquiries as received; and (iv) attend and participate in the April 1984 meeting of the NAS/NRC Fundamental Constants Committee. However, the main objective in FY 84 will be (v) to complete LSAFC83, to oversee its adoption for international use by CODATA, to submit a detailed report for publication in the J. Phys. Chem. Ref. Data, to prepare a short report for publication by CODATA, to prepare a semi-popular version for publication in Physics Today, and to give talks on the 1983 adjustment at the ninth CODATA Conference and CPEM 84.

PRECISION MEASUREMENTS GRANTS
(NBS Precision Measurements Grants Committee; B. N. Taylor, Chairman)

Objectives

The annual objectives are to award two new Precision Measurement Grants of $30 K (renewable for two additional years at the option of NBS), and to renew four to eight existing Grants. The Grants are awarded to scientists in academic institutions in order to (i) promote and encourage fundamental research in the field of measurement science in colleges and universities and train future measurement-oriented scientists, and (ii) foster contacts between NBS scientists and those researchers in the academic community who are actively engaged in such work.

The importance of research in the precision measurement-fundamental constants field has been covered in the project report entitled FUNDAMENTAL CONSTANTS DATA CENTER. While NBS has a strong interest in this area and much experimental work underway, it cannot do it all - there is much expertise and relevant work in the colleges and universities. It is the purpose of this project to tap this reservoir and to foster the training of students who might eventually become NBS staff by awarding grants to a selected number of outstandingly qualified, academic researchers. Only those individuals working in areas of immediate or potential future benefit to ongoing NBS programs are chosen as grantees. Thus, the work carried out by the grant recipients serves to compliment the efforts of the Bureau's own staff in closely related areas. Selection is based primarily upon the originality of the work proposed as described in formally submitted proposals.

Current Activities

The research supported under the PMG program includes experimental and theoretical studies of fundamental physical phenomena which may lead to improved or new measurement methods and standards; the determination of important fundamental physical constants; and general research and development on basic measurement techniques and instrumentation. To simplify the selection process, candidates are first requested to submit a biographical sketch and preproposal summary outlining the objective of their proposed research, why they believe it to be important, and the general approach to be used, including some indication of what they expect to accomplish in the three year time period covered by the Grant. On the basis of this material, four to eight candidates are selected by the NBS Precision Measurement Grants Committee and the Outside Advisory Committee (consisting of senior university professors) to submit more detailed proposals. The same committees evaluate these, and on the basis of this evaluation, the grantees are finally selected. The criteria used in evaluating the preproposals and full proposals include the importance of the proposed research to science, the feasibility of the research, and the past accomplishments of the applicant.

Accomplishments

A renewal proposal was prepared and sent to NSF requesting that they continue to support the renewal grants of the two new 30 k$ PMG's awarded with NSF funds in FY 81 (i.e., D. F. Bartlett, U. of Colorado and C. E. Johnson, North Carolina State U). The proposal was subsequently approved. The procedures outlined above for selecting candidates, which were first instituted in FY 77, were again used successfully in FY 83. Proposals were openly solicited via an advertisement in Physics Today, announcements in appropriate trade journals and newsletters, and the mailing of a brochure to the physics departments of all of the colleges and universities in the U.S. which grant bachelor's degrees in physics (about 850). Proposals were received from 29 candidates, four of whom were chosen to submit final, full proposals. The two grantees selected from these four were:

C. M. Caves, California Institute of Technology
Proposal Title: Quantum-Mechanical Analysis of High-Precision Measurements on Harmonic Oscillators

W. N. Hardy and A. J. Berlinsky, University of British Columbia
Proposal Title: Development of a Cryogenic Hydrogen Maser

For FY 83, the NBS Precision Measurement Grants Committee consisted of Drs. Deslattes, Hall, Taylor, and Wineland; the Outside Advisory Committee of Professors Fortson, Rich, Robinson, and Schuessler.

The following Grants were renewed in FY 83: D. F. Bartlett, U. Colorado, Eötvös Experiment - Cryogenic Version; D. A. Church, Texas A & M U., Low Energy, Highly Charged Ion Precision Spectroscopy; C. E. Johnson, N. C. State U., RF Spectroscopy of Atomic and Molecular Ions; M. G. Littman, Princeton U., Fine-Structure Constant Determination Using Precision Stark Spectroscopy; R. C. Dunford, Princeton U., Lamb Shift in Singly Ionized Helium; and D. C. Tsui, Princeton U., The Quantized Hall Resistance as a Primary Resistance Standard.

Plans

FY 84 plans naturally focus on renewing the four current Grants and awarding two new Grants. Visits to several recipients will also be made in conjunction with other travel.

Electricity Division Sponsored Seminars/Workshops

A Seminar on Electrical Measurement Assurance Programs, held January 24-28, 1983 at Griswold's Motel, Fullerton, CA.

Workshop on Spectroscopic Applications of Slow Atomic Beams, held 14-15 April 1983 at NBS Gaithersburg, MD.

A Seminar on Electrical Measurement Assurance Programs, held September 26-30, 1983 at the Holiday Inn, Peabody, MA.

Invited Talks

M. E. Cage, "A Possible Quantum Hall Effect Resistance Standard," National Conference of Standards Laboratories 1982 Workshop and Symposium, NBS Gaithersburg, MD, October 1982.

M. E. Cage, " The Quantum Hall Effect and the Development of a Resistance Standard," Special Colloquium of the Sigma Xi Society, NBS Gaithersburg, MD, March 1983.

R. F. Dziuba, "The Quantum Hall Effect in Two Dimensional Electron Gases: An Atomic Standard of Resistance," Washington Area Chapter of the Precision Measurements Association, NBS Gaithersburg, MD, January 1982.

W. G. Eicke, Jr., "Measurement Assurance Programs in a Field Environment," National Conference of Standards Laboratories 1982 Workshop and Symposium, NBS Gaithersburg, MD, October 1982.

B. F. Field, "Quantized Hall Effect for Resistance Measurements," Precision Measurements Association, Orange County Section, Anaheim, CA, September 1982.

B. F. Field, "A Precision DC Voltage Measuring System," Region Three National Conference of Standards Laboratories Meeting, Johns Hopkins Applied Physics Laboratory, Laurel, MD, September 1983.

G. M. Free, "Status of the NBS Electrical Conductivity Project," NBS Office of Non-Destructive Evaluation Seminar Series, NBS Gaithersburg, MD, October 1982.

W. D. Phillips, "Laser Cooling of Atomic Beams," Physics Department Colloquium, University of Virginia, Charlottesville, VA, November 1982.

W. D. Phillips, "Laser Deceleration of an Atomic Beam," Physics Department Colloquium, North Carolina State University, Raleigh, NC, November 1982.

W. D. Phillips, "Laser Cooling of an Atomic Beam," Colloquium, Johns Hopkins Applied Physics Laboratory, Laurel, MD, January 1983.

W. D. Phillips, "Laser Deceleration of an Atomic Beam," Physics Department Colloquium, Harvard University, Cambridge, MA, February 1983.

W. D. Phillips, "Laser Cooling of an Atomic Beam," Conference on Lasers and Electro-Optics, Baltimore, MD, April 1983.

W. D. Phillips, "Neutral Atomic Beam Experiments at NBS," Workshop on Spectroscopic Applications of Slow Atomic Beams, NBS Gaithersburg, MD, April 1983.

W. D. Phillips, "High Resolution Spectroscopy and Laser Cooling of Atoms," Society of Physics Students Induction Ceremony, Towson State University, Towson, MD, May 1983.

W. D. Phillips, "Laser Cooling of a Free Atomic Beam," Sixth International Conference on Laser Spectroscopy, Interlaken, Switzerland, June 1983.

W. D. Phillips, "Laser Cooling of a Free Atomic Beam," Division of Electrical Sciences Colloquium, National Physical Laboratory, Teddington, England, June 1983.

W. D. Phillips, "Trapping and Laser Cooling of Neutral Atoms," Physics Department Colloquium, Cornell University, Ithaca, NY, September 1983.

J. V. Prodan, "Cooling a Thermal Atomic Beam Using Laser Light," Joint Institute for Laboratory Astrophysics Colloquium, Boulder, CO, February 1983.

J. V. Prodan, "Chirping the Light - Fantastic? Recent NBS Atom Cooling Experiments," Workshop on Spectroscopic Applications of Slow Atomic Beams, NBS Gaithersburg, MD, April 1983.

J. V. Prodan, "Laser Production of a Very Slow, Cold Atomic Beam," Physics Department Colloquium, Colorado State University, Fort Collins, CO, May 1983.

J. V. Prodan, "Atomic Beam Velocity Modification Using Laser Light," 1983 Gordon Research Conference on Atomic Physics, Colby-Sawyer College, New London, NH, July 1983.

B. N. Taylor, "Quantum Electricity," 20th Anniversary Meeting of the Boston Chapter of the IEEE Society on Instrumentation and Measurement, Boston, MA, October 1982.

B. N. Taylor, "Status of the 1983 Least-Squares Adjustment of the Fundamental Constants," Annual Joint Meeting of the American Physical Society and American Association of Physics Teachers, New York, NY, January 1983.

B. N. Taylor, "The Fundamental Constants and Electrical Measurements," International Bureau of Weights and Measures Colloquium, Sèvres, France, March 1983.

B. N. Taylor, "Introduction to the Fundamental Constants," NBS Research Advisory Committee Seminar, "New Directions in Fundamental Constants," NBS Gaithersburg, MD, September 1983.

E. R. Williams, "Testing Physics via Improved Electrical Measurements," Physics Department Colloquium, State University of New York, Stony Brook, NY, January 1983.

E. R. Williams, "Dimensional Metrology and Its Avoidance in Electrical Measurements," Second International Precision Engineering Seminar, NBS Gaithersburg, MD, May 1983.

Publications FY 83

1. In Print. [NPL indicates publication did not appear in FY 83 but was not previously listed]

K. R. Baker and R. F. Dziuba, Automated NBS 1-Ω Measurement System, IEEE Trans. Instrum. Meas. IM-32, 154 (1983).

G. Birnbaum and G. M. Free, Eds., Eddy-Current Characterization of Materials and Structures, ASTM Spec. Tech. Publ. 722, PCN 04-722000-22 (American Society for Testing and Materials, Philadelphia, 1981). [NPL].

M. E. Cage and S. M. Girvin, The Quantum Hall Effect I, Comments Solid State Phys. 11, 1 (1983).

M. E. Cage, R. F. Dziuba, and B. F. Field, A Possible Quantum Hall Effect Resistance Standard, National Conference of Standards Laboratories Newsletter 23, No. 1, 16 (March 1983).

W. Y. Chen, J. R. Purcell, P. T. Olsen, W. D. Phillips, and E. R. Williams, Design and Construction of a Superconducting Magnet System for the Absolute Ampere Experiment, in Advances in Cryogenic Engineering, Vol. 27, R. W. Fast, Ed. (Plenum, New York, 1982), p. 97.

W. G. Eicke, Jr., T. Leedy, B. Moore, and C. Brown, Measurement Assurance Programs in a Field Engironment, National Conference of Standards Laboratories Newsletter 23, No. 1, 51 (March 1983).

G. M. Free, NBS Eddy Current Standards Program, in Eddy Current Nondestructive Testing, G. M. Free Ed., Natl. Bur. Stand. (U.S.), Spec. Publ. 589 (USGPO, 1981), p. 133. [NPL].

G. M. Free, Ed., Eddy Current Nondestructive Testing, Natl. Bur. Stand. (U.S.), Spec. Publ. 589 (USGPO, 1981). [NPL].

G. M. Free, G. Birnbaum, H. Berger, V. Kljuev, and Y. Fedosenko, Standards for Eddy Current Nondestructive Testing, in Proceedings of the Tenth World Conference on Nondestructive Testing, Vol. 6 (Moscow, 1982), p. 262. [NPL].

G. M. Free and J. Morrow, Transportable 1000 pF Standard for the NBS Capacitance Measurement Assurance Program, NBS Technical Note 1162, October 1982.

S. M. Girvin and M. E. Cage, The Quantum Hall Effect II, Comments Solid State Physics 11, 47 (1983).

C. R. Levy, Testing to Quantify the Effects of Handling of Gas Dielectric Standard Capacitors, NBS Technical Note 1161, October 1982.

W. D. Phillips, J. V. Prodan, and H. J. Metcalf, Neutral Atomic Beam Cooling Experiments at NBS, in Laser Cooled and Trapped Atoms, W. D. Phillips, Ed., Natl. Bur. Stand. (U.S.), Spec. Publ. 653 (USGPO, Wash. DC, 1983), p. 1.

W. D. Phillips, Ed., Laser Cooled and Trapped Atoms, Natl. Bur. Stand. (U.S.), Spec. Publ. 653 (USGPO, Wash. DC, 1983).

W. D. Phillips, J. V. Prodan, and H. J. Metcalf, Laser Cooling of an Atomic Beam, Conference on Lasers and Electro-optics Technical Digest, Optical Society of America (IEEE Cat. No. 83CH1852-3, 1983), p. 34.

J. V. Prodan, W. D. Phillips, and H. J. Metcalf, Laser Production of a Very Slow Monoenergetic Atomic Beam, Phys. Rev. Lett. 49, 1149 (1982).

J. V. Prodan and W. D. Phillips, Chirping the Light -- Fantastic? Recent NBS Atom Cooling Experiment, in Laser Cooling of an Atomic Beam, W. D. Phillips, Ed., Natl. Bur. Stand. (U.S.) Spec. Publ. 653 (USGPO, Wash. DC, 1983), p. 137.

B. N. Taylor, Constants, Fundamental, in Concise Encyclopedia of Solid State Physics, Ed. by R. G. Lerner and G. L. Trigg (Addison-Wesley, Reading Mass., 1983), p. 26.

D. Van Vechten, L. B. Holdeman, R. J. Soulen, Jr., and J. Toots, The Superconductive Energy Gaps of Thin-Film $AuAl_2$ and $AuIn_2$, J. Low Temp. Phys. 51, 329 (1983).

E. S. Williams, The Practical Uses of AC-DC Transfer Instruments, NBS Technical Note 1166, October, 1983.

2. In Press, In Review, or Nearing Completion

M. E. Cage, R. F. Dziuba, B. F. Field, C. F. Lavine, and R. J. Wagner, Status of the NBS-NRL Determination of the Fine-Structure Constant Using the Quantized Hall Resistance Effect, in Precision Measurement and Fundamental Constants II, Ed. by B. N. Taylor and W. D. Phillips, Natl. Bur. Stand. (U.S.), Spec. Publ. 617 (USGPO, Wash. DC, 1983).

M. E. Cage, B. F. Field, E. R. Williams, S. M. Girvin, A. C. Gossard, D. C. Tsui, and R. J. Wagner, Dissipation and Dynamic Non-Linear Behavior in the Quantum Hall Regime, Phys. Rev. Lett. 51 (October 10, 1983).

B. F. Field and G. M. Free, An Eddy Current Imaging System, NBSIR.

L. B. Holdeman and J. T. Holdeman, Jr., Support Electrode Torque on a Spherical Superconducting Gyroscope (submitted to IEEE Trans. Magn.).

M. Littman and W. D. Phillips, A New Method for Measuring the Fine-Structure Constant Using Stark Spectroscopy, NBS Spec. Publ. 617.

H. J. Metcalf and W. D. Phillips, Time Resolved Subnatural-Width Spectroscopy, NBS Spec. Publ. 617.

P. T. Olsen, W. D. Phillips, and E. R. Williams, A Measure of the NBS Ampere in SI Units, NBS Spec. Publ. 617.

W. D. Phillips and J. V. Prodan, Cooling Atoms with a Frequency Chirped Laser, Proceedings of the Fifth Rochester Conference on Coherence and Quantum Optics, Rochester New York, June 1983.

W. D. Phillips, J. V. Prodan, and H. J. Metcalf, Laser Cooling of Free Neutral Atoms in an Atomic Beam, Laser Spectroscopy VI, (Proceedings of the Sixth International Conference on Laser Spectroscopy) Springer Series on Optical Science Vol. 40 (Springer, Berlin).

B. N. Taylor and W. D. Phillips, Eds., Precision Measurement and Fundamental Constants II, Natl. Bur. Stand. (U.S.), Spec. Publ. 617 (USGPO, Wash. DC, 1983).

E. R. Williams, P. T. Olsen, and W. D. Phillips, The Proton Gyromagnetic Ratio in H_2O - A Problem in Dimensional Metrology, NBS Spec. Publ. 617.

Technical and Professional Committee Participation and Leadership

N. B. Belecki, member, ANSI C39/100, American National Standards Institute Committee on Electrical Standards, Instrumentation, and Devices; and SC.1, Subcommittee on Reference Voltage Devices.

N. B. Belecki, member, National Conference of Standards Laboratories Measurement Assurance Committee.

N. B. Belecki, member, National Working Group, OIML (International Organization of Legal Metrology) Pilot Secretariat 13, Measurement of Electrical and Magnetic Quantities.

N. B. Belecki, Co-chairman, U.S. National Working Group, OIML (International Organization of Legal Metrology) Reporting Secretariat 13.1, International Compatibility of National Primary Standards Used for Instrument Verification.

N. B. Belecki, member, TC-2, DC and LF Standards, Instrumentation and Measurements Committee of the Instrumentation and Measurement Society, Institute of Electrical and Electronics Engineers (IEEE).

R. D. Cutkosky, member, TC-2, DC and LF Standards, Instrumentation and Measurements Committee of the Instrumentation and Measurement Society, Institute of Electrical and Electronics Engineers (IEEE).

R. D. Cutkosky, Assistant Secretary, IEC TC25, International Electrotechnical Commission Technical Committee on Quantities, Units and Their Letter Symbols.

W. G. Eicke, Jr., member, ANSI C-18, American National Standards Institute Committee on Specifications for Dry Cells and Batteries.

G. M. Free, member, ASTM E7, American Society for Testing and Materials, Nondestructive Testing; ASTM E7, SC.7, Electrical and Magnetic Methods (vice chairman); E7, SC.9, Materials Inspection and Testing Laboratories; E7, SC.9, Editorial Review; and E7, SC7.02, Glossary (chairman).

G. M. Free, secretary, American Society for Nondestructive Testing, C1, Research Promotion Committee.

G. M. Free, member, American Society for Nondestructive Testing, C2, Electrical and Magnetic Methods Committee.

B. N. Taylor, member, Advisory Committee on Fundamental Constants of the Division of Chemistry and Chemical Technology, Numerical Data Advisory Board, National Academy of Sciences/National Research Council/ National Academy of Engineering.

B. N. Taylor, Chairman, NBS Precision Measurement Grants Committee.

B. N. Taylor, NBS representative, Consultative Committee on Electricity (CCE), International Committee on Weights and Measures.

B. N. Taylor, member, National Science Foundation (NSF) Interagency Atomic and Molecular Physics Group.

B. N. Taylor, member, ANSI C-42, American National Standards Institute Committee on Definitions of Electrical Terms.

B. N. Taylor, member, CODATA (Committee on Data for Science and Technology) Task Group on Fundamental Constants.

B. N. Taylor, Technical Advisor (Chairman, U.S. National Working Group) OIML (International Organization of Legal Metrology) Pilot Secretariat 13, Measurement of Electrical and Magnetic Quantities; and Co-chairman, U.S. National Working Group, Reporting Secretariat 13.1, International Compatibility of National Primary Standards Used for Instrument Verfication.

B. N. Taylor, member TC-2, DC and LF Standards, Instrumentation and Measurements Committee of the Instrumentation and Measurement Society (S-IM), Institute of Electrical and Electronics Engineers (IEEE); S-IM representative to the IEEE Research and Development Committee; member, Editorial Review Board of IEEE Transactions on Instrumentation and Measurement.

B. N. Taylor, NBS representative to Conference on Precision Electromagnetic Measurements (CPEM) Executive Committee and Comptroller, CPEM.

Collaborations, Consulting, Miscellaneous Activities

N. B. Belecki consulted throughout the year with the staff of the Office of Measurement Services on MAP activities at NBS and in industry. He also served as a member of NBS' Calibration Advisory Group.

N. B. Belecki and R. F. Dziuba are collaborating with metrologists from six Southern California companies (Beckman Instruments, Electrical Standards Repair Service, Ford Aerospace & Communications, Lockheed of California, Rockwell International Anaheim, and TRW) in a pilot experiment to develop methodology for a "self-help" group MAP in resistance. The goal is a procedure by which companies could set up and run their own MAP, including data reduction and error analysis, using NBS's calibration services and their own transport standards. Some of the equipment is being furnished by the NCSL Measurement Assurance Committee.

M. E. Cage collaborated with S. M. Girvin of the Surface Science Division (541) on two invited review articles on the quantum Hall effect published in Comments on Solid State Physics.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with S. M. Girvin of the Surface Science Division (541) on the theoretical aspects of the quantized Hall resistance experiment.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with D. C. Tsui of Princeton University, and A. C. Gossard and H. L. Störmer of Bell Laboratories, on quantized Hall resistance measurements of GaAs-AlGaAs heterojunctions.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with M. Razeghi of Thomson-CSF, France, on quantized Hall resistance measurements of GaInAs-InP heterojunctions.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with P. J. Stiles and D. Syphers of Brown University and J. Browning of Boston University on quantized Hall resistance experiments with Si MOSFET devices cooled to mK temperatures. These experiments are to be done using a superconducting magnet at the National Magnet Laboratory.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with R. J. Wagner of the Electronics Technology Division of the Naval Research Laboratory, and with M. Pecker of the Research Device Facility of the Naval Research Laboratory, in the fabrication and testing of Si MOSFETs using a new, jointly developed mask set. They are also collaborating on quantized Hall resistance measurements using the 15 T NRL superconducting magnet and Si MOSFET devices.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with G. P. Carver of the Semiconductor Materials and Processes Division (725) on setting up a testing procedure for selecting Si MOSFET samples for quantum Hall effect experiments.

R. F. Dziuba provided consulting support to approximately twenty-five companies on problems in precision resistance measurements and standards applications.

R. F. Dziuba and J. Q. Shields are collaborating with G. Small and coworkers, CSIRO, Division of Applied Physics, Australia, on the comparison of the NBS and CSIRO realizations of the SI ohm via the calculable capacitor by measuring a new type of one-ohm, transportable resistance standard.

W. G. Eicke has provided consulting services to personnel in the Office of Energy-Related Inventions in the area of electrochemical power.

W. G. Eicke is collaborating with OIR and the National Institute for Standards (NIS), Egypt, on the selection of new equipment for the NIS Electrical Measurements Laboratory.

B. F. Field is collaborating with C. Waters, Superconducting Technology, Inc., on the development of a portable, reliable, and easy-to-use 1 ppm commercial Josephson-effect voltage standard.

B. F. Field is collaborating with a number of companies (John Fluke Mfg. Co., National Semiconductor, Standard Reference Labs) on the evaluation of improved solid-state voltage standards.

J. R. Hastings and F. L. Hermach are collaborating with T. Matsumura of NRC, Canada by determining the ac-dc differences of one multi-junction and two single-junction NRC thermal converters. Matsumura visited NBS and conferred extensively on ac-dc measurement procedures; NRC lacks the equipment for these determinations to be performed there.

P. T. Olsen is collaborating with personnel of the Navy's Primary Standards Laboratory, East (Washington Navy Yard) on the calibration of magnetometers.

W. D. Phillips is collaborating with M. G. Littman of Princeton University on the spectroscopy of Rydberg atoms in electric fields and applications to the measurement of the fine-structure constant.

W. D. Phillips is collaborating with S. Ezekiel of M.I.T. on the production of a slow atomic beam for applications to high resolution resonance Raman spectroscopy.

W. D. Phillips is collaborating with C. Cohen-Tannoudji of Ecole Normale Superieur, Paris on the laser trapping of neutral atoms.

W. D. Phillips organized the NBS Research Advisory Committee sponsored seminar "New Directions in Fundamental Constants," held at NBS Gaithersburg Maryland, 15 September 1983.

B. N. Taylor is collaborating with E. R. Cohen, Rockwell International, and the CODATA Task Group on Fundamental Constants, on a new least-squares adjustment of the fundamental Physical constants to be completed in mid 1984 for international adoption by CODATA.

B. N. Taylor serves as Editor with D. R. Lide of NBS' quarterly Preprints on Precision Measurement and Fundamental Constants.

J. Toots is collaborating with D. W. Braudaway, Sandia, and K. Jaeger, Lockheed, on the implementation of a Josephson voltage standard at their respective laboratories by fabricating Josephson tunnel junctions.

E. R. Williams, P. T. Olsen, and W. D. Phillips are collaborating in the training of Song Junshou, an electrical engineer from Chongqing University, Sichuan, PRC.

E. R. Williams is collaborating with G. T. Gillies, Oak Ridge National Laboratory, on the development of a new approach to detecting free fractional charges.

TEMPERATURE AND PRESSURE DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1983

DIVISION CHIEF'S OVERVIEW

One of the major administrative efforts this past year was to hold a series of meetings with the Project Leaders. In these meetings a total of 12 major activities of the Division were identified, evaluated by a set of criteria and assorted changes made. As a result of this, all Division activities were restructured in terms of 8 major activities. This year's accomplishments are discussed within this framework. An abbreviated summary will be given at the Evaluation Panel Meeting. The following listing of the 8 projects forms the Table of Contents for the Annual Report that follows:

I. HIGH TEMPERATURE SCALE RESEARCH

The temperature range covered here extends from 904 K to approximately 2000 K. The goal is to develop a temperature scale accurate to 100 ppm based on a comparison of two instruments based on two physical laws: the ideal gas law and the Planck radiation law. A further consideration is to develop transfer standards based on special platinum resistance thermometers or an optical fiber thermometer. Development of the optical fiber thermometer using the Planck radiation law is a new task assumed by Division personnel this year with the direct support (financial and administrative) of the Director of NBS. It is coordinated with the other Division projects - gas thermometry and high-temperature PRT's - as will be explained below.

I.A. OPTICAL FIBER THERMOMETER

The principle goal of the Optical Fiber Thermometer (OFT) program is to establish values for the thermodynamic temperature of the thermometric fixed points, silver and gold, relative to that of aluminum and to provide a means of interpolating temperature between these fixed points with an uncertainty not exceeding 100 ppm. At present, serious discrepancies exist between various national laboratories as to the proper definition of the temperature scale above the antimony point (630.74 ^{o}C). The OFT appears to have the potential for making useful measurements at temperatures as low as 600 ^{o}C. Through its development and use as a primary thermometer, we hope to resolve the current uncertainty associated with temperatures measured in the interval 630 to 1064 ^{o}C and to provide the basis for the formulation of a new scale for that region.

The high temperature probe of the OFT is a single crystal of sapphire (10-50 cm long, ground and polished to a 1.5 mm diameter perpendicular to its C-axis); the radiometer portion of the OFT consists of a lens system and a narrow-band interference filter plus a silicon photodiode detector and associated electronics. At the peak wavelength of the filter, the attenuation loss in the fiber is extremely small.

In principle, once the OFT is calibrated at a single temperature within its range, it is capable of measuring thermodynamic temperatures over its entire range (600 to 2000 ^{o}C). In practice three major sources of error, in addition to the uncertainty in the assigned thermodynamic temperature of the calibration point, limit the accuracy with which the OFT can measure thermodynamic temperature. These are: (1) uncertainties in the optical properties of the probe; (2) uncertainties in the spectral response characteristics of the optical system (particularly the interference filter and detector); and (3) uncertainties in the linearity of the detector and the electronic circuitry. The experimental program is designed to provide state-of-the-art measurements of the various parameters of the OFT so that the overall inaccuracy of a determination of temperature will be less than 100 ppm.

The program is a cooperative effort of the TPD (CBS) and the Radiometric Physics Division (RPD) (Center for Radiation Research) under the leadership of R. Soulen (TPD). TPD has the responsibility for providing the test facilities in which many of the optical and all of the thermometric measurements will be made as well as expertise in the measurement of temperature and realization of the thermometric fixed points. Martin Reilly has the major scientific responsibility here. He has been programmed full-time to this project as of October 1, 1983.

The first phase of the program is: (1) the measurement of the reflectivity of pure sapphire, followed by (2) the measurement of the optical attenuation of candidate probes. Both properties will be determined as a function of wavelength (500 to 800 nm) and temperature (600 to 1100 °C).

The second phase of the program involves the characterization of the band pass of the interference filter and the linearity of the photodetector and associated electronics. This work will be done by RPD personnel under the leadership of J. Geist.

Work on these two phases was begun in the last quarter of FY 83: the major accomplishments being the setting up of the laboratory, a feasibility study of the OFT, and two publications.

Early in FY 84, the performance of the OFT will be compared with that of several long-stem high-temperature platinum resistance thermometers in order to determine the noise and long term stability at various temperatures between 600 to 960 °C. These measurements, as well as those of phase 1, will be made in a horizontal pressure-controlled heat pipe tube furnace which has a stable isothermal region (±0.005 °C) 25 cm in length.

Once the performance of the OFT is well understood, measurements at the aluminum, silver and gold fixed points will be made. Subsequently the OFT will be compared directly with the NBS Gas Thermometer from the aluminum point to as high a temperature as practical. This latter experiment will provide the definitive calibration for the OFT from which new values for the thermodynamic temperature of the gold and silver fixed points will be derived. We hope to complete this work during FY 84.

In a related development, a company has been established to provide these probes on a commercial basis (and with less accuracy) to a wide variety of users. It is expected that NBS will use the aforementioned facilities to provide a calibration service for these devices in FY 85. Also the NBS effort will provide much valuable information on stability, reproducibility and overall performance of OFT, which will assist in the commercialization of this concept. It is also possible that the OFT will perform sufficiently well to be considered as the international (i.e., BIPM) transfer temperature standard for the next formulation of the International Practical Temperature Scale in this temperature scale.

The Evaluation Panel undoubtedly knows as well as this Division Chief that the understaffed Division does not need added responsibility such as the OFT, but it seems to be too good a bet to miss.

I.B. GAS THERMOMETRY

Dr. L. A. Guildner retired, leaving the project entirely in the hands of his long-standing collaborator, R. E. Edsinger. Dr. J. F. Schooley (US, DC Ret.) was prevailed upon to temporarily set aside his low-temperature gas thermometer and to work on the high-temperature gas thermometer with Edsinger. As indicated below, several changes have been made with extremely encouraging results.

To review some history, the gas thermometry project has provided, up to the present time, values of thermodynamic temperature in the range 0-457 ^{o}C. These were published in the NBS Journal of Research in 1976 (Vol. 80A, 703-738) in the form of differences between thermodynamic temperatures and the IPTS-68. Among the results (obtained by immersing the gas thermometer in a stirred liquid bath) are the following:

Temperature, ^{o}C	T(KTTS) - T(IPTS-68), ^{o}C
100 (Steam pt)	-0.025
232 (Tin pt)	-0.044
419 (Zinc pt)	-0.066
457 (Limit of liquid bath)	-0.080

Since 1976, a new gas furnace has been built to replace the stirred liquid bath for higher-temperature measurements. The new furnace is provided with some eight distinct heating zones and the capability for introduction of Ar gas as a partial heat-transfer medium. Using the new furnace, the gas bulb with its enclosing casing of Inconel was heated to 960 ^{o}C for many days in order to outgas it and to work out the appropriate heating protocols for various temperatures.

During FY 83, test measurement runs with the new furnace up to the Al point gave results that were not plausible--indicated differences between the KTTS and the IPTS-68 were occasionally more than 0.5 ^{o}C. More careful study, including the practice of filling the gas bulb at the fiducial point (0 ^{o}C) in order to verify the extent to which the filling pressure was maintained during a measurement sequence and including measurements in the 0-457 ^{o}C range, indicated that the gas bulb had become defective, perhaps because of high-temperature creep. A destructive examination of this bulb indicated that indeed it had sagged enough for the bottom to contact the Inconel case at or near the ice point.

Therefore, the gas bulb was replaced with a new one. Three sets of measurements have been made with the new bulb. In the course of these measurements, the zinc-point difference published in 1976 has been reproduced within about twenty millidegrees, a substantial improvement in performance over the defective bulb, and preliminary measurements have been made up to the aluminum point.

The present project plans include the provision of an estimated thermodynamic temperature of the aluminum point to the Consultative Committee for Thermometry prior to its May 1984 meeting. Depending on these results the gas thermometer will be pushed to as high a temperature as possible, perhaps to the Au point.

I.C. HIGH TEMPERATURE PLATINUM RESISTANCE THERMOMETRY

Presently the thermocouple is the specified transfer standard in this temperature range and it is used to define IPTS-68. The need for a more accurate and stable transfer standard cannot be overstated. One possibility is the development of the OFT mentioned above. The success of the preliminary results notwithstanding, the glacial inertia of the BIPM (which will have the ultimate say on which transfer is to be used in the redefinition of the new temperature scale) makes the development of a platinum resistance thermometer which can withstand the rigors of exposure to this temperature range an important avenue to explore.

Until recently, NBS had two part-time efforts to fabricate and test homemade PRT's - one by R. E. Edsinger and one by J. P. Evans. Higher priorities elsewhere in the Division has caused both efforts to be dropped. Instead, NBS has engaged in a collaboration with Yellow Springs Instrument Company. YSI will make commercial units based on all technical information developed by the NBS programs and J. P. Evans of NBS will conduct most, if not all, evaluation of the resistors. The first commercial resistors from YSI are expected in November 1983.

J. P. Evans is now the NBS focus for all high-temperature PRT work and he is now fully integrated into all ramifications of the program. Evans provides the calibrated PRT's needed for the OFT program; he has evaluated the available high-temperature PRT's, and he is working on improving the NBS standard Ag, Au and Cu melting point cells. These activities are elaborated upon below.

Prior to the NBS/YSI agreement, J. Evans studied the stability of a group of four thermometers on loan from the National Institute of Metrology, Beijing, and a group of three thermometers manufactured before 1983 at the National Bureau of Standards.

The NIM thermometers have bifilar helix resistors of nominal 0.25-ohm resistance at 0 ^{o}C; the 0.4 mm diameter resistor wire is supported on a single notched blade of silica glass. The NBS thermometers have toroidal type resistors, in which the 0.25 mm diameter resistor wire is supported on a silica-glass tube notched at the ends; the resistance at 0 ^{o}C is about 0.37 ohm. The NBS thermometers have guarded leads while the NIM thermometers do not, but in other respects the thermometers are similar.

In the first experiment, the resistance of each thermometer was determined at each of the laboratory thermometric fixed points in an appropriate sequence. The thermometers were then heated for 100 h at 1100 ^{o}C and remeasured at the fixed points in order to assess thermometer stability and several other characteristics. In the second experiment, the thermometers were fitted with a special external electrical guard and then measured at the freezing point of silver. Resistance measurements both with the guard connected and without the guard connected yielded information about electrical leakage within the thermometers. In the third experiment, thermometer resistance was determined as a function of immersion depth in a zinc freezing point cell to determine thermometer immersion characteristics.

Numerical results of the tests, without analysis, were distributed to members of the CCT and to other interested national standards laboratories. NBS was the first to report on such data to the CCT even though over 20 resistors were distributed by NIM to all national standards laboratories at the same time.

These results, especially the importance of guarding, were of considerable help to YSI.

The results of the tests described above were evaluated to provide information on the long time stability at high temperatures of the thermometers, their short time stability upon temperature cycling, the temperature coefficient of resistance, immersion characteristics, heating effects of measuring currents, electrical leakage effects, thermometer durability, and agreement among thermometers of derived temperature values. It was found that there was little significant difference in the performance of the two groups of thermometers, and that as a class, the thermometers performed as well as or better than any thermometers previously reported.

One method of analysis used was to establish a "temperature scale" designated as t' by fitting a quadratic relation between resistance ratio and temperature at the tin and zinc points, and extrapolating this scale to the higher temperature fixed points. The average results obtained with this set of thermometers are compared with similar results from other sets of thermometers in Figure 1. The noticeable differences at the gold and silver points may be due either to the effects of electrical leakage or to real differences in fixed points.

Improvements in transfer standards have caused a closer examination of the quality of the NBS-maintained fixed points for this region. It was established that the Ag point was okay, but that a new Au point was needed. Evans made a new one using several improved techniques (commercially fabricated glassware, designed to permit final assembly to be done easily in the laboratory, high purity metal in shot and splatter form, heat pipe furnace for initial vacuum melting of the sample). Preliminary measurements indicate that the freezing point of the new cell is $\simeq$30 mK higher than the one used previously. In addition, the same techniques will be applied to the construction of copper freezing point cells. To this end, samples of high purity copper have been purchased from a commercial refiner and from the NBS Office of Standard Reference

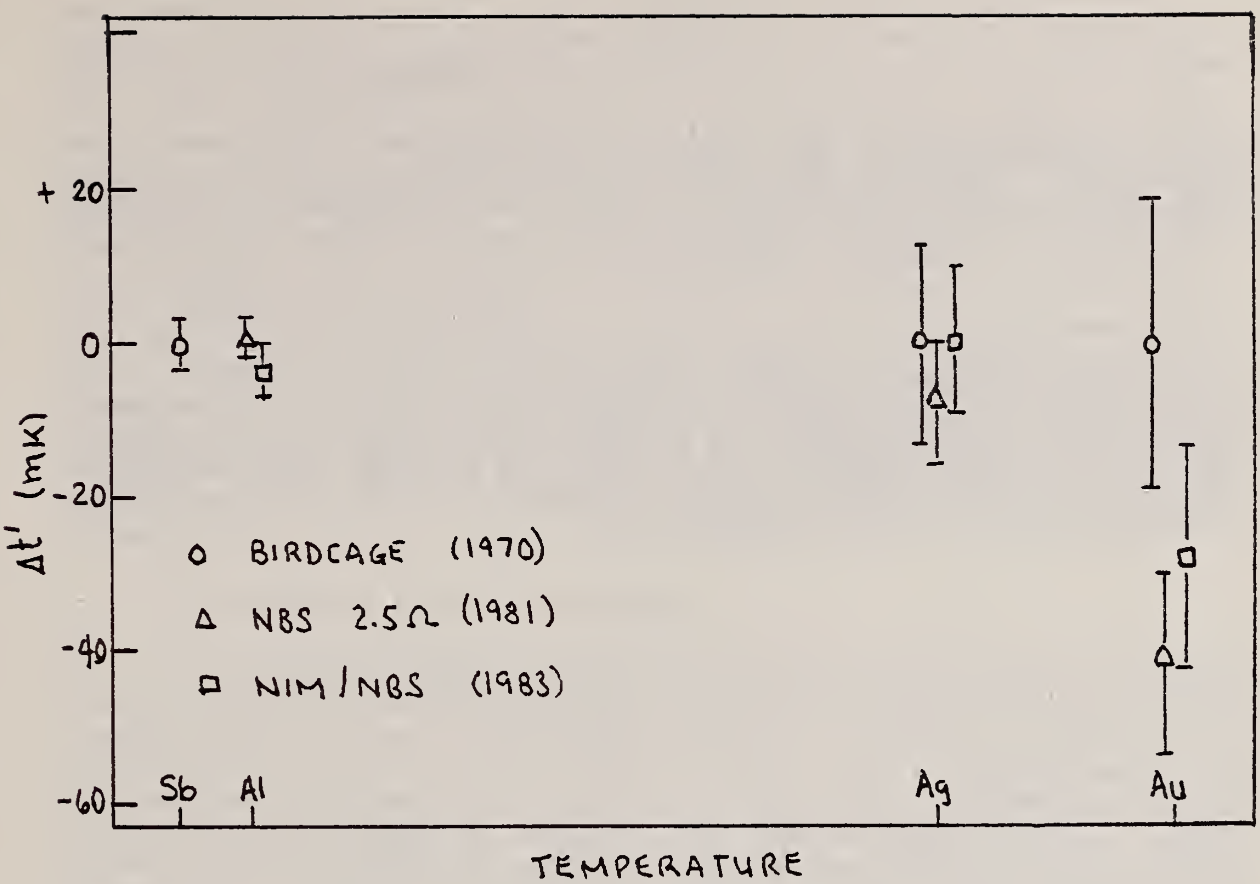


Figure 1. Variation of mean values of t' at fixed points for three types of PRT. Deviations are shown relative to "Birdcage" values. The error bars represent ±one standard deviation.

Materials. The major importance of this reference point is that it might replace the much more expensive Au point in the next IPTS.

We cannot discuss resistance thermometry and PRT's without mentioning the impact of R. D. Cutkosky's automatic resistance bridge used to measure them. R. S. Kaeser has built 12 of these for this Division and two others. The bridges in this Division are used to measure high-temperature PRT's at temperatures as high as 1330 K and are used to measure Rh-Fe resistance thermometers at temperatures as low as 0.5 K. Kaeser and Cutkosky received the IR-100 Award for this effort.

Mr. Cutkosky is turning his efforts to automatic capacitance measurements. A working prototype bridge capable of 0.01 ppm resolution has been built and efforts are now being devoted to development of stable reference capacitors. We look forward to finding applications for this bridge in Division activities.

An additional note on automation. W. S. Hurst and R. S. Kaeser are responsible for automation in general and through their efforts several new S-100 based microcomputers were added to the Division, including those for Kaeser, Schooley, the Division Office, the Pressure Group, and for the Optical Fiber Thermometry work. Minor modifications to the hardware configurations were made (most important, switching to Qume disk drives), improved versions of CDOS were implemented, and CDOS was customized for easing data acquisition tasks (clock functions improved, auto restart implemented, deficiencies in printer drivers corrected). A large task was a complete writing of Z80 code drivers to implement the full capabilities of the IEEE-488 instrumentation bus through the Pickles and Trout card. These greatly simplify the programming tasks, implement features not available in the drivers supplied, and execute 3 to 30 times faster than previous code. The drivers have been implemented in Cromemco SBasic and Microsoft's Fortran (F-80) and Basic (Basic-80). The drivers have been released to the NBS Microprocessor Committee and are in use throughout NBS.

II. IPTS-68

II.A. THERMOCOUPLES

These cover the range 904 K to 2300 K, and the thermocouple laboratory is managed by G. W. Burns with the assistance of M. S. Scroger. The activities generally fall into two categories: routine calibrations (M. Scroger) and non-routine calibrations (G. Burns).

- Routine Calibrations

(1) The laboratory is fully automated, greatly improving turnaround time, and test folder output. (2) About 70k$ in test fees were performed in FY 83 (270 thermocouples for 90 customers). (3) M. Scroger is continuing to work in her spare time to produce a training document which would be of use to a new trainee in the event of her leaving the laboratory.

- Non-routine Tests: Some Samples

(1) Two emf stability tests of 0.8 mm diameter Type K thermocouples (one at 1290 °C for 50 h and another at 1315 °C for 34 h) were carried out for the Aircraft Engine Group of the General Electric Co., (Cincinnati, Ohio). The G. E. Co. is using Type K thermocouples for monitoring the temperature during critical heat treatments of single crystal turbine blades in vacuum in the 1250 to 1300 °C range. Experience at G. E. with Type K thermocouples has shown that they may be used under such conditions for short periods of time with no appreciable changes in calibration. However, since no published data exists to support the use of Type K thermocouples in vacuum at such temperatures, G. E. wanted an experimental verification of thermocouple performance done by an independent laboratory to convince their military contractors that temperature determinations made during their heat treatments are reliable. Burns found in the 1290 °C test that the Type K thermocouples changed by not more than the equivalent of 1 °C during the first 15 hours of testing; the emf of the thermocouples had decreased after 50 hours of testing by the equivalent of about 4 to 5 °C. While the change in the thermocouple emf was relatively small, a substantial reduction in the diameter of the thermocouple wires occurred during the test, due to evaporation. In the test at 1315 °C, the thermocouple wires failed mechanically after about 34 hours of testing, as a result of excessive evaporation, but the thermocouples experienced a decrease in emf at 1315 °C equivalent to only about 4 °C.

(2) Special calibrations of some 1 mm diameter, Pt 30% Rh sheathed, Pt-40% Rh versus Ir-40% Rh thermocouples were carried out at the melting point of platinum (1769 °C) for the Pratt & Whitney Aircraft Co. Such thermocouples are used at Pratt & Whitney in jet engine development work for combustion temperature measurements. The calibrations were performed by the melting-wire method and were needed since

these thermocouples are a non-standardized type for which no emf-temperature tables exist. The repeatability of the thermocouples during successive platinum melts was found to be equivalent to about 1 ^{o}C.

(3) To assist ASTM Committee E20.04 with the development of a new standard covering W-3% Re/W-25% Re and W-5% Re/W-26% Re thermocouples, emf-temperature tables in both ^{o}C and ^{o}F were computed using existing polynomials and provided to the Committee in the appropriate format for inclusion in the standard.

(4) Progress on the project devoted to assisting the ASTM task group on immersion thermocouples for measuring temperature of molten metals was limited due to lack of funding and personnel. However, some thermocouple sheaths of boron nitride were fabricated for evaluation in molten steel. Whereas previously developed thermocouple sheaths consisting of molybdenum tubing having an outer coating of Cr_2O_3, Al_2O_3, and Mo applied by arc-plasma spray techniques were found to survive in molten iron for periods of 30 minutes, they are very expensive and difficult to fabricate. Recent work reported by the Kawasaki Steel Corporation in Japan indicates that thermocouple probes using boron nitride protection sheaths survive repeated use in molten steel (90 to 130 immersions over a period as long as 15 hours in molten steel in a continuous casting operation). As a result of these findings, we procured some 12-inch long rods of hot pressed boron nitride from Union Carbide Corporation and had six thermocouple protection tubes prepared from the rods by a local machine shop. Some stabilized zirconia tubing that will be joined to the boron nitride tubes with a high-temperature ceramic cement were also procured. Assembly and evaluation of the new thermocouple protection materials are planned for early FY 84.

(5) A number of calibrations of Ni-18% Mo versus Ni thermocouples were performed to assist the ASTM Committee E20.04 with resolving a problem concerning differences in industry used emf-temperature tables for this non-standardized thermocouple type. Ipsen Industries, a major manufacturer of heat treating furnaces and systems, sought help from ASTM in resolving differences between existing emf tables for this thermocouple. There are three tables now used by industry: two older tables produced by the General Electric Co. and a recently published table produced by the AMAX Specialty Metals Corporation, which at the present time is the sole manufacturer of the Ni-18% Mo/Ni thermocouple in this country. The two G. E. tables agree closely with the newer tables by AMAX Specialty Metals Corporation in the 500 to 1100 ^{o}C range, but about 1100 ^{o}C and below 500 ^{o}C substantial differences (as much as 15 to 20 ^{o}C) exist between the tables. Ipsen Industries, as well as a few other furnace manufacturers typically install the Ni-18% Mo/Ni thermocouple for controlling the temperature of heat treating furnaces that operate with vacuum or hydrogen atmospheres.

Several calibrations were performed by us on recently produced thermocouples obtained from the AMAX Specialty Metals Corp. The calibration results were compared with the existing tables and reported at the E20.04 Committee meeting on May 11, 1983. Due to the nature of the differences between our calibration data and the existing tables, the ASTM Committee recommended that NBS prepare a new emf-temperature tables for the thermocouple and that the NBS table be published in an appropriate ASTM publication to promote its industry-wide acceptance and usage.

Additional thermocouple materials have been obtained from the AMAX Specialty Metals Corp. for preparing the new tables. In addition, preliminary tests have been carried out to estimate the melting temperatures of the thermocouple materials and to assess their sort-term thermoelectric stability in argon at temperatures near the solidus temperature of the Ni-18% Mo thermoelement. Some short-term emf stability tests were also performed in high vacuum at about 1290 ^{o}C.

II.B. PLATINUM RESISTANCE THERMOMETERS

These devices provide a temperature scale extending from 904 K to 13 K. Several projects including a calibration service, MAP, and development of improved fixed points and thermometers are conducted by Dr. G. T. Furukawa with the assistance of Mr. W. G. Bigge.

- Fixed Points

The recent IPTS-68 specifies that a PRT will be calibrated at certain reference temperatures (fixed points). Dr. Furukawa has made many contributions to the evaluation of these fixed points; his attention this year was focused on the triple point of O_2. He evaluated some samples of specially purified O_2 using PRT's that participated in a 1974 international round robin. His results indicate that: (1) the NBS IPTS-68 has been maintained since 1974 on PRT's to within 0.2 mK at the O_2 triple point, and (2) the new triple point material is very pure.

In addition to evaluating and improving the IPTS-68 fixed points, additional fixed points are being studied by Division personnel Cd(321 ^{o}C), In (157 ^{o}C), Hg (-39 ^{o}C), Xe (-112 ^{o}C), and Kr (-158 ^{o}C) for use as redundant checks on calibration between the fixed points.

Furukawa continues to study Hg cells and has plans to purify Xe and Kr, while B. W. Mangum is assembling In cells for study.

- PRT's

YSI is now manufacturing PRT's now that L&N has sold them the rights. A study by Furukawa shows that the baton may have been dropped as it was passed from one company to the next (there is an unacceptably high moisture level inside the YSI PRT's) and YSI has been informed of the NBS results.

• MAP

We run a continuing MAP with standard PRT's. This past year, the MAP work with the White Sands Missile Range was completed - showing that calibrations at the fixed points were good to 3 mK. WSMR is quite satisfied with the results.

To test the quality of calibrations performed by industrial standards laboratories, NBS established a 20-member industrial MAP. To date, we have tested 10 subscribers and found that a few laboratories deviated from NBS by as much as 0.5 K, but most laboratories are capable of 0.01 K to 0.02 K level of performance.

• Thermometry Liaison

G. Furukawa has been active on several subcommittees of the ASTM E-20 Committee on Temperature Measurement:

E-20.03 - Helped write industrial PRT standard helped revise E-644.
E-20.04 - Helped review thermocouple standards.
E-20.07 - Helping to write ASTM Special Technical Publication on the application of fixed points in thermometer calibrations.
E-20.10 - Helping to write a monograph on resistance thermometry.

• Calibration

A total of 76 PRT's were calibrated for a total fee value of 72.7K$. Furthermore, five other PRT's were calibrated for other NBS users at no fee.

As a first step in automation of the calibration service, a Cutkosky bridge (the heart of the automation) is being compared with the Guildline dc comparator bridge (what has been used to date). Systematic differences have been found at these fixed points: Zn (0.2 mK), Sn (0.3 mK), and O_2 (0.04 mK). These are a factor of 2 or 3 larger than the reproducibility that is routinely obtained with the Guildline bridge. The source of the discrepancy is being sought.

II.C. LABORATORY THERMOMETERS

A total of 700 liquid-in-glass thermometers, 15 low-temperature thermocouples, and 39 assorted types of thermometers were calibrated by J. Wise.

A computer has been obtained to automate the data acquisition of the PRT thermometer used as the primary thermometer in this laboratory.

J. Wise and R. Soulen have written the draft of a document which will be used to establish L-I-G calibration laboratories in every state laboratory in the USA. This effort is in concert with the NBS Office of Weights and Measures.

II.D. GAS THERMOMETRY

Dr. C. Van Degrift finished an extensive study of the properties of solid He-3 at very low temperatures. He developed the technology of tunnel diodes to a fine art to accomplish those goals.

Late this FY he applied the same technology to the development of miniature gas thermometer sensors. An apparatus was built to test six prototypes from 0.4 K to room temperature. Six prototype thermometers were built with somewhat different properties so that several parameters may be studied in these prototypes. As can be seen from the table below all devices have an anticipated wide temperature range as well as high sensitivity. In late September, Dr. F. Pavese, of the IMGC (Italy) visited the laboratory and one of these devices was studied. It was found that epoxy in this unit led to unsatisfactory performance and some design changes are being pursued before any of the units are scaled with He-3 gas and used as actual gas thermometers.

Approximate Properties of Gas thermometers #1 Through 6

#	f(P=0) (MHz)	Diaphragm thickness (μm)	P(300 K) of He-3 (kPa)	Range (K)	dT/df (μK/Hz)
1	1041	112	100	0.72 - 90	0.26
2	873	140	10	0.48 - 70	4.5
3	897	211	10	0.48 - 120	15.4
4	948	295	10	0.48 - 40	43.
5	944	297	10	0.02 - 150	70.*

*only for T 30 K

III. LOW TEMPERATURE SCALE

This project is divided into two parts: the temperature region covered by the EPT-76 (0.5 - 30 K) and the region below 0.5 K covered by the temperature scale NBS-CTS-1 (0.010 K - 0.5 K).

III.A. EPT-76

E. R. Pfeiffer was assigned the lead responsibility for the EPT-76 program at NBS.

Some improvements in the cryogenic apparatus were made after experiments early in the FY indicated that changes were necessary. Also an improved Cutkosky bridge was incorporated into the measurement of the Rh-Fe Resistance Thermometers (RIRT). Furthermore, the protocol to make dc resistance readings was changed along with some software development.

Armed with these changes, a considerable portion of the 2nd and 3rd quarters of FY 83 was devoted to carrying out a final calibration/research run with the apparatus and analyzing the resultant data. The run began with cooldown on March 1 and ended about April 7. During this period the experiment ran 24 hours/day, usually seven days a week, with no major difficulties or interruptions and with the attention of only a single operator. Some specific results of the run are the following:

(1) Using the Cutkosky bridge, a new comparison of our EPT-76 reference Rh-Fe Resistance Thermometers (the two RIRT's carrying the smoothed NPL calibrations) showed that their temperatures generally agree within 0.15 mK over the range 0.5 K to 27.1 K. The current results generally confirm the results of a similar comparison reported last year. Both recent comparison results obtained using the Cutkosky bridge are far superior to the earlier results obtained with the dc measurement system which were reported at the 5th Temperature Symposium.

The bridge was used also for a new comparison of EPT-76 temperatures between 13.8 K and 27.1 K obtained from two NBS-calibrated capsule Platinum Resistance Thermometers (PRT's) against EPT-76 obtained from a reference RIRT. The PRT- and RIRT-based scales are in near agreement at the fixed point temperatures of 13.8044 K, 20.2734 K and 27.102 K, but at other temperatures the PRT's yield higher temperatures by as much as 0.8 mK.

(2) Compared EPT-76 obtained from two reference Germanium Resistance Thermometers (GRT's), HW-540 and HW-570, against EPT-76 from a reference RIRT. HW-540 served as the reference standard for the NBS 2-20 Scale calibrations which were sent to Australia for the GRT temperature scale intercomparison experiment of Besley and Kemp. HW-570 was recalibrated against HW-540 during that same NBS 2-20 calibration run. Thus, the NBS 2-20 calibrations on HW-540 and HW-570 are the

calibrations at NBS most closely tied to the calibrations used by Besley and Kemp which were the basis for the scale differences between EPT-76 and NBS 2-20. (The whereabouts of the actual GRT's used by Besley and Kemp is presently unknown.)

The above GRT's also carry (by transfer) the hydrogen fixed points of Cataland and Plumb, and calibrations (by transfer) on the 1958 Helium-4 Vapor Pressure Scale by Edlow and Plumb. HW-570 also carries the neon fixed point realizations of Furukawa. All of these calibrations and fixed points were converted to EPT-76 and compared with the EPT-76 realized from the reference RIRT. Differences as large as 2.5 mK were observed.

(3) Compared a GRT, CC-80, calibrated on EPT-76 by Rusby against EPT-76 from a reference RIRT. This GRT has consistently indicated higher temperatures than the reference RIRT's -- about 1.5 mK around 25 K, which has always seemed greater than the estimated imprecision of our experiments and has caused us some concern. However, the same comparison utilizing EPT-76 derived from the only NBS 2-20 calibration (in 1966) on CC-80 yields differences as large as -7.2 mK. Our conclusion is that this GRT's R-T characteristics have changed since both the NBS 2-20 and NPL calibrations and that, as a consequence, it should not be used as a reference GRT.

This experiment now qualifies NBS as having established a legitimate version of EPT-76. E. Pfeiffer will publish a document describing the program as the first task in FY 84. Establishment of the EPT-76 laboratory provides the basis for several other activities including a calibration service, MAP, and fixed point research (see below).

- Calibration Service

Calibrated six GRT's on EPT-76 from 1 K to 30 K for two commercial manufacturers of cryogenic instruments -- Lake Shore Cryotronics, Inc. and Cryosystems, Inc. The calibrations averaged 62 points each and were smoothed by our least-squares fit procedure by 13th order logR-logT polynomials with standard deviations (s.d.) of 0.19 ± 0.02 mK.

Calibrated a low-resistance RIRT on EPT-76 from 1 K to 30 K for Rockwell International Corp. The calibration of 62 points could be smoothed by a 12th order R-T polynomial with a s.d. of 0.10 mK. This was the first calibration of a customer's RIRT against our standard RIRT using the Cutkosky bridge. (The above s.d. compares with a s.d. of about 0.25 mK for a calibration last year of a high-resistance RIRT from 0.5 K to 10 K for J. F. Schooley. The improvement is due mainly to better data in the 1 K to 2 K region.)

The calibration billings for FY 83 to date total $7,342 for 7 thermometers compared with $3,677 for 4 thermometers in FY 82 (the FY 83 totals do not reflect the recent substantial fee increases).

Calibrated three GRT's for undesignated NBS use (one GRT from 0.3 K to 30 K, and two from 0.8 K to 30 K).

- MAP

Having set our own house in order we are ready to begin a "AP for this temperature region.

- Fixed Points

J. F. Schooley, when he is not collaborating with R. E. Edsinger in high-temperature gas thermometry, has reactivated the SRM 767 superconductive fixed point work. Presently this unit provides 5 of the 11 defining reference temperatures for EPT-76. The goal of this program is to provide a new SRM 767a which has superconductive transition temperatures which are sharper and to add a sixth superconductor (Nb). The SRM 767a is to be calibrated on the NBS-maintained EPT-76. In order to ensure that Pfeiffer's EPT-76 lab and Schooley's SRM 767a lab are providing the same EPT-76, both labs were equipped with recently updated Cutkosky resistance bridges. Pfeiffer provided Schooley with a RIRT calibrated in his lab. Pfeiffer also measured SRM 767a (unit Bravo) on his scale. W. S. Hurst assembled a laboratory microcomputer capable of driving the bridge; and G. A. Evans improved the techniques for annealing the elements Pb, In, Al, Zn, and Cd which make up the SRM 767. To this group we added samples of the element Nb in order to extend the range of the device.

Using a modified He-3 cryostat and considerably improved calibration procedures, Schooley has prepared a set of some ten new SRM 767a devices that are clearly superior to the old SRM 767. A new OSRM certificate has been prepared in order to issue the new devices under the catalog number SRM 767a. The properties of the new devices are given in the table below:

Material	Average T_c of 10 Devices (EPT-76), K	Range of T_c of 10 Devices, mK
Niobium	9.19-9.29	100
Lead	7.200 05	0.15
Indium	3.414 60	0.15
Aluminum	1.180 95	0.15
Zinc	0.850 15	0.10
Cadmium	0.519 98	0.08

In order to achieve the restricted range of transition midpoints shown in the table, we have imposed a limit of 1 mK on the acceptable width of all transitions excepting Nb, which is not available in better purity levels than about 99.995%. Furthermore, the calibration procedure involves the use of two standard SRM devices in each measurement run in addition to the Rh-Fe thermometer. Also, the earth's field is nulled during each run; we have found that it is not necessary to null it for each individual sample. Finally, we use only a single source of each element to prepare the samples.

We have compared the T_c values obtained by E. R. Pfeiffer in the Low Temperature Scale cryostat for one device with the T_c values obtained in the SRM 767a cryostat in order to evaluate the level of agreement maintained between the two laboratories. The results indicate an average level of 0.14 mK random deviation for the five samples examined.

Experiments yet to be performed before relegating this work to a simple maintenance of OSRM supplies include the following:

(1) Comparison of the T_c values of the SRM 767a with samples prepared from other high-purity sources of the elements;

(2) Measurement of the isotopic abundances for the polyisotopic elements (Pb, In, Zn, Cd);

(3) Re-measurement of the dependences of the T_c values upon magnetic field, to verify literature data.

III.B. NBS-CTS-1

This scale, developed at NBS and distributed worldwide via SRM 768, does not have international sanction. Research along parallel lines at other national standards laboratories (KOL; PTB-Berlin; Helsinki) should bring confirmation and the possibility of adoption of a provisional temperature scale from 2 mK to 500 mK by the CCT when the next scale is formulated.

The scale is based on a comparison of two absolute thermometers based on noise and nuclear orientation. Research in both of these areas this past year has been directed to understanding all systematics so that ultimately a scale accurate to 0.1% will evolve. Specifically:

- Noise Thermometry

J. Colwell, in collaboration with R. Soulen and H. Seppa (V.T.T., Helsinki) studied the influence of several parameters on the measured noise which indicate that systematics in the noise measurement can be reduced to 0.1%. The results were reported in the 7th International

Conference on Noise on Physical Systems, Montpellier, France, and were found to agree with theoretical models.

Stringent tests of reproducibility of the noise thermometer were performed by thermally cycling it to room temperature and to low temperature four times. The results are shown in the accompanying table, and indicate that the reproducibility is also 0.1% or better above 20 mK. (See last column.) Some minor problems degrade the reproducibility to the level of 0.5% at low temperatures. A systematic related to the influence of one noise thermometer parameter is suspected to be the culprit and steps to eliminate it are being taken.

R. D. Cutkosky developed a multiple processor system to speed up the calculation of the variances needed for the noise thermometer. The new instrument accepts data 100 times faster than the old system and greatly reduces the measurement speed for the noise thermometer.

The visit of two guest workers from Finland (T. Haavasoja and H. Seppa) and one from the KOL (A. Reesink) will ensure that close collaborations will be maintained between these institutions and NBS.

SUMMARY

o FOUR THERMAL CYCLES
o FOUR ADJ. OF NOISE THERMOMETER
o SRM 768, Serial No. 7

Approximate Temperature (mK)	Noise Temperature 10/82	1/4/83	1/27/83	4/12-18/83	Average	
12.5	12.44	12.53	12.47	---	12.48	(.4%)
T_c (W)	15.51	15.60	15.54	15.520	15.543	(0.26%)
19	18.84	18.99	18.91	---	18.91	(.4%)
T_c (Be)	22.66	22.67	22.69	22.692	22.678	(.08%)
30	29.79	29.89	29.84	---	29.84	(.17%)
43	---	43.06	43.00	---	43.02	(.13%)
53	53.01	---	53.04	---	53.02	(.04%)
60	---	59.42	59.63	---	59.52	(.24%)
T_c (Ir)	---	---	99.40	99.43	99.415	(.02%)
T_c ($AuAl_2$)	160.09	160.00	160.20	160.17	160.12	(.06%)
T_c ($AuIn_2$)	204.4	---	204.51	204.39	204.43	(.03%)

• Nuclear Orientation (NO)

In order to conduct NO thermometry to the 0.1% accuracy level, several systematics ignored by other practitioners in the field were carefully examined by H. Marshak. The effects of pulse pile-up, cascade summing, and proper fitting of the γ-ray background and lineshape on the NO thermometer were characterized. These and still other systematics were discussed in an exhaustive NBS J. of Research article, written this year by Marshak.

Marshak also wrote a chapter entitled "Nuclear Orientation Thermometry" for the book Low Temperature Nuclear Orientation, to be published in 1984. This work is a critical review of the field and indicates the state of the art of nuclear orientation thermometry.

• Transfer Standards

J. Colwell studied the behavior of two types of resistance thermometers (doped germanium and carbon) and that of a paramagnetic thermometer (cerium magnesium nitrate) from 0.01 K to 0.5 K. At the lowest temperature it is not clear that any of them will perform with reproducibility comparable with the temperature scale (0.1%).

Other laboratories claim that the He-3 melting curve offers far superior capabilities. Van Degrift has studied the melting curve of He-3 this year as well as the properties of solid He-3. Based on this experience, we feel confident that consideration of this option merits further work. Since Van Degrift is occupied with gas thermometry the coming year, Colwell will examine the suitability of the melting curve of He-3 as the alternate transfer thermometer for NBS-CTS-1.

A discrepancy in the reproducibility of the superconductive transition of W in SRM 768 was resolved by Colwell (a poorly performing germanium resistance thermometer was the culprit). The T_c is now performing at the 0.1% level.

W. R. Fogle, a Postdoctoral Research Associate from Berkeley, has been contributing to all phases of the research activity and has demonstrated a real talent for metrology.

IV. MEDICAL THERMOMETRY

The goal of this program is to develop a set of fixed temperatures and a means of using them to calibrate transfer standards for the temperature region of interest (0 - 200 ^{o}C) to the medical community. The program is under the responsibility of Dr. B. W. Mangum who is assisted part-time by G. A. Evans.

Specific accomplishments this FY include:

(1) The investigation of the triple point of succinonitrile as a temperature fixed point was completed and published (Clinical Chemistry). Some 23 triple-point cells of different sizes and containing succinonitrile of different purities were studied with regard to their melting and freezing behavior and their triple-point temperatures. The samples were prepared by zone-refining techniques, using two stages of zone refining and varying the number of passes per stage. The triple-point temperature was determined to be 58.0805 ^{o}C with an estimated uncertainty of ± 0.0015 ^{o}C relative to the IPTS-68. The standard deviation of the mean of 11 measurements on one of the purest samples was 0.0001 ^{o}C. Based on our results, a design of a cell has been adopted for the SRM's to be produced and tested next year. The results which we obtained on samples of different purities will be the basis for the production of the SRM samples. The OSRM has placed a contract for the production of 120 cells of succinonitrile and we will test them for suitability when they are delivered.

(2) We investigated the melting/freezing behavior of 100 triple-point cells of rubidium which constitute SRM 1969. The rubidium in these cells was of a higher purity than that which we had previously investigated. The reproducibility of the plateau of the melting and freezing curves for these cells is rather good. For the worst case, the spread in the values of the temperature of the midpoint of the plateau of the melting curve is less than 10 mK. The spread is 1 to 3 mK for most of the cells. The distribution of midpoint temperatures for those 100 cells is shown in figure 2. The melting range of the cells varied from 8 mK to 24 mK, with a mean value of 14 mK. A paper on the rubidium fixed point is currently being written for the SP-260 Series, giving the results on the 100 cells, how they were obtained and how the user of the SRM (SRM 1969) should proceed in realizing this fixed point.

(3) It is thought that an organic material, sealed in glass cells, with a fairly large heat of fusion would probably be easier for clinical laboratory personnel to use than the rubidium triple-point standard which by its nature must be sealed in stainless steel. With this in mind, some preliminary experiments on several small cells of pivalic acid (melting point of 35.98 ^{o}C) and 1 large cell of ethylene carbonate (melting point of 36.323 ^{o}C) were conducted to evaluate their feasibility to serve as a temperature fixed point near body temperature (37 ^{o}C). It appears that it is difficult to adequately purify the pivalic acid using zone-refining techniques, but some more attempts are to be made. The large cell of ethylene carbonate appears from the preliminary experiments to be better suited for freezing-point than for melting-point applications. We plan to investigate the melting and freezing behavior of some small cells of this material next year.

(4) In the course of investigating the rubidium, succinonitrile, pivalic acid and ethylene carbonate melting and freezing behavior, our thermistor thermometers have been calibrated several times against a long-stem platinum resistance thermometer in a copper block located in

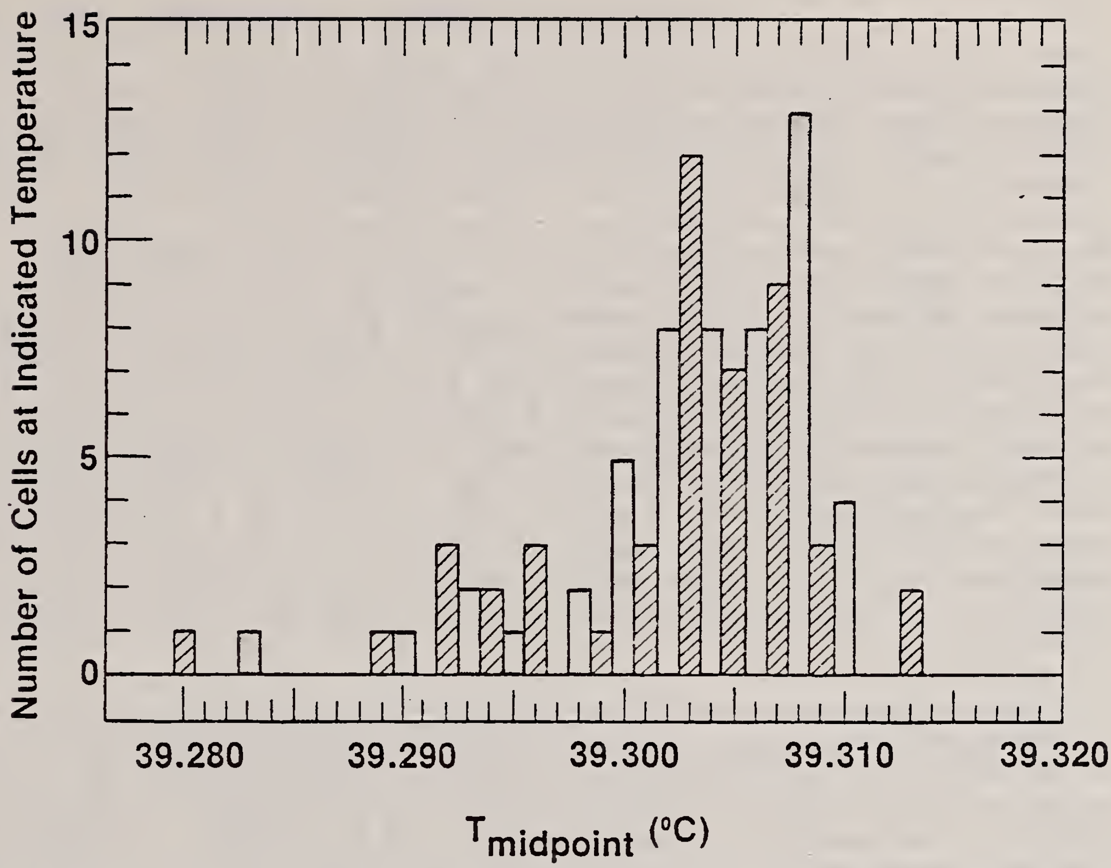


Figure 2. Histogram of midpoint temperatures of the 100 SRM 1969 cells investigated.

an oil bath. After showing the feasibility of using the triple point of succinonitrile as a temperature fixed point, we investigated the possibility of using this fixed point, along with the gallium melting point (provided by SRM 1968) and the triple point of water, and the equation

$$1/T = a + b \log R + c(\log R)^3$$

to calibrate thermistors, covering the temperature range from 0 °C to 60 °C. We found that temperatures from 0 °C to 60 °C derived from that three-point calibration agreed to within 1 mK with those measured with the platinum resistance thermometer in the fluid bath as well as with those derived from a many-point calibration using the equation

$$1/T = A + B \log R + C(\log R)^2 + D(\log R)^3$$

to fit the calibration data. A paper on this subject has been accepted for publication by RSI.

(5) The investigation of the melting/freezing behavior of high-purity indium in small Teflon cells has continued in order to test the

feasibility of using this point as a temperature fixed point, and, if we find it suitable, to develop it into an SRM. We tested cells of different size, different immersion depth and constructed with different kinds of high-temperature epoxy. Considerably more work is required on such small cells before we can decide if they will make a good SRM, but we think they will. In addition to the possible use of indium as an SRM temperature fixed point, there is the possibility of using it as a temperature fixed point for the International Practical Temperature Scale. In fact, a fixed point at about the melting point of indium is urgently needed for the calibration of capsule PRT's, to provide a more accurate calibration for the most accurate and precise work needed in research, and to provide a check on the routine calibration of SPRT's. With this in mind, we are proceeding to make a thorough investigation of the indium melting/freezing behavior and of the reproducibility of the melting/freezing-point temperature. We have acquired enough high-purity indium to make two cells of sufficient size for use with long-stem SPRT's and capsule SPRT's. Mangum designed the cells and recently they have been constructed in our shops. A system for filling the cells with indium must still be constructed. When that is finished and the cells thoroughly cleaned, the cells will be filled and the experiments started.

(6) During the year, we have been investigating the behavior of bead-in-glass-probe type thermistors over the temperature range from 0 ^{o}C to 100 ^{o}C after heating them to 300 ^{o}C and keeping them at that temperature for varying lengths of time. This provides an accelerated aging for the thermistors and should lead to more stable thermometers. The study will be completed by examining their behavior after cycling to temperatures lower than 300 ^{o}C. When this is completed, the data will be analyzed and a paper written on the results. This will be of great interest to a large number of users.

(7) The data obtained in the investigation of the stability of 100 small industrial platinum resistance thermometers from 5 companies, as determined by measurements over the temperature range from 0 ^{o}C to 100 ^{o}C following the thermal cycling of the sensors from 0 ^{o}C to about 250 ^{o}C, will be analyzed next year and a paper written on the results.

(8) We plan to begin an investigation of diode thermometers at temperatures below about 400 K. Some of the equipment has been acquired. The remaining equipment will be acquired next year, as will a selection of "the best" diode thermometers, and the experiments started.

V. DYNAMIC TEMPERATURE AND PRESSURE MEASUREMENTS

The goal of this project is to develop the means of measuring P and T with high temporal response (10 ns) and high spatial resolution (mm^3). The technique to be used is a CO laser diagnostic one. This is a joint effort involving the talents of Dr. G. J. Rosasco and Dr. W. S. Hurst.

Measurement and analysis of line broadening, line interference, and line shift as functions of pressure (4-200 kPa) at room temperature for the vibrational Q-branch Raman spectra of N_2, CO, and NO have been completed. The phenomena of "collisional narrowing", which arises from line interference, was shown to be very important for the accurate determination of temperature from the spectra of all these molecular species. Neglect of narrowing leads to systematic, pressure dependent (increasing with P) errors in temperature determinations, for example we have shown 40 K errors at 298 K and 1.0 atm. Calculations by researchers at United Technologies Research Center (UTRC) indicate errors of 300 K at 900 K and 10 atm caused by neglect of collisional narrowing. Important modifications of the theoretical spectral distribution functions have been tested at UTRC by use of NBS values of line broadening coefficients and detailed comparisons to our experimental spectra. The results are very encouraging; a reduction of errors in temperature to the 1% level have been demonstrated over a wide range of pressure. These more complex spectral distributions require, in addition to the traditional line broadening parameters, another N(N-1)/2 molecular parameters to describe an N-line spectrum. A first-order in density expression for the spectrum reduces the problem to the determination of only N-additional parameters. Further, it has been demonstrated that simple (scaling/fitting law) models for the J-dependence of state-to-state rotational relaxation can account quantitatively for both line broadening and mixing. The use of these models has been checked against the spectra of N_2 over the range 0.2-100.0 atm, 300-1500 K, by the group at UTRC and against the spectra of NO (0.2-1.0 atm, 300 K) at NBS. For the case of NO these rate laws are required to predict the spectra, because the perturbation approach fails for this strongly overlapped Q-branch spectrum. In all these tests the results have been excellent; thus, we are encouraged to think that "rate models" hold promise for predicting the molecular parameters needed for accurate deconvolutions of T and P over large ranges of T, P, and composition. Collaborative efforts have been established with researchers at Princeton University and the University of Maryland to develop, test (at NBS), and improve these predictive models. Fundamental questions, such as the T-dependence of the line broadening parameters and the effects of "foreign gas perturbers", will be addressed.

A new technique for measurement of the fundamental susceptibility elements (response functions) which determine diagnostic spectra has recently been developed. Termed, 3-beam phase modulated coherent Raman spectroscopy, this technique allows shot noise limited detection sensitivity (2- to 3-fold improvement over our best previous capability) and observation of signals linear in either the real or imaginary parts of the susceptibility. Further, use of this technique has reduced (by approximately a factor of 100) the magnitude of "background interferences" which arise from the interaction of the pump and probe beams on the surfaces of the mirrors of the multipass sample cell. We can apply this technique to the measurement of "non-resonant background" contributions to the susceptibility at about the 5% accuracy level. This represents at least a 4-fold improvement in measurement accuracy for a molecular parameter which must be known to accurately determine T and P from diagnostic (CARS) spectra. Measurements on specific systems are being discussed with researchers directly involved in diagnostic applications.

Significant progress has been made on the design and construction of the pulse amplifier (3-stage) which is necessary for our high temperature and foreign gas broadening work. The required pulse smoothing accessory for the Nd-YAG laser was ordered in FY 83. All other components have been designed and constructed and final system integration should begin early in FY 84. Assembly of the high-temperature, variable pressure furnace was begun is FY 83. Design and fabrication of auxiliary control and safety equipment is in progress and the system should be ready for testing in the 2nd quarter of FY 84. Calibration of photometric, frequency, temperature, pressure, and composition variables will begin in the 2nd quarter. A complete, calibrated spectrometer/sample system for high T, variable P will be on-line by the close of FY 84.

VI. PRESSURE: PISTON GAGES (10^5 Pa - 1.2 GPa)

- Calibration

W. Markus and G. Driver provide the calibration of piston gages in this region. In FY 83, a total of 110 piston-cylinder gage assemblies were calibrated for fees totalling 90k$.

- New Developments: 10^5 Pa

Presently the calibration service offered here with piston gages has an inaccuracy of 30-50 ppm. We are in the process of calibrating three high quality piston gages with the gas thermometer manometer used for the NBS high-temperature gas thermometer. The work has involved the talents of Dr. L. A. Guildner (retained on contract), B. Welch, and R. E. Edsinger. The goal is to reduce the inaccuracy to the 1-10 ppm level.

The calibration measurements (some 200 determinations) have been completed. The inaccuracy of the manometer is reported to be less than 2 ppm and the precision of each of the piston gages is better than 1 ppm. Remaining tasks are to complete the data analysis, document the calibration, and make the transfer to the calibration service transfer gages. We expect the total inaccuracy of the gas calibration service in this range to be under 10 ppm. We also expect the new service to be operational by January 1984.

A valuable spin-off from this gas gage project is a new way to determine piston gage quality. This consists of the measurement of the decay of the rate of rotation as a function of time. For a good gage, the curve approaches the time axis asymptotically; a poor gage stops rotating rather abruptly.

Part of the process of making the transfer from the manometer to the calibration service is the redetermination of the mass values of the applicable weight sets. We must also have the capability of weighing the customer's pistons and weight hangers. We have ordered a state-of-the-art mass comparator (1 kg capacity with 3×10^{-5} g standard deviation) which should be delivered in October 1983. G. Driver will become the operator after he has been properly trained by R. Schoonover. We will save both turnaround time and money by having our own mass measurement capability.

- New Developments: 25-35 MPa

During this past year J. Houck characterized two commercially available controlled-clearance piston gages for the 25 MPa pressure range, one for gas and one for oil, with the intent that they would become new primary standards. Unfortunately, neither gage proved to be satisfactory. The piston and cylinders are not of good enough quality.

We need to have roundness of piston and cylinder bore to within 0.5 μm, straightness to within 0.1 μm and clearance between piston and cylinder of 0.5 to 0.8 μm. Manufacture of such piston-cylinder sets is extremely difficult. We have recently learned of a company who may have mastered the art, and have ordered three piston-cylinder assemblies for trial. If we are fortunate, two of these will become the new primary standards for the 25 MPa range. We expect to have these new gages by the end of October 1983.

- New Developments: Elastic Distortion of Piston and Cylinder

Elastic distortion causes a serious limit of the accuracy of pressure measurement at higher pressures. There are four ways one can deal with the problem:

(1) Controlled-clearance piston gage. This device is provided with a means of applying an auxiliary pressure to the outside of the cylinder wall to counteract the pressure inside the bore. Since the effect due to the distortion of the cylinder is normally several times that due to the piston, controlling the cylinder distortion can offer significant advantages. The chief problem generally is obtaining quality pistons and cylinders with appropriate initial clearances.

(2) Calculation. The distortion can be calculated for gages of appropriate geometry using approximate equations based on elastic theory. The work we have done in the last few years on the pressure profile between the piston and the cylinder has contributed much to making such calculations meaningful.

(3) Similarity method. NPL developed this method. It requires two ideal piston-cylinder assemblies of identical geometry but of materials having different known elastic moduli. One then determines the ratio of the areas of the gages by cross-floating and calculates the distortion from the elastic moduli and the area data. Manufacturing the matched gages is an extremely difficult task. The recent BIPM intercomparison up to 100 MPa between NBS, NPL, LNE, PTB and IGMC also suggest that the similarity method does not give reliable results.

(4) Calibration. If one has a source of well-known pressures, then it can be used to calibrate a piston gage. The distortion can then be calculated by fitting various equations to the data. This method is rarely applicable in characterizing primary standards.

V. E. Bean has overall responsibility for this project. J. Houck is designing and building a piston gage that will combine methods (1) and (2). The geometry and mounting of the piston-cylinder assembly is such that the distortion can be calculated. As the pressure is increased, there comes a point where the gage will no longer operate satisfactorily due to too short a float time caused by the widening of the annulus. The mounting of the gage is such that above this pressure, the gage can be operated as a controlled-clearance gage. Using calculation for the low pressure end and controlled-clearance methods for the high pressure end will result in valuable cross-checks in the overlap region. In addition to the insight we expect to gain in the two methods, this program will develop the cylinder mounting methods to be used with the three new gages mentioned.

The equations currently used to calculate the distortion are based on three assumptions:

(1) The cylinder is infinite in length.

(2) The pressure is uniform.

(3) There are no shear stresses in the plane surfaces formed by slicing the cylinder into elemental disks dx thick.

In a piston gage, the cylinder length is finite, the pressure falls to zero within a rather short length, and the cylinder experiences shear stresses not allowed by assumption (3).

The proper way to calculate the distortion for a piston gage is to solve the biharmonic equations with appropriate boundary conditions. Dr. Bean is collaborating with Dr. Ruben Lazos, a guest worker from the Physics Department at the Universidad Autonoma Metropolitana-Azcapotzalco, Mexico City, Mexico. The calculations are being continued by Dr. Lazos, and when they are completed, they will be compared with measurements of the changes in the outer cylinder diameter conducted at NBS.

During 1981-82, a 100-MPa oil piston gage was circulated among LNE, IGMC, PTB, NPL and NBS with each lab calibrating it using their primary standards. Representatives of the five labs met in February 1983 at BIPM to prepare a report which will be eventually submitted to J. Phys. E. Figure 3 is a plot of the relative change in area of the gage as a function of pressure. There are several points to note:

(1) LNE calibrated the gage at the start and at the end of the round-robin. The gage area increased by 25 ppm between those calibrations. Neither LNE nor the maker of the gage were surprised at the change for they have seen it before with new piston-cylinder assemblies. The piston used in the round-robin was new, the original having been damaged. LNE and the gage manufacturer claim the increase in the area is due mainly to changes with use in the strains created during the manufacturing process and by now the area should be nearly constant with time and use. If all that is true, then it is unfortunate that an unseasoned gage was used for the round-robin, but it was apparently unavoidable.

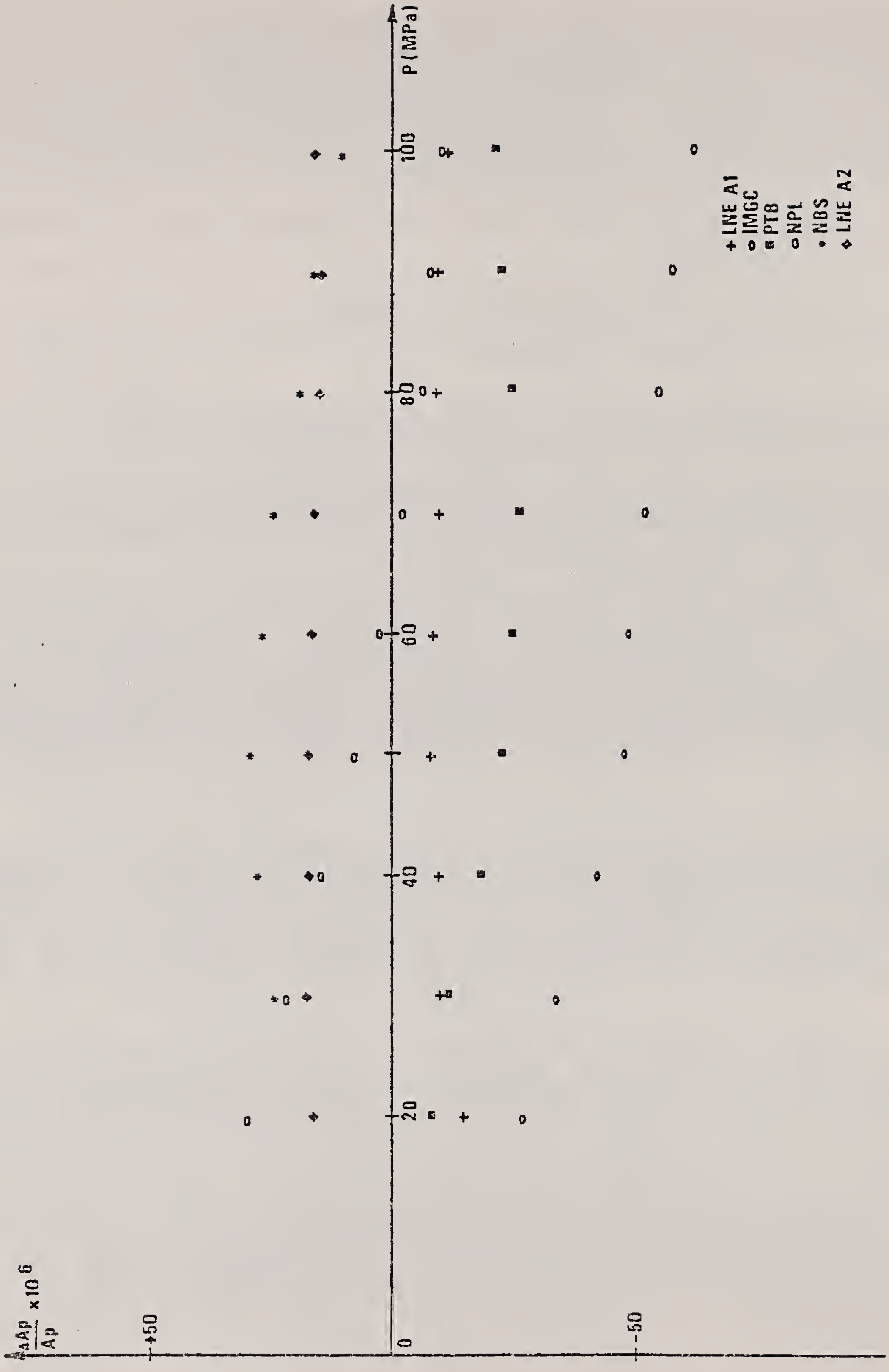

ΔAp/Ap x10^6
+50
0
-50
20
40
60
80
100
P (MPa)
+ LNE A1
IMGC
PTB
NPL
NBS
LNE A2

Figure 3.

(2) In figure 3, the labs are listed in chronological order. NBS calibrated the gage just before the second calibration at LNE. The agreement is excellent.

(3) The error bars at 100 MPa are reported elsewhere in the paper and have been added to figure 3. Only IMGC has larger error bars then NBS. The elastic distortion work is aimed specifically at reducing those error bars.

(4) All-in-all, the agreement between the various labs is quite good but the slope of the curves means that the disagreement will increase as the pressure increases. The differences in the slopes indicate that several labs should re-examine the distortion problem.

- Related Work

(1) BRL hydraulic load cell. We agreed to characterize a hydraulic load cell that is made much like a controlled-clearance piston gage. The army would like to use the device as a force transfer standard. We made a series of tests and the unit failed. It was returned to the manufacturer for rework. B. Welch will go to the factory in Boston to see the device demonstrated over the full range before we accept it again for tests.

(2) Sandia study on fluid compressibility. Sandia asked us to measure the compressibility of 10 fluids up to 1 GPa at room temperature. S. Wood is making the measurements. The project should be finished in early September 1983.

VII. VACUUM: BELOW 10^5 Pa (1 atm)

VII.A. Manometry 1 - 10^5 Pa (10^{-2}-1000 torr)

The core of the program is the Ultrasonic Interference Manometer (UIM) in which the height of a column of mercury is measured by an ultrasonic technique. The UIM is capable of very high precision (1 ppm) but its accuracy is presently limited to 100 ppm by the inaccuracy in the speed of sound in mercury. This project is led by Dr. C. Tilford who is assisted by R. Hyland.

Specific accomplishments this year include:

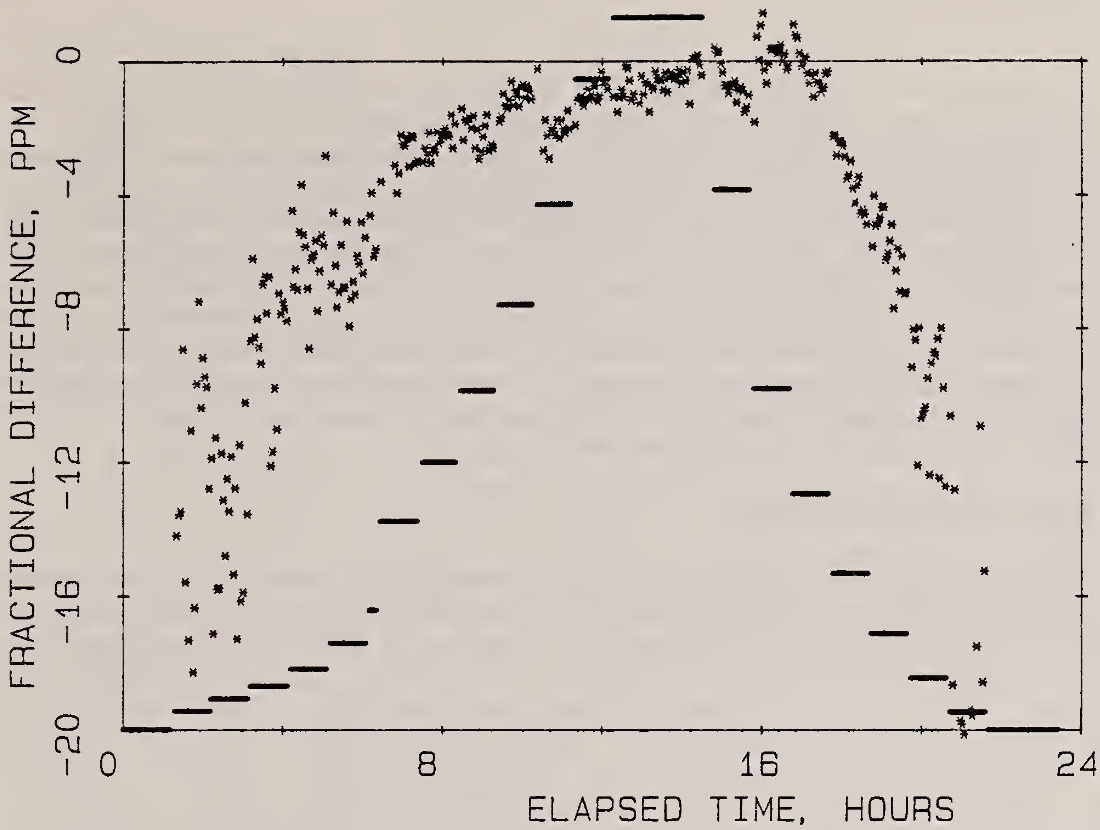
- Modifications and improvements in the NBS UIM.

- Construction of a second UIM for the National Physical Laboratory in New Delhi, India.

- Comparison of the two instruments shows that overall, the low pressure random errors (three sigma) are consistent with our existing estimate of 10^{-2} Pa (10^{-4} torr). At high pressures (140 kPa or 20 psi) the two instruments agree to within ± 3 ppm over periods of days with short-term (hours) sub-ppm imprecision. The ± 3 ppm is entirely consistent with our estimate of temperature uncertainties and we expect these could be reduced if active temperature control were used. An apparent reversible mechanical creep causes a shift that we believe is in the NBS manometer. The shift reaches a maximum value of about 10^{-1} Pa (10^3 torr) at around 15 to 20 kPa (150-200 torr). This amounts to an imprecision of 5 to 10 ppm at those pressures, which is very small. The accompanying figure 4 shows the quality of the results thus achieved. The UIM has been shipped to the NPL.

- The major factor limiting the high pressure accuracy of the ultrasonic manometer remains the uncertainty in the speed of sound in mercury. The long-dormant speed-of-sound apparatus was rehabilitated and modified to incorporate the recent advances in the ultrasonic and data acquisition systems. We expect to make measurement of the speed of sound with an inaccuracy of ~ 5 ppm, thereby rendering the UIM accurate to that level.

- In addition to work of a research nature, the ultrasonic manometer was also used for a number of for-fee calibrations, 16 being performed during FY 83. Most of these calibrations were performed on capacitance diaphragm gages. We have attempted to organize our growing body of data on widely used instruments in order to evaluate their limitations as transfer standards.



FRACTIONAL DIFFERENCE BETWEEN TWO ULTRASONIC MANOMETERS AS A FUNCTION OF TIME. PRESSURE WAS RAMPED IN STEPS FROM ZERO TO 106 kPa (1 ATM) AND BACK TO ZERO. SOLID LINES INDICATE THE PRESSURE, 100 kPa FULLSCALE. IDEALLY, THE FRACTIONAL DIFFERENCES SHOULD BE RANDOMLY SCATTERED ABOUT ZERO.

Figure 4.

VII.B. Vacuum 10^{-4} - 1 Pa (10^{-6}-10^{-2} torr).

Through the support of the Department of Energy, the Division was able to build a primary vacuum facility. This has been used to study two types of transfer gages: spinning rotor gages and ionization gages. This project is led by C. R. Tilford, who is assisted by K. McCulloh and R. Hyland.

- Primary Vacuum Facility

The high vacuum standard is currently being modified to include a set of constant pressure flow meters. These will permit a cross-check on the present volume meter and allow a direct check for nonlinearities. The apparatus also forms part of the leak standard apparatus discussed below.

• Ionization Gages

Evaluation of high vacuum ion gages as transfer gages continued at a reduced pace. Data were obtained for several different types of gages. The tests on one particularly promising gage were terminated when we learned that the gage is no longer commercially available. Long-term stabilty tests were started on the two most promising gage types found to date. Several manufacturers were contacted to see if they were interested in producing a gage with improved metrological properties that would also meet several practical requirements. One manufacturer has used the results of our work to guide his own research and has developed a new ion gage configuration that shows promise of significant improvement over the best currently available gages. Four ion gages were calibrated for fee in FY 83.

• Spinning Rotor Gages

The new NBS primary high vacuum standard for spinning rotor gages (SRG) was completed and evaluated. We estimate the uncertainty of this standard to be 1% for most gases. In January we initiated an interlaboratory comparison of this standard with the National Physical Laboratory (NPL) in Teddington, England, and the Physikalisch-Technische Bundesanstalt (PTB) in West Berlin. Results have been delayed by equipment problems at NPL and obscured by an apparent shift in one of the SRG balls. However, the results from NPL are consistent with a 1% uncertainty for our standard. These results will be factored into our decision as to whether or not to offer an SRG calibration service. We have received a number of requests for this service.

During the course of this year we used this new standard as part of a program to evaluate the stability of the SRG's. We experienced considerable difficulty in obtaining reproducible results with hydrogen, a gas not favored and little used by vacuum metrologists, but of obvious importance to the fusion energy program, a major sponsor of the vacuum standards work. Part of the problem may be due to surface interactions at the ball's surface. We believe a major contaminant may be water resulting from interactions between the hydrogen and adsorbed oxygen on the chamber walls. Apparently our previous work in calibrating ion gages with a SRG did not disclose this problem because the contaminants caused similar errors in the SRG and the ion gages. We have obtained reasonable results only by taking exceptional steps to maintain cleanliness.

• Extension of NBS Work to Lower Pressures

Through the leak standards program (see VIII) we expect to develop the ability to develop primary vacuum standards below our present limitation of 10^{-6} torr.

VIII. LEAK STANDARDS

Leaks are an important quality control measure for a variety of products ranging from beer cans to nuclear weapons. The economic implications are very large and the standards metrology is very primitive. We have been offered a significant level of financial support for an extended period of time (3-5 years) by Sandia Labs and the NBS Office of Nondestructive Evaluation to establish leak standards. Sandia's specific interest is verification of quality controls for nuclear fuel shipment casks. NBS's interest is more general but with emphasis on electronic device packaging. In part because the best existing standards, located at Sandia, are based on gas accumulation techniques, we have plans to base our standards mainly on flow techniques. This work will begin using our high vacuum gaging standard, but will eventually require measurements in the very high and ultra-high vacuum ranges. We will thus acquire standards of pressure in those ranges as a bonus. An initial comparison with Sandia leak standards is being organized, some equipment has been acquired, and we are advertising for a new professional to lead this work. The ball is presently being carried C. Tilford.

INVITED TALKS

Temperature and Pressure Division (522)

Vern E. Bean, "NBS Response to National Pressure Measurements Needs," Precision Pressure Measurement Workshop, Sandia National Laboratories, Albuquerque, NM, March 1, 1983.

R. D. Cutkosky, "Advantages and Limitations of AC Resistance-Thermometer Bridges -- Whether Maual or Automatic," American Society for Testing and Materials meeting of Committee E-20, Louisville, KY, May 11, 1983.

G. T. Furukawa, "Cryoscopic Determination of the Purity of Benzene by Calorimetry," Symposium on Purity Deterinations by Thermal Methods, Baltimore, MD, April 25, 1983.

W. S. Hurst, "Drivers for the IEEE-488 Bus Using the Pickles and Trout S-100 Board," NBS Microprocessors Group Meeting, February 1983.

W. S. Hurst, "Temperature Measurement in Gases Using Nonlinear Raman Spectroscopic Techniques," Pennsylvania State University, Department of Engineering Science, University Park, PA, July 1983.

R. W. Hyland, "Calibration Results for a Group of Capacitance Diaphragm Gages," 12th Annual Symposium on Applied Vacuum Science and Technology, Clearwater Beach, FL, February 14, 1983.

H. Marshak, "Gamma-Ray Spectrum Analysis in Nuclear Orientation Experiments," Freie Universitat, Berlin, West Germany, June 29, 1983.

G. J. Rosasco, "High-resolution Nonlinear Optical Measurements of the Temperature and Pressure Dependence of Molecular Spectra," NASA Langley Research Center, Hampton, VA, October 8, 1982.

G. J. Rosasco, "Nonlinear Optical Studies of Collisional Broadening and Narrowing in the Q-Branch Spectra of N_2 and CO," Princeton University, Department of Mechanical Engineeing and Aerospace Science, Princeton, NJ, October 1982.

G. J. Rosasco, "Nonlinear Optical Studies of Pressure Braodening and Narrowing in the Q-Branch Spectra of N_2 and CO," The Catholic University of America, Physics Department, Washington, DC, February 1983.

G. J. Rosasco, "Collisional Line Broadening and Mixing in Vibrational Q-Branch Spectra," 38th Symposium on Molecular Spectroscopy, Ohio State University, Columbus, OH, June 1983.

R. J. Soulen, Jr., "Noise and Impedance of an R-SQUID; Implications for Noise Thermometry," Physics Department, University of California, Berkeley, CA, February 22, 1983.

R J. Soulen, Jr., "Recent Advances in R-SQUID Noise Thermometry," Kammerlingh Onnes Laboratory, Leiden, The Netherlands, May 13, 1983.

C. R. Tilford, "Reliability of High Vacuum Measurement," 29th National Symposium of American Vacuum Society, Baltimore, MD, November 17, 1982.

C. R. Tilford and R. W. Hyland, "Stability of Capacitance Diaphragm Gages," Vacuum Measurement Standards and Calibration Conferene, Teddington, England, January 19, 1983.

C. R. Tilford and K. E. McCulloh, "Performance Characteristics of Different Hot Cathode Ion Gage Types," Vacuum Measurement Standards and Calibration Conference, Teddington, England, January 19, 1983.

C. R. Tilford, "Air Traffic Safety from the Perspective of a Metrologist," Conference on Safety Issues in Air Traffic System Planning and Design, Princeton, NJ, September 26, 1983. (Talk given by Dr. James Lechner).

C. T. Van Degrift, "Experimental Constraints on the Parameters Describing Unordered bcc ^3He," AIP Symposium on Quantum Fluids and Solids, Sanibel Island, FL, 1983.

PUBLICATIONS

Temperature and Pressure Division, 522

IN PRINT:

B. W. Mangum and G. T. Furukawa, "Report on the Sixth International Symposium on Temperature," (Abbreviated version), Metrologia 18, No. 3, 161-168 (1982).

B. W. Mangum and G. T. Furukawa, "Report on the Sixth International Symposium on Temperature," (Long version), J. Research NBS, 87, No. 5, 387-406 (September-October 1982).

G. J. Rosasco, W. Lempert, W. S. Hurst, and A. Fein, "Pressure Dependent Linewidth and Line-shift Measurements in the Vibrational Q-branch of N_2 from 4 to 200 kPa," Spectral Line Shapes, Vol. 2, ed. by K. Burnett (Walter de Gruyter and Co., Berlin, 1983), p. 635.

Charles R. Tilford, "Reliability of High Vacuum Measurements," J. Vac. Sci. Technol. A 1, No. 2, 152-162 (April-June 1983).

K. E. McCulloh, "Calibration of Molecular Drag Vacuum Gages," J. Vac. Sci. Technol. A 1, No. 2, 168-171 (April-June 1983).

G. J. Rosasco, W. Lempert, W. S. Hurst, and A. Fein, "Line Interference Effects in the Vibrational Q-branch Spectra of N_2 and CO," Chem. Phys. Lett. 97, 435 (1983).

R. D. Cutkosky, "Dedicated Multiprocessor System for Calculating Josephson-junction Noise Thermometer Frequency Variances at High Speed," Rev. Sci. Instrum 54, No. 7, 886-889 (July 1983).

B. W. Mangum, "The Sucinonitrile Triple-Point Standard: A Fixed Point to Improve the Accuracy of Temperature Measurements in the Clinical Laboratory," Clin. Chem. 29, No. 7, 1380-1384 (1983).

V. E. Bean, "Fixed Points for Pressure Metrology," Chapter 3 of High Pressure Measurement Techniques, G. N. Peggs, editor, (Applied Science Publishers Ltd., Essex, England, 1983) pp. 93-124.

H. Marshak, "Nuclear Orientation Thermometry," J. Research NBS, 88, No. 3, 175-219 (1983).

Paul H. E. Meijer and Daniele Clausse, "Rate of Ice Formation in Supercooled Water," Physica 119B (1983) 243-248.

ACCEPTED FOR PUBLICATION:

J. C. Houck, G. F. Molinar and R. M. Maghenzani. "An Intercomparison of Pressure Standards Between IMGC and NBS," J. Research NBS, 88.

Charles R. Tilford and Donald F. Martin, "Gas/Oil Interface and High Sensitivity Differential Pressure Indicator Used for the Comparison of Gas with Oil Piston Gages," Review of Scientific Instruments.

Paul H. E. Meijer, "General Considerations on Liquids at Normal and Super-cooled Temperatures with Special Attention to Water," Nuovo Cimento.

Sharrill D. Wood and Vern E. Bean, "Polynomial Representation of the Decker Equations of State for NaCl and CsCl," High Temperatures - High Pressures.

George T. Furukawa, Jeanette H. Piccirelli, and Martin L. Reilly, "Cryoscopic Determination of the Purity of Benzene by Calorimetry," Proc. Symposium on Purity Determinations by Thermal Methods, Baltimore, MD, April 1983.

Paul H. E. Meijer and Mustafa Keskin, "The Dynamic Behaviour of the Pople and Karasz Model," J. Physics and Chemistry of Solids.

E. Bodegom and and Paul H. E. Meijer, "Spinodal Decomposition and Phase Separation of Directionally Bonded Liquids Using the Four Cluster Approximation," J. of Chemical Physics.

Mustafa Keskin and Paul H. E. Meijer, "A Model for Quenching via Hidden Variables; Non-Equilibrium Behaviour of a System with Two Long Range Order Parameters," Physica A.

Paul H. E. Meijer, Mustafa Keskin and Erik Bodegom, "A Simple Model for the Freezing-In of Metastable States," Physics Review A.

E. Bodegom and Paul H. E. Meijer, "Long Term Behaviour of Phase Separation; Computations with the Non-Homogeneous, Time Dependent Cluster Variation Method," Physica A.

Richard W. Hyland and Arnold Wexler, "Formulations for the Thermodynamic Properties of Dry Air from 173.15 K to 473.15 K, and of Saturated Moist Air from 173.15 K to 372.15 K, at Pressures to 5 MPa," ASHRAE Transactions.

Richard W. Hyland and Arnold Wexler, "Formulations for the Thermodynamic Properties of the Saturated Phase of H_2O, (from 173.15 K to 473.15 K)," ASHRAE Transactions.

B. E. Welch and Vern E. Bean, "Pressure and Temperature Measurements in the Crevice Between the Piston and Cylinder of a Simple Dead-Weight Piston Gage," Metrologia.

B. W. Mangum, "The Triple Point of Succinonitrile and Its Use in the Calibration of Thermistor Thermometers," Review of Scientific Instruments.

H. Seppa, J. H. Colwell and R. J. Soulen, Jr., "Intrinsic and Extrinsic Noise Sources in an RF Biased R-SQUID," Proc. 7th International Conference on Noise in Physical Sciences, Montpelier, May 17-20, 1983.

Robert L. Berger, Thomas Clem, Victoria A. Harden and B. W. Mangum, "Newer Means of Temperature Measurement in Biochemistry," Chapter in *Methods of Biochemical Analysis*.

H. Marshak, "Precise Gamma-ray Multipole Mixing Ratios Using Nuclear Orientation," Proc. 6th International Conference on Hyperfine Interactions, J. Hyperfine Interactions, North Holland Press.

B. E. Welch and Vern E. Bean, "A Method to Determine the Pressure Dependent Distortion of a Simple Piston Gage Based on Dimensional Metrology," *High Pressure Science and Technology*, Proc. of the IX AIRAPT Conference, Albany, NY, July 25-29, 1983.

J. K. N. Sharma, Kamlesh K. Jain, Vern E. Bean, B. E. Welch, and Ruben J. Lazos, "Effects of Viscosity, Temperature, and Rate of Rotation on Pressure Generated by a Controlled-Clearance Piston Gauge," Review of Scientific Instruments.

R. D. Cutkosky, R. E. Edsinger, J. P. Evans and R. J. Soulen, Jr., "Progress in Temperature Measurement," Proc. ISA, Houston, 1983.

Sharrill D. Wood and Vern E. Bean, "Compression of Cl_4 at High Pressures," *High Pressure Science and Technology*, Proc. of the IX AIRAPT Conference, Albany, NY, July 25-29, 1983.

Vern E. Bean, Sharrill D. Wood and Ruben J. Lazos, "Pressure Dependence of Viscosity of Pressure Transmitting Fluids," *High Pressure Science and Technology*, Proc. IX AIRAPT Conference, Albany, NY, July 25-29, 1983.

Craig T. Van Degrift, "Experimental Constraints on the Parameters Describing Unordered bcc ^3He," AIP Conference Proc., Symposium on Quantum Fluids and Solids, Sanibel Island, FL, 1983.

J. K. N. Sharma, Kamlesh K. Jain, Vern E. Bean, B. E. Welch and Ruben J. Lazos, "Effects of Viscosity, Temperature, and Rate of Rotation on the Operation of a Controlled-Clearance Piston Gauge," High Pressure Science and Technology, Proc. IX AIRAPT Conference, Albany, NY, July 25-29, 1983.

Warren G. Hurley and Richard W. Hyland, "General Guidelines for the Field Calibration of Humidity and Moisture Indicators" NBS Building Science Series.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Temperature and Pressure Division (522)

V. E. Bean, Chairman, AIRAPT (International Association for the Advancement of High Pressure Science and Technology) Task Group on the International Practical Pressure Scale.

V. E. Bean, Member, BIPM (International Bureau of Weights and Measures) Consultative Committee for Mass and Related Quantities, Working Group on Medium Pressure.

V. E. Bean, Member, BIPM (International Bureau of Weights and Measures) Consultative Committee for Mass and Related Quantities, Working Group on High Pressure.

V. E. Bean, Member, ICSU (International Council of Scientific Unions) Committee on Data for Science and Technology, Task Group on Critical Interdisciplinary Survey of Property Data on High Pressure Phases.

G. W. Burns, Member, ANSI MC096, American National Standards Institute Committee on Temperature Measurement Thermocouples.

G. W. Burns, Member, ASTM E-20, American Society for Testing and Materials Committee on Temperature Measurement, Subcommittee E-20.04, Thermocouples.

R. D. Cutkosky, Assistant Secretary, IEC TC25, International Electrotechnical Commission Technical Committee on Quantities, Units, and Their Letter Symbols.

R. D. Cutkosky, Member, IEEE IM TC-2, Institute for Electrical and Electronics Engineers Instrumentation and Measurement Group, DC and LF Standards.

G. T. Furukawa, Member, ASTM E-20, American Society for Testing and Materials Temperature Measurement Committee; Subcommittee E-20.03, Resistance Thermometers; Subcommittee E-20.04, Thermocouples; Secretary, Subcommittee E-20.06, New Thermometers; Member, Subcommittee E-20.07, Fundamentals in Thermometry; and Subcommittee E-20.10, Publications.

W. S. Hurst, Member, ANSI MC088, American National Standards Institute Committee on Calibration of Instruments, Subcommittee SC.03, Temperature.

R. W. Hyland, Member, AVS C004, American Vacuum Society Committee on Standards, Subcommittee SC.01, Gaging.

B. W. Mangum, Member, NCCLS C002, National Committee for Clinical Laboratory Standards, Area Committee on Clinical Chemistry, Subcommittee SC.01, Enzyme Assay Condition, Working Group WG.01, Temperature Measurement and Control; and Member, NCCLS C010, Area Committee on Instrumentation; Secretary, Subcommittee SC.01, Temperature.
B. W. Mangum, Member, ASTM E-20, American Society for Testing and Materials, Temperature Measurement Committee; Member, Subcommittee E 20.03, Resistance Thermometers; Chairman, Subcommittee E-20.06, New Thermometers; Member, Subcommittee E-20.07, Fundamentals in Thermometry; Subcommittee E-20.08, Medical Thermometry, Working Group WG.02, Fever Thermometers; Working Group WG.02A, Electronic Fever Thermometers; Working Group WG.02B, Mercury-In-Glass Fever Thermometers; Working Group WG.02C, Disposable Fever Thermometers; Working Group WG.03, Continuous Clinical Temperature Monitoring Systems; Working Group WG.04, Clinical Laboratory Temperature Measurement; and Member, Subcommittee E-20.90, Executive Subcommittee.

B. W. Mangum, Member, OIML PS12, International Organization of Legal Metrology, Measurement of Temperature and Calorific Energy Committee, RS4, Electrical Thermistor Thermometers.

J. F. Schooley, Chairman, ANSI MC88, American National Standards Institute Committee on Calibration of Instruments.

J. F. Schooley, Member, CIPM CCT, International Committee on Weights and Measures Consultative Committee on Thermometry; and Delegate, Subcommittee WG3, Replacement of IPTS-68.

J. F. Schooley, Delegate, OIML PS12, International Organization of Legal Metrology Committee on Measurement of Temperature and Calorific Energy.

R. J. Soulen, Jr., Member, ASTM E-20, American Society for Testing and Materials Temperature Measurement Committee.

R. J. Soulen, Jr., Member, ASTM B001, American Society for Testing and Materials Committee Electrical Conductors, Subcommittee SC.08, Superconductors.

C. R. Tilford, Member, ASTM E021, American Society for Testing and Materials Space Simulation and Applications of Space Technology Committee, Subcommittee SC.04, Space Simulation Test Methods, Working Group WG.01, Revision of Standards E296-70 and E297-70.

C. R. Tilford, Chairman, AVC C004, American Vacuum Society Standards Committee; Member, Subcommittee SC.01, Gaging..

C. R. Tilford, Chairman, BIPM C002, International Bureau of Weights and Measures Consultative Committee on Mass and Related Quantities, Working Group WG.02, Working Group on Low Pressures.

C. R. Tilford, Chairman, RTCA SC150, Radio Technical Commission for Aeronautics, Special Committee for Minimum Performance Standards for (Aircraft) Vertical Separation Above Flight Level 290.

C. R. Tilford, Member, Board of Directors, Vacuum Technology Division of the American Vacuum Society.

J. A. Wise, Secretary, ASTM E-20, American Society for Testing and Materials, Temperature and Measurement Committee; Member, Subcommittee E-20.05, Liquid-in-Glass Thermometers and Hydrometers; and Secretary, Subcommittee E-20.90, Executive Subcommittee.

LENGTH AND MASS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1983

I. Overview

The Length and Mass Division (LMD) has the responsibility to: maintain the U.S. primary standards for length, mass, and density; provide the first level of transfer to secondary standards; and improve the standards and measurement instrumentation through basic and applied research.

Many activities occur in support of these responsibilities. Comparisons of the U.S. Standards are made with the International Bureau of Weights and Measures (BIPM) and with other national laboratories to ensure international concordance. A close working relationship is maintained with those divisions in the National Engineering Laboratory which have the responsibility for providing calibration services to other government agencies and the public. This cooperation not only concerns the first transfer of dimensional quantities but also includes the transfer of techniques and instruments, such as the portable laser length standard, the submersible balance, and the load cell mass comparator, each of which was developed in the LMD. Cooperative projects with outside institutions, such as state standards laboratories and universities, ensure that our activities are relevant to the problems of the measurement community. Solutions to these problems are sought through a program of research which strives to develop improved measurement instruments and techniques by an increased understanding of the fundamental physical principles upon which the standards are based and by the application of modern technology. Finally, the LMD is frequently called upon to offer information and assistance to private and public organizations which have the responsibility for state-of-the-art length and mass measurements but cannot get adequate support from the private sector.

The activities of the Division this year were shifted towards the mass area to expedite the completion of the vacuum compatible servo controlled kilogram comparator which was started in mid 1982. Much of the design work has been completed and construction is proceeding. Development of the electronic servo system will soon begin. The program to recalibrate the kilogram prototypes is well underway. Preliminary measurements have been completed in the Gaithersburg Laboratories. Calibrations at the BIPM are scheduled to begin in December and will be completed in February. The Division worked on two density projects this year. A liquid densitometer which is based on a novel principle has been designed and drawings have been prepared. Construction and testing will proceed in the Fall. The silicon density artifacts which were issued by the Office of Standard Reference Materials as a result of our activities last year have been used to certify the densities of certain glasses which will serve as reference densities for the ASTM.

A small group of theoreticians in the Division are developing methods to treat electric field effects on atomic processes and the time dependence of excitation processes under varying field conditions. In addition to the theoretical work, J.W. Cooper collaborates with workers in the Center for Radiation Research (CRR) on experimental programs.

II. Technical Activities

1. Length Measurements and Standards

The length activities were curtailed during FY 83 to permit Howard Layer to work on the servo-controlled kilogram mass comparator. Therefore, only a small fraction of his time was available for length research and development activities.

A. NBS Portable Laser Length Standard

ACCOMPLISHMENTS: The interest in the NBS portable laser length standard continues to be high not only from domestic sources but also from foreign countries which are in the process of building metrology laboratories to support industrialization. This instrument is now commercially available from a small company in Gaithersburg which has traditionally manufactured instruments developed at NBS. One of their instruments has gone to the group within Hewlett-Packard which manufactures the laser interferometer system and is used as an on-line reference standard to verify the laser wavelength specification. Prior to using the iodine stabilized laser, the accuracy of the Hewlett-Packard laser was specified as 5 parts in 10^7. The accuracy of their present instrument is specified as 1 part in 10^7 with stability of about one part in 10^8. Hewlett-Packard estimates the precision of the process used in this measurement to be about 1 part in 10^9. The NBS Laser Length Standard has now been integrated into the operations of the two of the most important length disseminating metrology institutions in the United States, NBS in Washington and HP in Santa Clara, and represents an excellent example of government to industry technology transfers.

PLANS FOR FY 1984: All of the goals of the iodine stabilized laser length standard have been achieved. Active efforts will be continued to transfer the technology to additional segments of society but no new technical initiatives are anticipated. A document which describes the design performance and application to metrology is substantially completed. This monograph will combine many aspects of laser length metrology in one document and, judged by our inquiries, will be well received.

B. Stabilized Mercury Lasers

The optically pumped mercury laser has been stabilized to an iodine transition using an internal cell. It is similar to the iodine stabilized HeNe laser but is expected to perform at a higher level of accuracy and precision. Its frequency (wavelength is 546 nm) can be measured relative to the cesium clock with the Boulder frequency chain doubled 1.15 μm transition in Ne and an additional CO_2 laser frequency.

ACCOMPLISHMENTS: The optical pumping cavity and the pump lamp have been redesigned and are operational. Because of the difficulty of pumping argon, which is the buffer gas used in the mercury pump lamp, a turbomolecular bakeable pumping system has been constructed and has recently been put into use.

PLANS FOR FY 1984: Detailed characterization of the laser performance has begun to determine the operating conditions for optimum performance. When the system is complete it will be taken to the NBS Boulder Laboratories to measure its frequency relative to the cesium clock. The goal of this project is to construct a practical laser similar to the iodine stabilized helium neon laser, but with better resetability and lower noise.

2. Mass Measurements and Standards

A. Recalibration of U.S. Kilograms by BIPM

ACCOMPLISHMENTS: Kilograms K20 and K4 (both platinum-iridium prototypes of the International Prototype Kilogram) along with two stainless-steel kilograms will be calibrated by BIPM. In preparation for this exercise, NBS was able to borrow a Pt.-Ir kilogram from BIPM (#650) for preliminary measurements in Gaithersburg. This artifact was used in a series of measurements on our best mass comparator. Preliminary results indicate that K20 probably has not changed by more than 10 μg since its last calibration in 1948, although other working standards have changed somewhat more dramatically. The BIPM calibration measurements are scheduled to begin in December 1983.

The automatic balance reader which was mentioned in FY 1982 has not been completed although all software necessary to collect and analyze the data has been written.

PLANS FOR FY 1984: Calibration of K20, K4, and the stainless-steel kilograms by BIPM will be completed. Richard Davis of the Division will handcarry the kilograms to BIPM and remain as a guest worker for approximately three months to participate in their calibration.

Upon their return to the NBS, the standards will be rechecked for internal consistency and then used in a recalibration of the stainless-steel working standards of the NBS calibration service. Six new vacuum-melted stainless steel kilogram weights have been acquired by the National Engineering Laboratory. We will assist them in the calibration and the maintenance of a heirarchical system which will require use of at least two of the new artifacts. We expect the automatic balance reader will be operational in time to facilitate these measurements.

B. Servo Controlled Kilogram Mass Comparator

ACCOMPLISHMENTS: All of the major components of the prototype system have been completed or are in the final stages of manufacture. The balance beam has been vacuum cast in both A356 high silicon aluminum and beryllium copper in an effort to determine which material and which mix of thermal and physical properties will produce the most stable operation. In addition to the beam, the balance consists of four major structural components: the plate on which the beam is mounted by means of a flat on the plate and a knife on the beam; the optics plate which contains the interferometer which measures the beam position; the base plate and cover which form the vacuum enclosure for the entire system. These plates are made of high silicon content aluminum and are artificially aged for stability. They are kinematically related to each other and to the laser and photodetector, which are placed outside and above the vacuum chamber to minimize the heat input to the balance. The knife, which is the fulcrum for the beam, has been cast from Tantung-G, a non-ferric tool steel which has a HRC of 60 and is non-magnetic.

The flat, which supports the knife, is made of boron carbide. This material is an electrical conductor so that the beam will not become electrostatically charged. The boron carbide flat was polished to less than one fringe over its entire surface by a gage block manufacturer. No such commercial service is available, however, for the knives and this technology had to be redeveloped. By using cast iron lapping discs and diamond abrasive, a knife edge has been generated by the intersection of two planes inclined 115 deg with respect to each other. Each surface is flat to within 1/10 of a fringe along its entire length. These appear to be the highest quality knives and flats that have ever been used at NBS.

The computer interface, which includes not only the controls for the beam servo and the weight handling mechanism but also several ports which will monitor pressure, temperature and other parameters, is complete. In addition some beam position measuring and curve fitting software has been written.

PLANS FOR FY 1984: The construction and assembly of the balance will continue and testing will begin immediately. The first objective is to get the mechanical part of the balance operational. The second is to align the angle interferometer which measures the beam position. Finally, the electronic servo will be incorporated. This system will then be used to test the balance design and the performance of the components. If the performance goals are met, the weight pan and the weight-changing mechanism will be constructed.

C. Surface Dependent Thermal Effects in Mass Calibration

ACCOMPLISHMENTS: An experiment was conducted to test effects which arise when masses undergoing calibration are not in thermal equilibrium with the surrounding air or with each other and when there are differences in their surface to mass ratio. The results of these measurements demonstrated that most ordinary mass calibrations and scientific mass measurements have undetected systematic errors which can be eliminated with better thermal control. The results of this experiment will be published in the proceedings of the National Conference of Weights and Measures.

PLANS FOR FY 1984: A kilogram balance will be set up in the isothermal environment of the sub-basement in the density laboratory to determine the magnitude of systematic thermal effects.

D. Density of Solids

ACCOMPLISHMENTS: The project to certify the density of 70 silicon artifacts has been finished and these have now been issued as Standard Reference Materials (SRMs). This fiscal year we were asked by the Office of Standard Reference Materials (OSRM) to certify the density of selected glasses. These glasses will serve as reference densities for ASTM C729 (Standard Test Method for Density of Glass by the Sink-Float Comparator). The measurements are now complete.

The two 800 g silicon artifacts which were sent to IMGC in Italy were returned at the end of the fiscal year. Preliminary analysis of the Italian data shows agreement in density measurements with NBS to slightly better than 1 ppm. This uncertainty includes traceability to the S.I. definitions of mass.

PLANS FOR FY 1984: The density of the silicon objects loaned to IMGC will be redetermined at NBS. This will complete a symmetric (A-B-A) intercomparison. The final results will be reported in a paper jointly authored by NBS and IMGC personnel.

E. Special Publication

ACCOMPLISHMENT: A new Industrial Measurement Series of Special Publications will be published by NBS. Division personnel and an industrial metrologist will co-author the first paper in this series entitled "A Primer for Mass Metrology." The goal of the publication is to integrate the many NBS publications covering mass metrology into a single coherent document for industrial metrologists. The new publication does not replace existing NBS documents but serves instead as a guide to their use.

PLANS FOR FY 1984: A final draft of the publication has been completed. The editorial review process will begin in October. Since the publication synthesizes the work of many people, careful review is especially important. Nevertheless, the publication should be available in the first half of FY 1984.

F. Liquid Densimeter

ACCOMPLISHMENTS: There is a need in metrology for a family of liquid density standard in the range from 0.6 g/cm^3 to 2.0 g/cm^3 for calibrating hydrometers to 100 ppm and the most precise vibrating tube densimeters to a 10 ppm or better. Since it is not practical to provide these standards with classical hydrostatic weighing or pycnometry, the Division is developing a new type of densimeter for the Standard Reference Material Program to be used in the certification of liquid density SRMs.

In principle, a force balance is isolated in one leg of a U-tube manometer by a diaphragm. The force balance is surrounded by an inert fluid while the other leg contains a sphere of known density surrounded by a fluid of unknown density. The unknown fluid height is adjusted such that each side of the diaphragm is at the same pressure and then the cell is exposed to the force imposed by the sphere mass via the diaphragm. The analysis and design of the instrument are complete. Construction and testing will begin in FY 1984.

G. Weights and Measurement Metrology

ACCOMPLISHMENTS: The examination of five state laboratories for their ability to perform advanced mass metrology is complete and has been reported. Significant conclusions are:

- Better instrumentation is required to measure the air temperature, pressure and relative humidity.
- Better thermal control is required in weighing areas.
- Computerized data reduction and analysis are necessary.

PLANS FOR FY 1984: The program will be continued in FY 1984 with an improved circulating package that will include an electronic barometer, thermometer and R.H. meter. In addition an HP-85 microcomputer and Division 523 software will be included. An effort will be made to recalibrate each participant's kilogram mass standards and eventually their entire metric weight set in their own laboratory.

3. Atomic Theory

A. Far UV Absorption of Atomic Barium

OBJECTIVE: To measure the absolute absorption cross section of barium from threshold (2379 Å) to approximately 400 Å.

CURRENT ACTIVITIES: The first step is making measurements in the region from threshold to ∿1200 Å. The equipment consists of (a) a monochromator mounted on the beam line of the SURF-II facility which is used as the radiation source, (b) a heat pipe capable of producing a well controlled column density of barium vapor, and (c) a detection system and control electronics. All of these are currently being assembled.

ACCOMPLISHMENTS: The apparatus for the experiment was assembled on SURF and the relative measurements made.

PLANS FOR FY 1984: The data reduction at relative cross sections will be completed. The column density in the barium absorption cell will be determined after the apparatus has been moved to the Physics Building and reassembled.

B. Theory of the Stark Effect

OBJECTIVE: To develop the theory of the Stark effect on atomic systems near ionization thresholds.

CURRENT ACTIVITIES: Theoretical methods are being developed to describe both the level positions and relative intensities of peaks observed in field ionization measurements. This work is a result of a collaboration with experimentalists performing field ionization measurements at Stonybrook and will be described in a paper currently being written. Two other papers are currently being written. One describes the generalization of the theory developed for the Stark effect on the photoexcitation of one electron system to the more general case where structure in the atomic core results in multiple ionization limits and autoionization can occur. The second paper will be a brief review of recent developments to appear in "Comments in atomic and molecular physics" and was solicited by the editor of that Journal.

ACCOMPLISHMENTS: The major accomplishment has been the successful extension of the theory to multichannel systems. In addition, a set of computer programs have been developed which provide detailed computations of the absorption cross sections with applied fields which can provide detailed comparisons with existing experimental data.

PLANS FOR FY 1984: The major effort during the next several months will be to complete the three papers now being written and thus document the work that has already been accomplished. Additional tasks will be making more computations and comparing them with existing experimental data and extending the theory to excited state photoionization. The latter effort will be attempted in order to provide some useful information on the effects of fields on the dielectronic recombination process.

C. Field Effects on Autoionizing States

OBJECTIVES: To study field effects on autoionizing states using multistep laser excitation.

CURRENT ACTIVITIES: An experiment has been started on three step excitation in order to study the effects of electric fields on a particular ionizing state in barium. This experiment is expected to be completed by the end of the year.

ACCOMPLISHMENTS: A paper on the low field effects on autoionizing states of gadolinium was completed and will be submitted to JOSA.

PLANS FOR FY 1984: The experiment on barium will be completed, probably within the next several months. If it is successful, detailed calculations will probably be carried out to compare with the results using the methods developed by D. Harmin.

D. Theoretical Laser Spectroscopy

OBJECTIVES: To provide theoretical support to experimental groups. Currently this involves developing a detailed theory of the properties of many level systems.

CURRENT ACTIVITIES: Current work is mainly directed towards examining the rather detailed results already in hand on the sodium n=3 system in order to: a) see if these developments can be extended to provide useful information to experimental groups doing optical pumping experiments, and b) write up the results in a definitive fashion.

ACCOMPLISHMENTS: The paper on "The Stark Effect in Hydrogen and Helium at High Fields" was accepted and has appeared. A paper on "Saturated Fluorescence in a Standing Wave Laser Field" has been completed and is currently being reviewed.

PLANS FOR FY 1984: The major task is the completion of the work on sodium, and its possible extension.

INVITED TALKS

Length and Mass Division (523)

David A. Harmin, "Stark effect lineshape theory," State University of New York at Stony Brook, December 5, 1982.

David A. Harmin, "Theory of the Stark effect," Yale University, Physics Department, New Haven, CT. January 26, 1983

David A. Harmin, "Stark effect in non-hydrogenic atoms," New York American Physical Society meeting, January 27, 1983.

David A. Harmin, "Theory of the Stark effect", Wesleyan University, Hartford, CT. April 14, 1983.

David A. Harmin, "Theory of the Stark effect", Kansas State University, Manhattan, Kansas. May 19, 1983.

Randall M. Schoonover, "Advanced mass calibration in state laboratories," (workshop given at the 86th National Conference on Weights and Measures) Sacramento, CA. July 18, 1983.

Randall M. Schoonover, "A surface-dependent thermal effect in mass calibration," 86th National Conference on Weights and Measures, Sacramento, CA. July 19, 1983.

PUBLICATIONS

Length and Mass Division (523)

J. W. Cooper and E. B. Saloman, "The Stark effect on the oscillator strength distribution of helium near the ionization limit," Phys. Rev. A26, 1452-1465 (1982).

G. Mehlman, J. W. Cooper and E. B. Saloman, "The absolute photoabsorption cross section of the K shell of atomic lithium," Phys. Rev. A25, 2113-2122 (1982).

Richard S. Davis, "Determination of silicon density to high precision using a submersible, servo-controlled balance," Metrologia 18, 193-201 (1982).

Randall M. Schoonover and Jerry Keller, "A surface-dependent thermal effect in mass calibration and what you can do about it," Proceedings of the 68th National Conference on Weights and Measures, Sacramento, CA, July 18-22, 1983.

R. M. Schoonover, "Advanced Mass Calibration in State Laboratories," NBS IR #2752 (August 1983).

Helen K. Holt, "Stark quenching of metastable 2S states in hydrogen and helium at high fields," Phys. Rev. A28, 1157-1159 (Aug. 1983).

J. W. Cooper, E. B. Saloman, and B. E. Cole, "Electric field effects on the absorption spectra of H_2 near the ionization limit," Phys. Rev. A28, 1832-1834 (Sept. 1983).

V. I. Mishin, G. Lombardi, D. E. Kelleher and J. W. Cooper, "Effects of very low electric fields on autoionizing states in gadolinium," to be submitted to JOSA.

Helen K. Holt, "Saturated fluorescence in a standing wave laser field," in review.

COMMITTEES

Length and Mass Division (523)

R. S. Davis, member, American Society for Testing & Materials, E41.06, Weighing Devices, subcommittee of E.41, Laboratory Apparatus.

R. M. Schoonover, member, American Society for Testing & Materials, E41.06, Weighing Devices, subcommittee of E.41, Laboratory Apparatus.

TIME AND FREQUENCY DIVISION
FISCAL YEAR 1983

I. OVERVIEW

This report is divided in two halves. The first nalf is an overview of the Division which is intended to provide an introduction for those who are unfamiliar with the Division's objectives and activities. The second half addresses the Division's short-term plans and accomplishments. It is arranged to permit an easy review of the Division's performance.

The National Bureau of Standards (NBS) is responsible for the development and maintenance of a system of measurements required to support the Nation's economy. The specific functions of NBS were assigned to the Department of Commerce by the Bureau's enabling legislation (15 U.S.C. 272) Portions of this legislation state:

"The Secretary of Commerce is authorized to undertake the following functions:

(a) The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements consistent with those standards,...

(e) Advisory service to Government agencies on scientific and technical problems.

(f) Invention and development of devices to serve special needs of the Government."

In carrying out these functions, the Secretary is authorized specific activities including:

"(1) the construction of physical standards;
(2) the testing, calibration and certification of standards and standard measuring apparatus;
(3) the study and improvement of instruments and methods of measurements,...
(11) the broadcasting of radio signals of standard frequency;"

The Time and Frequency Division, located in Boulder, Colorado is responsible for the standards of frequency and length, two of the six base units of the Systems Internationale (SI). The most important product of the Division is the service provided to science and industry. There is no sense in establishing and maintaining standards of measurement unless they are disseminated. Standards operation and research and development of standards and methods of measurement closely supports the services of the Division. The extension of standards and methods in range and accuracy and into new fields should receive sufficient emphasis to keep NBS prepared to satisfy the demands for services. Basic research related to standards is performed over a broad range of fields to challenge the talents of the staff and to stimulate the development of new ideas. Advisory service to Government agencies and the development of devices to serve the special needs of Government are important NBS roles which increase the efficiency of government by applying the special expertise of NBS to significant Government problems. This section presents the program of the Division in terms of these four basic functions.

SERVICE

In order to have useful standards of time, frequency, and length it is essential to provide a means of reference to these standards. This has been accomplished primarily via the radio broadcasts of stations WWV, WWVH, and WWVB and a time code disseminated from the GOES satellite system. NBS has also provided telephone time-of-day services, publications of time and frequency values of other radio stations as received at NBS, portable clock comparisons and calibrations. The meter is disseminated primarily by publication in scientific journals. Seminars are regularly scheduled to educate new entrants to the time and frequency field concerning methods of measurement.

Users of the Division's services fall into several broad categories:

Navigation

Celestial navigators need time to determine their precise location. An error of 2 seconds could cause a ship to miss its destination by about one kilometer. Thus military and commercial shipping and small boat owners depend in a life and death sense on the availability of the signals from WWV and WWVH.

More sophisticated electronic navigation systems such as LORAN-C and GPS need time much more accurately. When using these systems, an error of only 3 microseconds could cause the same one kilometer error.

Systems Control and Synchronization

Power companies use frequency to control electric power flow at 60 hertz. If they didn't, clocks could not maintain the correct time. They need time to monitor the power grid to help alleviate "brownouts" and massive power failures. They use it to help locate power outages and to know the exact time when outages occur. Time is also important for keeping track of power flow among the various companies in the interconnected network for billing purposes.

Radio & TV stations need accurate frequency to broadcast signals at exactly their assigned frequencies. They need accurate time to set station clocks so they can join the network at the right instant.

The aviation/aerospace industry needs accurate time for aircraft traffic control systems and for synchronization at satellite and missile tracking stations.

The telecommunications industry needs time accurate to one microsecond to synchronize satellite & other communications terminals spread over wide geographical areas.

Data Acquisition

The FAA records accurate time on its audio tapes along with the air-to-ground communications from airplanes. Having an accurate record of when particular events happened can be an important factor in determining the cause of a plane crash or equipment malfunction.

Geophysicists/seismologists studying lightning, earthquakes, weather, and other geophysical disturbances need time to enable them to obtain data synchronously and automatically over wide geographical areas. They use it for labeling geophysical events. Other scientists use time for controlling the duration of physical and chemical processes.

Astronomers use time for observing astronomical events, such as lunar occultations and eclipses.

Science and Metrology

Manufacturers need time and frequency to calibrate counters, frequency meters and test equipment.

Frequency is required by the broadcast industry for spectrum conservation.

Accurate spectra of molecules are needed to measure atmospheric concentrations.

Laser frequency measurements provide accurate calibration frequencies for spectroscopists and frequencies for radio astronomy.

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OBJECTIVE: Generate NBS time scales, UTC(NBS) and TA(NBS).
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NBS atomic time is generated from an ensemble of approximately ten commercial and laboratory cesium beam frequency standards and a laboratory hydrogen maser. The times of all the clocks are automatically measured every two hours with a precision of a few picoseconds. The UTC(NBS) time scale is computed immediately following a measurement cycle using a weighted average algorithm. The small dispersion of the clocks during the two hour interval between measurements makes it possible for NBS to provide UTC(NBS) to users with 1 ns precision at all times. Using data from the Bureau Internationale de l'Heure, UTC(NBS) is maintained within 1 μs of UTC.

At the end of each month, the TA(NBS) time scale is computed using a Kalman algorithm. This computation is optimum in the statistical sense for clocks having both white frequency noise and random walk frequency noise, an excellent model for the clocks in the NBS ensemble. The second of TA(NBS) is NBS's best estimate of the SI second based on yearly calibrations of the ensemble by NBS-6.

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OBJECTIVE: Broadcast time from radio stations WWV, WWVH and WWVB and the GOES satellites.

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NBS offers several around-the-clock time and frequency dissemination services to the general public. In 1923, radio station WWV was established by NBS and has been operated since that time. A sister station, WWVH was established in 1948, on the Hawaiian Island of Maui, and relocated to Kauai in 1971. In 1956, WWVB began low frequency broadcasts. WWV's signal is also offered by a telephone service, not toll-free, by dialing (303) 499-7111. A similar service from WWVH is available by dialing (808) 335-4363 in Hawaii.

Broadcasts from WWV and WWVH can be received on conventional shortwave receivers nearly anywhere in the world. Broadcast frequencies include 2.5, 5, 10, and 15 megahertz for both stations and 20 megahertz from WWV only. Accuracies within one millisecond can be obtained from these broadcasts if one corrects for the station's distance from the receiver. These services also provide standard frequencies, a BCD time code, astronomical time corrections, and certain public service announcements for other government agencies. The telephone service offers to individuals without receivers, the capability of obtaining NBS time and audio frequency signals. The caller can receive a time signal accurate to 30 milliseconds or better, about the maximum delay in cross-country telephone lines. WWVB offers a direct path signal of greater accuracy than WWV or WWVH, but a special 60-kilohertz low frequency receiver is required. WWVB's signal is a binary coded system, needing special decoding equipment. WWVB's coverage area is shown in Figure 1. These broadcast services are coordinated with similar operations in other countries through active participation in the international CCIR organization.

NBS time and frequency signals covering about 40 percent of the earth have been relayed via geostationary satellite since 1975 in an experimental service. The coverage area is shown in Figure 2. More than 8 years of experience has shown that such a system can offer continuous time and frequency reception that is much more dependable

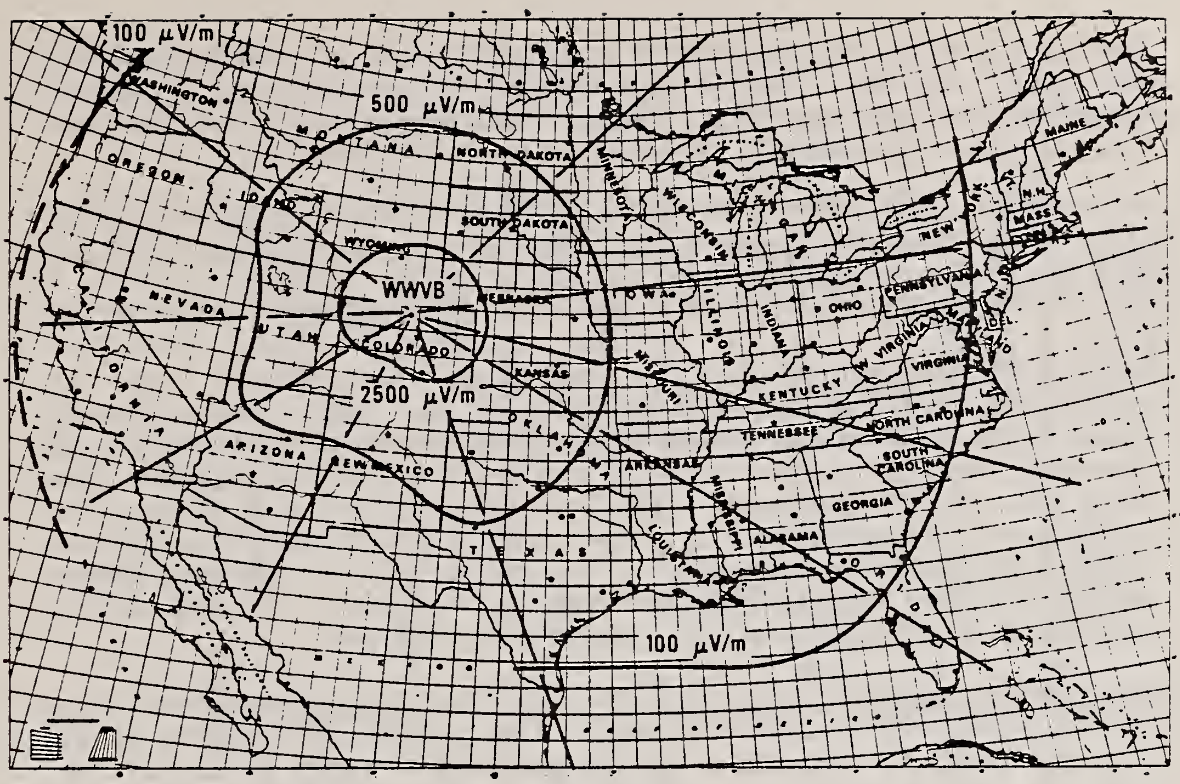

Figure 1

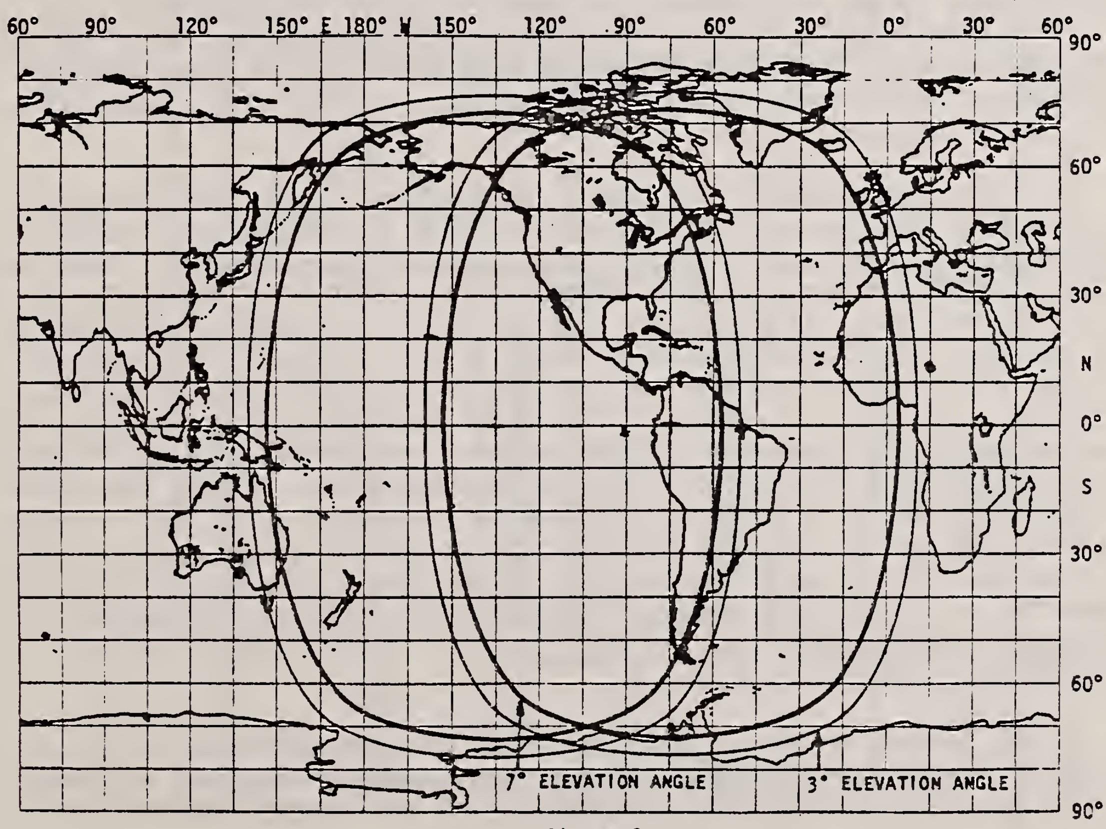

Figure 2

than ground-based AM and FM radio stations, is free from propagation anomalies, and has a better-than-100-microsecond accuracy. Table I summarizes the principal NBS time and frequency dissemination services. Table II gives some details of the HF radio broadcasts.

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OBJECTIVE: Provide seminars, calibrations and measurement assurance on a fully reimbursable basis.

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Calibration Services for Frequency and Time. An enhanced level of calibration activity has been encouraged since 1982. Those calibrations which require the special facilities of the National Bureau of Standards and those which require traceability to the national standards are actively welcomed. Some calibrations still fall into the category of special tests but a fee schedule is now published for two commonly requested measurements. In a period of less than two years, the calibration program, as measured by the value of calibrations performed, has increased by more than a factor of ten.

Measurement Assurance Services. Two new time and frequency dissemination services were started in 1983. They permit the user to obtain time and frequency traceable to the NBS with greater precision and less work than previously possible. The new services are suitable for users who require time transfer accuracies in the 3 nanosecond to 1 microsecond range or frequency calibration capability in the 1 part in 10^{11} to 1 part in 10^{14} range. However, even applications which do not require this level of precision may take advantage of these services because of their high degree of automation, simplicity of use, and degree of support from NBS.

Timing requirements at the 1 microsecond level and frequency calibration requirements at the part in 10^{11} to part in 10^{12} level can be satisfied using low frequency radio signals from broadcast stations such as WWVB or Loran-C. The NBS service consists of assisting the user to set-up a low frequency receiver and data logger system which is the most appropriate for his needs and his location. A typical system would contain a receiver, microcomputer, disc units and printer-plotter. The user's responsibility is to provide dedicated phone line and modem so that his data can be compared with data recorded at NBS, thus providing assurance that the measurements are valid. The user will also receive a bulletin, either by telephone or by mail, which reports the performance of many of the accurate signal sources. To assist the user in getting the most out of this system NBS will provide specific training on the actual equipment involved in its Seminar on Frequency Measurements and Calibrations. This will assist the user in resolving system failures.

The second service, based upon the NBS designed GPS receiver, provides much higher precision time and frequency data and a greater degree of automation. The receiver which is located at the users

TABLE I.

CHARACTERISTICS OF THE MAJOR NBS T&F DISSEMINATION SYSTEMS

DISSEMINATION TECHNIQUES		ACCURACY FREQUENCY SYNCHRONIZATION	ACCURACY FOR DATE TRANSFER	AMBIGUITY	COVERAGE FOR STATED ACCURACY
LF RADIO	STANDARD FREQUENCY BROADCAST (e.g., WWVB)	1×10^{-11} PHASE 24 h	ENVELOPE 1 - 10 ms	YEAR	USA - LIMITED (WWVB)
HF/MF RADIO	STANDARD FREQUENCY BROADCAST (e.g., WWV)	1×10^{-7}	1000 μs	CODE - YEAR VOICE - 1 DAY TICK - 1 s	HEMISPHERE
PORTABLE CLOCKS	PHYSICAL TRANSFER	1×10^{-13}	100 ns	N/A	LIMITED BY TRANSPORTATION
SATELLITE	GOES	3×10^{-10}	30 μs	1 YEAR	WESTERN HEMISPHERE

TABLE II.

STANDARD FREQUENCY AND TIME SIGNAL BROADCASTS IN THE HIGH FREQUENCY BAND

STATION	LOCATION LATITUDE LONGITUDE	POWER (kW)	ANTENNA	STANDARD FREQUENCIES USED: CARRIER (MHz)	STANDARD FREQUENCIES USED: MODULATION (Hz)	TIMES OF UT TRANSMISSIONS	ACCURACY	DUT1 CODE
WWV	Ft. COLLINS, COLORADO 40° 41' N 105° 02' W	2.5 10.0 10.0 10.0 2.5	VERTICAL $\lambda/2$ DIPOLE ARRAYS	2.5; 5.0; 10.0; 15.0; 20.0	1; 440; 500; 600	CONTINUOUS	1×10^{-11}	CCIR CODE: DOUBLE PULSE
WWVH	KEKAHA, KAUAI, HAWAII 21° 59' N 159° 46' W	5 10 10 10	PHASED VERTI-CAL HALF-WAVE DIPOLE ARRAYS	2.5 5.0 10.0 15.0	1; 440 500; 600	CONTINUOUS	1×10^{-11}	CCIR CODE DOUBLE PULSE

facility communicates its data automatically to an NBS computer which stores the raw data, determines which data elements are suitable for time transfer calculations and provides an optimally filtered value for the time and frequency of the user's clock with respect to the NBS Atomic Time Scales. The user is given an account on one of the NBS computers through which he may access both the raw data and the results of the NBS analysis. Tests between receivers in Colorado and Germany, France, Spain, Wyoming, and California have demonstrated an ability to perform time comparisons with a precision of 3 nanoseconds, and frequency comparisons with a precision of 1 part in 10^{14}.

In conjunction with its new time scale algorithms NBS has developed a time and frequency measurement system which is unsurpassed in many of its capabilities. This new system has vastly improved capability of calibrating any clock that might be sent to NBS. The full accuracy of the NBS time scale and primary frequency standard is readily available and measurements are made automatically every two hours on a clock being calibrated. These data are logged in the NBS time scale computer and the standards' characteristics and performance are readily documentable. Similarly, the person for whom the clock is being calibrated can be given an account in one of the NBS computers through which he may access the data in real time. This has proven to be very useful.

Time and Frequency Bulletin. The Division has continued the distribution of its Time and Frequency Bulletin to over 1500 users of NBS services. The preparation and mailing of this bulletin has been constantly improved to reduce costs and to increase its usefulness. The bulletin will continue to be improved and will be used to support our calibrations services.

Seminars. The Division seminars provide industry, calibration labs and the military with information and training on the use of frequency standards and time. Three separate seminars were offered in 1983 and all three were well attended. These will be continued as long as the demand is there. A special effort is made to have the seminars support the introduction of new services and to be of particular interest to the nation's calibration laboratories.

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OBJECTIVE: Maintain international coordination of time scales using the Global Positioning System.
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A satellite based time transfer system which was developed in the Time and Frequency Division between 1979 and 1982 is now operational. Several prototype receivers are operating in Braunschweig, Germany; Paris, France; Madrid, Spain; Canberra, Australia; as well as Boulder, Colorado; and Goldstone, California. A computer based automatic data collection network acquires the data from the receivers in Paris, Boulder, and Goldstone. This data is combined with the data from the

NBS Atomic Time Scale so that the time of the local clock is known with respect to NBS Atomic Time to a precision of 10 nanoseconds after one day of averaging.

Three receivers are being used to provide frequency calibrations between the sites of the NASA Deep Space Net at better than the 1 part in 10^{13} level. The receivers at Boulder, Paris, and Braunschweig, are being used to transfer clock data from NBS and the Physikalisch-Technische Bundesanstalt to the International Time Bureau in Paris. This new system is in the process of replacing Loran-C as the principal time transfer link for the SI second and the International Atomic Time Scale (TAI).

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OBJECTIVE: To provide reference frequencies from the microwave to the visible.

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Spectroscopic frequency references (measured with respect to the cesium standard). The pioneering work done by the Division to extend direct frequency measurements from the microwave to the visible portion of electromagnetic spectrum is now being used to measure the frequencies of atomic and molecular transitions which will be used by spectroscopists, astronomers, and atomospheric scientists. Before the advent of heterodyne spectroscopy (in which the frequency is measured with respect to cesium) spectral features were measured by wavelength techniques which were hundreds of times less accurate than these new direct frequency measuring techniques. The knowledge of the frequencies of various selected species allows the spectroscopist, astronomer or atmospheric scientist to carefully calibrate his spectrometer or receiver to the appropriate frequencies (or wavelengths).

The generation of reference frequencies with requisite accuracy involves accurate heterodyne frequency measurements and the reliable fitting and analysis of the data. Coordinated activity at NBS (between the Time and Frequency Division in Boulder and the Molecular Spectroscopy Divison in Gaithersburg) involves selection of suitable molecular calibration candidates, their frequency measurement and analysis, and dissemination of the results in the form of reference frequency tables.

Absorption frequency calibration standards must be readily obtained and easily handled with at least one calibration point every 15 GHz (0.5 cm^{-1}). The reference lines must be well resolved and free of accuracy-limiting fine structure each to an accuracy of ± 3 MHz.

The far infrared (0.1 to 5 THz, 3 mm to 60 μm). Several hundred optically pumped lasers have been measured and are used by laboratory spectroscopists to measure absorption features. Laser Magnetic Resonance (LMR) spectroscopy has been developed into one of the world's most sensitive techniques for observing and measuring frequencies of molecules. Laser magnetic resonance spectroscopy uses these known frequencies to predict the frequencies of free radicals used by astronomers and upper atmospheric researchers. The new technique of tunable far infrared spectroscopy (TuFIR) promises a much more general technique for measuring frequencies in this region.

The CO_2 laser which is stabilized to CO_2 itself furnishes the main frequency grid for all of our measurements and is widely used for reference purposes.

The infrared region (25 to 200 THz, 1.5 μm to 12 μm.). The frequencies of hundreds of lines of OCS, DBr, CO, and NO now furnish reference grids for this region. The methane line used to stabilize the He-Ne is especially noteworthy. It serves as an extra accurate reference for both metrology and spectroscopy.

Visible region (400 to 700 THz, 0.75 μm to 0.45 μm). The two major measurements (one yellow and one red) in molecular iodine which serve as the basis for the new meter also serve as excellent frequency and wavelength markers in the visible.

Status and availability of frequency calibration tables

Several molecules have been studied extensively and others have been studied on a limited basis. We list these below and indicate their coverage.

Carbonyl sulfide (multiband). Tables of OCS absorption lines have been provided for use as frequency calibration standards in the following regions of the infrared: 815-892 cm^{-1}, 1008-1092 cm^{-1}, 1649-1738 cm^{-1}, 1850-1921 cm^{-1} and 2013-2140 cm^{-1}. The absorption line frequencies and approximate intensities are calculated from spectroscopic constants which have been determined by fitting selected data from the literature. This data includes heterodyne frequency measurements for all except the 2013-2140 cm^{-1} region. The uncertainties of most of the recommended frequency standards are on the order of 1 to 10 MHz. Hot band transitions and transitions for some of the less abundant isotopic species are included in the tables in order to provide patterns for the unambiguous identification of the lines as well as to provide additional calibration standards in some cases. The calibrations atlas contains over 6600 entries.

Deuterium bromide (1-0 band), 1630-1985 cm^{-1}. Heterodyne frequency measurements have been made on selected deuterium bromide 1-0 band transitions ranging from P(20) to R(17). The measurements include electric quadrupole split triplets comprising the R(0) and P(1) transitions in the $D^{79}Br$ isotope. New DBr constants have been determined and a table of frequencies, believed to be accurate to 3 MHz, is available. Separation between line pairs ranges from about 6 cm^{-1} at 1980 cm^{-1} to 11 cm^{-1} at 1630 cm^{-1} hence this molecule has limited utility. It does however, span the OCS gap between 1738 and 1850 cm^{-1}

and partially covers another OCS gap between 1921 and 2013 cm^{-1}.

Carbon monoxide (2-0), 4120-4350 cm^{-1}. The 2-0 ro-vibronic band of $^{12}C^{16}O$ has been studied extensively by Fourier Transform Spectroscopy techniques and has become a widely accepted calibration standard. Current developments with a color center laser spectrometer have permitted the use of an alternate technique not only to confirm these results, but also to lead to an improved set of molecular constants. The data were combined in a least squares fit with seven unpublished microwave results to determine new constants which are an order of magnitude improved over prior results. A new frequency calibration table with some entries differing by as much as 15 MHz from Fourier Transform technique results has been published.

Nitrous oxide (multiband). An interim table of N_2O frequencies covering 522 to 657 cm^{-1} and 1115 to 1340 cm^{-1} is currently in print. Heterodyne frequency measurements were not available when the table was compiled and not many have been published at this time.

STANDARDS OPERATION, RESEARCH AND DEVELOPMENT

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OBJECTIVE: Establish the units of the International System for the "second" and the "meter."

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Operate NBS-6, the U.S. primary frequency standard. Since 1968, NBS has designed and developed three new cesium devices: NBS-4, NBS-5, and NBS-6. NBS-4 has a medium-length cavity of 50 cm, and was built to test new ideas for improving the stability of cesium devices. This standard is one of the most stable cesium clocks in the world, achieving a stability of 7×10^{-15}. It should be noted here that no previous NBS cesium frequency standards directly drove a clock; instead, they were used periodically to calibrate the frequency of an ensemble of commercial cesium beam clocks that ran continuously. NBS-4, because of its excellent stability, has served as a working clock in this ensemble since 1975.

NBS-5 was built on the framework of NBS-3 and in turn served as the basis for NBS-6, completed in 1975. The refinements incorporated over the years include greatly improved components to provide narrower resonance lines (25 hertz), the ability to reverse the direction of the atomic beam (which allows errors due to asymmetries in the cavity to be diagnosed), and other features aiding analysis of performance. It can also undergo routine maintenance without being completely turned off. NBS-6 has an accuracy of 8×10^{-14}, more accurate but not quite as stable as NBS-4. Used together, these two standards generate the U.S. standard second. A clock ensemble is used to carry the second forward in real time so that it is continuously available.

Provide frequency measurements of lasers suitable for realizing the proposed definition of the meter. The Comité Consultatif pour la Déinition du Métre (CCDM) has proposed "The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second." With this definition the meter could be realized from the wavelength of any laser which is stabilized to a narrow atomic or molecular absorption for which the frequency is known. The wavelength λ would be determined from the relation $\lambda = c/\nu$, where c is the fixed value of the speed of light and ν is the measured frequency of the laser. Thus, the realization of the meter requires the measurement of the absolute frequency of suitable spectral lines in the visible spectral region. To this end, The Division has completed two highly accurate frequency measurements of hyperfine transitions in molecular iodine used for laser stabilization. One is in the yellow spectral region, and the other, red.

The absolute frequency of a dye laser stabilized on the o hyperfine component of the $^{127}I_2$ 17-1 P(62) transition at 520 THz (576 nm) in iodine was measured with respect to the CH_4 stabilized 88 THz He-Ne laser. A 26 THz CO_2 laser, a color center laser at 130 THz, and a He-Ne laser at 260 THz, were used as transfer oscillators. The measured I_2 frequency was 520 206 808.547 MHz with a total uncertainty of 1.6 parts in 10^{10}.

The absolute frequency of the 473 THz He-Ne laser (633 nm), stabilized on the i hyperfine component of the $^{127}I_2$ 11-5 R(127) transition, was measured by comparing its frequency with a known frequency synthesized by summing the radiation from three lasers in a He-Ne plasma. The three lasers were an 88 THz CH_4 stabilized He-Ne laser (3.39 μm), a 125 THz color center laser (2.39 μm) with its frequency referenced to the $R_{II}(26)$ $^{13}C^{18}O_2$ laser, and a 260 THz He-Ne laser (1.15 μm) referenced to an I_2 stabilized dye laser at 520 THz (576 nm). The measured frequency is 473 612 214.789 MHz for the i hyperfine component with a total uncertainty of 1.6 parts in 10^{10}.

These frequencies, when used to realize the new meter, represent a 25-fold improvement over the present Krypton length standard. The General Conference on Weights and Measures will act on the CCDM recommendation in October 1983.

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OBJECTIVE: Make fundamental improvements in atomic frequency spectroscopy for future application to primary frequency standards.
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Atomic clock based on stored ions. As a step towards realizing a primary frequency standard based on stored ions, the Division has made a clock based on a ground state hyperfine transition in $^9Be^+$. The uncertainties in all systematic frequency shifts (such as those due to

Doppler effects) are smaller than those of the present U.S. primary time standard, NBS-6, which has an uncertainty of about one part in 10^{13}. However, the observed signal-to-noise ratio does not yet permit a complete evaluation below this level.

In these experiments, a few hundred $^{9}Be^{+}$ ions were confined in a Penning trap and laser cooled to temperatures less than 1 K. An oscillator was locked to a magnetic field independent hyperfine transition (∿ 300 MHz) using an optical pumping, double resonance technique. Measured stabilities were about equal to a commerical cesium clock. The hyperfine transition was driven for 20 s on each cycle which produced a linewidth of 0.025 Hz. During this time, the laser was shut off to avoid light shifts; this also allowed the ions to heat slightly from background gas collisions causing a second order Doppler shift of a few parts in 10^{14}. This problem can eventually be reduced by using cryogenic pumping since the present apparatus is at room temperature. Other systematic effects are below this level. Frequency stability and accuracy performance can be improved in the future by using an ion with a higher hyperfine frequency. For this reason, mercury ions with hyperfine transitions are around 30 GHz are now being studied.

Primary cesium standard development. The known limitations to the accuracy of NBS-6 lie with the microwave cavity phase shifts, exacerbated by the dispersive nature of the state selection magnets. In addition, there are unknown shifts of the cesium clock frequency associated with systematic effects which cannot be readily studied in conventional system. Replacing the magnets in a cesium standard with optical pumping and detection using laser diodes should allow the reduction of cavity phase shift uncertainties, and permit a better understanding of the limitations of cesium standards. A small laboratory version of the optically pumped cesium atomic beam frequency standard has been constructed, and is now under study.

Ion cloud/trapped ion studies. Studies are made of ion dynamics and the relation of these dynamics to trap design. It appears that the principle limitation to accuracy of a frequency standard based on stored ions will be the uncertainty to the second order Doppler (time dilation) frequency shift due to the rotation of the ion cloud. This rotation is a non thermal effect and is independent of the internal temperature of the cloud. Therefore detailed studies of ion cloud temperature, density and rotation are being made using a two-laser optical-optical double resonance technique.

New trap designs are now under study. Computer designed traps have shown the way to a trap which is far easier to construct and should give improved performance. All experiments up to this time have been operated in room temperature high vacuum systems. New designs will incorporate cryogenic pumping.

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OBJECTIVE: Develop metrology for precise time, frequency and length measurements.
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Techniques for characterization and measurement of frequency and frequency stability. The need for frequency measurements range from sub-audio to the ultraviolet. NBS has been a world leader in developing and disseminating the measures of frequency stability, their practical implementation, and accuracy. For example articles in the February 1966 issue of the Proceedings of the IEEE and the 1971 IEEE Transaction on Instrumentation and Measurement laid the foundation for specifying a practical way of defining frequency stability, which has become the defacto international standard in the field. The dual mixer concept of measuring time, frequency, and frequency stability made it possible to easily measure the difference between state-of-the-art frequency standards even if they are nominally the same frequency. This concept was introduced in 1975 by NBS and NRC (Ottawa, Canada), and is used in the new NBS time scale measurement system. Now picosecond precision time difference measurements can be made automatically on virtually any number of state-of-the-art clocks. Work in 1975 illuminated the limitations on frequency multiplication due to the phase noise in the standard or the multiplier chain, explaining numerous previous failures at precision infrared synthesis. This new understanding of the multiplication process then stimulated considerable improvement in the phase noise of crystal oscillators and signal processing equipment. In the rf region, the lowest noise crystal oscillators, buffer amplifiers, isolation amplifiers, and frequency multipliers presently available are a direct outgrowth of prototype designs and analysis developed at NBS. These new low noise devices have numerous applications in precision metrology as well as in the development of new frequency standards such as the passive hydrogen maser, stored ions, and cesium.

Frequency metrology from the far infrared to the visible has been greatly stimulated by the work at NBS. The early work on W-Ni point contact metal-insulator-metal (MIM) diodes, carried out simultaneously and independently by MIT and NBS, layed the groundwork for precision frequency synthesis in this spectral laser region.

An extremely important outgrowth of this work was the first frequency measurement of the 3.39 micron line of CH_4 followed by the wavelength measurement of the same line. The product of the frequency and wavelength produced a value for the speed of light nearly 100 times more accurate than the previously accepted value. This work coupled with recent frequency measurements of visible spectral lines has led to the replacement of the Krypton lamp as the length standard and the assignment of an exact value of the speed of light.

Recent work on the MIM diode has expanded the frequency difference range over which measurements can be made by a factor of 100 (in the visible). This is expected to greatly simplify frequency metrology because of the reduction in the number of frequency markers or reference lines necessary to fully cover this spectral region.

Techniques for characterizing noise in clocks. As part of the generation and dissemination of the SI second, it is necessary to have an ensemble of clocks as a memory of the rate given by the primary frequency standard. This is accomplished by running a set of clocks based on commercial frequency standards which, in general, don't have the accuracy of the primary standard but have very good frequency stability. These clocks when properly characterized can act as a good flywheel of the rate of NBS-6. The memory accuracy of the clock ensemble can be improved by either increasing the number of clocks or by wisely utilizing the clocks available. NBS has chosen to use sufficient clocks reliability, redundancy and variety (to avoid systematics from a particular manufacturer), but then to characterize the clocks with sufficient care so that optimum time and frequency can be generated from the ensemble as memory of the rate given by the NBS primary frequency standard.

One of the current time scale algorithms now in use has its philosophical basis in 1968. It is important to know how well this algorithm was approaching optimal performance given the set of clocks at hand so a cooperative effort was initiated with the Statistical Engineering Division. A method was developed, using Kalman filters, to model atomic clocks and obtain maximum likelihood estimates of the model parameters from data on the ensemble of clocks. Tests for the validity of the model and confidence intervals for the parameter estimates were made and shown to be statistically significant. Techniques were also developed for unequally spaced data. A study of the statistical significance of frequency drift yielded some important insights. In addition, a Kalman algorithm for estimating time from the ensemble of atomic clocks was developed. The algorithm allows for the addition or deletion of clocks and provides for automatic error detection and correction. Because of the success of this program, it is now used to generate the time scale TA(NBS) while the previous algorithm mentioned is still used to generate UTC(NBS). This effort resulted in the conclusion that the past algorithm was very near optimum in its performance.

Distance measurement techniques. The need to accurately determine the lengths of baselines on the surface of the earth arises in many different contexts, ranging from the calibration of tracks used for rocket tests to estimation of the relative motions of large geographical regions in seismically active zones.

Although no one technique can hope to satisfy these widely disparage needs, some general principles emerge from a survey of the field. Even for distances as short as 1000 m, the human surveyor and the steel tape are being replaced by instruments that measure distances in terms of the time of flight of electromagnetic energy along the path.

If the baseline is longer than about 50 km, line-of-sight measurements become more difficult, and indirect methods, such as satellite ranging or lunar ranging, are more practical.

In almost all cases, the measurements are made through the atmosphere; conversions of measured times-of-flight to physical distances require a knowledge of the atmospheric index of refraction.

The refractivity (the deviation of the index of refraction from unity) is about 300 ppm for visible wavelengths. Since it is often necessary to measure distances with fractional uncertainties of less than 0.1 ppm, the atmospheric correction is very important. The refractivity of the atmosphere is often determined by measuring the atmospheric pressure and temperature along the path. These measurements tend to be cumbersome; the sampling is usually done with airplanes or balloons, neither of which can respond to short period or short wavelength fluctuations.

Instruments which determine the refractivity of the atmosphere by measuring its dispersion have been proposed for some years. The dispersion across the visible is only about 17 ppm, so that dispersion measurements are technically difficult. Equally difficult are measurements which determine the humidity by measuring the power emitted at known water-vapor emission lines or by measuring the dispersion between optical and microwave frequencies.

We are currently constructing an instrument to determine the dry-air contribution to the refractivity by measuring the dispersion across the visible portion of the spectrum. The humidity will be determined by measuring the microwave-optical dispersion. Using these techniques, we expect to be able to measure baselines on the order of 50 km in length with uncertainties of a few mm.

A design for a long-baseline system using GPS satellites is also under consideration. Although initial measurements using uncorrected data may be useful in some contexts, these measurements will almost certainly require ancillary refractivity measurements if the uncertainties due to atmospheric water vapor are to be adequately removed. The GPS satellites are likely to play an important role in time and frequency dissemination and coordination as well, and techniques developed for correcting GPS-based geodetic measurements may prove to be very useful in other contexts.

Time transfer techniques. The use of communications satellites for time transfer at all levels of performance appears more promising in light of this year's efforts. Much of this is also due to a number of favorable changes in the available technology, economics, and demand. At the higher levels of performance, recent work reported by Japan and more recently the result of unpublished tests involving NBS, USNO, and COMSAT Laboratories have demonstrated one-half nanosecond time comparisons using the two-way time exchanges through a communications satellite. Additional laboratory tests indicated that 20 picoseconds were possible using the same techniques. Satellite tests were not possible at this time since FCC approval to use higher transmit power levels was not obtained in time. The tests were very encouraging and resulted in an informal agreement between NBS, USNO and the NRC in Canada to work together to develop a permanent network to serve these three laboratories. These organizations have began the acquisition of the necessary equipment to bring this concept to reality.

The use of communication satellites for the delivery of time and frequency information on a subscription basis also appears feasible with the application of technology originally developed and used by the DoD. The integration of this technology with careful baseband design (representation of the time and information) can produce a viable and fully reimburseable delivery system serving many important industrial and government needs in a very economic and reliable fashion here-to-fore not considered possible. Preliminary system examination by calculation and consultation with satellite industry engineers and scientists have confirmed initial feasibility. Potential industrial consumers of such a service have requested FY84 funds for NBS to further develop these concepts.

The use of routine tracking signals associated with U.S., Japanese, and European meteorological satellites for the transfer of time has been described in a CCIR report. This report has resulted in active interest in Europe, Japan, and Australia expressed by equipment purchases and experimental plans. NBS has assembled and sucessfully tested two complete receiving systems excluding baseband processing equipment. The necessary software has been written and installed into NOAA computers (NOAA is the satellite operator) to retrieve and store necessary tracking data as it is passed between the NOAA master ground station and their computers at Suitland, Maryland. Cooperative programs are being discussed between NBS and the Radio Research Laboratories in Japan.

Techniques for laser frequency synthesis Frequency synthesis is usually achieved in some non-linear device which adds - subtracts and multiplies the frequencies of the radiations incident on it. In the Time and Frequency Division we have used the W-Ni metal-insulator-metal (MIM) point contact diodes as detectors, harmonic generators, and mixers of coherent radiation from the microwave to the visible region of the electromagnetic spectrum. The MIM diode plays a very major role in the laser frequency synthesis chain which connects the cesium clock to the visible Iodine stabilized lasers and hence the realization of the meter from the new definition.

The MIM diode has been used for the past 15 years and the mechanical and electrical engineering improvements have been steady. Recent use of conical coupling along with off-axis parabolic focusing mirrors has led to an exciting new technique of generating tunable far infrared radiation.

Tunable coherent radiation can be generated in the uv, visible and near infrared regions of the electromagnetic spectrum with the use of tunable lasers and non-linear optics. Only recently have tunable sources been available in the far infrared and these did not allow complete coverage since the technique was the addition of microwave sidebands to several of the stronger far infrared lasers. Division scientists have now succeeded in generating tunable cw far infrared radiation via CO_2 difference frequency mixing in a tungsten-nickel, (MIM) diode. Previously, the MIM diode had been used mainly to make direct frequency measurements from 0.3 to 200 THz.

Two tenths of a microwatt of tunable, cw far infrared radiation has been generated by mixing 250 mw of radiation from each of two CO_2 lasers in a MIM diode. The difference frequency was radiated from the MIM diode, and was detected in a calibrated indium antimonide bolometer. The use of a waveguide CO_2 laser with its greater frequency tunability as one of the lasers used to generate the difference frequency, promises a complete coverage of tunable cw radiation in the entire far infrared band from 100 to 5000 GHz with the additional advantages of simplicity and high accuracy. Using this technique, it has been possible to readily detect the $J=5 \leftarrow J=4$ transition of CO (576 GHz) and the $J=1 \leftarrow J=0$ transition of HF (1.23 THz).

BASIC RESEARCH

Laser Fluorescence Mass Spectroscopy. As an outgrowth of studies on ion clouds stored in Penning traps for possible frequency standard applications, a sensitive way to make mass comparisons between different ions has been realized.

As an illustration of the technique, a small sample of $^9Be^+$ ions (about 25 ions in a cloud of approximately 100 μm diam.) was stored in a Penning trap (confined by static magnetic and electric fields). These ions were irradiated near the first resonance line (λ=313 nm) by a laser beam whose diameter was approximately equal to that of the cloud. This laser cooled the ions ($T \leq 0.1K$) and allowed observation of the laser fluorescence scattering from the ions. If the cyclotron motion of the ions was driven by resonant rf electric fields, the ion orbits increased in size causing a decrease in the fluorescence. In this way mass comparisons could be made by, for example, measuring the cyclotron frequencies of different Be^+ isotopes in the same magnetic field. In this experiment however, the $^9Be^+$ cyclotron frequency was compared to the $^9Be^+$ electron spin flip frequency to obtain the quantity $g_J(^9Be^+) \cdot m(^9Be^+)/m_e$ to an accuracy of 0.15 ppm. $g_J(^9Be^+)$ is the electron g factor in $^9Be^+$ and $m(^9Be^+)/m_e$ is the $^9Be^+$ to electron mass ratio. From measured values of the $^9Be^+$ to proton mass ratio and theoretical calculations of $g_J(^9Be^+)$, an indirect determination of the proton to electron mass ratio (m_p/m_e) to 0.34 ppm accuracy was obtained. (Previous to this measurement, the best accuracy reported for (m_p/m_e) was 0.14 ppm by direct comparison of the electron/proton cyclotron frequencies in a Penning trap.)

Strongly coupled plasma studies. In the language of plasma physics, the ion clouds in a Penning trap comprise a one component, non neutral ion plasma. As a result of measurements of cloud temperature and density we can show that we are approximately in the "strongly coupled" regime, that is where the ratio of electrostatic energy between nearest neighbors to the kinetic energy per ion is equal to or larger than unity. In this case the plasma will exhibit liquid properties and for large values of this ratio (around 150) will become a solid. A large body of theoretical work has gone into this problem but so far experiments on strongly coupled three dimensional plasmas have yet to be realized. (Strongly coupled electron plasmas in two dimension--e.g. electrons floating on liquid helium--have been experimentally studied.) Our techniques may in fact provide one of the few experimental relizations of three dimensional strongly coupled plasmas.

ADVISORY SERVICES

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OBJECTIVE: To advise and work with other governmental agencies and industry to incorporate advanced time, frequency and length metrology into their programs.
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During the past five years the Division has worked for other agencies in the areas of the development, improvement and utilization of frequency standards; frequency metrology; time generation; time transfer; length standards; and length metrology. The close relationship between NBS and other Agency objectives precludes the separation of activities by technical area. Thus, all of the preceeding functions are supported, in part, by other Federal Agencies. This section highlights three areas which may have very high short-term impact.

Cesium beam technology. Recent advances in cesium beam technology which have come from Division studies of optically pumped cesium clocks could improve the performance of commerical devices which are used in military applications. For example, this research could improve both the long term stability and the reproducibility after turn-on of satellite based cesium clocks. These improvements involve the use of laser diodes, cesium heat pipe ovens, optical pumping, and fluorescence detection of atoms.

Much of this work is performed under contract for other governmental agencies. In addition, the Division has established two Industrial Research Agreements with manufacturers of cesium clocks. These agreements permit the transfer of NBS research results to the private sector, and also brings guest scientists from industry to the governmental laboratory.

Hydrogen maser technology. The passive hydrogen maser is a new frequency standard developed at NBS, with partial military funding, which has demonstrated the capability of exceptional frequency stability from a few hours to a few weeks. Typical time dispersion per day is a factor of 4 to 5 better than the best available commerical cesium frequency standards.

Several Industrial Research Associates worked at NBS for two years. Although the research associates have departed NBS, the cooperation continues and the first passive hydrogen maser to be constructed in this program is nearing completion.

Low acceleration sensitivity quartz crystal resonators. Vibration sensitivity is presently one of the most severe difficulties encountered when using a frequency standard in non-laboratory environments. Although NBS no longer has an experimental quartz crystal research program, consulting support is being provided to the U.S. Army and its industrial contractors.

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OBJECTIVE: To design and test an instrument to measure the tilt of the surface of the earth.
****

The tilt of a point on the surface of the earth is defined as the angle between the local normal and the local acceleration of gravity. Measurements of tilt usually show both secular and periodic changes. The former have been proposed as precursory signals for earthquakes and as estimators of local tectonic activity, while the latter can be used to infer the elastic properties of the local material and to estimate the shape and size of sub-surface elastic anomalies.

Typical secular tilts are on the order of a few tenths of a micro-radian per year; these tilts are superimposed on diurnal and semi-diurnal changes of the same order of magnitude. To provide useful data, a tiltmeter must therefore have both sensitivity and stability at the nano-radian level.

We have designed a tiltmeter that satisfies these requirements. It consists of a horizontal pendulum mounted in a borehole approximately 30 m below the surface of the earth. The position of the pendulum is measured by making it the common arm of two parallel plate capacitors and by measuring the ratio of the capacitances using a capacitance bridge.

The instruments have been evaluated by verifying that the in-situ admittance to various extraneous effects such as fluctuations in ambient pressure and temperature is small; comparisons between the amplitudes and phases of the periodic effects and theoretical models based on the known lunar and solar driving forces have also been successful.

We have deployed an array of these instruments in Wyoming to study the secular stability of the Yellowstone Park area and to validate models of the elastic anomaly that is believed to underlie much of the park. We currently have five instruments at three sites in the park. The data from these sites is transmitted to Boulder for evaluation and analysis. In addition to the analyses discussed above, the data will be correlated with the work of other investigators in the area including determinations of gravity, uplift and heat-flow profiles.

****
OBJECTIVE: Measure frequencies of free radicals for radio astronomers.
****

Laser Magnetic Resonance (LMR) spectroscopy has been developed into an ultrasensitive technique (i.e., several orders of magnitude more sensitive than microwave spectroscopy) for observing and measuring reactions involving molecules. LMR techniques are singularly effective in measuring parameters necessary to model the effects of pollutants (e.g., fluorocarbons, nitric oxide, etc.) in the atmosphere.

The LMR technique uses a variable magnetic field to tune the molecular resonance into coincidence with a laser frequency. The free radicals or other species are located inside the laser cavity, and a flow system is used to measure reaction rates. This technique was used to measure the reaction rate of nitric oxide interacting with the hyperoxyl radical (HO_2), and the results significantly altered the previous estimates of the effects of the SST and fluorocarbon on the ozone content of the upper atmosphere.

Subsequently LMR was used to make the first laboratory observation of the CH_2 spectra. The CH_2 radical is an important building block for all organic molecules and is present as a free radical intermediary in many chemical reactions. Measurements of CH, CD_2 and CD were completed and the spectra of four molecules, GeH_3, GeH, and SiH, one atom, Si, were identified.

The new techniques of tunable far infrared spectroscopy promises to enhance the LMR technique by measuring some of the same free radicals at zero field. Zero field measurements will have a greater accuracy. The technique also will allow the measurement of all far infrared active molecules, not just paramagnetic ones.

INVITED TALKS

Time and Frequency Division (524)

J. Levine, "Technique of Electromagnetic Measurements," International Association of Geodesy Meeting, Tokyo Japan, May 1982.

D. W. Allan, "NBS Primary Frequency Standards Research and Metrology of Comparing Time Internationally at the Nanosecond Level," Radio Research Laboratory, Tokyo, Japan, September 1982.

D. W. Allan, "Using Global Positioning System Satellites to Measure Remote Clocks to An Accuracy of 10 ns", Tokyo Astronomical Observatory, University of Tokyo, Tokyo, Japan, September 1982.

D. W. Allan, "NBS Primary Frequency Standards Research; New NBS Time Scale System and International Time Comparison Techniques", National Research Laboratory of Metrology, September 1982.

D. W. Allan, "NBS Time and Frequency Research Work on Standards, the Time Scale, UTC(NBS) and TA(NBS), Clock Characterization and Measurements, and International Time and Frequency Comparison Methods," National Institute of Metrology, Beijing, Peoples Republic of China, September 1982.

D. W. Allan, "Shuttle Experiment to Demonstrate High-Accuracy Global Time and Frequency Transfer," Chinese Academy of Sciences, Beijing, Peoples Republic of China, September 1982.

D. W. Allan, "Primary Frequency Standards Research and Details of New NBS Time Scale System," National Institute of Metrology, Peoples Republic of China, September 1982.

D. W. Allan, "Measurement and Characterization of Clocks; Generation of Time and International T/F Comparison Methods, Northwest Polytechnical University, Zian, Peoples Republic of China, September 1982.

D. W. Allan, "Cesium Beam Frequency Standards and Time and Frequency Metrology Techniques," Shanghai Bureau of Metrology, Peoples Republic of China, September 1982.

D. W. Allan, "NBS Hydrogen Maser Work and Sub picosecond Dual Mixer Time Difference Measurements", Shanghai Observatory, Peoples Republic of China, September 1982.

H. Hemmati, "Generation of CW 194 nm Radiation by Some Frequency Mixing in an External Ring Cavity," Annual Meeting Optical Society of America, Tucson, Arizona, October 19, 1982.

K. M. Evenson, "Far Infrared Laser Magnetic Resonance: The Measurement of Submillimeter Lines of Astronomical Interest," and "The Direct Frequency Measurements of Visible Radiation (The New Meter and the Exact Value of the Speed of Light", National University of Mexico, October, 1982.

D. J. Wineland, "Particle Traps," Optical Soc. of America, Tucson, Arizona, October 20, 1982.

D. W. Allan, "Stochastic Models for Atomic Clocks," 14th Annual Precise Time & Time Interval Applications and Planning Meeting (PTTI), Nov. 1982.

W. Itano, "Time and Frequency Standard Based on Charged Particle Trapping," Conference on Applications of Accelerators in Research and Industry, Denton, Texas, November 8, 1982.

J. C. Bergquist, "Ultrahigh Precision Spectroscopy Using Stored Ions," NBS Research Seminar Series, NBS/Gaithersburg, January 11, 1983.

K. M. Evenson, "The Point Contact Diode at Laser Frequencies," 7th International Conference on Infrared and Millimeter Waves, France, January 1983.

D. W. Allan, "Accuracy of Time and Frequency Coordination and its Relationship to JPL's Deep Space Network," Jet Propulsion Laboratory, Pasadena, CA, February 1983.

D. W. Allan, "The Benefits of Ensemble Time As May Be Implemented in the GPS," Air Force Space Division, Los Angeles, CA, February 1983.

K. M. Evenson, "Optical Frequency Synthesis Spectroscopy," presented at the Workshop on Spectroscopic Applications of Slow Atomic Beams, NBS, Gaithersburg, MD, April 1983.

K. M. Evenson, "Tunable Far Infrared Laser Spectroscopy", National Research Council, Ottawa, Ontario, Canada, May 1983.

D. J. Wineland, "Cooled Ion Clocks," present invited colloquium, Harvard University, May 1983.

J. Levine, "The Geodimeter," Int. Geophysics University of California in San Diego, May 5, 1983.

D. W. Allan, "Separating the Variances of the Error Components in GPS" Vandenburg Air Force Base, Vandenburg, CA June 1983.

J. Bollinger, "Precision Measurement of Laser Cooled $^{9}Be^{+}$ Ions," 6th International Conference on Laser Spectroscopy (SICOLS), June 1983.

J. Jespersen, "Time and Frequency Measurement Programs," 37th Annual Symposium on Frequency Control, Philadelphia, Pennsylvania, June 1, 1983.

D. W. Allan, "National and International Time and Frequency Comparisons," 37th Annual Symposium on Frequency Control, Philadelphia, Pennsylvania, June 1, 1983.

J. Bollinger, "Accurate Laser Cooled Beryllium Ion Clock," 37th Annual Symposium on Frequency Control, Philadelphia, Pennsylvania, June 1, 1983.

D. J. Wineland, "Theoretical Calibrations of Fine Structure," presented at Atomic Physics Seminar at Yale University, July 1983.

G. Kamas, "Ask the Experts", National Conference of Standards Laboratories, Boulder, Colorado, July 1983.

S. R. Stein, "The Time and Frequency Program at the National Bureau of Standards," National Association of Watch and Clock Collectors, Inc., Colorado Springs, CO, July 23, 1983.

W. Itano, "Spectroscopy of Laser Cooled and Trapped Ions," Gordon Conference on Atomic Physics, New London, NH, July 5, 1983.

K. M. Evenson, "Tunable Far Infrared Laser Spectroscopy," UNICAMP, Campinas, Brazil, August 5, 1983.

D. J. Wineland, "Spectroscopy of Stored Ions Using Fluorescence Technique," SPIES Conference, San Diego, CA, August 1983.

J. S. Wells, "Heterodyne Frequency Measurements and Frequency Calibration Standards for Tunable Diode Lasers," SPIES Conference, San Diego, CA, August 1983.

K. M. Evenson, "Tunable Far Infrared Laser Spectroscopy," University Southhampton, England, September, 1983.

K. M. Evenson, "Far Infrared Spectroscopy of Free Radicals," 16th International Symposium on Free Radicals, Brussels, Belgium, September 1983.

R. Drullinger, "The Time and Frequency Division of NBS," International Symposium on Time and Frequency, Hangzhou, China, September 1983.

R. Drullinger, "Measuring Visible Frequencies: Redefining the Meter," International Conference on Lasers, Guangzhou, China Sept. 1983.

D. J. Wineland, "Laser Cooling and Ion Frequency Standards," Symposium on Atomic Spectroscopy, Berkeley, CA September 1983.

D. W. Allan, "GPS Common View Time Transfer," Workshop on Time and Frequency, Ottawa, Ontario, Canada October 5-6, 1983.

D. W. Allan, "The Benefits of Ensemble Time for GPS," Defense Mapping Agency, Washington, DC October 1983.

PUBLICATIONS

Time and Frequency Division (524)

(J. A. Barnes), (R. H. Jones), (P. V. Tryon), D. W. Allan, "Stochastic Models for Atomic Clocks," Proceedings of the 14th Annual Precise Time and Time Interval (PTTI) Applications of Planning Meeting at NASA Goddard Space Flight Center, (November 1982).

R. E. Beehler, "GOES Satellite Time Code Dissemination, Proceedings of the 14th Annual Precise Time and Time Interval Applications and Planning Meeting at NASA Goddard Space Flight Center, (1982).

D. W. Allan, "Millisecond Pulsar," Letter to Editor, Science, Vol. 220, 776, 1983.

K. M. Evenson, D. A. Jennings, F. R. Petersen, R. E. Drullinger, "Optical Frequency Synthesis Spectroscopy," Proceedings of Workshop on Spectroscopic Applications of Slow Atomic Beams, Gaithersburg, MD, 27-37, (April 1983).

D. J. Wineland, Wayne Itano, J. C. Bergquist, "Frequency Standard Research Using Stored Ions," Proc. of Workshop on Spectroscopic Applications of Slow Atomic Beams, Gaithersburg, MD, 1926, (April 1983).

L. Lewis, "Limitations of Atomic Beam Frequency Standards," Proceedings of Workshop on Spectroscopic Applications of Slow Atomic Beams, Gaithersburg, MD, 38-46, (April 1983).

S. R. Stein, "The Design of Atomic Frequency Standards and Their Performance in Specific Applications," Proceedings of Workshop on Spectroscopic Applications of Slow Atomic Beams, Gaithersburg, MD 9-18, (April 1983).

(E. C. C. Vasconcellos), (J. C. Wyss), F. R. Petersen, K. M. Evenson, "Frequency Measurements of Far Infrared cw Lasing Lines in Optically Pumped $CHC\ell_2F$," International Journal of Infrared and Millimeter Waves, Vol. 4, No. 3, 401-6, (1983).

D. J. Wineland, J J. Bollinger, Wayne M. Itano, "Laser Fluorescence Mass Spectroscopy," Physical Review Letters, Vol. 50 No. 9, 628-631, (1983).

M. Weiss, "Position Location Using Sequential GPS Measurements," Record of Plans 82 Conference, September 29, 1982.

J. S. Wells, F. R. Petersen, A. G. Maki, "Heterodyne Frequency Measurements of Carbonyl Sulfide Transitions at 26 and 51 THz, Improved OCS, $O^{13}S$ and OC^{34} Molecular Constants," Journal of Molecular Spectroscopy 98, 104-412 (1983).

R. E. Drullinger, K. M. Evenson, D. A. Jennings, F. R. Petersen, J. C. Bergquist, L. Burkins, and H.-U. Daniel, "2.5 THz Frequency Difference Measurements in the Visible Using Metal-Insulator-Metal Diodes," Appl. Phys. Lett. 42, 137 (1983).

J. Levine, Design of a Deep Borehole Tiltmeter, Proc. 9th International Symposium on Earth Tides, New York, 1981, 273-281. Published by E. Schweizerbart'sche Verlagsbuchhandlung, D-7000 Stuttgart, FRG, 1983.

J. Levine, "Performance of a Deep Borehole Tiltmeter," Proc. 9th International Conference on Earth Tides, New York, 1981, 47-57. Published by E. Schweizerbart'sche Verlagsbuchhandlung, D-7000 Stuttgart, FRG, 1983.

J. Levine, "Multiple Wavelength Geodesy, Proc. 9th GEOP Conference, 99-102, (1978).

(Hamid Hemmati), J. C. Bergquist, Wayne Itano, "Generation of cw 194 Radiation by Sum Frequency Mixing in an External Ring Cavity," Optics Letters, No.2, 73-75 (1983).

(J. M. Brown), K. M. Evenson, "The Microwave and Far Infared Spectra of the CH Radical," The Astrophysical Journal, 268: L51-L56, (May 1983).

Wayne Itano, D. J. Wineland, (Hamid Hemmati), J. C. Bergquist, J. J. Bollinger, "Time and Frequency Standards Based on Charged Particle Trapping," IEEE Transactions of Nuclear Science, Vol. NS-30, No. 2, 1521-1523 (1983).

D. A. Jennings, C. R. Pollock, F. R. Petersen, R. E. Drullinger, K. M. Evenson, E. C. Beaty, J. S. Wells, J. L. Hall, H. P. Layer, "Direct Frequency Measurement of the I_2 Stabilized He-Ne THz Laser," Optics Letters, 8, 136 (1983).

C. R. Pollock, D. A. Jennings, F. R. Petersen, J. S. Wells, R. E. Drullinger, E. C. Beaty, K. M. Evenson," Direct Frequency Measurements of Transitions at 520 THz (576 nm) in Iodine and 260 THz (1.15 μm) in Neon," Opt. Lett. 8, 133 (1983).

(J. A. Barnes), (R. H. Jones), (P. V. Tryon), D. W. Allan, "Noise Models for Atomic Clocks," Proceedings of the 14th Annual Precise Time and Time Interval Applications and Planning Meeting (PTTI).

D. A. Howe and F. L. Walls, "A Compact Hydrogen Maser with Exceptional Long-Term Stability," IEEE Trans. On Instrumentation and Measurement, Vol. IM-32, No. 11, 218 (March 1983).

S. R. Stein, D. Glaze, J. Levine, J. Gray, D. Hilliard, D. Howe and (L. Erb), "Automated High-Accuracy Phase Measurement System," IEEE Transactions on Instrumentation and Measurement, Vol. IM-32, No. 1, 227 (March 1983).

J. C. Bergquist, H. Hemmati, and W. M. Itano, "High Power Second Harmonic Generation of 257 nm Radiation in an External Ring Cavity," Optics Communications, Vol. 43, 437-442 (1982).

W. M. Itano, "Chemical Shift Correction to the Knight Shift in Beryllium," Physical Review B, Vol. 27, 1906-1907.

PUBLICATIONS IN PROCESS

To Be Published

D. J. Wineland, Wayne M. Itano, J. J. Bollinger, J. C. Bergquist, H. Hemmati, "Spectroscopy of Stored Ions Using Fluorescence Techniques", Proceedings SPIE Conference on Laser Based Ultrasensitive Spectroscopy and Detection.

(J. J. Gagnepain), (M. Olivier), F. L. Walls, "Excess Noise in Quartz Crystal Resonators," Proceedings of the 37th Annual Frequency Control Symposium.

R. E. Drullinger, "The Time and Frequency Division of NBS", Proceedings of the International Conference on Time and Frequency, Hangzhou, China, (Sept. 1983).

R. Drullinger, "Measuring Visible Frequencies: Redefining the Meter," Proceedings of the International Conference on Lasers, Guangzhou, China, Sept. 1983.

J. S. Wells, F. R. Petersen, "Calibration Standards for Tunable Diode Lasers," Proceedings of SPIE's 27th Annual International Technical Symposium.

(Trevor J. Sears), (A. R. W. McKellar), (P. R. Bunker), K. M. Evenson, (J. M. Brown), "Infrared and Far Infrared Transition Frequencies for the CH_2 Radical" Astrophysical Journal of Letters.

(H. Hemmati), J. C. Bergquist, "Generation of Continuous Wave 243 Radiation by Sum Frequency Mixing," Optics Communications.

D. W. Allan, "National and International Time and Frequency Comparisons," 37th Annual Frequency Control Symposium.

J. J. Bollinger, Wayne Itano, D. J. Wineland, "Accurate Laser Cooled Beryllium Ion Clock, Proceedings of the 37th Annual Frequency Control Symposium.

(Mazataka Mizushima), K. M. Evenson, (J. A. Mucha), D. A. Jennings, (J. M. Brown), "Laser Magnetic Resonance of the O_2 Molecule at 699 μm," Journal of Molecular Spectroscopy.

(Masimo Inguscio), K. M. Evenson, "Direct Measurement of the $^3P_o-3^3P$, Fine Structure Splitting and the g-Factor of Atomic Silicon by Laser Magnetic Resonance," Astrophysical Journal of Letters.

(P. R. Bunker), (Trevor J. Sears), (A. R. W. McKellar), K. M. Evenson, (P. J. Lovas), "The Rotational Spectrum of the CD_2 Radical Studied by Far Infrared Laser Magnetic Resonance," Journal of Chemical Physics.

G. Kamas, J. L. Jespersen, "A New Frequency Calibration Service Offered by The National Bureau of Standards," 37th Annual Frequency Control Symposium.

D. A. Jennings, R. E. Drullinger, K. M. Evenson, R. F. Petersen, J. S. Wells, "The Speed of Visible Light," Physical Review Letters.

C. R. Pollock, F. R. Petersen, D. A. Jennings, J. S. Wells, A. G. Maki, "Absolute Frequency Measurements of the 2-0 Band of CO at 2.3 μm; Calibration Standard Frequencies from High Resolution Color Center Laser Spectroscopy. J. Mol. Spectrosc. 99, 357 (1983).

R. E. Drullinger, K. M. Evenson, D. A. Jennings, F. R. Petersen, J. C. Bergquist, Lee Burkins, and H.-U. Daniel," 2.5 THz Frequency Difference Measurements in the Visible Using Metal-Insulator-Metal Diodes," Appl. Phys. Lett. 42, 137 (1983).

J. J. Bollinger, D. J. Wineland, Wayne M. Itano, J. S. Wells, "Precision Measurements of Laser Cooled $^9Be^+$ Ions," Proceedings of the 6th International Conference on Laser Spectroscopy.

D. J. Wineland, Wayne M. Itano, (R. S. Van Dyke Jr.), "High Resolution Spectroscopy of Stored Ions," Advances in Atomic and Molecular Physics.

(M. A. Zumberge), (J. E. Faller), (J. Gscwind), "Results from a United States Absolute Gravity Survey," Journal of Geophysical Research.

(J. M. Brown), K. M. Evenson, "The Far Infrared Laser Magnetic Resonance Spectrum of the CH Radical and Determination of Ground State Parameters," Journal of Molecular Spectroscopy.

D. W. Allan, "Frequency and Time Coordination", Chapter 13, Precision Frequency Control.

F. L. Walls, J. J. Gagnepain, "Special Applications", Chapter 15, Precision Frequency Control.

F. L. Walls, Chapter 14 "Other Means for Precision Frequency Control", Precision Frequency Control.

D. J. Glaze, S. R. Stein, "Pico Second Time Difference Measurements Utilizing CAMAC Based IEEE-488 Acquisition Hardware", NBS Tech Note No. 1056.

(Trevor J. Sears), (P. R. Bunker), (A. R. W. McKellar), K. M. Evenson, (J. M. Brown), "The Far Infrared Laser Magnetic Resonance Spectrum of the Methylene Radical CH_2," Journal of Chemical Spectroscopy and the Royal Society of Chemistry.

K. B. Persson, "A Derivation of Schroedinger's Equations from Classical Physics," American Journal of Physics.

D. J. Wineland, "Spectroscopy of Stored Ions Using Fluorescence Technique," Proceedings of SPIES Conference, San Diego, CA.

S. R. Stein, "Frequency and Time, Their Measurement and Characterization," Chapter 12, Precision Frequency Control.

F. R. Petersen, E. C. Beaty, C. R. Pollock, "Improved Rovibrational Constants and Frequency Tables for the Normal Laser Bands of $^{12}C^{16}O_2$," J. Mol. Spectrosc. 102, xxx-xxx (1983).

F. R. Petersen, J. S. Wells, K. J. Siemsen, A. M. Robinson, and A. G. Maki, "Heterodyne Frequency Measurements and Analysis of CO_2 Laser Hot Band Transitions," J. Mol. Spectrosc.

F. R. Petersen, J. S. Wells, and A. G. Maki, "Improved Deuterium Bromide 1-0 Band Molecular Constants from Heterodyne Frequency Measurements," J. Mol. Spectrosc.

C. R. Pollock, F. R. Petersen, D. A. Jennings, J. S. Wells, and A. G. Maki, "Absolute Frequency Measurements of the $00^{0}2$-$00^{0}0$, $20^{0}1$-$00^{0}0$, and $12^{0}1$-$00^{0}0$ Bands of N_2O by Heterodyne Spectroscopy," J. Mol. Spectrosc.

R. J. Saykally, K. M. Evenson, D. A. Jennings, and F. R. Petersen, "Frequency Measurements of cw FIR Lasing Transitions in CD_3OH," Int. J. of Infrared and mm Waves.

K. M. Evenson, M. Inguscio, D. A. Jennings, and F. R. Petersen, "The Point Contact Diode at Laser Frequencies," Appl. Phys. Lett.

M. Inguscio, F. R. Petersen, and K. M. Evenson, "Pressure Effects on the Frequency of cw Optically Pumped FIR Lasers."

H. Hemmati, J. C. Bergquist, and W. M. Itano, "Sum Frequency Generation of Narrowband cw 194 nm Radiation in Potassium Pentaborate", Proceedings of the 6th International Conference on Laser Spectroscopy.

D. W. Allan, D. Glaze, J. E. Gray, R. Jones, J. Levine, and S. R. Stein, "Recent Improvement in the Atomic Time Scales of the National Bureau of Standards," Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1983.

D. W. Allan and M. Weiss, "Separating the Variances of Noise Components in the Global Positioning System," Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1983.

D. W. Allan, "Clock Characterization Tutorial," Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1983.

G. Kamas, "Ask the Experts," Proceedings of the National Conference of Standards Laboratories," July 1983.

S. R. Stein, G. Kamas, and D. W. Allan, "New Time and Frequency Dissemination Services at the National Bureau of Standards," Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 1983.

(E. N. Forston) and L. L Lewis, "Atomic Parity Nonconservation Experiments," Physics Reports.

SEMINARS ORGANIZED

Time and Frequency Division (524)

<u>Seminar on Frequency Standards & Clocks</u>, July 14 and 15, 1983, Boulder, Colorado.

<u>Seminar on Frequency Measurements & Calibrations</u>, October 25, 26, and 27, 1983, Boulder, Colorado.

SPECIAL REPORTS

"National Bureau of Standards Global Positioning System (GPS) Users Manual," M. Weiss, D. Davis, and D. Allan, 1983.

"Investigation of the Hydrogen Source for Masers," K. B. Persson and F. L. Walls. Prepared in fulfillment of Navy contract.

"The Optically Pumped Alkali Beam/Cell and Beam Tube for Utility Atomic Frequency Standards," Mark Feldman. Prepared for Dept. of the Air Force, Rome Air Development Center.

"A Breadboard Optically Pumped Cesium Beam Frequency Standard," L. Lewis. Prepared for Dept. of the Air Force, Rome Air Development Center, RADC/ESE (Contract No. RADC 83-11.)

"Separating the Variances of Noise Components in the Global Positioning System," D. W. Allan. Prepared for Air Force Space Division, Los Angeles Air Force Station, Los Angeles, CA 90009.

"Laser Diode Characterization Program," L. L. Lewis, Special Division Report.

"Laser Diode Evaluation," L. L. Lewis and M. Feldman. Prepared for Dept. of the Air Force, Space Division/YEC (Contract No. SD30039).

"Recirculating Cesium Oven Development," R. Drullinger and D. Glaze. Prepared for Dept. of the Air Force, Space Division/YEC (Contract No.30039).

"Commercial Cesium Oven Characterization," D. Glaze. Prepared for Naval Research Laboratory (Contract No. N00173-83-F-D098).

"Industrial Time Service--Plan for a Feasibility Study," D. W. Hanson.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Time and Frequency Division (524)

D. W. Allan, Study Group VII, International Radio Consultative Committee (CCIR).

D. W. Allan, IEEE IM TC-3 Frequency and Time.

D. W. Allan, 1982 PTTI Program Committee.

D. W. Allan, NASA Team Member for Shuttle Timing experiment.

D. W. Allan, International Astronomical Union member.

R. E. Beehler, CCIR Study Group 7; International Chairman of Interim Working Party 7/4 on "Improved Time Coordination and Dissemination Using Satellites".

R. E. Beehler, 1983 SFC Technical Program Committee.

K. M. Evenson, URSI Commission D.

K. M. Evenson, Chairman for next Free Radical Meeting.

D. A. Jennings, Member CCDM

D. W. Hanson, Member Technical Advisory Committee for TDRSS, NASA Satellite Program.

J. L. Jespersen, Chairman IRIG Timing Committee.

G. Kamas, Measurement Assurance Subcommittee, National Conference of Standards Laboratories.

J. Levine, Microprocessor Standards Action Group.

J. Levin, Chairman, Electronic Shops.

J. Levine, Computing Policy Committee, Colorado University.

J. Levine, Computing Allocation Committee, Colorado University.

J. Levine, Taskforce on Library Automotion (CAR2), Colorado University.

J. Levine, National Academy of Sciences, Committee on Geodesy.

S. R. Stein, Consultative Committee for the Definition of the Second (CCDS), CCIR.

S. R. Stein, Committee fo MIL-C-3098 revision.

S. R. Stein, Executive Committee, PTTI Applications and Planning Meeting.

S. R. Stein, Chairman Technical Program Committee, Frequency Control Symposium.

S. R. Stein, MNL Merit Pay Performance Review Panel.

D. J. Wineland, Committee for NBS Precision Measurements Grants.

D. J. Wineland, Program Committee of the Division of Electron and Atomic Physics, American Physical Society.

QUANTUM PHYSICS DIVISION

SUMMARY OF ACTIVITIES

Fiscal Year 1983

I. OVERVIEW

The Quantum Physics Division (QPD) was created as the vehicle for the NBS participation in the Joint Institute for Laboratory Astrophysics (JILA), which is a cooperative enterprise of the National Bureau of Standards and the University of Colorado. The statement of mission says that the division:

- Engages in research in atomic and molecular physics at the forefront of the field and performs basic, highly accurate measurements and theoretical analyses that help establish a reliable foundation for scientific and technological measurements and data.
- Performs work such as the measurement of natural constants, the development of new basic standards and the determination of key data and processes in atomic and molecular physics.
- Maintains, through its associaton with the University of Colorado and through its Visiting Scientist Program, active contact with and experience in advanced research in physics.
- Disseminates information of its scientific activities to other areas of NBS through visits and longer-term interchange of personnel.

When JILA was formed twenty-one years ago, "Laboratory Astrophysics" focused special attention on aspects of astronomy and atomic physics which were relevant to the well-defined national interest in space which prevailed at that time. However, since its inception, JILA has responded to the changing national needs and to the requirements of its parent organizations. The association of atomic and molecular science and astrophysics at JILA has been mutually beneficial. Experimental and theoretical contributions have been made not only to these areas but also to laser physics, precision measurements, geophysics, and data and measurements necessary for new energy sources; to the collection and evaluation of scientific data; and to the education of scientists. The need for JILA to be dynamic in its focus and programs was stated in the Amendment to the Memorandum of Understanding signed in 1976 by NBS and CU. The QPD is one of the divisions in NBS with heaviest emphasis on basic research and the advancement of measurement science from a fundamental point of view, and the ability to carry this out is emphatically enhanced and leveraged by the location of the QPD on the CU campus and participation of doctoral and postdoctoral students.

The Quantum Physics Division currently has substantial research programs in five general areas:

1. Fundamental and precision measurements.

2. Geophysical measurement methods.

3. Chemical Physics.

4. Atomic and molecular physics and interactions.

5. Astrophysical measurement.

Activities in these areas will be discussed in Section II, Technical Activities, later, but a portion of the highlights for the past year are worth noting here.

- One of the most exciting developments is the careful measurements of the small shift ($\sim 10^3$ Hz out of 10^{15} Hz) of Rydberg energy levels due to their strong radiative coupling with ambient thermal radiation fields.

- Another outstanding event was the first direct observation and measurement of the important process of dielectronic recombination, showing a substantial and important disagreement with theory.

- A notable discovery was that the SiH_3 radical and H_2 and SiH_3 based chain-reactions dominate silane discharges and the deposition of amorphous silicon films. There are strong and far-reaching implications from these studies relating not only to silane pyrolysis, but the pyrolysis of hydrocarbons as well.

- A successful collaboration with Bell Laboratories has led to a very precise ($<10^{-8}$) measurement of the 1^3S-2^3S spacing in the very fundamental and exotic atom, positronium.

- First-ever results were obtained for fully state-resolved thermal energy charge transfer reactions under single collision conditions.

- Dramatic patterns in angular distributions of photoelectrons from two-photon photoionization of alkaline earth atoms show clearly the effects of state mixing, and the deduced mixing coefficients are an excellent test of the important multi-channel quantum defect theory.

Currently, there are 172 total personnel in JILA distributed according to Figure 1. This figure fluctuates substantially over a year's time, since there is an annual scientific turnover of 40 to 50 persons.

One notes from the figure that of the 138 research scientists in JILA, that 97 (or 70%) are postdoctorals and students. Another 16 are visitors, for a total of 113 (or 82%) students, postdoctorals, and visitors. There is thus a high level of youthful vitality and turnover in the scientific staff, while providing at the same time for stability, maturity, and focus of programs through the Fellows of JILA. As envisioned in the establishment of the Institute, both NBS and CU continue to benefit from the "partnership." The University gains a large community of international scholars (Visiting Fellows Program) and a substantial adjoint faculty which trains graduate students, teaches courses, serves on committees, etc. These roles are more completely detailed elsewhere in this report. The Bureau of Standards gains the scientific activity and productivity of 70-80 scientists through the supervisory activities of the core 14 senior NBS Fellows -- thus the Bureau enjoys a very leveraged operation. NBS Fellows currently supervise 28 graduate students working on Ph.D.'s, supervise 28 postdoctorals, and enjoy the direct collaboration of more than a dozen visiting scientists.

The permanent Ph.D. Staff or "Fellows of JILA" of which there are 24 form a collegial governing body which sets policy subject to review by the Director of NBS and President of CU. A Chairman of the Fellows is elected bi-annually as the principal officer of the Institute, and is responsible for operating the Institute within the limits of policy set forth by the Fellows. As of January 1983, the Chairman of JILA is Dr. David Norcross. An Executive Committee assists the Chairman with policy matters of shorter duration or lesser moment than would command attention of the Fellows, and the Executive Officer deals with most administrative matters as delegated by the Chairman. Of the 24 Fellows, 10 are CU full-time faculty from the Departments of Physics, Chemistry, and Astro-Geophysics, 13 are NBS employees in the QPD, and 1 is an NBS employee in the Time and Frequency Division. NBS Fellows hold adjoint appointments in one of the three academic departments. While sharing responsibility for the success of the Institute, the NBS and the University of Colorado each has full operational responsibility for its own employees who are physically located in and hold positions as Fellows or Members of JILA. Thus, these parent bodies apply exactly the same personnel review and reassignment procedures to each staff member in JILA as would be applied to the

JILA STAFFING

1983 - 1984

TOTAL - 172

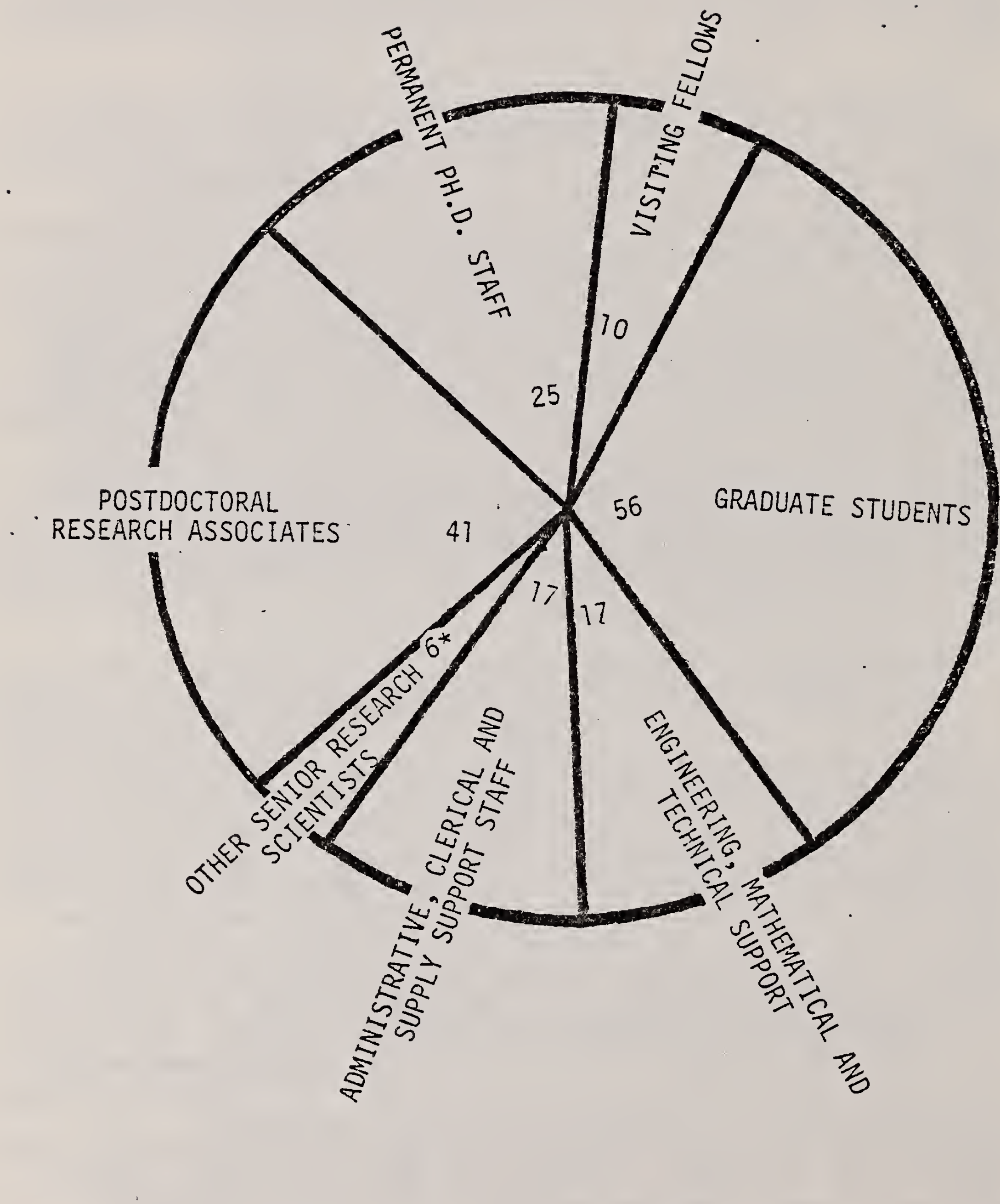

Fig. 1.

same staff member were that person rostered in another administrative unit and location, without consideration of any special privileges or liabilities deriving from participation in JILA or from designation as a Fellow.

Dr. Katharine Gebbie (NBS) is still inactive as a Fellow of JILA while on temporary assignment (1981-1983) to NBS Gaithersburg. Dr. William Reinhardt (CU) returned to JILA this fall after a year at NBS Gaithersburg as the first NBS-JILA exchange Fellow. Drs. Peter Conti (CU) and Richard McCray (CU) are on Sabbatical leave this year and are inactive as Fellows of JILA. Dr. Mitch Begelman (CU) was hired into the Department of Astrophysical, Planetary, and Atmospheric Sciences (formerly Astrogeophysics) as a Member of JILA, with one of the recently vacated "slots" in mind. Dr. Keith Burnett (CU), elected a Fellow of JILA last year, will be going on leave during the next year to Imperial College, where he has taken a faculty position. Recruitment of a faculty position in Physics with membership in JILA was conducted during the past year. After screening a large field of candidates, no offer was made, and recruiting will begin anew this year.

In accordance with the Advisory Panel advice, JILA has evaluated its posture relative to computing during the past year, and decided that a modern mid-sized computer will serve the needs of the Institute most effectively. A proposal to NSF and several other agencies with a strong matching funds component from the University has been sent out.

The Visiting Fellows Program is one of the most important parts of the Institute, bringing 10 distinguished scientsits to the Institute each year on a competitive basis. NBS management recognizes the value of the program and has provided inflationary increases to the budget, allowing the program to stay vigorous. Last year was the first JILA-NBS Gaithersburg Visiting Fellow exchange. Dr. Bill Reinhardt of JILA was in residence at NBS Gaithersburg for the past year. This year Dr. James Snyder of NBS Gaithersburg is in residence at JILA as the exchange fellow.

An essential component of the operation of the Institute as a whole is the NSF group grant. This grant, which is subjected to direct approval of the National Science Board, was renewed last year for a four-year period after very favorable peer reviews from the atomic and molecular physics community.

The productivity of the Institute as measured in terms of publications remains high. Figure 2 shows a plot of numbers of publications versus year. There have been over 2700 titles published from JILA over its 21-year history, and over 15,000 requests are received per year for reprints. Of course, not only numbers, but quality, creativity, and impact must be considered in truly measuring productivity. The more detailed discussion of the technical programs, publications, and activities of the Quantum Physics Division in Sections II and III will help to demonstrate these dimensions of productivity.

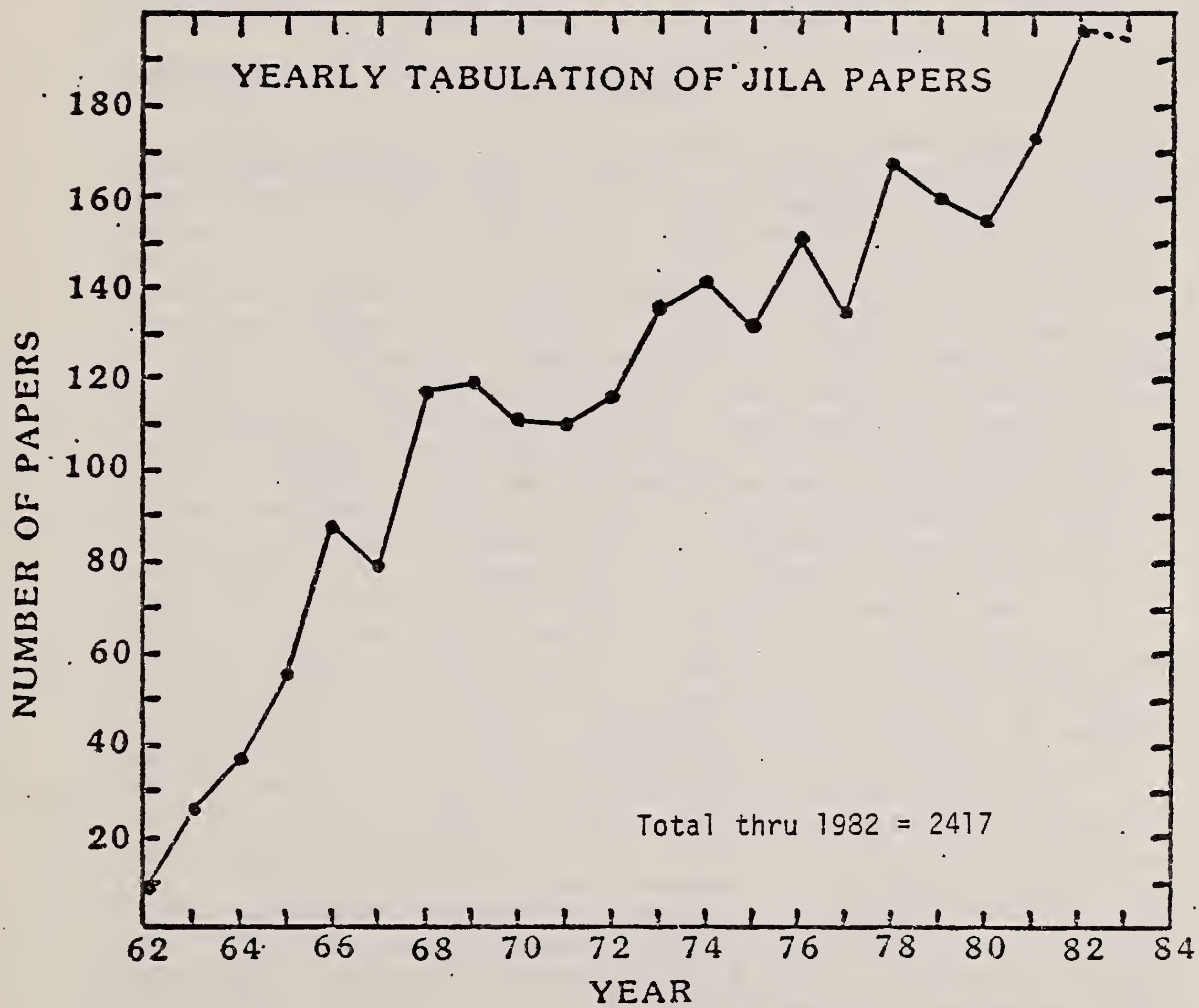
YEARLY TABULATION OF JILA PAPERS
NUMBER OF PAPERS
180
160
140
120
100
80
60
40
20
Total thru 1982 = 2417
62
64
66
68
70
72
74
76
78
80
82
84
YEAR

Fig. 2.

II. TECHNICAL ACTIVITIES

This section contains brief narrative descriptions of research programs currently underway or recently completed. An alternative insight to these activities can be gained by reference to Sec. III where tables are found of publications, invited talks, Visiting Fellows, and seminars and colloquia, academic activities of NBS personnel, consulting, and technical and professional committee participation and leadership.

Fundamental and Precision Measurements

Black-body shift. One of the most exciting developments is the careful measurement by J.L. Hall and L. Hollberg of the small shift of Rydberg energy levels due to their strong radiative coupling with ambient thermal radiation fields. Laser frequency control certainly has been the principal difficulty in this work in the past, as the Rydberg atom level shifts amount only to 1 or 2 kHz out of the transition frequency of 10^{15} Hz. A powerful spectroscopic method can be based on the use of rf phase-modulation of the external laser beam to produce rf sidebands on the light. The frequency of modulation is sufficiently high that essentially no laser amplitude noise of a technical nature is able to contaminate the observed signals. The signal/noise ratios obtained are excellent and allow unprecedented accuracy and precision in locking the cw dye laser relative to an iodine absorption reference line. A programmable frequency synthesizer driving an acousto-optic frequency shifter unit allows tuning the highly stable dye laser relative to the I_2 line. A stability of a few kHz for months is available along with sub kHz linewidth and short-term stability. With this dye laser source it has been possible to carefully study the shift of the Rb Rydberg energy level 36S using the method of two-photon Ramsey fringes. To emphasize the role of the ir radiation in causing shifts and decays of the Rydberg levels, Hollberg and Hall arranged a higher temperature black-body source inside the atomic beam vacuum system. A chopper alternately blocks and passes this radiation in synchronism with the laser frequency steps and signal averager channel advance steps. Typical two-photon Ramsey-fringe responses are shown in Fig 1, where part A shows the central Ramsey-fringe and one of the 10 surrounding Zeeman-split neighboring fringes. Part B shows a 3x expanded view of this central fringe. Parts C & D show further 4-fold-expanded traces of the central fringe, in C with the chopper stopped and open, and in D with the chopper functioning. Least squares fits give a shift of 1420 ± 140 Hz at the laser frequency due to the black-body radiation field. Shifts of this type are known to be present even in the primary standard of frequency, the cesium atomic beam tube.

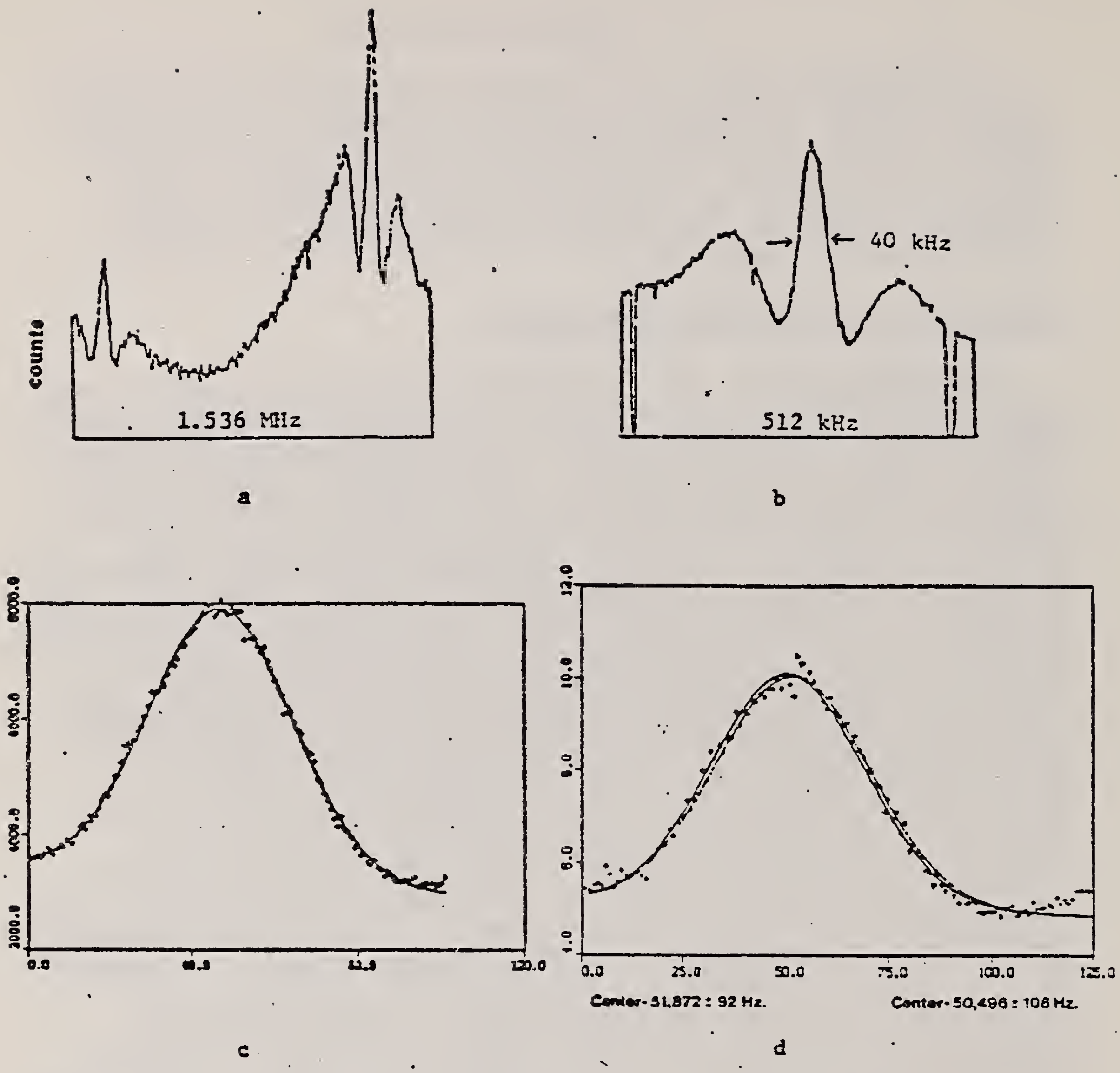

Fig. 1.
Ramsey profiles of Rb 5S-36S F=3 two-photon transition at 5954.2952 Å
a) Scan over central and first neighboring Zeeman componenets. b) Expanded sweep (3x) of central $|m_F|$ = 3 Ramsey component. Note asymmetry due to laser ac Stark effect. A few points are missing due to brief unlock of cavity buildup. c) Central Ramsey fringe taken at 800 Hz/channel at the laser frequency. Blackbody source on, chopper open. d) Central Ramsey fringe, 1 kHz/channel. Chopper synchronized with laser steps and channel advance. Blackbody temperature 875 K. Odd channels (chopper open) are shifted by the blackbody radiation relative to even channels (chopper blocking). Least-squares fits give 1420±140 Hz shift at the laser frequency.

During the next year this work will be replaced with a new start on atomic beam slowing, using a frequency-swept laser, in collaboration of Hall with W.D. Phillips at NBSG.

High Resolution IR Spectra. A second area of "delicious" physical results from Hall's group is the study of rotational-vibrational state dependance of hyperfine coupling "constants" in the HF molecule, studied with a frequency-controlled color center laser. The HF ro-vibronic spectrum is very strong and occurs in the 2.6 μm region where a powerful stabilized laser would be of considerable use in science and metrology, for example in forming one route to the visible -- from CO_2 or the superb OsO_4 transitions known in the 10 μm spectral region. Thus study of the hyperfine and recoil spectra of HF was a natural preliminary to the ultimate use of the HF-stabilized color center laser. The two spin 1/2 nuclei H and F can combine to give 4 states as may be seen from the spectrum of Fig 2. The additional lines arise as "cross-over" lines in our nonlinear optical heterodyne saturation spectroscopy technique. The principal hyperfine interaction energies are the spin-rotation coupling of each nuclei with the rotation. Basically the rotation, taken with a bit of admixed ionic wavefunction, leads to a magnetic field at the fluorine site for example, due to the moving proton. The observed interaction is the result of vibrational averaging over the dynamically-evolving electronic distributions as a function of the instantaneous internuclear separation. Factors which affect this averaging, such as increase of the average internuclear separation with vibrational excitation, give remarkably large effects since the vibrational potential for HF is so strongly anharmonic. For example about a dozen terms are needed in a Dunham expansion to give a reasonable accord with the observed ir ro-vibrational spectrum. Even so it is surprising to find that the hyperfine coupling constant C_f increases 17% with vibrational excitation. Even the zero-point vibrations increase the value 6% over the stationary nuclei value at the minimum of the Hartree-Fock potential curve. These high resolution laser methods show a clear dependence for C_H also, -3% for $v=0 \rightarrow v=1$. In this work we have a really remarkable glimpse inside the operation of the Born-Oppenheimer approximation. This work was started several years ago by Hall in collaboration with T. Baer and D. Nesbitt, and excellent sequential postdocs whose energies were mostly directed to stabilizing the color center laser, building up the ir optical heterodyne spectrometer system, and getting the first spectra. The HF work was completed this year by Ch. Breant, a superb advanced-level student from Villetaneuse, France.

Laser Stabilization. One interesting advance from J. Hall's group in producing a relatively simple laser system for metrology has been provided by a suggestion by a theoretical consultant (J. Shirley) in combination with the superb experimental skills of a visiting professor from Shanghai. The idea is ultimately closely related to some of the published 4-wave mixing schemes, for example the work of the Paris group (J.J. Snyder, et al). Basically, we lock for rf modulation transferred onto a laser beam by molecules which are also exposed to a strong FM-modulated counter-running saturating beam. This system operates at the shot noise limit and so is incredibly sensitive. For example the S/N ratio on the usual 612nm I_2

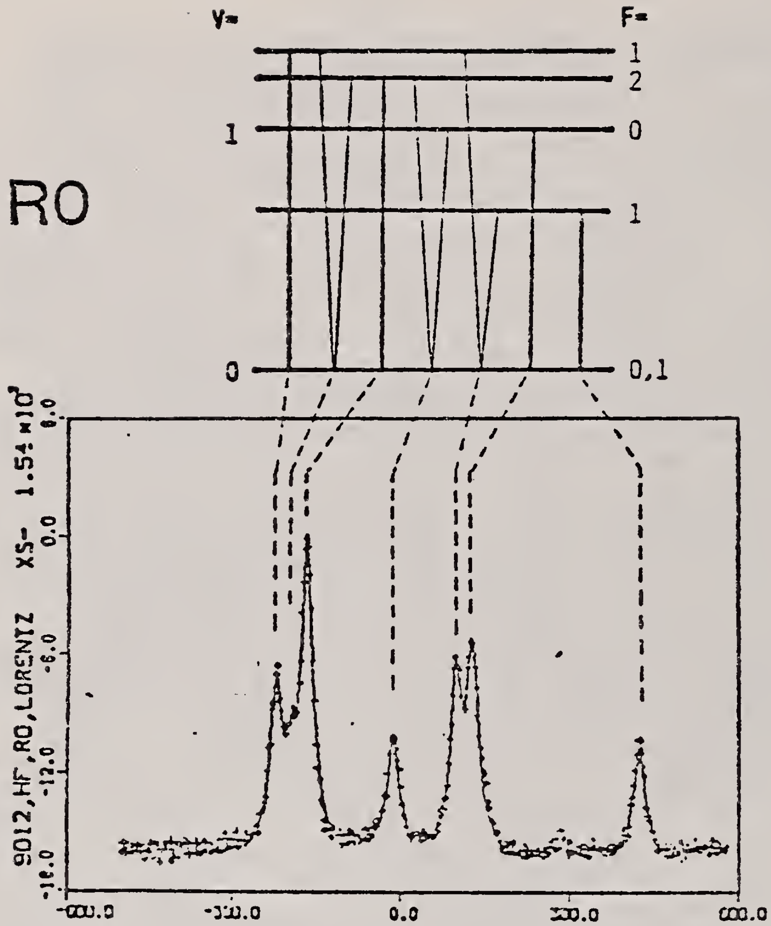

Fig. 2. R(0) spectrum, showing origins of four main transitions and three "crossing" (three-level) resonances. Width - 12.24 kHz HWHM. Data are represented by + symbols, while the full line is a least-squares fit with Lorentizian shapes. Frequency axis in kHz.

metrological line can be 250:1 in a 10 kHz bandwidth for a cell located outside the laser resonator! Proper stabilization to this resonance would give a few Hz stability at 1 second. Perhaps equally important, the resonances obtained are ideally antisymmetric with no underlying Doppler background or offsets due to scattered saturating beam light. In this regard the new system represents a major step relative to both our previous work on optical heterodyne spectroscopy and the French work on 4-wave mixing. The first experimental test beating with the dye laser reference was not completely satisfactory due to excessive noise in the dye laser system, reaching a stability level of "only" 300 Hz. After the vibration-shielded environment is ready we will try the Ar^+ stable laser with the excellent I_2 lines at 514.5nm and 501.7nm. We have already shown accuracy capability in the sub kHz domain -- a factor of about 100 fold improvement over today's I_2-stabilized lasers. A patent disclosure and application on this technique are in preparation. The Zeeman-stabilized laser patent finally was issued after almost two years' delay.

Another major activity of J. Hall's labs has been the attempt to push the laser stabilization toward or to the fundamental limit, set in our system by photoelectron shot noise. This work has been guided in part by Dr. J. Hough a visiting Fellow from Glasgow. Two independent dye lasers have been stabilized onto their own independent high finesse Fabry-Perot reference etalons, with the performance being judged by frequency and time domain analysis of the resulting optical beat signals between the two lasers. Of course vibrations and acoustic disturbances are the most troublesome, but a clever pendulum suspension introduced by Hough vastly reduced the coupling of floor vibrations into the cavity reference system. The final results are still totally dominated by remediable problems, but show an interesting level of performance: The lasers are separately locked to their cavities with Hertz-level stability, but the optical reference cavities are still being vibrated "strongly." The overall result is a linewidth of $\sim$250Hz with a discrete building vibration at $\sim$29Hz causing a 700Hz excursion. We are now planning to build a better vibration-shielded room, and use a more suitable laser system (Ar^+ laser) for the experiments. Analysis shows the ready prospect for sub-Hertz stability for a few seconds' averaging. Applications to gravity wave detector research elsewhere (Cal Tech, MIT, Munich) are immediate. The projected results will also form an important underpinning of the JILA proposal now being discussed to build a million kilometer gravity wave antennae in space as discussed below (P.L. Bender, J.E. Faller, and J.L. Hall). Finally, this sub Hz level of laser performance is absolutely required by the present radiative cooling experiments on Hg^+ now underway at NBS (Wineland and Bergquist). Additionally, assuming we are successful in radiatively-cooling atomic beams, this level of performance will be needed for investigation of several optical frequency standard candidate transitions including Ca (657nm), Ba (878nm) and the two-photon line in Ag (661nm).

Positronium wavelength. J. Hall has been part of a highly successful outside collaboration with two Bell Labs scientists, A. Mills and S. Chu, in which the objective is to provide high accuracy measurements of the optical energy levels of Positronium. This purely leptonic atom is free of proton structure effects which cause uncertainty in the evaluation for hydrogen of QED interactions such as the Lamb shift. Therefore high accuracy data on the optical energy levels of Positronium represents a whole new and very powerful area for the continuing dialogue between QED theory and experiment. On the other hand, the central approximation is not valid for Ps since the positron and electron are equally massive. Thus, the Dirac equation solutions are unavailable and our basic intellectual poverty is exposed by the need for massive perturbative or expansion techniques to address the fundamental two-body Coulomb problem. Experimentally the measurements rest on the development (by A. Mills) over a dozen years of an effective source of slow positronium atoms--about 3 or 10 such atoms are in the detection volume illuminated on each laser pulse. The laser system (due to S. Chu) and metrology concept (due to S. Chu & JLH 11) involve a continuously operating dye laser at 486nm. This frequency stabilized and precisely tuneable laser feeds a chain of pulsed dye amplifier modules to bring the pulse power up to the multi-Megawatt level needed for the non-linear two-photon Doppler-free absorption $1^3S \rightarrow 2^3S$ in Ps. A plane parallel Fabry-Perot interferometer inside the positronium production chamber serves as a spectral and angular filter for the high power laser beam to narrow the spectral linewidth, and minimize the light's k-vector spread, thereby increasing the measurement precision and accuracy. The Ps two-photon resonance frequency is measured relative to sub Doppler saturated absorption peaks in a Te_2 vapor cell. The 32 MHz offset frequency between Ps and Te_2 is expected to be known to sub MHz accuracy with the removal of the final systematic effects, due to the Relativistic Doppler Effect (Ps is really light!). The wavenumber of the Te_2 line is determined with an expected accuracy of 10 MHz (for the first publication by a JILA-supplied Lambdameter, reference laser, and metrologist at Bell Labs). Later, an ultra accurate Te_2 measurement will be made using the JILA vacuum Lambdameter. We note that Te_2 also has good reference lines near the Deuterium β and Hydrogen β lines. Thus, the JILA high accuracy measurements of Te_2 will be directly useful to ourselves and others (T.W. Hansch and V.W. Hughes) interested in the H, D, Ps comparison. It is interesting that the exotic atom of Ps has required less than 1 1/2 years to go from first observation of its optical spectrum to $< 10^{-8}$ precision measurement -- the long-term investment in developing the powerful tools of precision laser spectroscopy has a clear and dramatic payoff!

Eötvös Experiment. P. Keyser and J. Faller have under construction a large (1.27 m diam) torsion pendulum apparatus with which to test for the equivalence of gravitational and inertial mass. This large Eötvös apparatus utilizes the surrogate fluid fiber which was developed at JILA, and which was used in the earlier (and smaller - 0.25 m diam) Eötvös apparatus of M. Keiser and Faller. The new apparatus is designed to take advantage of sensitivity increase (which scales as the diameter of the apparatus to the five-halves power) with size for this type of apparatus. Construction on the large Eötvös apparatus is now complete and the large system has been successfully floated and periods of up to 4 hours with "reasonable" Q's having been observed. Contamination problems in the fluid limited the initial run to about six weeks. These problems are now thought to be understood. The interaction of aluminum and water is apparently very complex -- depending critically on the particular type of aluminum and also critically on the temperature of the water and whether or not surfactants are present. A number of experimental "fixes" are presently undergoing testing. During the initial run, the system was floated with the upper electrode strucuture in place but without the full lid -- rather a plastic covering was used so as to permit visual (as well as electronic) observation. While we are in the process of testing the various candidate protective surface coatings, we are also machining a series of observational windows (and also holes for periodic flushing of the water and for purging and filling the upper portion with (inert) argon) into the main lid.

Gravitational Waves. Work has continued (P.L. Bender, J.E. Faller) on the feasibility of a future laser gravitational wave detection experiment in space. One major objective is to search for gravitational wave pulses with periods of minutes to a few hours and with fractional strain amplitudes of roughly 10^{-20} or larger. The detection of such pulses would provide an entirely new and unique capability for studying events in the universe that involve very large masses. This includes present collisions of massive black holes, which may exist at the centers of many galaxies and probably provide the energy source for quasars, as well as collisions of such objects during the earlier history of the universe when galaxy formation was taking place. The second objective is to detect continuously emitted gravitational waves from both known and unknown rotating binary stars. The sensitivity needed to be confident of detecting such signals in the period range of minutes to a few hours is 10^{-21} in a one-day measurement interval. The basic concept for the experiment has been described in earlier annual reports. Three test masses in orbit about the sun with separation of 10^6 km or more would be used, and variations in the separations would be determined by laser heterodyne measurements.

D. Hils and Y.M. Chan joined the effort this year, and work during the year concentrated on a collaboration with J. Hough (Visiting Fellow), J.L. Hall, and others on the dye laser stabilization experiments using optical resonators described above.

Continuation of the collaboration to carry out similar experiments with a stability goal of 1 Hz for a 1 sec averaging time is planned. Argon ion lasers would be employed because results for this type of laser can be used directly in the promising ground-based laser gravitational wave experiments now going on at Cal Tech, Munich, Glasgow, MIT, and elsewhere. The space experiments probably would use helium-neon lasers with only a few milliwatts of output power in order to maximize reliability, and such lasers would be easier to stabilize than the argon ion ones.

The demonstration of the very high stability discussed above would aid in providing confidence that short term laser phase jitter would not interfere with the laser heterodyne detection system for the gravitational wave experiments in space. Work also is being started on the design of a short-baseline experiment to demonstrate the sensitivity of the detection method for measuring very small displacements with periods of minutes to hours. For a nominal beat frequency of 1 kHz, the times for approximately 1000 zero crossings would be averaged and used in the later analysis. The desired sensitivity for one case being studied corresponds to 10^{-5} radians in phase, so great care is needed in order to avoid spurious phase effects due to signal level changes or other effects.

An active weekly meeting has been held which has included P. Bender and J. Faller; Visiting Fellows, Erast Gliner, Ken Baird and James Hough; and fifteen to twenty-five student and postdoc participants. These meetings or seminars are serving to more accurately define the problems and issues of this extensive proposed experiment.

Geophysical Measurement Development

Gravity Gradiometer. Recognizing the need in the case of the Eötvös experiment to keep track of changes in the external gravitational field as well as the potential of a fluid-supported pendulum apparatus when properly modified as a gradiometer, Faller is proceeding at present with the testing of two 0.25 m diam fluid gradiometers. This development -- in addition to its importance for the Eötvös work--is seen to have application to tunnel and intrusion detection as well as security for nuclear stockpiles. Commercial applications of these devices for sink holes etc. are being explored. The same aluminum-water interaction problems as discussed above for the Eötvös work also apply to these smaller floats. Indeed, because of the smaller size and therefore shorter turn-around times, they are being used for the various tests to identify the best fix to these problems. Application of these devices to tests of the equivalence of active and passive gravitation mass as well as to tests of the inverse square law of gravitation are under study with a new NRC postdoc: Kerry Hoskins. In addition the construction of a series of somewhat smaller floats fabricated from solid pieces of Al (to give greater mechanical integrity) is under consideration.

Absolute Gravimeter (g). Over this past year, J. Faller has continued the development of a new absolute gravimeter. The absolute determination of g, the acceleration due to the earth's gravity, has long been a measurement of considerable importance. While the value of g continues to play a significant role in the determination of certain physical constants and standards, with the accuracies obtainable today, its measurement now has broad applications to geophysics. A primary concern over the past several years has been the detection, understanding, and elimination of systematic errors. In the Spring of 1982, we used this instrument to carry out a survey at twelve sites in the United States. Over a period of eight weeks, the instrument was driven a distance of nearly 20,000 km to sites in California, New Mexico, Colorado, Wyoming, Maryland, and Massachusetts. The time required to carry out a measurement at each location was typically one day. As a result of this field testing a number of fairly minor instrumental problems and inconveniences were identified. We are correcting these in the new instruments which we are building in connection with the cooperative field programs which we are setting up with institutions in Canada, West Germany, Austria, Finland, China and the USA. Over the next several years, our intention is to see absolute gravity measurements become both useable and used in the field. With the new instruments we are making, we expect to improve (perhaps by a factor of two) on the 6-10 μgal (2 cm height sensitivity) accuracy of our present instrument. Given reasonable success with these new instruments in the field, the last years of this century should see absolute gravity measurement mature both as a new geodetic data type and as a useful geophysical tool.

Geopotential Research Mission Accuracy. The proposed NASA mission called GRAVSAT was described last year. It involved flying two spacecraft about 100 to 300 km apart in the same polar orbit with an altitude of roughly 160 km. The separation between the spacecraft would be measured every 2 to 4 sec with roughly 10^{-4} cm precision. Variation in the satellite-to-satellite distance would be used to determine variations in the earth's gravitational field with a resolution of about 100 km.

The original concept has now been changed to include measurements of the earth's magnetic field on one satellite, and the more currently used is the Geopotential Research Mission (GRM). P. L. Bender has worked with NASA's GRM Data Analysis Group on studying methods for analysing the gravity field data and on improving earlier estimates of the expected accuracy. NBS work suggesting that the power spectrum of the noise involved in the system for measuring the satellite-to-satellite distance might be considerably different than previously assumed was described last year. During FY/83 Bender was asked to investigate the overall noise spectrum and error correlation question, and reported the results to the GRM Data Analysis Group. The conclusion reached is that the power spectrum of the measurement system noise over the frequency range of importance does not follow single models and cannot be determined from available data. Thus additional laboratory measurements on the brassboard system which was assembled earlier are needed. It also was recommended that these measurements should be made at the system signal levels expected in the flight measurements.

The main work during the year by Bender connected with GRM involved the development of a new method for estimating the expected accuracy of the final geopotential information based on various models for the measurement errors. Earlier studies had used the approximation that the relative velocity of the two spacecraft would vary as the difference in potential (ΔT) divided by the average velocity. "($\Delta T/\nu$)" approximation was accurate for most terms in a spherical harmonic expansion of the potential, but breaks down badly for low frequency terms. This included particularly terms which are nearly sectorial. However, different frequency terms for a given degree and order are affected differently, so the low frequency part of the frequency spectrum of the "signal" is changed. A resulting "signal equation" which gave the correct general behavior but still had a small error was produced, and the remaining error was corrected recently by C. C. Goad and C. A. Wagner of the National Geodetic Survey.

The other part of the work was based on ideas developed earlier in discussions with B. Bertotti when he was a JILA Visiting Fellow. The method starts from doing a spherical harmonic decomposition of residuals from the calculated values for the spacecraft separation or relative velocity data. Some prefiltering to correct for the finite spacecraft separation and prewhiten the data is needed. The approximate geopotential can then be solved for using the "$\Delta T/\nu$" approximation. Finally, a matrix based on the correct "signal equation" is used to correct the results. The solution obtained is not strictly optimum, but it seems likely to be a good approximation and to be considerably simpler to find than a rigorous solution. Tests of the method have not yet been made, but will be carried out if NASA funding for this work is obtained.

Worldwide Crustal Movements. Further consideration has been given by P. L. Bender to estimating the limiting sources of error in laser range measurements to the LAGEOS satellite. This work was stimulated partly by the upgrading of several NASA laser ranging stations to 2 to 3 cm accuracy capability recently and the planned upgrading of other stations. The changes included the installation of sub-nanosecond pulse length lasers and faster photodetectors. A new mobile station being built in the Netherlands seems likely to be capable of calibration to better than 0.5 cm accuracy, so that "normal points" formed from the data taken over 1 or 2 minute intervals should have about this accuracy. The NASA stations hopefully can be improved further to meet this instrumental accuracy level also. However, the atmospheric propagation correction will give a comparable uncertainty. The overall expected future accuracy for determining the orbit of the LAGEOS satellite is 1 to 2 cm. This would lead to similar accuracy for intercontinental and transcontinental baselines.

University GPS Consortium for Tectonics Studies. It has become clear that signals from the Global Positioning System satellites can be used very effectively to determine accurate geodetic baselines and to study crustal movements. Commercial GPS receivers are now available from two sources, and a third type of receiver is being developed by NASA. Major programs for geodetic uses of GPS receivers have been started by the National Geodetic Survey and by NASA. In order to make the necessary equipment available for use in academic research programs also, a University GPS Consortium has been set up. It consists initially of the University of Colorado, Columbia, Cal Tech, Princeton, and the University of Texas. Two-frequency water vapor radiometers of the type developed and tested by NOAA will be used to determine the correction to the speed of propagation for radio waves due to water vapor in the atmosphere. The expected accuracy for short baselines is 1 cm for the vertical and 2 cm for the horizontal. For baselines approaching 10 km in length the main accuracy limitation initially is likely to be uncertainties in the GPS satellite orbits. The Consortium would rely on close cooperation with NASA, the National Geodetic Survey, and other agencies to make use of regionally determined accurate GPS orbits and avoid duplication of efforts. P.L. Bender, J.E. Faller, and J. Levine (Div. 524.10) expect to work closely with the Consortium to help in improving the measurement techniques and in determining the accuracy achieved in field measurements. J. Levine would aid particularly in designing the initial experiments, while P.L. Bender would participate in understanding the atmospheric propagation uncertainties and the limitations due to the GPS satellite orbit inaccuracies. The absolute gravimeters developed by J.E. Faller and co-workers would be used in parallel with the baseline determination to enhance the understanding of the tectonic processes being studied.

Chemical Physics

Much of the work in this category could probably be included in the category "Atomic and Molecular Physics and Interactions," or conversely, some of the work in that category could be included here. However, it is important to emphasize that JILA has a very strong chemical physics program with three Fellows rostered in the Department of Chemistry (Lineberger (CU), Reinhardt (CU), and Leone (NBS)). It is Leone's work that is described here as part of the QPD program.

Energy Transfer. The study of energy transfer is important to make high power lasers more efficient, to describe accurately collisional excitation processes and emissions in the upper atmosphere and in interstellar media, and to interpret a wide variety of chemical reaction dynamics problems such as occur in combustion. In addition, energy transfer processes are one area for which accurate theoretical interpretations of the results are possible.

C. Wight and S. Leone are studying one of the simplest and most basic energy transfer processes, that of T-V or translation-to-vibration excitation. The method involves production of translationally fast H and D-atoms by photodissociation of molecules such as H_2S, HBr, HCl, and HI with the short wavelengths of an excimer. The fast atoms collide with other diatomic molecules, such as CO, NO, HCl, and DCl, and the vibrational excitation produced upon collision is detected by spectrally resolved infrared emission. A most important and interesting aspect of this collision process is that the H-atoms are potentially reactive, and thus the interactions include both strong attractive as well as repulsive forces. Complete vibrational distributions for CO and NO excitation have been obtained for collisions with H-atoms at 2.3 eV center-of-mass (Fig. 3). Direct excitation up to v=6 is observed, with the characteristic steep fall off of excitation to higher v's as predicted by theory. Accurate trajectory calculations performed by G. Schatz at Northwestern University has shown that the vibrational levels v=4-6 in CO are due to a transient COH complex in which the CO bond is superextended, resulting in the higher excitation. This directly shows the influence of an attractive feature in the potential energy surface for H + CO. Recently, results have also been obtained on the absolute efficiencies of these T-V processes and on the extent of chemical exchange in systems like H + DCl which can result in both DCl or HCl product excitation.

H. Haugen and S. Leone are studying another long-standing problem in energy transfer, that of V-R or vibration-to-rotation excitation in HF molecules upon vibrational relaxation. This process is thought to produce high rotational states which are in near resonance with the vibrational energy, and may be important in the analysis and efficiency of high-powered HF lasers. The V-R process is also of fundamental theoretical interest and has been suggested since the earliest days as a mechanism for the fast vibrational relaxation. A tuneable infrared F-center laser is used to probe the high-J populations following relaxation of HF(v=1) molecules excited in a brief pulse with a chemical laser. The rates of relaxation of the high rotational states (J=12-14) are obtained as well as the fraction of the total relaxation that proceeds through these levels. The results are: J=12, 3-6%; j=13, 0.5-2%; and j=14, 0.05-0.3%. The important conclusion is that a non-negligible fraction of the

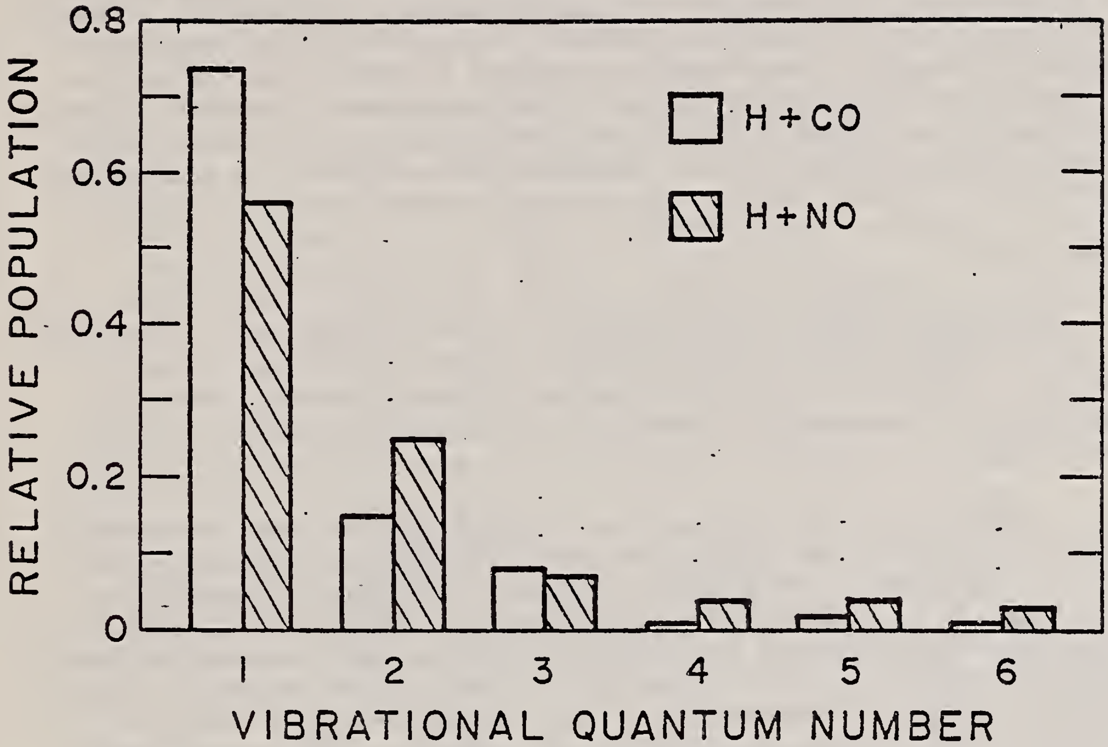

Fig. 3.
Vibrational population distributions produced by T-V collisions of 2.3 eV H atoms with CO and NO.

relaxation does take place through these high states, and that rotation probably does play a significant role in the relaxation.

M. Hale and S. Leone are studying electronic excitation transfer processes in atomic calcium vapor. Recently they investigated the fine structure changing collisions within the second $^3P_{2,1,0}$ manifold. The closeness of the levels in this case gives a statistical branching among the levels. A study of the 4s5p ^1P and 4s6s ^1S relaxation pathways shows that the predominant energy transfer upon collisions with buffer gases occurs to those states whose wave functions are most heavily mixed with the initially excited state. Those states which are very pure in wave function character are avoided. It appears that several new insights into the fundamental principles that govern inelastic processes in two electron atoms will be obtained through these studies.

Ion-Molecule Collision Dynamics. Ions are important in all kinds of media, e.g. plasmas, lasers, and the upper atmosphere. This program is designed to push the state-of-the-art in measurement capability in ion reaction dynamics and ion excitation and de-excitation processes.

L. Hüwel, D. Guyer, Lin G.-H. and S. Leone have obtained several of the first results on fully state-resolved thermal energy charge transfer reactions under single collision conditions. Complete vibrational and rotational distributions for the N^+ + CO and Ar^+ + N_2 charge transfer reactions are obtained using a novel supersonic beam ion source apparatus. Only a small fraction of the incoming ions are reacted in order to preserve the single collision conditions. Saturated laser-induced fluorescence is used to obtain high signal count rates on the low densities of product ions. The results show a high degree of sensitivity to the potential surfaces for the two different reactions. The CO^+ product is born with very low excitation, consistent with a Frank Condon distribution of excited states on ionizing the CO. The N_2^+ is born very hot, consistent with an energy resonance picture of the charge exchange process.

C. Hamilton and S. Leone are studying the dynamics of polyatomic negative ion reactions by analysis of the product vibrational states. These reactions are of interest to test the ideas of whether statistical population distributions result from long-lived ion-molecule complexes. The first reaction, SF_6^- + H, produces HF(v) and SF_5^-. The measurements are carried out by infrared chemiluminescence in a flowing afterglow. This reaction is found to yield HF in a narrow distribution of states which is very different from statistical predictions. It appears that this reaction may proceed via an avoided crossing, where a crossing to the H^- + SF_6 species first occurs. The narrow distribution of vibrational levels may correspond to the small range of internuclear separations between the H and F at the time of the avoided crossing.

R. Klein, R. McGinnis (JILA Research Fellow for Teachers), and S. Leone used laser optogalvanic spectroscopy for the first time to determine the threshold photodetachment of a molecular anion, namely CN^-. Previous studies by other workers have only recently observed atomic negative ion photodetachment by the optogalvanic effect. In the recent work in JILA, the photodetachment threshold measurement was carried out on densities of negative ions in the range of 10^8-10^{10} cm^{-3}, and the electron affinity of CN was determined to a factor of 10 better accuracy than previously known. The method has tremendous potential to elucidate other details of ion spectroscopy and electron affinities of other polyatomic radical species.

Photofragmentation and Neutral Reaction Dynamics. L. Kovalenko, M. Smith, and S. Leone are studying molecular photofragmentation processes that lead to free radicals, such as CH_3, and their subsequent reactivity and deactivation. Recently a study of the enhancement of reactivity by translational excitation has been completed. Using time and wavelength resolved infrared emission techniques, it has been possible to show that the enhancement of CH_3 reactivity toward Cl_2 and Br_2 in the so-called "hot" radical literature is due primarily to the translational energy, and not due to the vibrational excitation in the radical after photolysis. J. Smedley and S. Leone are studying the formation of molecular exciplexes of excited I*-atoms produced in photolysis. These results are important in the correct evaluation of photochemical quantum yields. Future studies will investigate the possible mode specificity of several radical reactions that produce simple polyatomic product molecules and will study the details of the photofragmentation of metal-iodide bonds to produce excited I* species.

Surface Reaction Dynamics. A new program is being started by K. Carleton and S. Leone to measure product molecules that are excited in reactions on well-characterized single crystal surfaces. All of the components for an ultrahigh vacuum system which is designed to probe product states by laser-induced fluorescence and infrared chemiluminescence are being obtained, and soon the shop will begin work on the fabrication. A prototype, low vacuum apparatus has been constructed to test out the detection methods and to survey reactions for interesting product excitation. An extensive search of the catalytic literature has been used to define which general types of reactions might yield product excitation without merely equilibrating with the surface before desorption. Preliminary results in the literature from several groups indicates that this area will be a rich field of investigation and will provide a tremendous amount of new information concerning the dynamics of molecules reacting on catalytic surfaces.

Atomic and Molecular Physics and Interactions

Electron Collisions with Polar Molecules N. T. Padial and D. W. Norcross have been studying vibrational excitation of HCl by electrons. The results of their first set of calculations for total (curve labled 'SE' in Fig. 4) and differential cross sections disagree with measurements both in shape and magnitude (more than a factor of ten too low). This is attributed primarily to the neglect of polarization effects, but is in sharp contrast to results for the similar molecule HF, in which other workers obtained both correct shape and magnitude using the same approximation.

In order to include polarization effects, they have developed a local, parameter-free model potential that can be easily generated as a function of internuclear distance. It employs the free-electron-gas correlation expression at short distances and the asymptotic form of the polarization potential at larger distances. The potential is added to the usual static and exchange terms to complete the specification of the total e-molecule interaction potential. Calculations have been done for e-H_2 and e-N_2 collisions as test cases. Total cross sections in both cases are in good agreement with the results of experiment and much more elaborate calculations. This model was then applied to vibrational excitation of HCl (curve labled 'SECOP' in Fig. 4).

In most of these calculations a local, free-electron-gas model of the exchange potential is employed. The test calculations on N_2 showed that a more exact treatment of exchange led to improved results, and the residual discrepancy in the HCl results is therefore attributed to the weakness of the exchange model used. Work is in progress to improve the representation of exchange by incorporating in their scattering codes an essentially exact, but separable, form based on an L^2 expansion of the exchange kernal. The first step in this project, generalization of their codes for generating the static interaction potential and single-center wave functions to accept Cartesian gaussians in addition to STOs, has been completed.

Electron Impact Excitation of Atoms and Ions R. B. Christensen and D. W. Norcross have completed scattering calculations in LS coupling with the Distorted Wave approximation for eight Mg-like ions (Ni and lighter). These involve transitions among ten of the lowest states. Calculation of energy levels and transition probabilities (including E2 and M1 transitions) in intermediate coupling for the heavier ions has also been initiated. This employs the Breit-Pauli approximation and the original LS-coupling structure models; it is the first step to ultimately evaluating the collision cross sections in intermediate coupling. In collaboration with A. U. Hazi, the calculations are presently being extended to heavier ions (e.g., Kr and Mo).

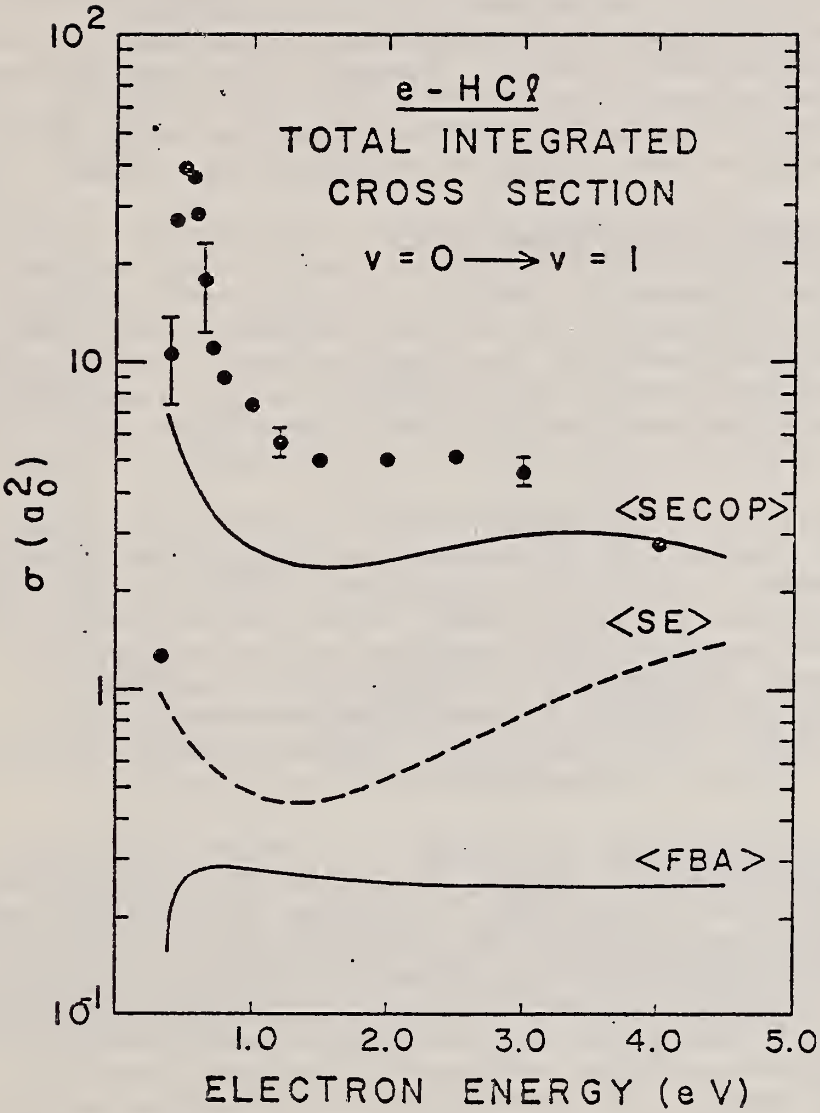

Fig. 4. Vibrational excitation of HCl. The results of calculations in the first Born approximation (FBA) and in the static-exchange approximation, both without (SE) and with (SECOP) the inclusion of polarization effects, are compared with the measurements of Rohr and Linder (1976).

The recent experiments of A. Gallagher and B. Stumpf on excitation out of the first excited state of Na have stimulated a new set of calculations by B. Christensen-Dalsgaard and D. W. Norcross. Of particular interest is the apparent (within experimental resolution) finite threshold for excitation of the 3d state, which may be due to a near threshold resonance. Standard close-coupling codes have been modified to treat core effects with a model potential, thereby permitting more accurate specification of the target structure and much less expensive calculations for many-electron systems.

Scattering Theory and Numerical Methods. The derivation of the first nonadiabatic correction in a model for one or more electrons outside a spherically symmetric core has been reconsidered by D. W. Norcross. Previous derivations of this term employed an additional appeal to perturbation theory for the outer electrons. He showed that this is not an essential restriction, confirmed earlier conclusions that no three-body (two electrons plus core) term of this type exists, and sketched an alternative derivation leading to the same result.

A new method for solving general scattering equations in the asymptotic region (large r) is being developed by D. W. Norcross and a new graduate student, J. Kelly, in collaboration with H. Saraph and M. J. Seaton. It is based on variable-phase theory, and involves integration of the phase-amplitude equations cast in the form of integral equations. The potential advantages of this method are increased speed and stability - a global propagator that can be partitioned into open- and closed-channel subsets prevents numerical blow-up without recourse to repeated numerical stabilization.

Experimental Electron-Ion Collisions. In a major breakthrough dielectronic recombination was for the first time directly observed and measured. D.S. Belić, G.H. Dunn, T.J. Morgan, D.W. Mueller and C. Timmer used crossed beams of electrons and Mg^+ ions, and made measurements of delayed coincidences between the stabilizing photon near 280 nm and the resultant neutral atom, and cross sections were determined. Fig. 5 shows a plot of cross section versus energy, and in addition to the measurements represented by crosses, there are three theoretical curves. The dashed curve is from a DW calculation of Y. Hahn and K. LaGatutta, and the solid curve is due to A. Burgess using methods commonly applied now worldwide for plasma modelling. It's seen that the measured values are several times larger than theoretical ones. The dotted curve represents an approximate calculation by LaGatutta and Hahn to account for extrinsic fields in the interaction region. Since extrinsic fields are also a major issue in any real environment -- Tokamak, stellar atmosphere, etc. -- the experiment is being modified so that these effects can be more completely understood.

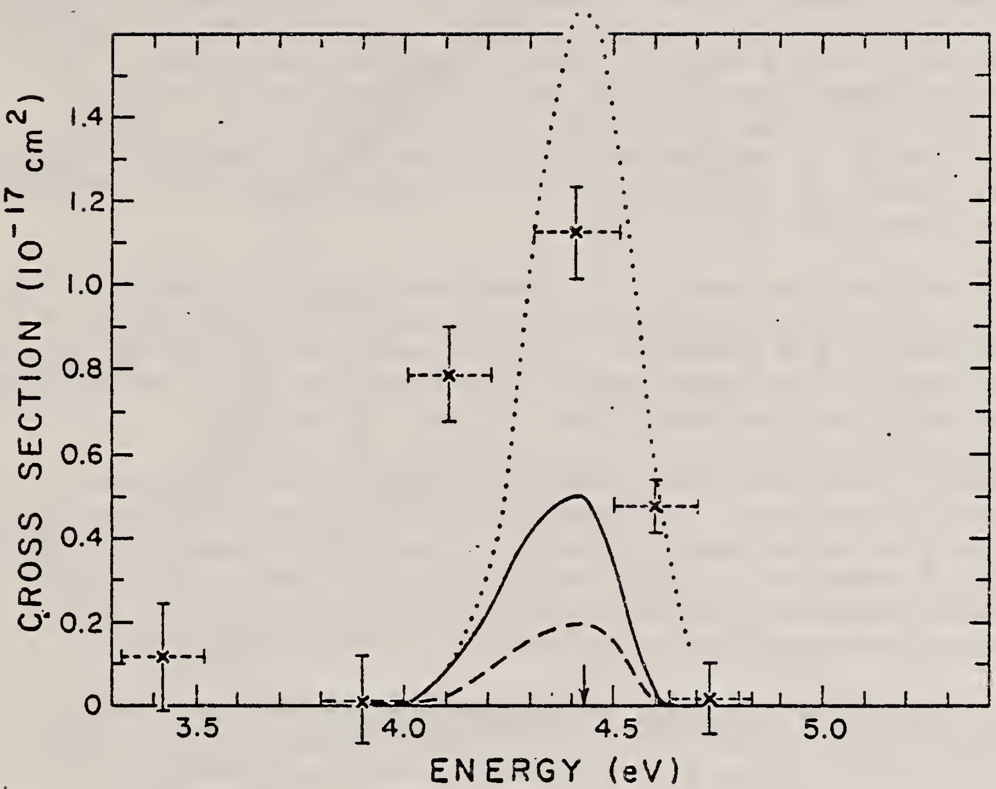

Fig.5. Cross section versus electron energy for dielectronic recombination of Mg+: e + Mg+ → Mg**→ Mg* + hℓ. Points are experimental. Dashed curve, theory of LaGatutta and Hahn; solid curve theory of Burgess; dotted curve, approximate attempt of LaGatutta and Hahn to acccount for extrinsic fields.

At Oak Ridge National Laboratory, D. Mueller, T. Morgan, and G. Dunn collaborating with D. Crandall, D. Gregory, and R. Phaneuf measured electron impact ionization of Fe^{2+}, Ti^{2+}, B^{2+}, Cl^{2+}, F^{2+}, and Ar^{2+}. Most are important species in the controlled fusion program as impurities or diagnostic ions. Results for Ti^{2+} are shown in Fig 6. Indirect processes such as excitation-autoionization enhance the cross section by more than a factor of two in the threshold region. The structure or "hump" near 40 eV is not understood, and is perhaps as sharp a structure as has been found in an ionization curve. We speculate that it is resonant-excitation-double-autoionization (REDA), a process invoked by Henry and Mszane to explain our earlier results on Na-like ions (Mg^+, Al^{2+}, Si^{3+}).

Good progress was made by C. Timmer and G. Dunn on design of new apparatus for studying electron-ion collisions, and construction was begun on parts of the apparatus. In this apparatus, trochoidal analyzers merge and de-merge beams of electrons and ions, and disperse electrons which are scattered from the ions. By using a position-sensitive detector at the output of the analyzers, information on scattered electrons with respect to both angle and energy loss is obtained. With almost 100% collection efficiency this will offer great advantages for measuring excitation compared to the fluorescence method we've used previously (efficiency $\sim 10^{-4}$), and will show up important processes like excitation-autoionization and resonant-excitation-double-autoionization in a distinctive way.

Ion Molecule Reactions at low Temperatures. With activated charcoal installed in the bore of the superconducting magnet of the Cold Penning Trap, it has been possible to make measurements on processes doing various isotopic substitutions. For example, S. Barlow and G. Dunn have been able to make measurements of rates in the range $10K \leq T \leq 25K$ of the group: $NH^+_3 + H_2 \rightarrow NH_4^+ + H$; $ND_3^+ + H_2 \rightarrow ND_3H^+ + H$; $NH_3^+ + D_2 \rightarrow NH_3D^+ + D$; and $ND_3^+ + D_2 \rightarrow ND_4^+ + D$. Data of others at high temperatures indicate an activation barrier about 0.1 eV high despite about 1 eV exothermicity, yielding a curve k versus T with a positive slope for $T > 100K$. Our low temperature data show a negative slope indicating that at low temperatures a complex is formed and during the lifetime of the complex quantum mechanical tunneling occurs. This hypothesis is given strength by the isotopic data, since reactions with D_2 as the target occur at a much slower rate, consistent with the slower tunneling of a massive particle. Though tedious and difficult, our technique remains, so far as we know, the only one for measuring such reactions at these low temperatures.

Space charge shifts in traps. J. Jeffries, S. Barlow, and G. Dunn developed theory for the shift of ion cyclotron resonance lines in an ion trap due to space charge. The work has been written up and is in press. The work is important not only in Penning traps of the

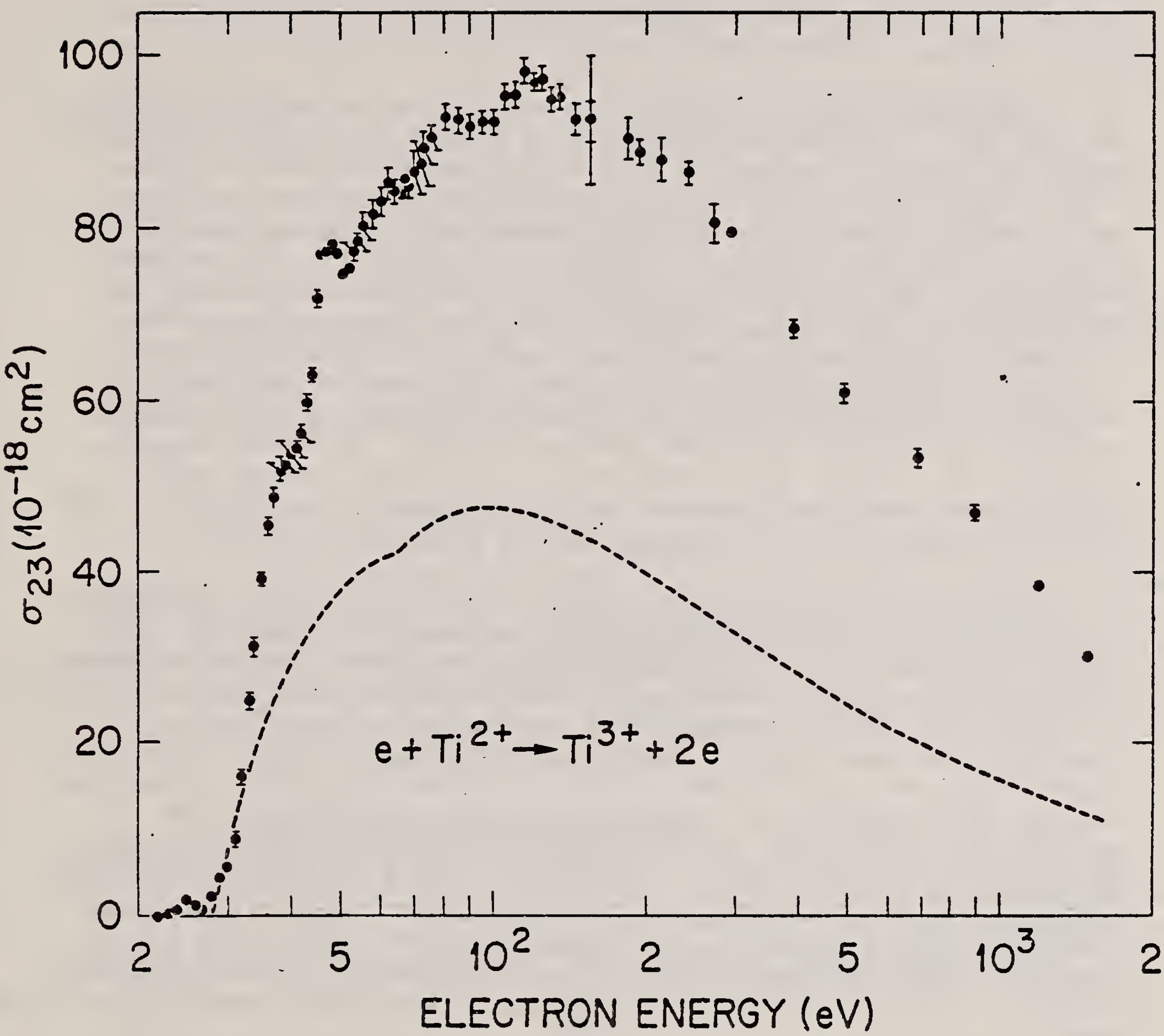

Fig. 6. Cross Section versus energy for electron-impact ionization of Ti^{2+}. Points are experimental, dash curve is Lotz prediction for direct process. Note dramatic structure near 40eV.

type used in our labs, but in ICR cells used throughout the chemistry world and sold commercially. McIver et al have shown how our theory can be used in ICR cells to increase the accuracy of absolute mass determinations by almost an order of magnitude, and their paper will be published as a companion to ours.

Atom-atom inelastic collisions. M. O'Callaghan and A. Gallagher are initiating studies designed to give much more detailed information regarding inelastic atom-atom collisions than is available using present techniques. They plan to use the absorption and emission of radiation by the atom-atom collision complex in order to investigate details of the interaction potentials responsible for the inelastic processes. Previous studies of inelastic atom-atom collisions have measured cross sections, differential or total, and inferred the interactions indirectly from comparing these to calculated cross sections. The method being studied here will give more direct information regarding these interactions by absorbing and emitting radiation during the collision, and particularly in the region of crossings or avoided level crossings. The initial systems being studied are transitions between the higher states to sodium (e.g. the 6S to 5P transition) due to inert gas collisions.

Collisions between excited atoms. S. Davidson and A. Gallagher, continuing the studies of high density sodium vapor in strong laser fields initiated with J. Huennekens, have been measuring the processes $Na^* + Na^* \rightarrow Na\ (n\ell) + Na$ where the final state, $n\ell$, may be any of the S, P, D, and F states energetically available in the collision. Previous measurements by J. Huennekens and Gallagher obtained the rate coefficients for transfer only to the $n\ell$=5S and 4D states. These new studies are also aimed at attaining temperature dependences and J dependences of the rate coefficients in order to test detailed models of the Na^*-Na^* interactions. J. Huennekens and A. Gallagher have also completed and now published their studies of associative ionization ($Na^*+Na^* \rightarrow Na_2^+$ + electron. All these processes under study are competing steps leading to laser induced discharges, superfluorescent emission, and other high-order processes in these highly excited vapors.

Analysis of silane discharges. H. Chatham, A. Gallagher and A. V. Phelps are investigating models of dc discharge sheath regions in order to calculate the types of ions produced and ion processing that occurs in silane discharges. These calculations will yield the relationship of the mixture of $Si_xH_n^+$ ions at the cathode to the discharge models and ion neutral chemistry taking place in the discharge. These calculations utilize cross sections for electron collisional dissociative ionization and ion molecule reactions measured in the previous year and described in previous reporting periods. The purpose is to yield detailed diagnostics of the critical chemical processes leading to amorphous silicon thin-film deposition in these discharges.

Silane neutral chemistry. R. Robertson and A. Gallagher are investigating the neutral silane radical (SiH_n) reactions in the gas and on the surface of silane chemical vapor deposition and discharge deposition systems. This is being done by mass spectrometer detection of the radicals in the presence of large backgrounds of the parent gas, utilizing differences in ionization potentials. This work is leading to the first definitive data on the dominant neutral species in silane discharge and silane pyrolysis, as well as to the characterization of surface decomposition and surface reactions on amorphous silicon surfaces. The most important discovery so far is the dominance of the SiH_3 radical and of hydrogen and SiH_3-based chain reactions as dominant processes in these gases. These studies will be extended during the next year into more complete quantitative measurements of surface reactions, surface decomposition, and of electron collisional dissociation of silane into neutral radical products.

Excitation of metastable H_2. H. Tischer and A.V. Phelps began work on this project with the measurement of the pressure dependence of the uv continuum emitted by the $a^3\Sigma_g^+$ state of H_2, since this state has been reported to be collisionally coupled to the metastable state. After considerable effort devoted to the study of the literature on the properties of the $c^3\Pi_u$ metastable state of H_2, they have begun a search for laser induced fluorescence from the metastables under collision dominated conditions. At present there is no reliable data on the collisional destruction of this state.

Vibrational Excitation of D_2 and H_2. S.J. Buckman and A.V. Phelps completed measurements of the infrared emission from mixtures of D_2 or H_2 and CO or CO_2. These data have been partially analyzed to obtain coefficients for electron excitation of the D_2 molecules by low energy electrons. Figure 7 shows a comparison of the measured excitation coefficients with values calculated using our recommended cross section sets for D_2 and CO_2.

Electron induced dissociation of H_2 and O_2. M.A. Islam and A.V. Phelps have completed the development of a new technique for measuring coefficients for the dissociation for molecules by low energy electrons. This technique was developed using H_2 and they are currently applying the method to O_2.

Excited states in discharges. P.A. Vicharelli and A.V. Phelps have continued the development of models of the time dependent electron ionization and deionization processes in high pressure, high energy electrical discharges. During FY 83 they have developed an improved computer code to calculate the growth of current and the development of a constricted discharge in He. This code is designed

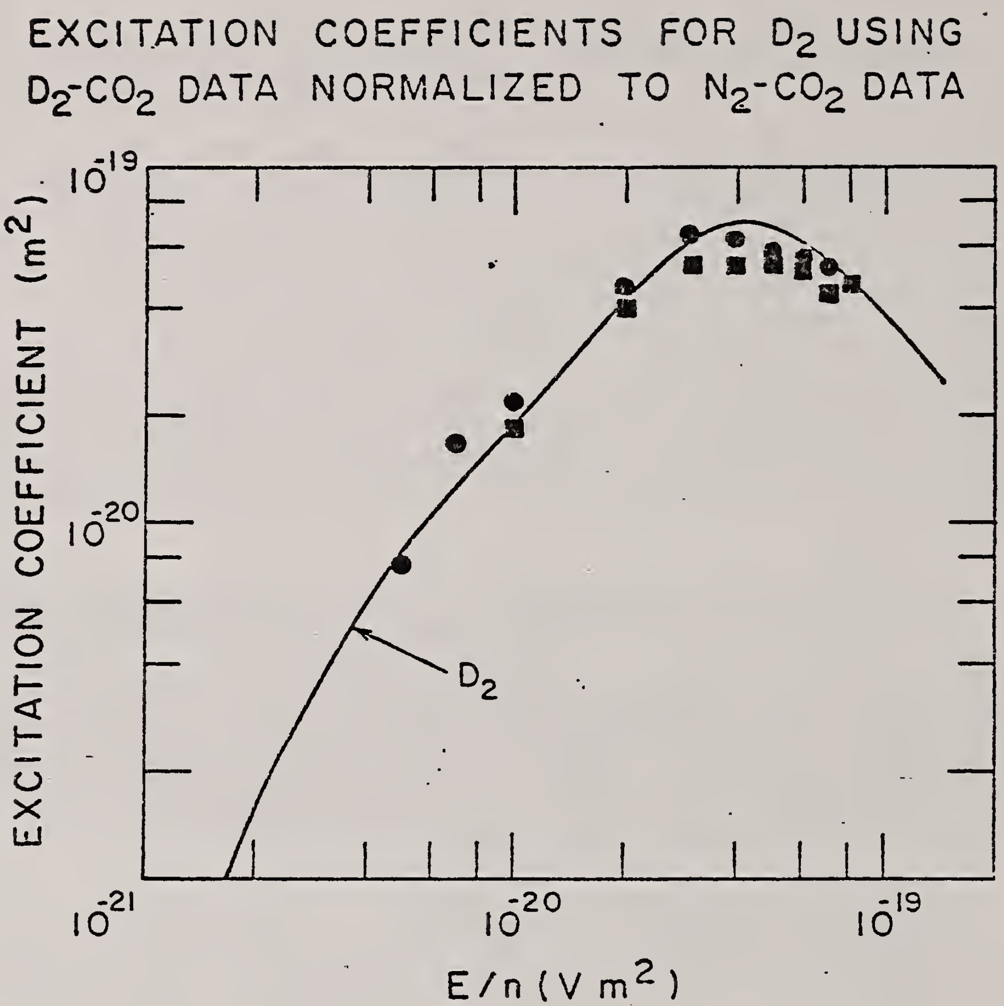

Fig. 7. Excitation coefficients for the production of vibrationally excited D_2 by low energy electrons in D_2-CO_2 mistures. E/N is the ratio of the applied electric field to the total gas density. The points are experimental data normalized to data for N_2-CO_2 mixtures. The curve is calculated using our Boltzmann code and our recommended cross sections.

to allow incorporation of the multi-step collisional ionization equations developed and tested during FY 82. A point of particular interest has been to establish procedures for calculating the rates of gas heating resulting from collisions of neutral atoms with highly excited atoms. This heating mechanism has recently been found to be important in alkali metal-rare gas discharges by W.L. Morgan of Lawrence Livermore Laboratories and A.V. Phelps.

Electron transport and reactions. In collabortion with L.C. Pitchford of Sandia National Laboratories, A.V. Phelps has continued calculations of electron transport and reaction coefficients in gases at high electric fields. A paper describing their investigation of the effects of various approximations to the distribution in energy of secondary electrons was published. Considerable effort was devoted to the evaluation of literature and in the modification of computer programs so as to provide more reliable electron transport and ionization coefficients at very high electric field to gas density ratios and at high frequencies as required by current DoD/DoE projects.

Laser-induced collisional processes. S. Geltman has been continuing his theoretical study of laser-induced collision processes. This type of process might be used to rapidly cause a population transfer between particular states of two atomic species, with potential application in the development of lasers. The specific process studied is the laser-induced collisional charge transfer

$$Ca^+(4s\ ^2S_{1/2}) + Sr(5s^2\ ^1S_0) + h\nu \rightarrow Ca(4s^2\ ^1S_0) + Sr^+(5p\ ^2P_{1/2,3/2})$$

for which experimental data exists on the line shapes and cross section magnitudes. The long-range potential curves for the initial and final atom-ion pairs and the resulting line shapes have been calculated on the basis of radiative transitions between two molecular ion states. An alternative treatment using atomic basis states is also in progress, and preliminary indications are that it will give much better agreement with experiment than the one based on molecular ion potential curves.

Small angle electron-atom scattering. In collaboration with R. K. Nesbet of the IBM Research Laboratory, S. Geltman has been theoretically investigating the high energy (15-25 KeV) forward (0-8 milliradians) elastic scattering of electrons on atoms. They have carried through the calculation for a hydrogen atom target, in which all excited states are represented by a single polarization pseudostate, up to and including the 2nd Born approximation. In this approximation no strong forward elastic peak is found, in apparent disagreement with the experimental findings for rare gas atom targets. A complex optical potential deduced from the pseudostate model appears to give the observed forward shadow diffraction pattern, and this would imply that low-order Born approximations are too slowly convergent to give the correct result for forward elastic scattering, even at such high energies.

Static and microwave electric field ionization of Rydberg states. This work was started by S. Geltman, while on a Humboldt award at the Max Planck Institute for Quantum Optics in Garching, in collaboration with J.A.C. Gallas and J. Bergou. This calculation is being done using both the spherical and parabolic representation for bound and continuum states in a Coulomb field. The treatment of continuum states in the parabolic representation has been developed, since it has not been covered adequately in the literature to date. Perturbation theory of arbitrarily high order is being used to solve the time-dependent Schrodinger equation, and to obtain the resulting ionization probabilities. All intermediate states within the degenerate manifold of the initial Rydberg state are included, which is expected to be a valid approximation for the low frequencies considered. The results of this dynamic calculation will be compared with simpler static and tunneling models of the ionization process, and with existing experimental data -- including the finding that the threshold field strength for microwave ionization varies as n^{-5} rather than the n^{-4} one would expect from a simple barrier-lowering picture.

Photoionization of Aligned Rydberg Atoms -- Photoelectron Angular Distributions. Highly excited atoms with well defined alignment (in specific magnetic substates) are conveniently produced using resonant excitation by carefully polarized laser light. G. Leuchs (JILA visitor) and S. J. Smith have developed techniques for measuring photoelectron angular distributions from such states, effectively providing a new spectroscopic tool for analyzing angular momentum characteristics of such Rydberg states. E. Matthias (Visiting Fellow), P. Zoller (Visiting Fellow), D. S. Elliott, and N. D. Piltch, with Leuchs and Smith, have demonstrated the power of this type of spectroscopy in a study of the perturbed Rydberg (6snd) series in atomic barium. The source of perturbation is a doubly excited (5d7d) state which lies between the 6s26d and 6s27d states, introducing 5d7d admixtures into nearby states in the Rydberg series as well as mixing the singlet and triplet series. Fig. 8 shows measured photoelectron angular distributions for the perturbed singlet and triplet series, and to two different continua. Angular distributions for n=19, to the 6s continuum, can be taken as unperturbed.

In each case the experimental result can be fitted to an expansion in spherical harmonics (represented by the solid lines) and the coefficients of the expansion can be interpreted in terms of mixing coefficients Z_i in the wave function form

$$|6snd,J=2\rangle = Z_1 \,|\, 6snd\,^1D_2 \rangle + Z_2 \,|\, 6snd\,^3D_2\rangle + Z_3 \,|\, 5d7d,J=2 \rangle$$

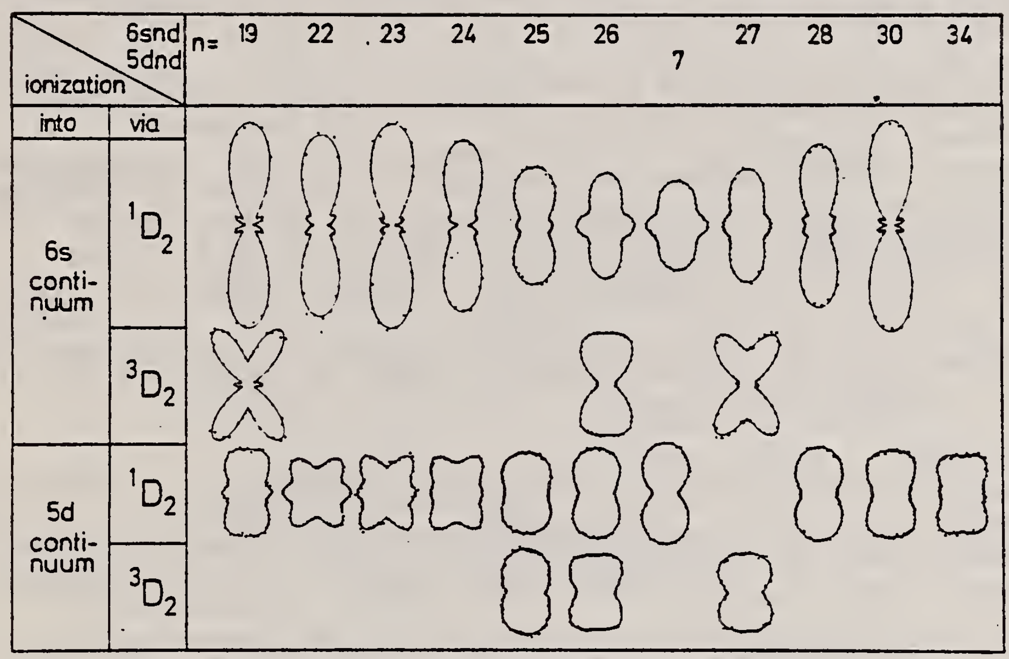

Fig. 8. Measured photoelectron angular distributions (x) for barium Rydberg states to the 6s and 5d continua, distinguished by electron time-of-flight. Photoelectron angular distributions fo the 5d7d doubly excited perturber are also included. The top half of the figure, corresponding to a residual ion in the ground state, exhibits mainly singlet-triplet mixing. The bottom half, for the residual ion excited, shows lower photoelectron anisotropy since the excited ions retain some alignment.

as Zoller has done using multi-channel quantum defect theory. The photoelectron angular distributions are particularly sensitive to singlet-triplet mixing coefficients, which are just the parameters needed to remove ambiguities in the multi-channel quantum defect analysis based on barium term energies only (K. T. Lu, private communication; M. Aymar, private communication). Leuchs and Smith are preparing a remeasurement with improved resolution and other refinements in order to provide accurate data for the quantum defect analysis. Measurements in calcium and other multi-valence-electron atoms are being considered.

D. S. Elliott, working in Munich with H. Walther and G. Leuchs (former JILA Visiting Fellows) as part of an NSF sponsored U.S.-Germany Cooperative Science Program, participated in a successful pioneering investigation on the influence of laser power in changing photoelectron angular distributions through a.c. Stark shifts of participating levels. Elliott and S. J. Smith also participated (again in Munich through the Cooperative Science Program) in a study of the behavior of photoelectron angular distributions as the duration of the photoionizing pulse is shortened into the pico-second range (so that coherent superpositions of Rydberg states of different orbital angular momentum are excited).

The Role of Fluctuations in Non-Linear Absorption K. Arnett, M. Hamilton, D. S. Elliott, and S. J. Smith have initiated a comprehensive series of measurements of the role of fluctuations in the sodium 3s-4d two photon absorption process, as the first phase of a program of measurements of the significance of fluctuations in non-linear optical processes, a subject of current theoretical interest. These measurements are based on a considerable program of technical development in JILA, including implementation of highly stabilized (∿50 kHz) one-watt ring laser, following an original design by J. L. Hall. K. Arnett, a thesis student, has extended methods developed by Elliott for superimposing random phase (and frequency) fluctuations onto the relatively monochromatic cw laser beam. The purpose is to make the laser broad band in a fully controllable manner. Accousto-optic and electro-optic modulation methods are used to generate a laser line shape with widths up to 35 MHz with line shapes ranging from Lorentzian to nearly Gaussian ±1 GHz from line center. With the completion of the 3s-4d two-photon absorption measurements, we will take up study of the role of fluctuations in a saturated $3S(F=2,M_F=2) \rightarrow 3P_{3/2}(F=3,M_F=3)$ optically pumped two-level system, by optical double resonance ($3P \rightarrow 4D$ probe) with detection in the 330 nm decay radiation. In addition to line shape and line width of the primary laser, probe response will be studied as a function of laser power and detuning.

JILA Atomic Collision Data Center

1983 Accomplishments. During FY83 the JILA Data Center under direction of Jean Gallagher carried on an active program to compile and evaluate data in the areas of electron and photon collisions with atoms, ions, and simple molecules. Several projects entailed collaboration of the Data Center staff with visiting scientists who participated in the review and evaluation of data in their fields of expertise. The results of completed projects are listed in the "Publications, 1983" section below. Projects started in 1983 and currently under way are described in the "Work in Progress" section.

Publications, Data Center publications in 1983 include:

1. "Angular and Energy Distributions of Secondary Electrons from Helium: I. Slow Electrons Ejected by Electron Impact," Yong-Ki Kim, Phys. Rev. A (in press).

2. "Evaluted Theoretical Cross Section Data for Charge Exchange of Multiply Charged Ions with Atoms. II. Hydrogen Atom-Partially Stripped Ion Systems," J. W. Gallagher, B. H. Bransden, and R. K. Janev, JPCRD (in press).

   "III. Atom ($Z \geq 2$)-Ion Systems," R. K. Janev and J. W. Gallagher, JPCRD (submitted).

3. "Survey and Review of Inelastic Collisions Data for Diatomic Halogens," Jeffrey I. Steinfeld, JPCRD (submitted).

Work in Progress

1. "Total Cross Sections for Proton Impact Ionization of Gaseous Targets." This review is being prepared by M. E. Rudd, Y.-K. Kim and D. Madison in collaboration with the Data Center staff. The authors spent two weeks at JILA in May 1983 planning the content and their contributions to the review. Dr. Rudd spent the successive six weeks reviewing the experimental methods and data (which had been collected by the Data Center), determining criteria for judging the accuracy of the data, and with P. Ruttenberg of the Data Center, developing formulas to represent the data. Dr. Kim will compare the acquired data with photoionization cross sections in the high energy limit. Dr. Madison will calculate cross sections for atomic targets using the distorted wave approximation, and these will be compared with the experimental data. The authors expect to combine the results of these efforts into a first draft during the winter of 1983/84. This review will be submitted to Review of Modern Physics.

2. Cross Sections and Equilibrium Yields for Charge Exchange between Hydrogen (and Deuterium) Atoms, Molecules, and their Ions with Metal Vapors. This work is being done with Drs. T. J. Morgan (JILA Visiting Fellow, 1982-83), A. S. Schlachter, R. E. Olson, and Wilmer Anderson. The appropriate references have been identified, and the data collected in a series of figures. These data will be evaluated and recommended data will be presented in an article to be submitted to the Journal of Physical and Chemical Reference Data. A second article which would be an in-depth review of the experimental and theoretical techniques associated with these data is being considered.

3. "Scaling Laws for Inelastic Collision Processes in Diatomic Halogens." In connection with the compilation of energy transfer data for diatomic halogens done with Professor J. I. Steinfeld, a series of scaling laws were applied by the Data Center staff to the few existing extensive data sets to determine which law provides the best representation of the data. Although the findings of this study were judged to be not of sufficient orginality to justify submission as an article to a regular scientific journal, the work and its findings will be documented in Data Center Report No. 23 which should be complete early in 1984.

4. "Partial Channel Photoionization Cross Sections in Molecules -- Theory and Experiment." Work started on this compilation in December of 1982, when Professor P. W. Langhoff, a theoretical chemist from Indiana University, visited JILA to plan the project. Letters requesting information on sources of data were circulated to prominent workers in the field, and an extensive bibliography of pertinent literature was compiled. Dr. Langhoff spent August, 1983, at JILA reviewing the accumulated materials and identifying appropriate data for five molecules. These data are being acquired on Data Center files. Dr. Langhoff will return to JILA in November of 1983 to continue work on the review with Dr. C. E. Brion who has done significant experimental work in the field. The final report will be submitted to the Journal of Physical and Chemical Reference Data.

5. "Multiphoton Bibliography, 1981-82." In response to many requests from workers in the field, a two-year update to NBS Special Publication LP-92, is planned. Dr. N. D. Piltch worked during the summer of 1983 identifying appropriate articles in the scientific literature and indexing these. After the references and indexing have been entered into a computer file and sorted, the bibliography will be printed in the established Data Center format.

6. Data base management system for atomic collisions data. This system has been designed and prototyping has been completed. Loading of the data has begun and will continue into FY84. New and/or

improved programs have been developed for data storage and retrieval in the form of bibliographic listings, data tables, and figures. These will be interfaced with the new data base management system.

FY1984 Plans. A major effort will entail continuation and completion of the six projects described above (work in progress).

An exciting new project planned for FY84 is a review of the atomic Stark effect, a topic of fundmental scientific interest to which recent developments in both theory and experiment have led to increased understanding. The review will be written by Drs. W. P. Reinhardt and P. M. Koch, who are experts in the theoretical and experimental aspects of the field, respectively.

Another new project will be done in connection with a proposed compilation of collision strengths and rates for the electron impact excitation for selected transitions in ions of astrophysical interest. In collaboration with Dr. A. K. Pradhan of JILA, recommended data will be compiled in a more general sense; i.e., for all ions and transitions for which data are available.

Vigorous efforts are continuing to complete high quality evaluated compilations and to plan and coordinate new, timely reviews in areas of current interest. Jean Gallagher, the Data Center Manager, has also been actively exploring potential for collaborations with the Data Centers at Oak Ridge National Laboratory and the Queen's University at Belfast.

Astrophysical Measurements

Wind-blanketing and the Stellar Temperature Scale. D. G. Hummer and postdoctoral research associate D. C. Abbott have been investigating the effect on the temperature scale for hot stars of the radiation scattered back into the photosphere of the star by the stellar wind surrounding the star. This so called wind blanketing causes the surface layers of the star to become hotter than without the wind. One of the principle parameters of stars is the effective temperature, defined such that the total energy flux leaving the star is σT_{eff}^4; this is fixed by the nuclear energy sources deep in the star. Effective temperatures are determined observationally by measurement of spectral line intensities, which give the surface temperature T_0, which is then related to T_{eff} by theory. As the effect of wind blanketing is to raise the surface temperature relative to the effective temperature, the values of the effective temperature obtained will be too large if wind blanketing is ignored. This effort has concentrated on the O-type star Zeta Puppis, for which extensive and accurate observations are available. About ten years ago an effective temperature of 50000°K was obtained by comparing line strengths of He I and He II with model results. Recently a German group obtained T_{eff} = 42000°K by using more elaborate models, and the present work has lowered this value to 39000°K by including wind blanketing. Detailed comparison of line profiles is underway to demonstrate that wind blanketed models provide a better description of the star than models which do not account for this effect. These results have reported on these results at a number of conferences and will be prepared for publication when the calculations are completed within the next few months.

Escape-Probability Theory for Radiation in Media with 3-Dimensional Flows. D. G. Hummer and G. B. Rybicki (Center for Astrophysics) have developed an escape probability theory for spectral lines formed in a gas undergoing general three-dimensional motion with supersonic speeds. Under these conditions only regions for which some component of the relative velocity vanishes are coupled radiatively, and the radiative transfer problem is much simplified. However the mathematical description of the radiation is still very complex, and in particular a number of special functions arise which are expressed by complicated three-dimensional integrals. All but one of the integrations could be evaluated analytically, and in some important special cases rational expressions for rapid computer evaluation of the functions have been obtained, thus facilitating the application of this theory. Functions giving exactly the probability that photons escape in a particular direction in axially-symmetric configurations have been derived, so that the computation of both the total intensity and the line profile seen by a distant observer of, say, an accretion disk, involves a one-dimensional, rather than a two-dimensional, integration. Again rational expressions have been obtained for rapid computer evaluation. This work is in press. Application of this theory to the accretion disks associated with dwarf novae are being made by Dr. Hummer's research assistant Douglas Carroll as part of his thesis work.

Collisional-radiative Recombination. D. G. Hummer and Dr. P. J. Storey of University College London have been engaged in the calculation of intensities of recombination lines allowing for the effects of both l-changing and n-changing collisions. Recently they have completed an improved treatment of the n-changing collisions, as well as collisional ionization and three-body recombination, which become important for higher densities. Preliminary results have been obtained for one, two and three-electron ions, and the final results for H I and He II are now being computed and prepared for press. In order to provide results for infrared lines, which are being observed at increasing wavelengths for a growing number of astronomical objects, intensities are tabulated for all transitions with principal quantum numbers up to 50. Dr. Hummer is now generalizing these calculations to include the effects of optical depth in the recombination lines, in order to extend the conditions under which these results can be applied.

Infra-red Recombination Lines from Wolf-Rayet Stars. D. G. Hummer in collaboration with Drs. P. J. Storey and M. J. Barlow of University College London have been developing methods of using the infra-red recombination lines and the free-free continuum of Wolf-Rayet stars to determine ionic abundances and electron temperatures. This can be done, using the results of the collisional-radiative recombination calculations of Hummer and Storey, in a nearly model-independent way, which is a very great advantage in dealing with objects about whose atmospheric structure we know very little. Recently this approach has been generalized to treat stars in which the lines formed in the wind are optically thick, making possible the determination of column densities in the wind, as well. In order to improve the accuracy of the latter determination, Dr. Hummer is developing some very simple models to calculate the probability that a recombination-line photon escapes rather than being absorbed by the free-free continuum.

Hyperspherical-coordinate theory of two-electron correlation phenomena. B. Christensen-Dalsgaard (University of Aarhus) has been working for three years at JILA on problems of two-electron correlation in atomic structure and scattering under the supervision of D. G. Hummer. She has analyzed these problems using hyperspherical coordinates, in which the individual radial coordinates r_1 and r_2 are replaced by $R = (r_1^2 + r_2^2)^{1/2}$ and $\alpha = \arctan(r_1/r_2)$, and has written a set of extremely efficient computer codes to solve the Schroedinger equation for both bound and continuum states. The properties of a number of H^- and He resonances which she obtained agree very well with experiment, and required much less computational effort than other methods. A combined hyperspherical and close-coupling method which she has recently developed for scattering problems combine the advantages of both methods. She has submitted her thesis to the University of Aarhus in July and returns to Denmark in October.

Reliable Estimates for Stellar Mass Loss Rates. Linsky and his colleagues have begun a comprehensive program aimed at obtaining for the first time reliable estimates of the rate at which stars lose matter to space. He is concentrating on stars somewhat cooler and more luminous than the Sun. One indicator of mass loss is asymmetry in the ultraviolet emission lines produced by the absorption and emission of the expanding gas in a volume much larger than the star itself. Such asymmetries are routinely observed in the MG^+ resonance lines near 280 nm in many stars by the International Ultraviolet Explorer (IUE) satellite, but they have heretofore not been analyzed. S. Drake and Linsky have developed a computer code that properly includes nearly coherent scattering in the atom's rest frame, an extended spherical geometry for the wind, and expansion. An example of these calculations is shown in Fig. 9. They are now comparing such calculations with observations to estimate mass loss rates for

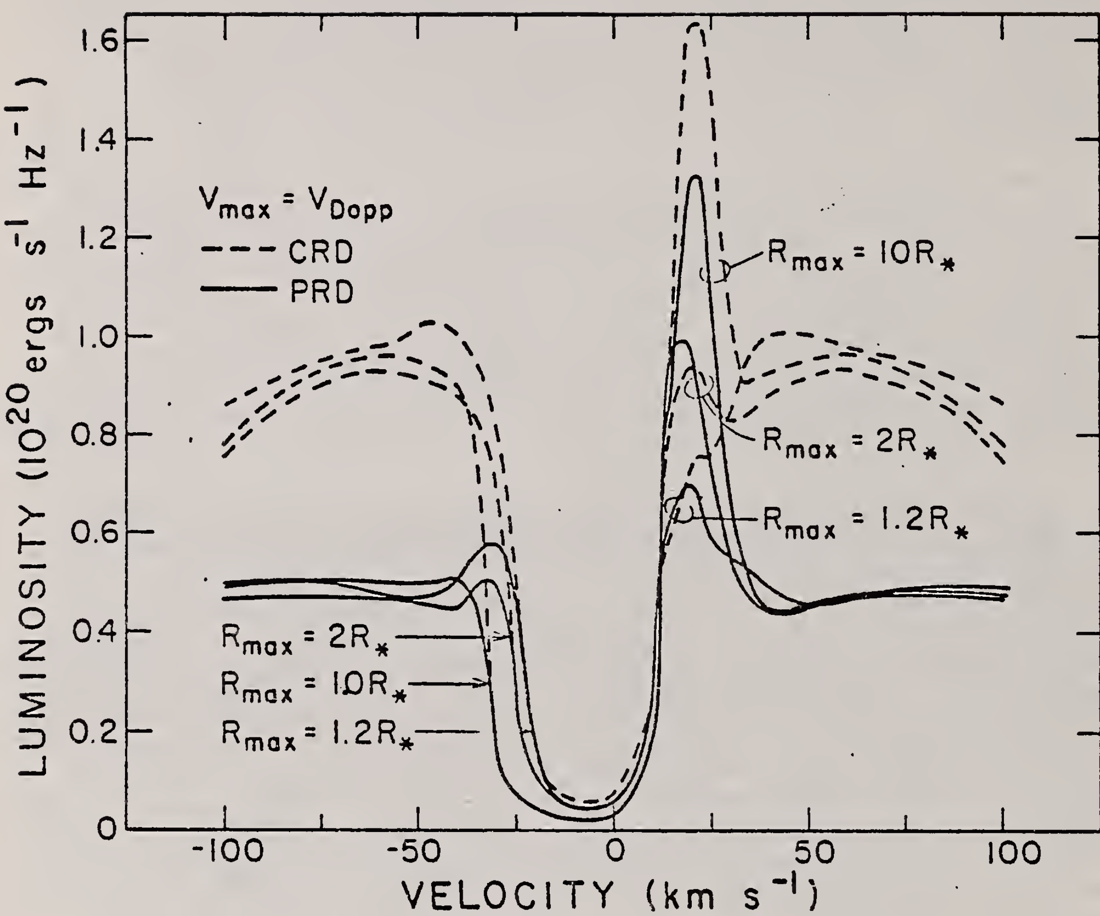

Fig. 9. Typical examples of asymmetric emission lines, indicative of mass loss from stars, computed by S. Drake and Linsky. The solid lines are Mg^+ resonance lines computed including nearly coherent scattering in the atom's rest frame for a wind extending out to 1.2, 2, and 10 times the stellar radius. The dashed lines are for the same cases except making the unrealistic assumption that scattering completely redistributes photons in frequency within the absorption profile.

specific stars. In addition, they are observing the same stars with the Very Large Array (VLA), a 27 antenna radio interferometer in New Mexico, to detect free-free continuum microwave emission produced in the wind. The strength of this emission is an important constraint on the mass loss rate.

Microwave Emission Processes in Stellar coronae. Linsky and his colleagues have been studying the million degree plasma located in coronae that surround stars similar to the Sun by two techniques. Thermal Bremsstrahlung (free-free emission) produces X-rays that are detected by the NASA Einstein X-ray Observatory satellite. On the basis of such data they have shown which types of stars have coronae (and thus are solar-like) and which types do not. D. Gary and Linsky have now extended this study to the microwave region by observing many stars with the VLA radio interferometer. They detect strong emission from many stars at levels far in excess of that predicted by free-free emission alone. They propose that the emission is due to thermal electrons spiralling in coronal magnetic fields. Depending on the observed harmonic of the local cyclotron frequency, the emission is called gyro-resonant or snychrotron. They infer coronal magnetic fields of roughly 300 Gauss, and find that the emission occurs preferentially above dark starspots, which presumably have strong magnetic fields like spots on the Sun. They are now conducting experiments to understand the emission processes in more detail.

Stellar Spectroscopy in the Vacuum Ultraviolet. Spectroscopic studies of ultraviolet emission lines have provided very sensitive tools for deriving the plasma properties (density, temperature, flow velocities, departures from thermodynamics equilibrium) of stellar atmospheres. Linsky and his colleagues and collaborators at JILA and elsewhere have pioneered techniques for deriving plasma properties and model stellar atmospheres by the analysis for collisionally excited ultraviolet resonance lines observed with the IUE satellite in the spectral range 120-320 nm. During the last year they have analyzed an excellent high resolution spectrum of the star Beta Draconis (see Fig. 10), obtained as the longest exposure with the IUE satellite. Using density-sensitive line ratios, emission line strengths, and line opacity arguments, they derived a detailed model for the outer atmosphere of this star with densities nearly an order of magnitude lower than the Sun. From the observed Doppler shifts of optically thin lines, they deduced systematic downflows as they now have detected in other stars. They showed that the star has a 10^7 K corona, probably confined by magnetic loops, and that the atmosphere is likely heated by MHD waves. Linsky is a co-Investigator on the science teams responsible for building the High Resolution Spectrograph on Space Telescope, which will be a very sensitive instrument for spectroscopy in the 120-320 nm spectral range, and for planning the Far Ultraviolet Spectrograph Explorer satellite, which will be capable of spectroscopy in the 10-120 nm spectral range. Spectroscopy in this new spectral range will pose new challenges for the development of plasma diagnostic techniques.

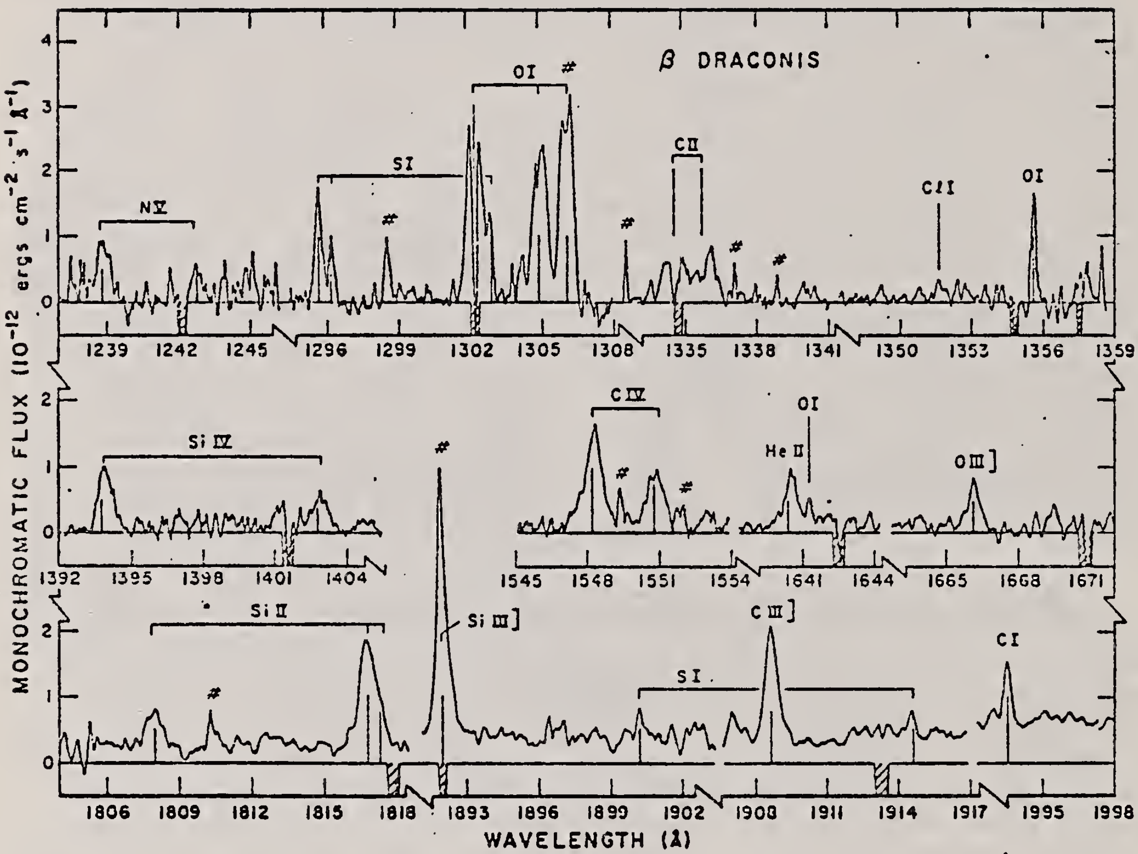

Fig. 10. A composite high dispersion spectrum (resolving power $\lambda / \Delta\nu \approx 10{,}000$) of the star Beta Draconis obtained with the International Ultraviolet Explorer (IUE) satellite. Note that the spectrum contains emission lines of ions formed over a wide range of temperatures. The density sensitive intersystem lines of O III, Si III, and C III are indicated by the] symbol.

III. PUBLICATIONS AND INTERACTIONS

Included in the following pages of this section are tables of

- JILA Visiting Fellows for 1982-83 and 1983-84.
- Publications during the past year of NBS Fellows and Visiting Fellows.
- Invited papers (talks) of NBS personnel of QPD.
- Technical and professional committee participation and leadership of QPD personnel.
- Consulting by QPD personnel.
- Trips of QPD personnel sponsored by others.
- Conferences sponsored.
- Seminars and colloquia.
- Other items of interest to the Panel.

III. PUBLICATIONS AND INTERACTIONS

VISITING FELLOWS

Quantum Physics Division (525)

FY 1983 VISITING FELLOWS	HOME INSTITUTION	AREA OF WORK
Nils O. Andersen	Physics Laboratory II H. C. Orsted Institute DK - 2100 Copenhagen Denmark	Heavy particle collisions.
Kenneth M. Baird	Division of Physics Nat'l Research Council Ottawa, Ontario Canada K1A 0R6	Application of lasers to precise length measurements.
Richard M. Crutcher	Astronomy Department University of Illinois Urbana, IL 61801	Radio, optical, & ultraviolet spectroscopy of interstellar gas.
Erast Gliner	formerly the A. Joffe Physico-Technical Institute of the U.S.S.R. Leningrad, U.S.S.R.	Mathematical physics and gravitation.
James Hough	Department of Natural Philosophy University of Glasgow Scotland G12 8QQ U.K.	Detection of gravitational radiation.
Eckart Matthias	Institut für Atom und Festkörperphysik Freie Universität Berlin West Germany	Atomic spectroscopy.
David A. Micha	University of Florida Gainesville, Fl 32611	Ion scattering & collisions in intense laser fields.

VISITING FELLOWS

Quantum Physics Division (525)

FY 1983 VISITING FELLOWS	HOME INSTITUTION	AREA OF WORK
Thomas J. Morgan	Physics Department Wesleyan University Middletown, CT 06457	Heavy particle collisions.
Jozef Smak	Copernicus Astronomical Center Bartycka 18 00-716 Warsaw Poland	Mass transfer in binary star systems.
Peter Zoller	Theoretical Physics Institute University of Innsbruck Austria	Multiphoton physics & quantum optics.

1983 RESEARCH FELLOWSHIP FOR TEACHERS

Richard P. McGinnis	Tougaloo College Tougaloo, MS 39174	Laser spectroscopy, computer/instrument interfacing, & laser-induced chemical reactions.

NBS/JILA EXCHANGE FELLOW

William P. Reinhardt	Joint Institute for Laboratory Astrophysics University of Colorado Boulder, CO 80309	Theoretical Chemical Physics.

VISITING FELLOWS

Quantum Physics Division (525)

FY 1984 VISITING FELLOWS	HOME INSTITUTION	AREA OF WORK
Carl G. J. Aminoff	Helsinki University of Technology Department of Technical Physics SF-02150 Espoo 15 Finland	Laser spectroscopy, velocity selective optical pumping.
Paul Ewart	Clarendon Laboratory University of Oxford Parks Road Oxford OX1 3PU England	Laser spectroscopy, photoionization, line broadening.
David M. Gibson	New Mexico Institute of Mining & Technology Department of Physics Socorro, NM 87801	Stellar coronae.
Ingolf Hertel	Freie Universitat Berlin Fachbereich Physik (FB20) Institut fur Molekulphysik (WE2) Boltzmannstrasse 20 1000 Berlin 33 West Germany	Laser studies of crossed beam processes.
Wei-Tou Ni	Department of Physics National Tsing Hua Univ. 855 Kuang Fu Road Hsinchu, Taiwan Republic of China	Gravitation theories, empirical foundations of gravitation and general relativity.

VISITING FELLOWS

Quantum Physics Division (525)

FY 1984 VISITING FELLOWS	HOME INSTITUTION	AREA OF WORK
A. Ravi Prakash Rau	Department of Physics Louisiana State University Baton Rouge, LA 70803	Theoretical atomic physics.
Eric Weitz	Department of Chemistry Northwestern Univ. Evanston, IL 60201	Energy transfer processes in the gas phase and in rare gas matrices, unimolecular reactions.
Karl H. Welge	University of Bielefeld Bielefeld West Germany	High Rydberg states in magnetic fields.

1984 RESEARCH FELLOWSHIP FOR TEACHERS

Irene R. Little-Marenin	Department of Astronomy Whitlin Observatory Wellesley College Wellesley, MA 02181	Stellar atmospheres, spectroscopy, spectral classification, and chromospheres of late-type stars.

NBS/JILA EXCHANGE FELLOW

James J. Snyder	Quantum Metrology Group Bldg. 221, Room A141 National Bureau of Standards Washington, D. C. 20234	Laser wavelength determination and improved frequency determining algorithms.

PUBLICATIONS

Quantum Physics Division (525)

*(K.V. Sobha) and G. S. Agarwal, Effect of Spatial Dispersion on the Classical Field Enhancement Factors near a Rough Surface, Solid State Commun. 43, 99-103 (1982).

*(P. Ananthalakshmi) and G.S. Agarwal, The Spectral Characteristics of Signals in Optical Hanle Effect, Phys. Rev. A 25, 3379-3381 (1982).

*G. S. Agarwal and (S. S. Jha), Surface-Enhanced Second-Harmonic Generation at a Metallic Grating, Phys. Rev. B 26, 482-496 (1982).

*G. S. Agarwal and J. Cooper, Effective Two-Level Description of Pressure Induced Extra Resonances in Four-Wave Mixing, Phys. Rev. A 26, 2761-2767 (1982).

*G. S. Agarwal and (S. B. Jha), Surface-Enhanced Raman Scattering in a Two-Oscillator Electromagnetic Model, Phys. Rev. B 26, 4013-4021 (1982).

*G. S. Agarwal, S. L. Haan, K. Burnett, and J. Cooper, Photoemission Spectra in Intense Laser Field Induced Autoionization, Phys. Rev. A 26, 2277-2280 (1982).

*G. S. Agarwal and C. V. Kunasz, Dipole Radiation in the Presence of a Rough Surface. Conversion of a Surface-Polariton Field Into Radiation, Phys. Rev. B 26, 5832-5842 (1982).

*G. S. Agarwal, (A. T. Friberg and E. Wolf), Elimination of Distortions By Phase Conjugation Without Losses or Gains, Opt. Commun. 43, 446-450 (1982).

*G. S. Agarwal, Phase Conjugate Optics, Current Science 52, 193-198 (1983).

*G. S. Agarwal, (A. T. Friberg and E. Wolf), Scattering Theory of Distortion-Correction By Phase Conjugation, J. Opt. Soc. Am. 73, 529-538 (1983).

*G. S. Agarwal and C. V. Kunasz, Four-Wave Mixing in Stochastic Fields: Fluctuation-Induced Resonances, Phys. Rev. A 27, 996-1012 (1983)

*S. L. Haan and G. S. Agarwal, Recombination Effects in Autoionization, in Spectral Line Shapes Volume 2, Proceedings, Sixth International Conference, Boulder, CO, July 12-16, 1982 (K. Burnett, Ed., de Gruyter, Berlin, NY, 1983), pp. 1013-1032.

*Entries with stars are those resulting from the work of JILA Visiting Fellows.

NOTE: Names in parentheses are authors who are not connected with JILA--NBS or CU.

PUBLICATIONS

Quantum Physics Division (525)

*G. S. Agarwal and (S. S. Jha), Surface Enhanced Nonlinear Optical Processes in Molecules in a Two-Oscillator Electromagnetic Model, Phys. Rev. B (in press).

*G. S. Agarwal, S. L. Haan, and J. Cooper, Photoemission Spectra From Autoionizing States Under Recycling Conditions, Phys. Rev. A (in press).

*G. S. Agarwal and S. V. ONeil, Effect of Hydrodynamic Dispersion of the Metal on Surface Plasmons and Surface Enhanced Phenomena in Spherical Geometries, Phys. Rev. B (in press).

*G. S. Agarwal, Coherent and Incoherent Effects in Laser-Induced Autoionization, in Proceedings, Fifth Rochester Conference on Coherence and Quantum Optics (Plenum, New York, in press).

*G. S. Agarwal, Finite Boundary Effects in Quantum Electrodynamics, in Proceedings, NATO Conference on Quantum Electrodynamics and Quantum Optics (A. Barut, Ed., Plenum, in press).

*K. M. Baird, Frequency Measurements of Optical Radiation, Phys. Today 36, 52-57 (1983).

P. L. Bender, Scientific Goals of Laser Range Measurements, in Proceedings, Fourth International Workshop on Laser Ranging Instrumentation (P. Wilson, Ed., Geodetic Institute, Univ. of Bonn, 1982), Vol. II, pp. 502-511.

D. R. Larden and P. L. Bender, Preliminary Study of GPS Orbit Determination Accuracy Achievable from Worldwide Tracking Data, in Proceedings, Third International Geodetic Symposium on Satellite Doppler Positioning (Physical Science Laboratory, New Mexico State Univ., Las Cruces, 1982), Vol. 2, pp. 1247-1252.

P. L. Bender and D. R. Larden, Topex Orbit Determination Using GPS Signals Plus a Sidetone Ranging System, in Proceedings, Third International Geodetic Symposium on Satellite Doppler Positioning (Physical Science Laboratory, New Mexico State Univ., Las Cruces, 1982), Vol. 2, pp. 1253-1258.

P. L. Bender, Geophysical Reasons For Monitoring Contemporary Plate Motions and the Earth's Rotation, in Proceedings, Workshop on Multiple Uses of the Very Long Baseline Array, National Research Council (in press).

PUBLICATIONS

Quantum Physics Division (525)

*R. A. Bernheim, (L. P. Gold and T. Tipton), Pulsed Optical-Optical Double Resonance Spectroscopy of the Gerade Excited States of $^7Li_2$, in Proceedings of the International Conference on Lasers '81, December 14-18, 1981 (Society for Optical and Quantum Electronics, McLean, Va. 1982), pp. 193-198.

*R. A. Bernheim, (L. P. Gold and T. Tipton), Rydberg States of Li_2 and Molecular Constants of Li_2^+, Chem. Phys. Lett. 92, 13-15 (1982).

*R. A. Bernheim, (L. P. Gold and T. Tipton), Rydberg States of $^7Li_2$ by Pulsed Optical-Optical Double Resonance Spectroscopy: Molecular Constants of $^7Li_2^+$, J. Chem. Phys. 78, 3635-3646 (1983).

*J. W. Gallagher, B. H. Bransden, and R. K. Janev, Evaluated Theoretical Cross Section Data For Charge Exchange of Multiply Charged Ions with Atoms, II. Hydrogen Atom-Partially Stripped Ion Systems, J. Phys. Chem. Ref. Data (in press).

*B. H. Bransden, The Theory of Charge Exchange and Ionization By Heavy Particles, in Proceedings, NATO Advanced Study Institute in Atomic & Molecular Processes in Controlled Thermonuclear Fusion (Plenum, NY, in press)

*(W. Boland) and T. de Jong, Carbon Depletion in Turbulent Molecular Cloud Cores, Astrophys. J. 261, 110-114 (1982).

*(F. Willems) and T. de Jong, Infrared Observations of OH/IR Stars, Astron. Astrophys. 115, 213-215 (1982).

*(P. F. Bowers) and T. de Jong, VLA Positions of OH/IR Stars, Astron. J. 88, 655-657 (1983).

*T. de Jong, OH/IR Stars. Late Stages of Evolution of Intermediate-Mass Stars, Astrophys. J. (in press).

R. A. Falk and G. H. Dunn, Electron-Impact Ionization of Be^+, Phys. Rev. A 27, 754-761 (1983).

R. A. Falk, G. H. Dunn, (D. C. Gregory and D. H. Crandall), Measurement of the Contribution of Excitation Autoionization to Electron-Impact Ionization of Ions: Ti^{3+}, Zr^{3+}, Hf^{3+}, and Ta^{3+}, Phys. Rev. A 27, 762-770 (1983).

PUBLICATIONS

Quantum Physics Division (525)

D. S. Belic, G. H. Dunn, T. J. Morgan, D. W. Mueller, and C. Timmer, Dielectronic Recombination: A Crossed-Beams Observation and Measurement of Cross Section, Phys. Rev. Letters 50, 339-342 (1983).

R. A. Falk, G. Stefani, R. Camilloni, G. H. Dunn, (R. A. Phaneuf, D. C. Gregory, and D. H. Crandall), Measured Electron Impact Ionization of BE-Like Ions. B^{+}, C ($^{2+}$), N($^{3+}$), O($^{4+}$), Phys. Rev. A 28, 91 (1983).

J. B. Jeffries, S. E. Barlow, and G. H. Dunn, Theory of Space Charge Shift of Ion Cyclotron Resonance Frequencies, Int. J. Mass Spectrom. and Ion Physics (in press).

J. E. Faller, Tunnel Detection Utilizing Field-Stationary Gravity Gradiometers, in Symposium on Tunnel Detection, July 21-23, 1981 (Colorado School of Mines, Golden, CO, 1982), pp. 247-257.

M. A. Zumberge, R. L. Rinker, and J. E. Faller, A Portable Apparatus for Absolute Measurements of the Earth's Gravity, Metrologia 18, 145-152 (1982).

J. E. Faller, Y. G. Guo, R. L. Rinker, and M. A. Zumberge, Advanced Absolute Gravity Determination, in Proceedings of the General Meeting of the International Association of Geodesy, Tokyo, May 7-15, 1982 (J. Geodet. Soc. Japan Special Issue, 1982), pp. 309-318.

M. A. Zumberge, J. E. Faller, and R. L. Rinker, A New Portable, Absolute Gravimeter, in Precision Measurement and Fundamental Constants II (B. N. Taylor and W. D. Phillips, Eds.) NBS Spec. Publ. 617 (in press).

(A. J. F. Metherell, C. C. Speake, Y. T. Chen) and J. E. Faller, Optimizing the Shape of the Attracting Mass in Precision Measurements of G, in Proceedings, Second International Conference on Precision Measurement and Fundamental Constants (in press).

J. E. Faller, R. L. Rinker, and M. A. Zumberge, A New and Portable Absolute Gravimeter, in Proceedings, Symposium on Measurements of Recent Crustal Movements, Especially With Gravimetric and Geodetic Methods, Tectonophysics (in press).

J. E. Faller, M. A. Zumberge, and R. L. Rinker, The JILA Absolute Gravimeter, in Proceedings, 9th International Symposium on Earth Tides (in press).

PUBLICATIONS

Quantum Physics Division (525)

R. L. Rinker and J. E. Faller, 'Super Spring' -- A Long Period Vibration Isolator, in Proceedings, Second International Conference on Precision Measurement and Fundamental Constants (in press).

P. T. Keyser, J. E. Faller, and K. H. McLagen, New Laboratory Test of the Equivalence Principle, in Proceedings, 2nd International Conference on Precision Measurement and Fundamental Constants (in press).

J. E. Faller and P. L. Bender, A Possible Laser Gravitational Wave Experiment in Space, in Precision Measurement and Fundamental Constants II (B. N. Taylor and W. D. Phillips, Eds., NBS Spec. Publ. 617, in press).

J. E. Faller, P. L. Bender, Y. M. Chan, J. L. Hall, D. Hils, and J. Hough, Laser Gravitational Wave Experiment in Space, in 10th International Conference on General Relativity and Gravitation - Contributed Papers (B. Bertotti, F. deFelice, and A. Pastorini, Eds., Consiglio Nazionale della Ricorche, Roma, 1983) Vol. 2, pp. 960-962.

P. T. Keyser, J. K. Hoskins, and J. E. Faller, New Laboratory Test of the Equivalence Principle, in Proceedings, 10th International Conference on General Relativity and Gravitation (in press).

J. E. Faller, The Physics of Basketball: An Introduction to Scientific Thinking, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

J. E. Faller, Telescopes and the Forces That Mold Them. An Introduction To Optics and Mechanical Design, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

J. E. Faller, G. M. Keiser, and P. T. Keyser, The Fluid-Fiber Based Torsion Pendulum, An Alternative to Simply Getting A Bigger Hammer, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

J. E. Faller, Little 'G'. An Introduction to Dropping Things, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

PUBLICATIONS

Quantum Physics Division (525)

J. E. Faller, Introductory Remarks, Opening Ceremony, January 31, 1983, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

J. E. Faller, Y. G. Guo, T. M. Niebauer, and R. L. Rinker, Promise and Plans for the JILA Gravimeter, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

J. E. Faller and W. A. Koldewyn, A Prototype Measurement of the Newtonian Gravitational Constant Using an Active Magnetic Suspension Torsion Fiber, in International School and Symposium on Precision Measurement and Gravity Experiment, Taipai, Taiwan (in press).

M. A. Zumberge, J. E. Faller, and (J. Gschwind), Results From an Absolute Gravity Survey in the United States, J. Geophys. Res. (in press).

J. E. Faller, Y. G. Guo, (J. Gschwind), T. M. Niebauer, J. Xue, R. L. Rinker, The JILA Portable Absolute Gravity Apparatus, to appear in Proceedings 1983 IUGG General Assembly (Hamburg, August 15-27) (in press).

J. Huennekens and A. Gallagher, Cross Sections for Energy Transfer in Collisions Between Two Excited Sodium Atoms, Phys. Rev. A 27, 771-784 (1983).

J. Huennekens and A. Gallagher, Resonance Broadening of the Sodium D Lines, in Spectral Line Shapes Volume 2, Proceedings, Sixth International Conference, Boulder, Colorado, July 12-16, 1982 (K. Burnett, Ed., de Gruyter, Berlin, New York, 1983), pp. 665-678.

J. Huennekins and A. Gallagher, Self-Broadening of the Sodium Resonance Lines and Excitation Transfer Between the $3P_{3/2}$ and $3P_{1/2}$ levels, Phys Rev. A 27, 1851-1864 (1983).

A. Gallagher, Far Wing Radiation From Atom-Molecule Collisions, in Spectral Line Shapes Volume 2, Proceedings, Sixth International Conference, Boulder, Colorado, July 12-16, 1982 (K. Burnett, Ed., de Gruyter, Berlin, New York, 1983), pp. 755-767.

J. Huennekens and A. Gallagher, Radiation Diffusion and Saturation in Optically Thick Na Vapor, Phys. Rev. A 28, 238 (1983).

PUBLICATIONS

Quantum Physics Division (525)

B. Kamke, W. Kamke, K. Niemax, and A. Gallagher, Rb and Cs Broadening of the Na Resonance Lines, Phys. Rev. A (in press).

J. Huennekens and A. Gallagher, Associative Ionization in Collisions Between Two Na(3P) Atoms, Phys. Rev. A (in press).

H. Chatham, D. Hils, R. Robertson & A. C. Gallagher, Reactions of He^+, Ne^+, and Ar^+ with CH_4, C_2H_6, SiH_4, & Si_2H_6, J. Chem. Phys.(in press)

R. Robertson, D. Hils, H. Chatham, and A. Gallagher, Radical Species in Silane Discharges, Appl. Phys. Lett. (in press).

S. Geltman, Separated-Atom Theory of Laser-Induced Collisional Ionization of Cs by Sr, in Photon-Assisted Collisions and Related Topics (N. K. Rahman and C. Guidotti, Eds., Harwood Academic Publishers, Chur, London, New York, 1982), pp. 35-53.

S. Geltman, Threshold Behavior For Ionization By Electrons and Positrons, J. Phys. B (Lett.) (in press).

*E. Gliner and (I. Dymnikova), A Covariant Concept of Gravitational Energy, Phys. Rev. D (in press).

*E. Gliner, Equivalence Relation Between Energy and Geometry, in Proceedings, Congress of the International Association of Mathematical Physics (in press).

*E. Gliner, New Analytical Axisymmetrical Solutions in Magnetohydrostatics, in Proceedings, Congress of the International Association of Mathematical Physics (in press).

(R. W. P. Drever), J. L. Hall, F. V. Kowalski, (J. Hough, G. M. Ford, A. J. Munley, and H. Ward), Laser Phase and Frequency Stabilization Using an Optical Resonator, Appl. Phys. B 31, 97-105 (1983).

R. Blatt, W. Ertmer, and J. L. Hall, Cooling of an Atomic Beam With Frequency-Sweep Techniques, in Laser-Cooled and Trapped Atoms, Proceedings of the Workshop on Spectroscopic Applications of Slow Atomic Beams, NBS Gaithersburg, MD, 14-15 April 1983 (W. D. Phillips, Ed.) NBS Spec. Publ. 653 (1983), pp. 142-153.

PUBLICATIONS

Quantum Physics Division (525)

W. Ertmer, R. Blatt, and J. L. Hall, Some Candidate Atoms and Ions For Frequency Standards Research Using Laser Radiative Cooling Techniques, in Laser-Cooled and Trapped Atoms, Proceedings of the Workshop on Spectroscopic Applications of Slow Atomic Beams, NBS Gaithersburg, MD, 14-15 April 1983 (W. D. Phillips, Ed.) NBS Spec. Publ. 653 (1983), pp. 154-657.

J. L. Hall, Some Remarks on the Interaction Between Precision Physical Measurement and Fundamental Physical Theories, in Proceedings, NATO Advanced Study Institute on General Relativity and Quantum Electronics, ed. by P. Meystre, K. S. Thorne, and M. O. Scully (Plenum Press, NY, in press).

J. L. Hall, H. G. Robinson, T. Baer, and L. Hollberg, The Lineshapes of Subdoppler Resonances Observable with FM Side-Band (Optical Heterodyne) Laser Techniques, in Proceedings, NATO Advanced Study Institute on General Relativity and Quantum Electronics, ed. by T. Arrechi and H. Walther (Plenum Press, NY,in press).

J. L. Hall, Tunable Laser Stabilization Techniques For UltraHigh Resolution Spectroscopy, in Proceedings, International Conference on Lasers, Beijing, China (in press).

P. Nachman, M. D. Rayman, and J. L. Hall, Relativistic Time Dilation. A Latter-Day Ives-Stillwell Experiment, in Proceedings, 2nd International Conference on Precision Measurement and Fundamental Constants (in press).

Ch. Breant, T. Baer, D. Nesbitt, and J. L. Hall, State-Dependent Hyperfine Coupling of HF Studied With a Frequency-Controlled Color-Center Laser Spectrometer, in Proceedings, Sixth International Conference on Laser Spectroscopy, ed. by H. P. Weber and W. Lütz (Springer-Verlag, Heidelberg, in press).

L. Hollberg and J. L. Hall, Measurement of Energy Level Shifts of Rydberg Atoms Due to Thermal Fields, in Proceedings, Sixth International Conference on Laser Spectroscopy, ed. by H. P. Weber and W. Lütz (Springer-Verlag, Heidelberg, in press).

L. Hollberg, Ma Long-sheng, M. Hohenstatt, and J. L. Hall, Precision Measurements By Optical Heterodyne Techniques, in Proceedings, Society of Photo-Optical Instrumentation Engineers (in press).

PUBLICATIONS

Quantum Physics Division (525)

D. G. Hummer,(M. J. Barlow, and P. J. Storey), The Infrared Recombination-Line Spectra of Wolf-Rayet Stars, in Wolf-Rayet Stars: Observations, Physics, and Evolution, IAU Symposium #99 (C. De Loore, & A. Willis, Eds., Reidel, Dordrecht, 1982), pp. 79-83.

J. Cooper, R. J. Ballagh, K. Burnett, and D. G. Hummer, On Redistribution and the Equations For Radiative Transfer, Astrophys. J. 260, 299-316 (1982).

(M. J. Barlow) and D. G. Hummer, The WO Wolf-Rayet Stars, in Wolf-Rayet Stars: Observations, Physics, and Evolution, IAU Symp. 99 (C. de Loore and A. J. Willis, Eds., Reidel, Dordrecht, 1982), pp. 387-392.

D. G. Hummer and (G. B. Rybicki), Second-Order Escape-Probability Approximations in Radiative Transfer, Astrophys. J. 263, 925-934 (1982).

D. G. Hummer, Radiative Transfer Problems in Planetary Nebulae, in Planetary Nebulae, IAU Symposium 103 (D. R. Flower, Ed., Reidel, Dordrecht, 1983), pp. 211-218.

D. G. Hummer, Co-editor, (with P. G. Burke, I. G. Percival, and W. B. Eissner) of Atoms In Astrophysics, in Honor of Professor M. J. Seaton on his 60th Birthday (Plenum Press, New York)

D. G. Hummer, The Generalized Exponential-Integral $V(x,y) = \int^{\infty} \exp(-xt)\, \ell n\,(t+y)dt/t$ and computer algorithms for $y = 0,1$, J. Quant. Spectrosc. Radiat. Transfer (in press).

(G. B. Rybicki) and D. G. Hummer, The Specific Luminosity of a Three-Dimensional Medium in Terms of the Escape Probability, Astrophys. J. (in press).

*R. K. Janev and D. S. Belic, Quasi-Resonant Charge Exchange Collisions Between Multiply Charged Ions, J. Phys. B. Atom. Molec. Phys. 15, 3479-3487 (1982).

*R. K. Janev and B. H. Bransden, Charge Exchange Between Highly Charged Ions and Atomic Hydrogen: A Critical Review of Theoretical Data, IAEA Report, INDC(NDS)-135/GA (1982).

PUBLICATIONS

Quantum Physics Division (525)

*R. K. Janev, Electron Capture into Excited States in Collisions of Highly Charged Ions with Atoms: A Theoretical and Experimental Challenge, Comments Atom. Molec. Phys. 12, 277-300 (1983).

*R. K. Janev, Excited States Created in Charge Transfer Collisions Between Atoms and Highly Charged Ions, in Symposium on the Production and Physics of Highly Charged Ions, Stockholm, June 1-5, 1982, Physica Scripta (in press).

*R. K.Janev, D. S. Belic, and B. H. Bransden, Total and Partial Cross Sections for Electron Capture in Collisions of Hydrogen Atoms with Fully Stripped Ions, Phys. Rev. A (in press).

*R. K. Janev and D. S. Belic, Electron Capture into Excited States in $H + Ar^{18+}$ Kr^{36+} and Xe^{54+} Charge Transfer Collisions, Physica Scripta (in press).

*R. K. Janev, J. W. Gallagher, and B. N. Bransden, Evaluated Theoretical Cross Section Data for Charge Exchange of Multiply Charged Ions with Atoms. I. Hydrogen Atom-Fully Stripped Ion Systems, J. Phys. Chem. Ref. Data (in press).

*(L. P. Presnyakov) and R. K. Janev, Excitation and Ionization Processes in Electron-Multiply Charged Ion Collisions, in Proceedings, VINIS Symposium (in press).

D. J. Nesbitt and S. R. Leone, Laser Initiated $C\ell$ /Hydrocarbon Chain Reactions: Time-Resolved Infrared Emission Spectra of Product Vibrational Excitation, J. Phys. Chem. 86, 4962-4973 (1982).

S. R. Leone, Infrared Fluorescence. A Versatile Probe of State-Selected Chemical Dynamics, Accts., Chem. Res. 16, 88-95 (1983).

M. A. Smith and S. R. Leone, Product Vibrational State Distributions in Thermal Energy Associative Detachment Reactions: $F^- + H,D \rightarrow HF(v)$, $DF(v) + e^-$, J. Chem. Phys. 78, 1325-1334 (1983).

C. E. Hamilton, M. A. Duncan, (T. S. Zwier, J. C. Weisshaar) G. B. Ellison, V. M. Bierbaum, and S. R. Leone, Product Vibrational Analysis of Ion-Molecule Reactions by Laser-Induced Fluorescence in a Flowing Afterglow: $O^- + HF \rightarrow OH(v=0,1) + F^-$, Chem. Phys. Lett. 94, 4-9 (1983)

PUBLICATIONS

Quantum Physics Division (525)

M. A. Smith, V. M. Bierbaum, and S. R. Leone, Infrared Chemiluminescence From Vibrationally Excited NO^+. Product Branching in the $N^+ + O_2$ Ion Molecule Reaction, Chem. Phys. Lett. 94, 398-403 (1983).

C. A. Wight and S. R. Leone, Excimer Laser Photolysis Studies of Translational-To-Vibrational Energy Transfer in Collisions of H and D Atoms with CO, J. Chem. Phys. 78, 4875-4886 (1983).

V. M. Bierbaum, G. B. Ellison, and S. R. Leone, Flowing Afterglow Studies of Ion Reaction Dynamics Using Infrared Chemiluminescence and Laser-Induced Fluorescence, in Gas Phase Ion Chemistry, Vol. 3, "Ions and Light," (M. T. Bowers, Ed., in press).

D. R. Guyer, L. Hüwel, and S. R. Leone, Single Collision Ion-Molecule Reactions at Thermal Energy: Rotational and Vibrational Distributions from $N^+ + CO \rightarrow N + CO^+$, J. Chem. Phys. (in press)

J. E. Smedley and S. R. Leone, Relative Quantum Yield of $I^*(^2P_{1/2})$ in the Tunable Laser UV Photodissociation of $i\text{-}C_3F_7I$ and $n\text{-}C_3F_7I$: Effect of Temperature and Exciplex Emission, J. Chem. Phys. (in press).

M. O. Hale and S. R. Leone, Laser Excited, State Detected Calcium-Rare Gas Collisional Energy Transfer: $Ca(4s5p\ ^1P_1)$ Spin Changing and $Ca(4s5p\ ^3P_1)$ Fine Structure Changing Cross Sections, J. Chem. Phys. (in press).

PUBLICATIONS

Quantum Physics Division (525)

M. Schindler, R. E. Stencel, J. L. Linsky, (G. S. Basri and D. J. Helfand), Ultraviolet and X-Ray Detection of the 56 Pegasi System (KO IIp + WD): Evidence for Accretion of a Cool Stellar Wind Onto a White Dwarf, Astrophys. J. 263, 269-276 (1982).

R. E. Stencel, J. L. Linsky, (T. R. Ayres, C. Jordan, A. Brown and O. Engvold), High Dispersion Far Ultraviolet Spectra of Cool Stars, in Advances in Ultraviolet Spectroscopy: Four Years of IUE Research, NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead, and R. D. Chapman, Eds., NASA Goddard Space Flight Center, 1982), pp. 259-262.

R. Hammer, J. L. Linsky, and (F. Endler), On the Correlation Between Chromospheric and Coronal Emission, in Advances in Ultraviolet Spectroscopy. Four Years of IUE Research NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead and R. D. Chapman, Eds., NASA Goddard Space Flight Center, 1982), pp. 268-272.

(T. R. Ayres, T. Simon), and J. L. Linsky, Evolution of Chromospheres and Coronae in Solar Mass Stars: A Far Ultraviolet and Soft X-Ray Comparison of Arcturus (K2 III) and Alpha Centauri A (G2 V), Astrophys. J. 263, 791-802 (1982).

(T. Simon) and J. L. Linsky, Ultraviolet Observations of Yellow Giant Stars, in Advances in Ultraviolet Spectroscopy: Four Years of IUE Research, NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead, and R. D. Chapman, Eds., NASA Goddard Space Flight Center, 1982), pp. 273-276.

(T. Y. Ayres), J. L. Linsky, (A. Brown, C. Jordan, and T. Simon), High Dispersion IUE Spectra of Active Chromosphere G and K Dwarfs, in Advances in Ultraviolet Spectroscopy: Four Years of IUE Research, NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead, and R. D. Chapman, Eds.. NASA Goddard Space Flight Center, 1982), pp. 281-284.

N. Marstad, J. L. Linsky, (T. Simon, M. Rodono, C. Blanco, S. Catalano, E. Marilli, A. D. Andrews, C. J. Butler, and P. B. Byrne), Results of an IUE Program of Monitoring the Ultraviolet Emission Line Fluxes of Four Binary Systems: HR 1099, II Peg, Ar Lac, and BY Dra, in Advances in Ultraviolet Spectroscopy: Four Years of IUE Research, NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead, and R. D. Chapman, Eds., NASA Goddard Space Flight Center, 1982), pp. 554-557.

PUBLICATIONS

Quantum Physics Division (525)

J. L. Linsky, The Structure and Energy Balance of Cool Star Atmospheres, in Advances in Ultraviolet Spectroscopy: Four Years of IUE Research, NASA Conf. Publ. 2238 (Y. Kondo, J. M. Mead, and R. D. Chapman, Eds., NASA Goddard Space Flight Center, 1982), pp. 17-32.

J. L. Linsky, (A. Boggess, S. Bowyer, J. Caldwell, W. Cash, J. Cohen, A Dupree, R. Green, E. Jenkins, M. Jura, D. Leckrone, H. W. Moos, B. Savage, M. Shull, T. Snow, J. G. Timothy, E. Weiler and D. York), Current NASA Studies for a Far-Ultraviolet Spectrographic Explorer (FUSE), in Proceedings of Third European IUE Conference, Madrid, May 1982, ESA SP-176 (European Space Agency, Paris, 1982), pp. 473-485.

(D. E. Gary), J. L. Linsky, and (G. A. Dulk), An Unusual Microwave Flare with 56 Second Oscillations on the M Dwarf L726-8 A, Astrophys. J. (Letters) 263, L79-83 (1982).

(M. S. Giampapa, L. Golub, R. Rosner, G. S. Vaiana), J. L. Linsky, and (S. P. Worden), A Heating Mechanism for the Chromospheres of M Dwarf Stars, in Second Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun (M. S. Giampapa and L. Golub, Eds., SAO Special Report 392, 1982), Vol. 1, pp. 73-79.

J. L. Linsky, P. L. Bornmann, (M. Rondono, V. Pazzani, A. D. Andrews, C. J. Butler, and P. B. Byrne), Variability of Cool Stars at Optical and Ultraviolet Wavelengths. II. The Binary (?) Flare Star AU Mic, in Proceedings of Third European IUE Conference, Madrid, May 1982, ESA SP-176 (European Space Agency, Paris, 1982), pp. 165-167.

J. L. Linsky, Cool Luminous Stars, Adv. Space Res. 2, 249-260 (1983).

(B. M. Haisch), J. L. Linsky, P. L. Bornmann, R. E. Stencel, (S. K. Antiochos, L. Golub, and G. S. Vaiana), Coordinated Einstein and IUE Observations of a 'Disparitions Brusques' Type Flare Event and Quiescent Emission from Proxima Centauri, Astrophys. J. 267 280-290 (1983).

(T. R. Ayres, K. Eriksson), J. L. Linsky, and R. E. Stencel, The Narrow Ultraviolet Emission Lines of the Red Dwarf, AU Microscopii (dM1.6e), Astrophys. J. (Letters) 270, L17-L21 (1983).

(D. E. Gary), J. L. Linsky, and (G. A. Dulk), VLA Observations of Quiescent and Flare Microwave Emission from Late-Type Stars: A Unique Probe of Coronal Magnetic Fields, in Proceedings, IAU Symposium 102 (J. O. Stenflo, Ed., Reidel, Dordrecht, in press).

PUBLICATIONS

Quantum Physics Division (525)

J. L. Linsky, The Role of Magnetic Fields in Stellar Chromospheres and Transition Regions, in Solar and Stellar Magnetic Fields. Origins and Coronae Effects, IAU Symposium 102 (J. D. Stenflo, Ed., Reidel, Dordrecht, in press).

J. L. Linsky, The Quiescent Chromospheres and Transition Regions of Active Dwarf Stars: What Are We Learning from Recent Obvservations and Models? in Proceedings, IAU Colloquium 71 (Reidel, Dordrecht, in press).

(T. R. Ayres), R. E. Stencel, J. L. Linsky, (T. Simon, C. Jordan, A. Brown, and O. Engvold), Red-Shifts of High-Excitation Species in the Far-Ultraviolet Spectra of Late-Type Stars, Astrophys. J. (in press).

(T. R. Ayres), J. L. Linsky, (T. Simon, C. Jordan, and A. Brown), Outer Atmospheres of Cool Stars. XV. High Dispersion Ultraviolet Studies of Active Chromosphere G-K Dwarfs, Astrophys. J. (in press).

(T. R. Ayres, F. H. Schiffer, III) and J. L. Linsky, Outer Atmospheres of Cool Stars. XIII. Capella at Critical Phases, Astrophys. J. (in press).

J. L. Linsky and (D. E. Gary), Microwave Emission from the Coronae of Late-Type Dwarf Stars, Astrophys. J. (in press).

K. Eriksson, J. L. Linsky, and T. Simon, Outer Atmospheres of Cool Stars. XIV. A Model for the Chromosphere and Transition Region of Beta Ceti (G9.5 III), Astrophys. J. (in press).

S. A. Drake and J. L. Linsky, The Formation of Emission Lines in the Expanding Chromospheres of Luminous Cool Stars. I. The Importance of Atmospheric Extension and Partial Redistribution Effects, Astrophys. J. (in press).

S. A. Drake and J. L. Linsky, First Detection of Winds in Red Giants by Microwave Technqiues, Astrophys. J. (Letters) (in press).

*D. A. Micha, Variational Determination of Self-Consistent Interactions in Atomic Collisions, Int. J. Quantum Chem. (Proceedings, Bates Symposium 1983, in press).

*R. E. Mickens, Uniformly Valid Asymptotic Solutions of Chemical Rate Equations for Irradiation-Produced Point Defects, Acta Phys. Pol. (in press).

PUBLICATIONS

Quantum Physics Division (525)

*(H-L Dai, E. Specht, M. R. Berman), and C. B. Moore, Determination of Arrhenius Parameters for Unimolecular Reactions of Chloroalkanes by IR Laser Pyrolysis, J. Chem. Phys. 77, 4494-4506 (1982).

*(J. S. Wong) and B. C. Moore, Inequivalent C-H Oscillators of Gaseous Alkanes and Alkenes in Laser Photoacoustic Overtone Spectroscopy, J. Chem. Phys. 77, 603-615 (1982).

*T. J. Morgan, Atomic Physics of Negative Ions: A Report on the US-Mexico Joint Workshop, Comments At. Mol. Phys. 12, 319-326 (1983).

D. W. Norcross, Magnetohydrodynamic Electrical Power Generation, in Applied Atomic Collision Physics, Vol. 5, Special Topics (H. S. W. Massey, E. W. McDaniel and B. Bederson, Eds., Academic, New York, 1982), Chap. 3, pp 69-85.

D. W. Norcross and (L. A. Collins), Recent Developments in the Theory of Electron Scattering By Highly Polar Molecules, in Advances in Atomic and Molecular Physics (Academic, New York, 1982), Vol. 18, pp. 341-397.

D. W. Norcross, Recent Developments in the Theory of Electron Collisions with Polar Molecules, in Recent Developments in Electron-Atom and Electron-Molecule Collisions, Proceedings of the Dares Study Weekend (Science and Engineering Council, Daresbury Laboratory, 1982), pp. 64-69.

D. W. Norcross, Numerical Methods for Asymptotic Solutions of Scattering Equations, in Atoms in Astrophysics (P. G. Burke, W. D. Eissner, D. G. Hummer, and I. Percival, Eds. Plenum, New York, 1983), pp. 55-73.

N. T. Padial, D. W. Norcross, and (L. A. Collins), Vibrationally Elastic Scattering of Electrons By HCℓ, Phys. Rev. A 27 141-148 (1983).

D. W. Norcross, On the Non-Existence of the First Nonadiabatic Correction for Two Electrons in the Field of a Core, Phys. Rev. A (in press).

D. W. Norcross, Theory and Computations for Electron Collisions with Polar Molecules, in Proceedings, U. S./Japan Seminar on Electron-Molecule Collisions and Photoionization Processes, 26-29 October, Caltech (in press).

PUBLICATIONS

Quantum Physics Division (525)

A. V. Phelps, Transport Data for the Modeling of Electrical Breakdown and Discharges, in Electrical Breakdown and Discharge in Gases: Fundamental Processes and Breakdown (E. K. Kunhardt and L. H. Luessen, Eds., Plenum, New York, 1983), pp. 109-132.

C. Yamabe, S. J. Buckman, and A. V. Phelps, Measurement of Free-Free Emission from Low Energy Electron Collisions with Ar, Phys. Rev. A (in press).

C. Yamabe and A. V. Phelps, Excitation of the O_2 ($a^1\Delta_g$) State by Low Energy Electrons in O_2-N_2 Mixtures, J. Chem. Phys. 78, 2984-2989 (1983).

S. Yoshida, A. V. Phelps, and (L. C. Pitchford), Effect of Electrons Produced by Ionization on Calculated Electron-Energy Distributions," Phys. Rev. A 27, 2858-2867 (1983).

*E. L. Robinson, (S. O. Kepler, and R. E. Nather), Multicolor Variations of the ZZ Ceti Stars, Astrophys. J. 259 219-231 (1982).

*H. G. Robinson and (C. E. Johnson), Measured g_J Factor Ratio of $^4He^+$ ($1^2S_{1/2}$) and ^4He (2^3S_1), in Second International Conference on Precision Measurement and Fundamental Constants (in press).

*G. Shaviv and (E. E. Salpeter), Gas Dynamics of Flow Past Galaxies, Astron. Astrophys. 110, 300-315 (1982).

*J. Smak, On the Nature of Dwarf Novae, Astrophys. J. (in press).

R. Roy, D. S. Elliott, D. Meschede, F. M. Pipkin, and S. J. Smith, Collisional Dependence of Spectral Line Shapes in CO_2, Chem. Phys. Lett. 93, 603-607 (1982).

R. Roy, D. S. Elliott, D. Meschede, F. M. Pipkin, and S. J. Smith, Collisional Dependence of Spectral Line Shapes in CO at Low Pressures, in Spectral Line Shapes Volume 2, Proceedings, Sixth International Conference, Boulder, Colorado, July 12-16, 1982 (K. Burnett, Ed., de Gruyter, Berlin, New York, 1983), pp. 651-662.

E. Matthias, P. Zoller, D. S. Elliott, N. D. Piltch, S. J. Smith, and G. Leuchs, Influenence of Configuration Mixing in Intermediate States on Resonant Multiphoton Ionization, Phys. Rev. Lett. 50, 1914-1917 (1983).

PUBLICATIONS

Quantum Physics Division (525)

D. S. Elliott, R. Roy, and S. J. Smith, Role of Field Fluctuations in Nonlinear Absorption, in Spectral Line Shapes Volume 2, Proceedings, Sixth International Conference, Boulder, Colorado, July 12-16, 1982 (K. Burnett, Ed., de Gruyter, Berlin, New York, 1983), pp. 989-998.

(G. Leuchs) and S. J. Smith, Photoelectron Angular Distribution in Resonant Multiphoton Ionization of Atoms, in Proceedings of the International School on Lasers and Applications, 29 June - 7 July 1981, Vilnius, Lithuania (in press).

(G. Leuchs), E. Matthias, D. S. Elliott, S. J. Smith, and P. Zoller, Resonant Multiphoton Ionization via Rydberg States - Angular Distribution of Photoelectrons, Proceedings of the Sixth International Conference on Laser Spectroscopy, Interlaken, Switzerland, June 27-July 1, 1983, ed. by H. P. Weber and W. Lutz (Springer-Verlag, Heidelberg, in press).

*D. Spence, (R. G. Wang and M. A. Dillon), Pseudo-Optical Absorption Spectra in $HgC\ell_2$ and $HgBr_2$ from 4 to 14 eV, Appl. Phys. Lett. 41, 1021-1023 (1982).

*(G. Alber) and P. Zoller, Spin Polarization By Selective Laser Induced Interference, Phys. Rev. A 27, 1713-1716 (1983).

*J. Cooper and P. Zoller, Radiative Transfer Equations in Broadband, Time-Varying Fields, Astrophys. J. (in press).

*P. Zoller and J. Cooper, Nonlinear Noise Fields and Strongly Driven Atomic Transitions, Phys. Rev. A. (in press).

*P. Zoller, Noise and Fluctuations in Multiphoton Processes, in Proceedings, Fifth Rochester Conference on Coherence and Quantum Optics (A. Barut, Ed., Plenum , New York, in press).

PUBLICATIONS

Quantum Physics Division (525)

("in preparation" or "submitted")

*B. H. Bransden, (T. Scott, R. Shingal and R. K. Roychoudhury), Elastic and Inelastic Scattering of Electrons By Atomic Hydrogen at Intermediate Energies in a Coupled Channel Second Order Potential Model, J. Phys. B. Atom. Molec. Phys. (submitted).

*R. M. Crutcher, Optical and Radio Study of the Taurus Molecular Cloud Toward HD 29647, Astrophys. J. (submitted).

*(B. L. Lutz) and R. M. Crutcher, Observations of Interstellar C_2 Toward Three Heavily Reddened Stars, Astrophys. J. (Letters). (submitted).

*L. W., Davis and (G. Patsaros), Comment on Representation of Vector Electromagnetic Beams, Phys. Rev. A. (submitted).

J. A. Luine and G. H. Dunn, Ion Molecule Reactions Near 10K, Phys. Rev. Lett. (submitted).

D. S. Belic, R. A. Falk, G. H. Dunn, D. Gregory, C. Cisneros, and D. H. Crandall, Electron-Impact Excitation of Na-Like Ions: Mg^+ and Al^{+2} Phys. Rev. A (to be submitted).

D. S. Belic, R. A. Falk, C. Timmer, and G. H. Dunn, Electron-Impact Ionization of Metal Ions: Al^+, Cd^+, Hg^+, Phys. Rev. A (to be submitted).

G. H. Dunn, Electron Impact Ionization, a book to be published by Springer, edited by Gordon Dunn and Tilman Mark (in preparation).

G. H. Dunn, Ionization of Ions, a chapter for the book <u>Electron Impact Ionization</u> written by Gordon Dunn (in preparation).

G. H. Dunn, Absolute Cross Sections for Electron Impact Excitation of Mg^+ and Al^{2+}, for Physical Review A (in preparation).

G. H. Dunn, Absolute Cross Section Measurement for Electron Impact Ionization of Twice Charged Ions Ti^{2+}, Fe^{2+}, Ar^{2+}, Cl^2 , and $F^{2+}$for Physical Review A (in preparation.

G. H. Dunn, Absolute Cross Section Measurements for Electron Impact Ionization of Al^+, Cd^+, and Hg^+ for Physical Review A (in preparation).

PUBLICATIONS

Quantum Physics Division (525)

("in preparation" or "submitted")

G. H. Dunn, Transverse Ion Acoustic Modes in a Non-Neutral Plasma for JQRST (in preparation).

G. H. Dunn, Collisions in Ion Traps, a chapter for Advances in Atomic and Molecular Physics, a book edited by D. R. Bates and B. Bederson (in preparation).

H. Chatham, D. Hils, R. Robertson, and A. Gallagher, Total and Partial Electron Collisional Ionization Cross Sections for CH_4, C_2H_6, SiH_4 and Si_2H_6 , J. Chem. Phys. (submitted).

R. Robertson, D. Hils, and A. Gallagher, Silane Pyrolysis, Chem. Phys. Lett. (submitted).

*E. Gliner, The Influence of Quantum Evaporation on the Course of Gravitational Collapse, Phys. Rev. D. (submitted).

*E. Gliner and (V. A. Osherovich), Model of a Solar Coronal Transient with Forerunner, Astron. Astrophys. (submitted).

*E. Gliner, Combined Effect of Potential and Nonpotential Magnetic Field on Equilibrium in Stellar Atmospheres, Astrophys. J. (submitted).

(T. R. Ayres, T. Simon) and J. L. Linsky, Sigma Geminorum (Kl III + ?): Variability of the Ultraviolet Emission Lines Near Conjunction, Astrophys. J. (Letters, submitted).

R. Hammer and J. L. Linsky, The Chromospheric-Coronal Relationship in Cool Stars. I. on the Assumption that the Global Energy Balance Determines the Location of the Transition Region, Astron. Astrophys. (submitted).

F. M. Walter, J. L. Linsky, (T. Simon, L. Golub, and G. S. Variana), Stellar Chromospheres and Coronae in the Ursa Major Cluster, Astrophys. J. (in preparation).

(W. B. Landsman, R. C. Henry, H. W. Moos), and J. L. Linsky, Observations of Hydrogen and Deuterium Toward Alpha Centauri A, Astrophys. J. (submitted).

PUBLICATIONS

Quantum Physics Division (525)

("in preparation" or "submitted")

A. Brown, (C. Jordan), R. E. Stencel, J. L. Linsky, and (T. R. Ayres), High Resolution, Far Ultraviolet Study of Beta Draconis (G2Ib - II): Transition Region Structure and Energy Balance, Astrophys. J. (in preparation).

*(Z. C. Kuruoglu) and D. A. Micha, Collision Dynamics of Three Interacting Atoms, The Faddeev Equations in a Diabatic Electronic Basis, J. Chem. Phys. (submitted).

*(J. A. Olson) and D. A. Micha, A Selfconsistent Eikonal Treatment of Diabatic Rearrangement, Model $H^+ + H_2$ Calculations, J. Chem. Phys. (submitted).

(N. T. Padial) and D. W. Norcross, A Parameter-Free Free-Electron-Gas Model of the Correlation Polarization Potential for Electron-Molecule Collisions, Phys. Rev. A (in preparation).

(R. B. Christensen) and D. W. Norcross, Cross Sections for Electron Impact Excitation of Li II, Phys. Rev. A (in preparation).

D. W. Norcross and (K. T. Taylor), Multichannel Photodetachment Theory, Phys. Rev. A (in preparation).

D. W. Norcross and (K. T. Taylor), Photodetachment of K^-, Phys. Rev. A (in preparation).

D. W. Norcross, N. T. Padial, (T. N. Rescigno, A. E. Orel, A. U. Hazi, and B. V. McKoy), Ro-Vibrational Excitation of HF By Electrons: Differential, Momentum Transfer, and Energy Loss Cross Sections, Phys. Rev. A (in preparation).

*J. Smak, Accretion in Cataclysmic Binaries. III. Helium Binaries, Acta Astron. (submitted).

*J. Smak, Eruptive Binaries. XI. Disk-Radium Variations in U Gem, Acta Astron. (submitted).

*J. Smak, Accretion Disks in Dwarf Novae, Astrophys. J. (submitted).

INVITED TALKS

Quantum Physics Division (525)

P. L. Bender, "Measuring Plate Tectonic Motions by Space Techniques," Physics Department Colloquium, Colorado State University, Fort Collins, Colorado, September 13, 1982.

P. L. Bender, "Continental Drift Measurements via Laser Ranging," 13th Winter Colloquium on Quantum Electronics, Snowbird, Utah, January 12, 1983.

P. L. Bender, "Geophysical Reasons for Monitoring Contemporary Plate Motions," Workshop on Multidisciplinary Uses of the Very Long Baseline Array, National Research Council, Washington, D. C., April 8, 1983.

G. H. Dunn, "Electron-Ion Collisions: A Menagerie for Atomic Physics," National Bureau of Standards, Gaithersburg, Maryland, December 1982.

G. H. Dunn, "Electron-Ion Collisions," Department of Physics, University of Wisconsin, Madison, Wisconsin, December 1982.

G. H. Dunn, "Ion Traps: A Modern Tool for Atomic Physics," Department of Physics, Colorado State University, Fort Collins, Colorado, February 1983.

G. H. Dunn, "Electron-Ion Collisions: A Menagerie for Atomic Physics, Physics Department, Denver University, Denver, Colorado, February 23, 1983.

G. H. Dunn, "Electron-Ion Collisions: Resonances," Invited paper at the 1983 Gordon Conference on Atomic Physics, New London, New Hampshire, July 4, 1983.

G. H. Dunn, "Dielectronic Recombination of Some Singly Charged Ions," Invited paper at XIII International Conference on the Physics of Electronic and Atomic Collisions, West Berlin, August 1983.

G. H. Dunn, "Excitation, Ionization, and Recombination in Electron-Ion Collisions," Invited paper, Symposium on Atomic Collision Data For Diagnostics and Modelling of Fusion Plasmas," Nagoya, Japan, August 29, 1983.

J. E. Faller, "Introductory Remarks," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

INVITED TALKS

Quantum Physics Division (525)

J. E. Faller, "The Physics of Basketball: An Introduction to Scientific Thinking," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J. E. Faller, "Telescopes and the Forces That Mold Them: An Introduction to Optics and Mechanical Design," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J. E. Faller, "Little "g": An Introduction to Dropping Things," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J. E. Faller, Y. G. Guo, T. M. Niebauer, and R. L. Rinker, "Promise and Plans for the JILA Gravimeter," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J. E. Faller and W. A. Koldewyn, "A Prototype Measurement of the Newtonian Gravitational Constant Using an Active Magnetic Suspension Torsion Fiber," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J. E. Faller, G. M. Keiser, and P. T. Keyser, "The Fluid-Fiber Based Torsion Pendulum: An Alternative to Simply Getting a Bigger Hammer," 1983 International School and Symposium on Precision Measurement and Gravity Experiment, Taipei, Republic of China, January 24 - February 2, 1983.

J E. Faller, "Two Experiments: The Measurement of g, and a Proposed Experiment to Detect Gravity Waves in Space," Department of Physics, Colorado State University, Fort Collins, Colorado, April 25, 1983.

J. E. Faller, "The JILA Absolute Gravimeter," Institute for Geodesy and Geology, University of Vienna, Vienna, Austria, June 29, 1983.

J. E. Faller, "Modern Gravimetry," WILD Heerbrugg, Ltd., Heerbrugg, Switzerland, July 1, 1983.

INVITED TALKS

Quantum Physics Division (525)

J. E. Faller, "g and Eötvös Experiments: An Introduction to Dropping Things," Research Advisory Committee Sponsored Talks on Precision Measurements, NBS - Gaithersburg, Maryland, September 15, 1983.

Geltman, "Free-Free Transitions Near Feshbach Resonances," Max Planck Institute for Quantum Optics, Garching, West Germany, June 8, 1983.

(L. Hollberg) and J. L. Hall, "Optically-Pumped Dimer Lasers as Stable Optical Oscillators,' "Presented by L. Hollberg, Lasers 82 Conference, New Orleans, Louisiana, December 1982.

(R. Blatt, W.Ertmer) and J. L. Hall, "Cooling of an Atomic Beam with Frequency-Sweep Techniques," Workshop on Spectroscopic Application of Slow Atomic Beams," NBS, Gaithersburg, Maryland, April 1983.

(W. Ertmer, R. Blatt) and J. L.Hall, "Some Candidate Atoms and Ions for Frequency Standards Research Using Laser Radiative Cooling," Workshop on Spectroscopic Application of Slow Atomic Beams," NBS, Gaithersburg, Maryland, April 1983.

J. L. Hall, (with Ch. Breant, T. Baer, and D. Nesbitt), "State-Dependent Hyperfine Coupling of HF Studied With a Frequency-Controlled Color-Center Laser Spectrometer," Sixth International Conference on Laser Spectroscopy (SICOLS), Interlaken, Switzerland, June 1983.

J. L. Hall, (with L. Hollberg), "Observation of Energy Level Shifts of Rydberg Atoms Due to Thermal Fields," Sixth International Conference on Laser Spectroscopy (SICOLS), Interlaken, Switzerland, June 1983.

J. L. Hall, (with L. Hollberg, Ma Long-Sheng, and M. Hohenstatt), "Precision Measurements By Optical Heterodyne Techniques," presented by L. Hollberg, SPIE Symposium on Ultra Sensitive Detection, San Diego, August 1983.

J. L. Hall, "Frequency Stabilization of Tuneable Dye and Color Center Lasers," 2nd International Conference on Lasers, Guangzhow, China, September 6-10, 1983.

INVITED TALKS

Quantum Physics Division (525)

J. L. Hall, Five Lectures on laser wavelength metrology; progress toward phase-stable lasers; reference lasers based on hard-sealed He-Ne laser tubes; high sensitivity laser spectroscopy using of sideband techniques; and cooling atomic beams using frequency-swept laser sources, Beijing Institute of Opto-Electronic Technology, Beijing, China, September 19 - October 2, 1983.

S. R. Leone, "Laser and Infrared Chemiluminescence Studies of Ion Chemistry," Air Force Geophysics Laboratory, Hanscom Air Force Base, Massachusetts, October 1982.

S. R. Leone, "Laser Studies of Reactive Dynamics," Harvard/MIT Seminar, Harvard University, Cambridge, Massachusetts, October 1982.

S. R. Leone, "Laser Studies of Chemical Dynamics," Department of Chemistry Seminar, University of Denver, Denver, Colorado, November 1982.

S. R. Leone, "State-Detected Chemical Reaction Dynamics," National Bureau of Standards, Chemical Physics Center Colloquium, December 1982.

S. R. Leone, "State-Detected Molecular Reaction Dynamics," Department of Chemistry Colloquium, University of Wyoming, Laramie, Wyoming, February 1983.

S. R. Leone, "State-Detected Molecular Reaction Dynamics: Establishing the Relationship Between Reactivity and Energy Transfer," Department of Chemistry Colloquium, Northwestern University, Evanston, Illinois, February 1983.

S. R. Leone, "Laser Studies of Free Radical Kinetics," Notre Dame Radiation Laboratory, South Bend, Indiana, February 1983.

S. R. Leone, "State-Detected Molecular Reaction Dynamics: Establishing the Relationship Between Reactivity and Energy Transfer, Department of Chemistry Seminar, University of Southern California, Los Angeles, California, April 1983.

S. R. Leone, "Vibrational Energy Disposal in Products of Ion-Molecule Reactions," 1983 Conference on the Dynamics of Molecular Collisions, Gull Lake, Minnesota, June 28, 1983.

INVITED TALKS

Quantum Physics Division (525)

S. R. Leone, "State-Specific T → V,R and V → R Energy Transfer," 8th International Conference on Molecular Energy Transfer, Cirencester, United Kingdom, July 5, 1983.

J. L. Linsky, "The Roles of Magnetic Fields in Stellar Chromospheres and Transition Regions," Astrogeophysics Department, University of Colorado, Boulder, Colorado, December 6, 1982.

J. L. Linsky, "Gyroresonant Microwave Emissions From Stellar Coronae," Physics Department, Johns Hopkins University, Baltimore, Maryland, February 1, 1983.

J. L. Linsky, "The Outer Atmospheres of Stars: New Information From X-Ray and Ultraviolet Observations," Physics Department, Johns Hopkins University, Baltimore, Maryland, February 3, 1983.

J. L. Linsky, "Microwave Observations of Stars with the VLA: Measuring Stellar Magnetic Fields with a Radio Telescope Interferometer," National Membership Laboratory, NBS, Gaithersburg, Maryland, February 4, 1983.

J. L. Linsky, "The 1980's: A Golden Age for Cool-Star Research," Division of Astronomical Sciences, National Science Foundation, Washington, D. C., March 9, 1983.

J. L. Linsky, "What Ultraviolet, X-Ray, and Microwave Observations Are Telling Us About Stellar Flares and Flare Stars," Armagh Observatory, Armagh, N. Ireland, April 8, 1983.

J. L. Linsky, "The Roles of Magnetic Fields in Stellar Chromospheres and Coronae," Armagh Observatory, Armagh, N. Ireland, April 8, 1983.

J. L. Linsky, "The Physical Nature of Winds and Flows in Cool Giants and Supergiants," The Role of Ultraviolet Observations in Astronomy, Cumberland Lodge, England, April 13, 1983.

J. L. Linsky, "What the VLA is Telling Us About Stellar Coronae," High Altitude Observatory, NCAR, Boulder, Colorado, April 21, 1983.

J. L. Linsky, "Observations of RS CVn Systems: Evidence for Variability, Atmospheric Inhomogeneities, Spots, Plages, and Flares," Third Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Center for Astrophysics, Cambridge, Massachusetts, October 5, 1983.

INVITED TALKS

Quantum Physics Division (525)

D. W. Norcross, "Theory and Computations for Electron Collisions with Polar Molecules--Recent Progress," U. S. - Japan Seminar on Electron-Molecule Collisions and Molecular Photoionization Processes, California Institute of Technology, October 26, 1982.

D. W. Norcross, "The Theory of Electron-Molecule Collisions," International Symposium on Molecular Scattering Theory and Quantum Chemistry, University of Florida, Palm Coast, Florida, March 3-5, 1983.

D. W. Norcross, "Theoretical Progress on Electron Collisions with Polar Molecules," Symposium on Wave Functions and Mechanisms from Electron Scattering Processes, Villa Monte Cucco, Italy, July 24-25, 1983.

D. W. Norcross, "Overview of Asymptotic Methods," Workshop on Asymptotic Methods, London, England, December 19-20, 1983.

S. J. Smith, "Multiphoton Ionization and Photoelectron Angular Distributions from Highly Excited and Aligned Atomic States," Department of Physics, University of Wisconsin, October 1982.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

P. L. Bender, Associate Editor, Physical Review Letters.

P. L. Bender, Member, Scientific Committee, 10th International Conference on General Relativity and Gravitation.

P. L. Bender, Member, Working Group 1 on Recent Plate Movements and Deformation, Inter-Union Commission on the Lithosphere.

P. L. Bender, Member, Crustal Dynamics Working Group, NASA.

P. L. Bender, Member, Section Committee, Physics Section, American Association for the Advancement of Science.

G. H. Dunn, Member, IAEA Committee on Atomic Data For Fusion.

G. H. Dunn, Member, National Research Council Committee on Atomic and Molecular Science.

G. H. Dunn, Member, Panel on New Instruments and Facilities in Atomic and Molecular Science.

J. E. Faller, Member, Special Study Group 3.37 "Special Techniques of Gravity Measurements," of the International Gravity Commission.

J. E. Faller, Member, Plans Committee of the Geodesy Section of the AGU.

J. E. Faller, Member, Fellows Committee of the AGU, Chairman for External Awards.

J. E. Faller, Member, Working Group II of the International Gravity Commission.

J. L. Hall, Delegate, Consultative Committee for the Definition of the Meter (BIPM), Sevres, France, 1970 - present.

J. L. Hall, Member, International Steering Committee for Conferences on Laser Spectroscopy.

J. L. Hall, Member, NBS Committee for NBS Precision Measurement Grants.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

J. L. Hall, Member, Committee on Long Range Policy and Objectives,, Optical Society of America.

J. L. Hall, Member, 1984 Meggers Award Committee, Optical Society of America.

D. G. Hummer, Member, Editorial Board, Computer Physics Communications.

S. R. Leone, Co-Chairman, Gordon Conference on Molecular Energy Transfer for 1985.

S. R. Leone, Editorial Advisory Board, Chemical Reviews, 1982 - 1985.

J. L. Linsky, Member, Kitt Peak National Observatory Users Committee, Association of Universities for Research in Astronomy, Inc.

J. L. Linsky, Co-Investigator, ST (Space Telescope) High Resolution Spectrograph Experiment.

J. L. Linsky, Member, Far Ultraviolet Spectrograph Explorer Working Group, NASA.

J. L. Linsky, Member, National Solar Observatory Users Committee, Association of Universities for Research in Astronomy, Inc.

J. L. Linsky, Member, Proposal Evaluation Committee for the International Ultraviolet Explorer, NASA.

J. L. Linsky, Member, Editorial Board, Solar Physics.

J. L. Linsky, Member, International Organizing Committee for the Eighth International Colloquium on EUV and X-Ray Spectroscopy of Astrophysical and Laboratory Plasmas (August 27-29, 1984).

J. L. Linsky, Member, Organizing Committee for the Conference "IUE - Observing at the Limit," (August 15-17, 1983).

D. W. Norcross, Chairman, Local Committee for Annual Meeting of Division of Electron and Atomic Physics, Boulder, Colorado, 1983.

D. W. Norcross, Member, Program Committee, Division of Electron and Atomic Physics of the American Physical Society, 1981 - 1984.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

D. W. Norcross, Member, Working Group supervising Collaborative Computational Project 2 (Continuum States of Atoms and Molecules) of the U. K. Science and Engineering Research Council, 1983 - present.

S. J. Smith, Member, Local Committee for Annual Meeting of Division of Electron and Atomic Physics, Boulder, Colorado, 1982.

S. J. Smith, Member, Organizing Committee, Eighth International Conference on Atomic Physics, Götteburg, Sweden, 1983.

S. J. Smith, Member, Organizing Committee, Ninth International Conference on Atomic Physics, Seattle 1984.

S. J. Smith, Chair, Fellowship Committee, Division of Electron and Atomic Physics of the APS.

S. J. Smith, Co-Chairman, Third International Conference on Multiphoton Processes, Crete, September 1984.

S. J. Smith, Editorial Board, Metrologic.

CONSULTING

Quantum Physics Division (525)

P. L. Bender

Dr. Bender is consulting with the following:

the Geodynamics Branch at the Goddard Space Flight Center concerning data analysis for the proposed Geopotential Research Mission;

the University GPS Consortium concerning the accuracy of determining tectonic motions with signals from the Global Positioning System satellites; and

the Systems and Applications Section at the Jet Propulsion Laboratory concerning the JPL part of the NASA Crustal Dynamics Program.

S. Geltman

Dr. Geltman does consulting and advising with the Service de Physique Atomique, CEN de Saclay, France, on problems related to laser ionization of gases.

J. L. Hall

Dr. Hall is consulting with the Theoretical Astrophysics Group at Cal Tech in the area of laser techniques for gravity wave detection; and informally with colleagues in industry involved with stable laser design and application.

D. G. Hummer

Dr. Hummer consults for the following:

X-ray laser project at Livermore and Los Alamos Labs, and

is one of three foreign consultants for the UK Collaborative Computational Project on Stellar Atmospheres, sponsored by the U. S. Science Research Council.

S. R. Leone

Dr. Leone has done informal consulting with the Air Force Weapons Laboratory on lasers and laser chemistry.

CONSULTING

Quantum Physics Division (525)

J. L. Linsky

Dr. Linsky has consulted with the following:

the Association of Universities for Research in Astronomy, Inc. (AURA)

concerning long term planning for stellar observations with the McMath Solar Telescope, and

NASA and the National Academy of Sciences concerning the proposed Far Ultraviolet Spectroscopic Explorer satellite.

D. W. Norcross

Dr. Norcross is consulting with the Theoretical Atomic and Molecular Physics Group at Livermore Labs on problems related to laser modeling and is a Visiting Scientist (consultant) to Division T-4 of the Los Alamos Laboratories on problems related to electron collisions with atoms, ions, and molecules.

A. V. Phelps

Dr. Phelps does informal consulting and advising with DoD and DoE laboratories and their industrial and University contractors in the area of atomic and molecular processes in high power switches, laser induced breakdown charged particle beam propagation. In the case of Lawrence Livermore National Laboratories and Sandia National Laboratories this has been formalized by the granting of jointly funded support for a postdoc.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

P. L. Bender

January 10-11, 1983 - Washington, D. C.
Served on subcommittee of the Physics Advisory Committee of the National Science Foundation to review the NSF Gravitational Physics Program.
Sponsor: National Science Foundation.

February 28 - March 2, 1983 - Greenbelt, Maryland.
Attended NASA Workshop on Spaceborne Gravity Gradiometry.
Sponsor: Science Applications, Inc.

April 8, 1983 - Washington, D. C.
Attended Workshop on Multidisciplinary Uses of the Very Long Baseline Array.
Sponsor: National Research Council.

May 12-13, 1983 - Washington, D. C.
Attended meeting of the Physics Advisory Committee of the National Science Foundation where the review of the NSF Gravitational Physics Program was completed.
Sponsor: National Science Foundation

G. H. Dunn

December 1982 - Madison, Wisconsin.
Presented Physics Department Colloquium.
Sponsor: University of Wisconsin, Madison.

July 3-8, 1983 - New London, New Hampshire.
Attended Gordon Conference on Atomic Physics and gave an invited paper.
Sponsor: Gordon Conference.

August 27 - September 3, 1983 - Nagoya, Japan.
Symposium on Atomic Collision Data for Diagnostics and Modelling of Fusion Plasmas. IAEA Committee Meeting on atomic data for fusion.
Sponsor: International Atomic Energy Agency.

J. E. Faller

January 24 - February 2, 1983 - Taipei, Taiwan (China).
Participated in the PMGE (Precision Measurement and Gravity Experiment) School and Symposium.
Sponsors: Ministry of Education, National Bureau of Standards, National Tsing Hua University, & Academia Sinica.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

A. C. Gallagher — February 24-25, 1983 - Madison, Wisconsin.
Presented a colloquium , "Watching Atoms Collide," Physics Department, University of Wisconsin.
Sponsor: University of Wisconsin.

S. Geltman — March 8 - June 15, 1983 - Garching, West Germany.
Received Senior U. S. Scientist Award of the Humboldt Foundation of the Federal Republic of Germany and worked with Professor Walther at the Max Planck Institute for Quantum Optics.
Sponsor: Humboldt Foundation of the Federal Republic of Germany.

J. L. Hall — March 13-18, 1983 - Murray Hill, New Jersey.
Collaboration in measurement of optical energy levels of positronium.
Sponsor: Bell Laboratories.

June 7-8, 1983 - Annapolis, Maryland.
Participated on Committee on Objectives and Policy of the Optical Society of America and attended lectures in the American Physical Society meeting in Baltimore
Sponsor: Optical Society of America.

June 9-10, 1983 - Murray Hill, New Jersey.
Collaboration in measurement of optical energy levels of positronium.
Sponsor: Bell Laboratories.

June 27 - July 1, 1983 - Interlaken, Switzerland.
To attend the Sixth International Conference on Laser Spectroscopy (SICOLS) and to present an invited lecture at the Conference.
Sponsor: (SICOLS) Conference Program Committee.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Hall

September 19 - October 2, 1983 - Beijing, China.
To present, under UNESCO sponsorship, a series of lectures on laser metrology and to interact with the staff of the Laser Parameter Testing Center on a consultant basis.
To visit several other scientific labs in the Beijing area including the Beijing Institute of of Opto-Electronic Technology, Peking University, and the National Institute of Metrology.
Sponsor: UNESCO.

D. G. Hummer

December 28, 1982 - January 5, 1983 - Cambridge, Massachusetts.
Worked with Dr. George Rybicki at the Harvard-Smithsonian Center for Astrophysics on theory of line formation in accretion disks.
Sponsor: Smithsonian Institution.

July 5-29, 1983 - London, England.
Consulted for U. K. Science Research Council and worked at University College London with Drs. Storey and Barlow on collisional-radiation recombination and applications to infrared lines of Wolf-Rayet stars.
Sponsor: U.K. Science Research Council.

S. R. Leone

October 12-16, 1982 - Boston, Massachusetts.
Visited the Air Force Geophysics Laboratory and presented a seminar entitled "Laser and Infrared Chemiluminescence Studies of Ion Chemistry."
Sponsor: Air Force Geophysics Laboratory.

Visited Harvard/MIT and participated in a joint seminar and presented a talk entitled "Laser Studies of Reactive Dynamics."
Sponsor: Harvard/MIT.

February 1, 1983 - Laramie, Wyoming.
Visited the Chemistry Department of the University of Wyoming and presented a seminar entitled "State-Detected Chemical Reaction Dynamics."
Sponsor: The University of Wyoming.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

S. R. Leone	February 3 - 5, 1983 - Chicago, Illinois. Presented a talk to the Chemistry Department of Northwestern University entitled "State-Detected Molecular Reaction Dynamics: Establishing the Relationship Between Reactivity and Energy Transfer." Sponsor: Northwestern University.
	February 23-25, 1983 - South Bend, Indiana. Gave a seminar at the Notre Dame Radiation Laboratory entitled "Laser Studies of Free Radical Kinetics." Sponsor: The University of Notre Dame.
	March 20-24, 1983 - Seattle, Washington. Received the American Chemistry Society Nobel Laureate Signature Award for Graduate Education in Chemistry. Sponsor: The J. T. Baker Company
	April 14-17, 1983 - Los Angeles, California. Visited The University of Southern California and presented a chemistry colloquium entitled "State-Detected Molecular Reaction Dynamics: Establishing the Relationship Between Reactivity and Energy Transfer. Sponsor: University of Southern California.
	June 26 - July 10, 1983 - Gull Lake, Minnesota. Attended and presented an invited talk at the Conference on Dynamics of Molecular Collisions. Sponsor: Conference on Dynamics of Molecular Collisions in MW.
	August 21-26, 1983 - Baltimore, Maryland. Attended and presented an invited talk at the Eleventh International Conference on Photochemistry. Sponsor: Eleventh International Conference on Photochemistry.
J. L. Linsky	December 9-10, 1982 - Sunspot, New Mexico. Attended meeting of the National Solar Observatory Users Committee. Sponsor: Association of Universities for Research in Astronomy, Inc.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Linsky

January 3-5, 1983 - Tucson, Arizona.
Attended meeting of the Kitt Peak National Observatory Users Committee.
Sponsor: Association of Universities for Research in Astronomy, Inc.

January 13-14, 1983 - Greenbelt, Maryland.
Attended meeting of the Far Ultraviolet Spectroscopic Explorer Science Working Group.
Sponsor: ORI, Inc., a NASA Contractor.

January 17-18, 1983 - Greenbelt, Maryland.
Evaluation of proposals for observing time on the International Ultraviolet Explorer satellite.
Sponsor: ORI, Inc., a NASA Contractor.

February 1-7, 1983 - Greenbelt, Maryland.
Observations with the International Ultraviolet Explorer Satellite.
Sponsor: ORI, Inc., a NASA Contractor.

March 8, 1983 - Washington, D. C.
Made presentation to the Committee on Space Astronomy and Astrophysics.
Sponsor: National Academy of Sciences.

April 7-10, 1983 - Armagh, N. Ireland.
Presented invited colloquia and consulted with members of the Observatory staff.
Sponsor: Armagh Observatory.

July 5-8, 1983 - Annapolis, Maryland.
Attended meeting of the Far Ultraviolet Spectroscopic Explorer Science Working Group.
Sponsor: ORI, Inc., a NASA Contractor.

July 21, 1983 - Greenbelt, Maryland.
Attended meeting of the Far Ultraviolet Spectroscopic Explorer Science Working Group.
Sponsor: ORI, Inc., a NASA Contractor.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Linsky	July 22, 1983 - Sunspot, New Mexico. Attended meeting of the National Solar Observatory Users Committee. Sponsor: Association of Universities for Research in Astronomy, Inc.
	August 17-18, 1983 - Tucson, Arizona. Attended meeting of the Kitt Peak National Observatory Users Committee. Sponsor: Association of Universities for Research in Astronomy, Inc.
D. W. Norcross	October 26-29, 1982 - Pasadena, California. Attended the United States-Japan seminar on Electron-Molecule Collisions and Molecular Photoionization Processes. Sponsor: California Institute of Technology.
	March 3-5, 1983 - Palm Coast, Florida. Attended the International Symposium on Molecular Scattering Theory and Quantum Chemistry and gave an invited talk. Sponsor: University of Florida.
	December 19-20, 1983 - London, England. To attend a meeting of the Working Group supervising Collaborative Computational Project 2 (Continuum States of Atoms and Molecules), the Workshop on Asymptotic Methods, and to give an invited talk at the latter. Sponsor: U. K. Science and Engineering Research Council.
A. V. Phelps	November 8-10, 1982 - Washington, D.C. Participated in workshop on Nuclear Lightning and presented a paper at the Naval Research Lab. Sponsor: Naval Research Lab.
	March 14-16, 1983 - Washington, D. C. Participated in a workshop on the Relativistic Electron Beam Heating of Air and presented a paper. Sponsor: Lawrence Livermore Labs.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

A. V. Phelps

July 7-8, 1983 - Albuquerque, New Mexico.
Consulted with Sandia National Laboratories.
Sponsor: Sandia National Laboratories.

S. J. Smith

October 7-9, 1982 - Madison, Wisconsin.
Gave a Physics Department Colloquium on the subject of Multiphoton Ionization and Photoelectron Angular Distributions from Highly Excited and Aligned Atomic States.
Sponsor: University of Wisconsin.

April 20 - 22, 1983 - Knoxville, Tennessee.
Attended workshop on atomic and molecular physics.
Sponsor: Department of Energy.

June 1 - September 30, 1983 - Munich, West Germany.
Collaborated with Professor Dr. H. Walther, a Director of the Max Planck Institute for Quantum Optics, and a Professor at the University of Munich, and with Dr. G. Leuchs, University of Munich, in an experimental study of multiphoton processes, using lasers, leading to ionization in an atomic potassium beam.
Sponsor: NSF

SPONSORED CONFERENCES

Quantum Physics Division (525)

Fourteenth Annual Meeting of Division of Electron and Atomic Physics of the American Physical Society, May 23-25, 1983, at JILA. David W. Norcross was the local Chairman.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Informal Seminars

Name/Affiliation/Title/Date

W. Michaelis (Physikalisch-Technische Bundsanstalt, W. Germany) - PTB's Work on G, October 19, 1982.

Teiichiro Ogawa (Kyushu University, Japan) - Translational Energy Distributions and Production Mechanisms of the Excited Hydrogen Atom Produced in Controlled Electron Impact on Water and Methane, November 1, 1982.

Ove Poulsen (University of Aarhus, Denmark) - Resonant Laser/Fast-Beam Interactions: Saturated Absorption and Two-Photon Absorption, November 11, 1982.

Nancy D. Piltch (University of Arizona) - Molecular Ion Spectroscopy, November 12, 1982.

Alan R. Johnston (University of Nebraska, Lincoln) - Near Threshold Excitation of He(   ) by Electron Impact, November 23, 1982.

David Abbott (JILA) - Monte Carlo Calculations: Early-Type Stars and the Wolf-Rayet Phenomenon, December 13, 1982.

Tom Stephenson (University of Chicago) - Vibrational State Dependence of Intersystem Crossing Rates in Benzene, January 10, 1983.

John Prodan (NBS, Gaithersburg) - Informal Talk about Atom Cooling Experiments at NBSG, February 8, 1983.

Mike Simon (SUNY, Stony Brook) - Infrared and Radio Observations of Regions of Star Formation, February 11, 1983.

Steve Strom (Kitt Peak National Observatory) - Herbig-Haro Objects, February 14, 1983.

Harvey Tananbaum (Center for Astrophysics, Harvard) - Quasars, February 14, 1983.

Roberta Humphreys (University of Minnesota) - The Brightest Stars as Extragalactic Distance Indicators, February 28, 1983.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Informal Seminars (continued)

Name/Affiliation/Title/Date

William G. Harter (Georgia Tech) - What Good Are Molecular Constants? Order and Disorder in Rotor Dynamics, March 17, 1983.

Peter Zoller (JILA Visiting Fellow) - Configuration Interaction and Multiphoton Ionization, April 7, 1983.

Pat Palmer (Chicago) - VLA Line Work, April 19, 1983.

Michael J. Seaton (University College London) - Quantum Theory of Di-Electronic Recombination, April 21, 1983.

Steve Beckwith (Cornell University) - Speckle Interferometric Studies of Mass Loss from Red Giants and Carbon Stars, April 26, 1983.

Robert Field (Massachusetts Institute of Technology) - Does Ligand Field Theory Work for Diatomic Molecules?, May 2, 1983.

Dan Kerner - (Visitor) Atomic Photoionization Cross Section: Timedependent Picture, May 5, 1983.

Anthony F. Starace (University of Nebraska, Lincoln) - Hyperspherical Coordinate Description of Two Electron Systems, May 19, 1983.

David Bates (Queen's University, Belfast) - The Oxygen Green Line in the Nightglow, May 26, 1983; The Formation of Molecules in Interstellar Clouds by Radiative Association, May 27, 1983.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Chemical Physics Seminars

Name/Affiliation/Date

A. R. Ravishankara (Georgia Tech) - October 1, 1982.

L. Viehland (St. Louis Univ.) - October 8, 1982.

F. Kaufman (Univ. of Pittsburgh) - October 22, 1982.

D. Herrick (Univ. of Oregon) - October 29, 1982.

W. Farneth (Univ. of Minnesota) - November 5, 1982.

M. Durup (Orsay) - November 12, 1982.

T. D. Lee (Columbia Univ.) Franz Mohling Memorial Lecture - November 19, 1982.

F. Crim (Univ. of Wisconsin) - December 3, 1982.

C. Wittig (Univ. of Southern Calif.) - December 10, 1982.

N. Lane (Rice Univ.) - December 17, 1982.

S. E. Harris (Stanford Univ.) - January 28, 1983.

R. Saykally (Berkeley) - February 4, 1983.

D. Brenner (Aerospace Corp.) - February 11, 1983.

R. Curl (Rice Univ.) - February 18, 1983.

D. J. Nesbitt (Berkeley) - February 25, 1983.

B. E. Kohler (Wesleyan Univ.) - March 4, 1983.

P. C. Engelking (Oregon) - March 11, 1983.

R. Hall (Exxon) - March 18, 1983.

D. Spence (Argonne) - April 1, 1983.

A. C. Parr (NBS) - April 8, 1983.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Chemical Physics Seminar

Name/Affiliation/Date

G. B. Bjorkland (IBM) - April 15, 1983.

L. B. Harding (Argonne) - April 22, 1983.

J. I. Steinfeld (MIT) - April 29, 1983.

W. C. Lineberger (Univ. of Colorado) - May 6, 1983.

J. Bowman (Illinois Institute of Technology) - September 9, 1983.

W. P. Reinhardt (Univ. of Colorado) - September 23, 1983.

B. Kay (Sandia National Laboratory) - September 30, 1983.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

JILA Colloquium Speakers

Name/Affiliation/Title/Date

Peter Zoller (JILA Visiting Fellow) - Light Statistics and Multiphoton Processes, September 29, 1982.

Judah Levine (JILA Fellow) - An Introduction to Terrestrial Acupuncture, October 19, 1982.

James Faller (JILA Fellow) - Old Gravity, a New Tool for Geophysics, October 26, 1982.

Hartmut Schmidt (University of California, Berkeley) - Preparation of Molecular States in an Ion-Atom Crossed-Beam Scattering Experiment by Laser Excitation, November 2, 1982.

Peter Bender (JILA Fellow) - Ocean Currents and Worldwide Gravity From Satellite Data, November 9, 1982.

Peter L. Knight (Imperial College, London) - Turning Off Spontaneous Decay, November 16, 1982.

Richard N. Zare (Stanford University) - Studies of State to State Chemistry, November 30, 1982.

Neil Lane (Rice University) - On the Threshold of Excitation: Theoretical Studies of Inelastic Electronic and Atomic Collision Processes, December 14, 1982.

S. Prasad (Harvard University) - Superfluorescence: Its Initiation in a Large Spherical Sample, February 22, 1983.

Laurent Levy (Cornell University) - NMR Studies in Spin Polarized Hydrogen, March 1, 1983.

Tom Baer (Spectra Physics, Inc.) - Nuclear Motion and the Hyperfine Coupling Constants in Hydrogen-Fluoride, March 7, 1983.

James Hough (JILA Visiting Fellow) - Laser Interferometers for Gravitational Wave Detection -- Current Status and Future Prospects, March 16, 1983.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

JILA Colloquium Speakers

Name/Affiliation/Title/Date

Nils Andersen (JILA Visiting Fellow) - Studies of Excitation in Simple Collision Systems, March 29, 1983.

Bret Cannon (Cambridge University, England) - V-V and V-T Relaxation in HCN(011) and HCN(101), April 12, 1983.

David A. Micha (JILA Visiting Fellow) - Scattering of Atoms by Many-Atom Systems, April 12, 1983.

Wilmer Anderson (University of Wisconsin) - Charge Changing and Excitation Collisions with Alkali Atom Targets, April 19, 1983.

David L. Ederer (National Bureau of Standards) - Photoionization from Laser Excited States by Synchrotron Radiation, April 26, 1983.

Robert Field (Massachusetts Institute of Technology) - Simulated Emission Spectroscopy: Intramolecular Vibrational Redistribution in H_2CO and HCCN?, May 1983.

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	University and Department Committees Served On
Duncan, M. A.	NBS Laser Safety Committee
Dunn, G. H.	Graduate Committee, Department of Physics
	JILA Executive Committee
	JILA Shops Committee
	JILA Data Center Advisory Committee
	Member, several thesis & examinations committees
	NML EEO Coordinator
Faller, J. E.	Chairman, JILA Shops Committee
Gallagher, A. C.	JILA Space Committee
	Thesis Committees for:
	Mike Hale (Chemistry Department, University of Colorado)
	Joe Alford (Physics Department, University of Colorado)
	S. Davidson (Physics Department, University of Colorado)
	M. O'Callaghan (Physics Department, University of Colorado)
	R. Robertson (Physics Department, University of Colorado)
	H. Chatham (Physics Department, University of Colorado)

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	University and Department Committees Served On
Geltman, S.	Secretary for JILA Visiting Scientists Program
	JILA Executive Committee
	Chairman of Thesis Committee,
	Stanley L. Haan (Physics Department, University of Colorado)
Hall, J. L.	Thesis Committees for:
	L. Hollberg (Physics Department, University of Colorado)
	M. D. Rayman (Physics Department, University of Colorado)
	Zhu Miao (Physics Department, University of Colorado)
Hummer, D. G.	Thesis Committees for:
	Douglas Perry (Astro-Geophysics Department, University of Colorado)
	Douglas Carroll (Physics Department, University of Colorado)
	Bob Russell (Astro-Geophysics Department, University of Colorado)
	Ana Torres (Astro-Geophysics Department, University of Colorado)
	Steve McCandless (Astro-Geophysics Department, University of Colorado)

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	University and Department Committees Served On
Hummer, D. G.	Thesis Committe for:
	Dan Kerner (Chemistry Department, University of Colorado)
	Chairman, JILA Computing Committee
	Comprehensive Exam Committee, Department of Astro-Geophysics, University of Colorado
Leone, S. R.	Selection Committee - Junior Faculty Development Awards, University of Colorado
	Search Committee - Department of Chemistry, University of Colorado
	NBS Research Advisory Committee
Linsky, J. L.	Thesis Committees for:
	P. L. Bornmann (Astro-Geophysics Department, University of Colorado)
	S. Saar (Astro-Geophysics Department, University of Colorado)
	N. Marstad (Astro-Geophysics Department, University of Colorado)
	M. Schindler (Astro-Geophysics Department, University of Colorado)
Norcross, D. W.	JILA Executive Committee - through December 1982.

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	University and Department Committees Served On
Norcross, D. W.	Chairman of JILA - January 1983 - December 1984
	Preliminary Exam Committee, Department of Physics, University of Colorado
	Thesis Committee,
	M. A. Smith (Chemistry Department, University of Colorado)
Phelps, A. V.	JILA Data Center Advisory Committee
	Thesis Committees for:
	V. F. Benage, Jr. (Physics Department, University of Colorado)
	R. H. Chatham, III. (Physics Department, University of Colorado)
	R. M. Robertson (Physics Department, University of Colorado)
	R. E. Rodenburg (Physics Department, University of Colorado)
	R. A. Swanson (Astro-Geophysics Department, University of Colorado)
	H. E. Evans (Astro-Geophysics Department, University of Colorado)
Smith, S. J.	JILA Executive Committee
	Chemical Physics Committee, Department of Physics, University of Colorado
	Chairperson, Search Committee for Joint JILA-Department of Physics Position in Experimental Physics.

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Graduate Students Supervised	Postdoctoral Research Associates Supervised
Bender, P. L.	J. E. Alwood	M. A. Vincent
Dunn, G. H.	S. Barlow M. Schauer K. Timmer	D. Belić D. Mueller
Faller, J. E.	P. Keyser T. Niebauer B. Rinker J. Xue	(NRC)-J. K. Hoskins
Gallagher, A. C.	H. Chatham S. Davidson R. Robertson M. O'Callaghan	D. Hils B. Stumpf
Geltman, S.	S. Haan	
Hall, J. L.	L. Hollberg M. Rayman M. Zhu	R. Blatt (DFG, West Germany) W. Ertmer (DFG, West Germany) Chr. Breant M. Long-Sheng (Visiting Prof. from PRC) (NRC)-P. Nachman T. Ohta (Visiting Prof. from Kyoto)
Hummer, D. G.	D. Carroll Birte Christensen-Dalsgaard R. Russell	D. C. Abbott

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Graduate Students Supervised	Postdoctoral Research Associates Supervised
Leone, S. R.		
	(NSF Fellowship)-K. Carleton	V. Bierbaum (25%)
	D. Guyer	(NRC)-D. Dolson
	M. Hale	(NRC)-M. Duncan
	(NSF Fellowship)-C. Hamilton	H. Haugen
	L. Kovalenko	L. Huwel (Max Planck Fellowship)
	G. H. Lin	C. Wight
	J. Smedley	A. Langford
	M. Smith	
Linsky, J. L.	P. Bornmann	A. Brown
	B. Gross	K. Carpenter
	N. Marstad	S. Drake
	S. Saar	R. Hammer
	M. Schindler	F. Walter
Norcross, D. W.	B. Christensen-Dalsgaard	F. da Paixao
		A. Jain
		N. Padial
Phelps, A. V.		S. J. Buckman
		M. A. Islam
		H. Tischer
		P. A. Vicharelli
Smith, S. J.	K. Arnett	D. Elliott
		M. Hamilton
		N. D. Piitch

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Courses Taught at the University of Colorado
Bender, P. L.	Physics 451 - Modern Optics (Fall 1983)
Gallagher, A. C.	Physics 695 - Collisional Line Shapes (Fall 1982)
	Physics 695 - Collisional Line Shapes (Fall 1983)
Geltman, S.	Recitation - Physics 111 (Fall 1982)
Hummer, D. G.	Radiative Transfer AG-515 (Spring 1983)
Leone, S. R.	Chemistry 550 - Chemical Dynamics (Spring 1983)
Norcross, D. W.	Recitation - Physics 111 (Fall 1982)
	Recitation - Physics 111 (Fall 1983)
Smith, S. J.	Physics 332 (Fall 1982)

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Scientists Working at JILA on Sabbatical or Other Leave (other than Visiting Fellows)
Bender, P.	Bruno Bertotti Pavia, Italy
Conti, P.	Phil Massey DAO Canada
	A. Tutukov Moscow U.S.S.R.
	G. Wallerstein University of Washington Seattle, WA
Cooper, J & Burnett, K.	Christian S. Diatta Faculte des Sciences Universite de Dakar-Fann Senegal
	P. L. Knight Imperial College England
Cooper, J.	B. J. O'Mara University of Queensland St. Lucia Queensland, Australia 4067
Faller, J.	Y Guo Nim China
	Tsuneya Tsubokawa International Latitude Observatory Mizusawa-Shi, Iwate-Ken 023 Japan
Gallagher, J. (Data Center)	C. E. Brion The University of British Columbia Vancouver, B. C. Canada

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Scientists Working at JILA on Sabbatical or Other Leave (other than Visiting Fellows)
Gallagher, J. (Data Center)	D. W. O. Heddle Royal Holloway College University of London England
	Peter W. Langhoff Indiana University Bloomington, IN
	J. Rumble NBS-Gaithersburg
	J. I. Steinfeld MIT Cambridge, MA 02139
Garstang, R.	Alf Litzen Lund Sweden
Geltman, S.	G. Leuchs University München West Germany
Hall, J.	Rainer Blatt Johannes Gutenberg Universitat West Germany
	Christian Breant Labortoire de Physique des Lasers Universite Paris-Norde France
	Wolfgang Albert Ertmer Institute fur Argewandte Physik der Universitat Bonn West Germany
	Ma Long-Sheng East China Normal University Shanghai People's Republic of China

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Scientists Working at JILA on Sabbatical or Other Leave (other than Visiting Fellows)
Hall, J.	Tatehisa Ohta Doshisha University Kyoto 602 Japan
Hummer, D.	Birte Christensen-Dalsgaard University of Aarhus Aarhus Denmark
Leone, S.	Robert Klein Institut f. Anorg. Chemie der j. W. Goethe-Universitat West Germany
Levine, J.	Hirokazu Matsumoto National Research Laboratory of Metrology Ibaraki 305, Japan
	Koichi Tsukahara Crustal Dynamics Department Geophysical Survey Institute Ministry of Construction Tsukuba-Gun, Ibaraki-Ken, 305 Japan
Linsky, J.	Carole Jordan Oxford University Oxford, England
	Theodore Simon Institute for Astronomy University of Hawaii Honolulu, HI 96822
	Robert Stencel NASA Headquarters Washington, D. C.

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

Name	Scientists Working At JILA on Sabbatical or Other Leave (other than Visiting Fellows)
Linsky, J.	Dominic Zarro Australian National University Canberra, Australia
Norcross, D.	M. J. Seaton University College London London, England
Smith, S.	Gerhard Leuchs University Munchen West Germany
Toomre, J.	Douglas O. Gough Institute of Astronomy Cambridge, England
	Frank Hill Sac Peak Observatory

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This report is Part II of the 1983 Annual Report of the Center for Basic Standards and contains a summary of the technical activities of the Center for the period October 1, 1982 to September 30, 1983. The Center is one of the five resources and operating units in the National Measurement Laboratory.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Astrophysics; atomic and molecular physics; electrical standards; fundamental constants; gravity measurements; laser physics; length standards; mass standards; pressure and vacuum standards; temperature standards; time and frequency standards; X-ray and gamma-ray wavelength standards

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