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Technical Activities 1980 Center for Absolute Physical Quantities

Karl G. Kessler, Director

Center for Absolute Physical Quantities
National Measurements Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, DC 20234

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Prepared for:
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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, ***Secretary***

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NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

This report summarizes research projects, measurement method development, calibration and data evaluation activities carried during Fiscal Year 1980 in the NBS Center for Absolute Physical Quantities. These activities fall in the areas of: quantum metrology; measurements and standards for the electrical units, temperature and pressure, length and mass, time and frequency; and quantum physics.

Key words: Electrical measurements and standards; length and mass measurements and standards; temperature and pressure measurements and standards; time and frequency; quantum metrology; quantum physics.

INTRODUCTION

This book is Part II of the 1980 Annual Report of the Center for Absolute Physical Quantities and contains a summary of the technical activities of the Center for the period October 1, 1979 to September 30, 1980. The Center is one of the five resources and operating units in the National Measurement Laboratory.

The summary of activities is organized in seven sections, one for the technical activities of the Center Office staff, one for 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. An organization chart of the Center is included at the end of the text.

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 Absolute Physical Quantities, B160 Physics Building, National Bureau of Standards, Washington, D.C. 20234.

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CENTER OFFICE

SUMMARY OF ACTIVITIES

FISCAL YEAR 1980

The Center Office includes several scientists who, in addition to their administrative support function also engage in a variety of technical activities.

Technical activities of the Deputy Center Director, Dr. Ralph P. Hudson, include research, technical writing and international committee activities related to low temperature physics and thermometry. During the past year, the properties of CMN (cerous magnesium nitrate) power in the millikelvin region were analyzed to reconcile the thermometric behavior of powdered CMN with that of single crystal CMN. Dr. Hudson continues to serve as Consulting Editor in Low Temperature Physics for the forthcoming new edition of the McGraw-Hill Encyclopedia of Science and Technology and has written new entries on Adiabatic Demagnetization, Low Temperature Thermometry, and Low-Temperature Physics. He was invited to write a general review on the measurement of temperature published in a recent issue of Review of Scientific Instruments. Dr. Hudson contributes extensively to the international communication of progress in low temperature thermometry and provides valuable technical assistance to the NBS temperature program.

Mr. John W. Cooper provides theoretical assistance within the Center and in other Centers to experimental groups working in the area of atomic physics. He provides suggestions for key experiments to be performed using current resources, assists in the planning and carrying out of such experiments and provides interpretations and supporting calculations.

As a part of his duties as assistant to the Center Director, Dr. W.G. Schweitzer provides collaborative support to the Length and Mass Measurements and Standards Division in the area of laser technology, laser spectroscopy and precise laser wavelengths for standards in metrology and spectroscopy.

PUBLICATIONS

B. E. Cole, J. W. Cooper, D. L. Ederer, G. Mehlman and E. B. Saloman, "Stark Effect on Autoionizing Resonances in the Rare Gases," J. Phys. B. Atom. Molc. Phys. 13, L175 (1980).

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R. P. Hudson, "Adiabatic Demagnetization," McGraw-Hill Encyclopedia of Science and Technology.

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R. P. Hudson, K. Mitsui and R. L. Rusby, "Third Report of Working Group No. 5, Comité Consultatif de Thermométrie, B.I.P.M.," 13th Session, Sévres, France, June 17-19, 1980.

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OTHER

R. P. Hudson and B. W. Mangum, "On the Question of an IPTS below 1K," 13th Session, Comité Consultatif de Thermométrie, B.I.P.M., Sévres, France, June 17-19, 1980.

R. P. Hudson, "Susceptibilities of CMN Powder and Single Crystal at Very Low Temperature: Are They Consistent?", Poster Session, Cornell Symposium on Liquid and Solid ^{3}He, Cornell University, Ithaca, N.Y., July 21-25, 1980.

INVITED TALKS

R. P. Hudson, "Practical Thermometry at Low Temperatures", chaired session and led discussion, Conference on Low Temperature Thermometry, The Institute of Physics, London, England, October 1, 1979.

R. P. Hudson, "Millikelvin Thermometry", conducted round-table session at XVth International Congress on Refrigeration (I.I.R.) in Venice, September 23-29, 1979.

COMMITTEE MEMBERSHIPS

K. G. Kessler, Chairman, American Physical Society, Committee on Arrangements, Washington Meeting.

K. G. Kessler, Chairman, Earle Plyler Award Committee, American Physical Society.

K. G. Kessler, Board of Directors and Executive Committee, Optical Society of America.

K. G. Kessler, Chairman, Optical Society of America, Publications Committee.

K. G. Kessler, NBS representative, Consultative Committee for the Definition of the Meter.

K. G. Kessler, member, American Institute of Physics Publishing Policy Committee.

K. G. Kessler, Representative for the OSA to the AAAS Consortium of Affiliates for International Programs.

K. G. Kessler, member, Commission 14, International Astronomical Union.

R. P. Hudson, member, Fritz London Memorial Award Committee 1973-81 (Chairman, 1976-8).

R. P. Hudson, member, Advisory Committee on Thermometry, International Committee on Weights and Measures.

R. P. Hudson, Chairman of Working Group 5, Study of Practical Low Temperature Thermometers below 30K, Advisory Committee on Thermometry, International Committee on Weights and Measures; 1974-80.

R. P. Hudson, Chairman of Working Group 4, Extension of IPTS below 14K, Advisory Committee on Thermometry, International Committee on Weights and Measures; 1980-.

R. P. Hudson, member, International Institute of Refrigeration, Commission A1/2, Cryophysics & Cryoengineering.

R. P. Hudson, member, National Committee for 16th International Conference on Low Temperature Physics (LT16), August 1981.

R. P. Hudson, member, General Committee, Joint ISA-AIP-NBS Symposium on Temperature, March 1982; Editor-in-Chief of Proceedings.

R. P. Hudson, Consulting Editor in Low Temperature Physics for the McGraw-Hill Encyclopedia of Science and Technology and its Yearbooks.

J. W. Cooper, member, Atomic & Nuclear Data, Editorial Board.

QUANTUM METROLOGY GROUP
SUMMARY OF ACTIVITIES
FISCAL YEAR 1980

I. Overview

The Quantum Metrology Group is a diverse collection of scientists engaged in no less than six experimental and theoretical areas all of which involve precision measurements. Some of the experiments are at the forefront of measurement technology. Because of our diversity and small numbers, we are not a division and are thus attached to the Office of the Director of CAPQ. The fields in which we have active programs include gravity, quantum theory of measurement, atomic theory, laser spectroscopy, X-ray spectroscopy using laboratory and synchrotron radiation sources, precision X- and γ-ray standards, and solar and plasma physics. Our staff includes nine full-time and four part-time/retired scientists at the Ph.D. level. In the near future an additional staff person will be added to fill the vacancy created by the retiree. The collaboration for six months of a Guest Worker from Czechoslovakia proved beneficial during the past year and we look forward to collaborating during the coming year with a Guest Worker from France. Both Guest Workers arrived with external support and collaborated in the X-ray spectroscopy and γ-ray standards work.

The catalyst for the Group is its leader, R. Deslattes, whose interests over the years have included all of the above mentioned areas. In August 1980, Deslattes took a one-year leave of absence from NBS to head the Physics Division of NSF, but keeps in contact with the Group by spending approximately two days a month at NBS. He also will participate directly in a measurement at the Stanford Synchrotron Radiation Laboratory (SSRL). In Deslattes' absence the administrative responsibility is being shared by J. Snyder and E. Kessler, Snyder having responsibility for gravity, theory, and lasers, and Kessler having responsibility for X-rays, γ-rays, and solar and plasmas.

The six major areas of activity are described in the following highlights. However it is proper that a few of these be amplified in this overview because of their stage of development.

A joint initiative by our group in CAPQ, by the Center for Materials Science, and the Naval Research Laboratory for construction of a beamline at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory was funded in mid FY 79. Two beam ports and four beamlines will be implemented with this group having responsibility for one of the beamlines. A subgroup to accomplish this task has been assembled from new hires (P. Cowan, T. Jach - 50%, and R. Spal - 40%) and NBS staff (R. LaVilla and A. Henins). The beamline will operate in a photon energy range 0.5 to 5.0 keV and will be separated from the storage ring by a window so that materials which would be incompatible with the high vacuum technology can be studied. The line will include mirrors, a primary monochromator, a sample chamber, a secondary monochromator, and an electron spectrometer. The NSLS X-ray storage ring is scheduled to be operational by early 1982. The first task which will be attempted at NSLS will be X-ray studies of inner-shell processes on noble gases. This work is an extension of studies which have been done at SSRL.

This group has had a program (led by G. Luther) for the past several years to measure the gravitational constant "G". The earlier results from this work had up to now been somewhat disappointing because of problems related to unexpected systematic drift in the torsion pendulum. This problem now appears to be essentially solved, and the experiment has progressed very rapidly over the past year. We believe that data already collected will result in a new value for "G" that is roughly an order of magnitude better than the best presently known value.

II. TECHNICAL ACTIVITIES

1. Precision X-ray and γ-ray Measurements

E. Kessler, A. Henins, R. Deslattes, W. Sauder

Objectives

Accurate wavelength standards in the 20 keV to 5 MeV region is the primary objective of this project. For maximum use in comparisons with theoretical calculations, these standards need to be related to the Rydberg, R_∞. The standards have taken the form of: a) X-ray transitions which are used for testing relativistic self-consistent field calculations; b) γ-ray transitions which are used for calibrating Ge detectors used in mesic X-ray work and bent crystal spectrometers (relative energy measuring instruments); and c) absorption edge determinations used in kaonic X-ray measurements. The targeted accuracy is 0.1 to 1 ppm for γ-rays, a few ppm for X-rays, and 15 ppm for edge measurements.

Two fundamental constant determinations might result from wavelength measurements in the above mentioned regions. A measurement of the electron-positron annihilation wavelength should lead to a value for the fine structure constant. A measurement of capture γ-ray cascades for which the mass equivalent can be measured by mass spectroscopy should lead to a mass-wavelength conversion factor.

Current Activities

Two facilities exist for precision X-ray and γ-ray wavelength measurements. They are both two axis flat crystal spectrometers equipped with angle measuring interferometers. Knowledge of the angles through which the γ- or X-rays have been diffracted along with knowledge of the lattice spacing of the crystals permits the wavelengths to be calculated. One of the instruments is located at the NBS reactor (γ-ray measurements) while the other is located at the Radiation Physics Building (primarily X-ray measurements).

Almost all activity in the past year has been concentrated on X-ray measurements at the Radiation Physics Building facility. The instrument is coupled to the 4 MeV electron Van de Graaff where high Z K series X-rays are being measured. Because of low intensity only $K\alpha_1$, $K\alpha_2$, $K\beta_1$, and $K\beta_3$ can be measured with an accuracy of a few ppm in a reasonable time. We have completed measurements on Ag, Er, Au, Pb, and U and are planning measurements on Xe, Sm, W, and Th. Our measurements are compared to relativistic self-consistent field calculations in order to illuminate deficiencies in our theoretical understanding of atomic energy levels. In an earlier publication in which available X-ray measurements were compared to theoretical predictions, a discrepancy linear in Z was clearly evident. However our recent measurements on U suggest that the discrepancy decreases for Z greater than $Z \sim 85$. The planned measurements mentioned above should provide more information concerning the experimental-theoretical discrepancy as a function of Z.

A manuscript on the mass of the kaon is in the final stages of preparation. Our contribution to this work was the measurement of the K absorption edge of metallic Er foils (E $\sim$ 57.5 keV) which had been used by Gary Lum and Clyde Wiegand of Lawrence Berkeley Laboratory (LBL) in a critical absorption measurement of kaonic potassium X-rays. By combining the measured transmission of the kaonic X-rays (LBL) with the absorption vs. energy determination (NBS), a new value for the mass of the negative kaon (m_K = 493.640 ± 0.054 meV/c^2) was determined. This result is in good agreement with the value recommended in the recent Review of Particle Properties (m_K = 493.657 ± 0.02 MeV/c^2). Although this result does not represent a major breakthrough, it does eliminate concern about high order radiative terms.

Analysis of data recorded in the 40.6 keV γ-ray of ^{99}Mo was completed. We were requested to measure this line by a group of researchers from Columbia and Yale who used the line as a standard to calibrate pionic X-ray spectra in order to determine a more accurate value for the pion mass. This line is very difficult to measure with a flat crystal spectrometer because of low intensity (strong self absorption and branching ratio of 2%) and short half life ($T_{1/2}$ = 67h). Although statistics were so poor that no detailed profile analysis was possible, a peak was clearly evident on the summed data. The measured energy of this line is 40.58347 keV (± 4.2 ppm). Because the uncertainty of the pionic X-ray measurements is $\sim$ 6 ppm, further improvement of the standards will reduce the total uncertainty very little. Although we have been encouraged by the Columbia/Yale group to remeasure this line with the flat crystal spectrometer, we feel that a bent crystal measurement of this line is more likely to lead to increased accuracy. The pionic mass measurement has recently been published in Physical Review Letters and a separate manuscript on the measurement of the 40.6 keV line has been prepared.

Because the efficiency of the double flat crystal spectrometer is a few x 10^{-11}, only very intense lines can be measured. Curved crystal spectrometers have an efficiency $\sim$ 10^3 greater than flat crystal spectrometers and are thus better suited for weak lines. In the mid 60's a DuMond type curved crystal spectrometer was installed at the University of Colorado cyclotron, but has not been used for several years. The spectrometer has been transferred to NBS and is being upgraded by: 1) installing precision angular contact bearings on the axis, 2) installing a low friction ball screw drive, 3) equipping the axis with an angle measuring interferometer, and 4) bending high quality crystals to a radius of four meters. Much of the machine work is nearing completion and the spectrometer should be operational by early December.

The first task to which the bent crystal instrument will be applied is the measurement of satellite lines from high Z K series X-rays. The X-rays will again be produced at the NBS 4 MeV electron Van de Graaff. Previous measurements on hyper satellite lines (double K vacancies) from heavy elements have differed by more than three standard deviation from theoretical calculations and we hope to shed more light on this controversy.

Accomplishments

In work prior to 1979, a number (~ 30) of optically-based γ-ray wavelength standards were established in the 0.06 to 1.1 MeV range. These standards proved useful in calibrating muonic and pionic X-ray spectra, bent crystal spectrometers, and Ge detectors.

In the past year this work has been extended to include measurements on high Z X-rays, the Er K absorption edge, and the ^{99}Mo 40.6 keV γ-ray line. The Er edge and ^{99}Mo measurements are in the process of publication while the high Z X-ray work will be reported when additional measurements are completed.

A long manuscript which documents in detail our measurement procedures and results has been accepted for publication in Annals of Physics.

Future Plans

Our future work will be directed toward extending our optically-based γ-ray standards: 1) toward higher energies, and 2) toward less intense transitions.

Higher energies:

Our goal is to make precision wavelength measurements in the 5 MeV region where the sources will be direct neutron capture sources in a reactor. The scientific values of the high energy measurements are more 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 made with a mass spectrometer, and better resolution of complex nuclear spectra in the 2 MeV range. Around 2 MeV, the flat crystal spectrometer has a resolution 100 times as great as a bent crystal spectrometer so that intense blended spectra should be resolved. The Institut Laue Langevin (ILL), Grenoble, France, has a high flux reactor with source manipulation capability. Within the coming year, we hope to submit a proposal to ILL for placing a flat crystal spectrometer at their reactor.

Knowledge concerning the behavior of our flat crystals at high energies is essential so that we can predict linewidths and resolutions that will be obtained with capture gamma-ray sources. To this end, we plan to make γ-ray measurements on transitions from $^{110\mu}$Ag which has energies up to 1.5 MeV. This source can be irradiated in the NBS reactor and removed to our measurement facility located in the Reactor Building.

Weaker transitions:

Completion of a precision bent crystal spectrometer should permit us to measure weaker transitions. We hope to be able to provide the scientific community with X-ray and γ-ray standards accurate to a few ppm in regions in which intense transitions are not available. The ^{99}Mo 40.6 keV line mentioned above could be more easily measured with a precision bent crystal spectrometer.

Recent discussions concerning the non-zero mass of the neutrino have created an interest in the 18 keV region because the end point of the β spectrum of tritium is $\sim$ 18 keV. Accurate energy standards may be necessary for some of the experiments being planned. These standards can probably be most easily measured with a precision bent crystal facility.

2. X-ray Diagnostics of Laboratory and Astrophysical Plasmas
A. Burek, R. Deslattes, A. Henins

Objectives

This project applies crystal diffraction theory and technology to the study of X-ray spectra from laboratory and astrophysical plasmas. In particular we have been involved in optimizing efficiency and resolution in spaceborne instrument design and crystal utilization. We provide state-of-the-art calibration to help secure maximum scientific return from each mission. Our work explores new approaches including development of geometries and diffraction systems having characteristics not available otherwise.

Current Activities

Critical effort in this area was prompted by a contract from Lockheed via NASA to develop technology for and proceed with X-ray radiometric and diffraction optics calibration of a large number of large aperture flat and curved crystals to be used as dispersing elements in a high resolution X-ray polychromator to study solar flares. Now that the Solar Maximum Mission (SMM) is in orbit and returning high quality X-ray spectra, we are continuing to work with the SMM team on various aspects regarding the applications of crystal calibration to the analysis of data. These activities involve development of ray tracing techniques for experimentally determined curved crystal figures, development of methods for deconvolving instrument functions from observed spectra and evaluation of effects of off-axis reflections. A paper applying similar techniques to the analysis of high resolution solar X-ray data has been accepted for publication in the Astrophysical Journal. As part of a Guest Investigator program funded by NASA, an observing program has been defined and incorporated in the mission observing sequence that will study the evolution of hot plasma in magnetically confined coronal loops. This observing program utilizes certain unique features of the physics of anomalous X-ray Bragg diffraction near absorption edges in crystals to obtain plasma diagnostic information not otherwise possible. A complementary laboratory study and theoretical modeling of Bragg diffraction from resonant bound states in crystals has been completed.

The calibration exercise for SMM has generated a large amount of data concerning the X-ray radiometric and diffraction properties of real crystals that is of importance to workers in the plasma physics and synchrotron radiation communities. We are compiling and extending this data which we hope to publish. With regard to applications in the synchrotron radiation area, we have identified, obtained and evaluated two promising crystals that could make synchrotron primary monochromator construction possible for wavelength regions hitherto inaccessible to synchrotron users.

We are continuing to pursue the development of novel crystal dispersing elements and have devoted some time to the problem of fabricating large lithium fluoride panels for a space experiment. We are also investigating the application of epitaxially grown heavy metal crystals and multilayer structures to monochromator construction.

Development of such dispersing elements would dramatically decrease the expense and enhance the prospects for high resolution X-ray spectroscopy of X-ray stars.

Accomplishments

We have continued to work with the SMM team on various aspects of data analysis and have provided X-ray calibration data to a number of other groups in the X-ray astronomy and plasma physics communities. In particular, working in collaboration with NRL we successfully completed an analysis that showed that "new" unidentified lines in solar flare spectra were, in fact, crystal effects. Extension of the SMM program of crystal evaluation has identified new crystals of great potential use to synchrotron radiation users. Laboratory and theoretical work is complete on a Guest Investigator experiment that will study high temperature solar plasma.

Finally, a proposal to DOE for the development of efficient crystal spectrometers and X-ray interferometers for inertially confined plasma studies has been submitted and although not funded yet has been given favorable reviews.

Future Plans

Now that the SMM spectrometers are operational, we hope to proceed with data analysis as part of the SMM Guest Investigator observing program. The proposal with DOE will involve the development of new types of crystal spectrometers for laser plasma fusion studies and the investigation of ways of applying X-ray interferometry to X-ray plasma diagnostics. An essential part of this effort is providing calibrated "benchmarks" to aid in the development of new instrumentation in this field.

3. One- and Two-Electron Spectra*
K. Harvey, G. Luther (50%)

Objectives

We are applying tunable lasers and laser-related techniques in fundamental studies of simple atomic systems. The present effort aims to obtain adequate technological capability in regard to sources of coherent radiation with appropriate linewidths, intensities, and tuning ranges together with techniques for wavelength measurement. We are also developing, in a systematic way, atomic beam technology based on the use of lasers for state selection and state analysis.

Current Activities

An atomic beam of optically pumped metastable hydrogen has been demonstrated and is being optimized. This source will be exceptionally valuable to the future progress of precision hydrogen spectroscopy here, as well as to the current attempts at other laboratories to measure parity violation in atoms as predicted by unified gauge theories of the weak and electromagnetic interaction.

A precision measurement of an infrared transition between Rydberg states in atomic hydrogen, which coincides with a CO_2 laser line, is being pursued. This transition, which is in a region of the hydrogen spectrum not yet examined with high resolution, has already been observed here in a dc discharge with moderate resolution.

A detector employing a thermionic diode is being investigated to determine its details of operation and its application to the study of the Rydberg states of various atomic species.

The investigation of the energy of the first excited state of He using anti-Stokes scattering was initially unsuccessful, and is presently somewhat in a state of limbo due to the departure of the post-doctoral student (Shay) who was primarily involved with the experiment.

Accomplishments

The hydrogen atomic beam chamber, which was funded through the NML Director's reserve in 1979, is essentially complete. Lyman alpha and Lyman beta lamps have been constructed and successfully operated. A beam of metastable hydrogen has been produced using the Lyman beta lamp.

The thermionic detector has been thoroughly investigated with an alkali vapor and the mechanism for its sensitivity and internal gain established. The results of this investigation have been submitted for publication.

Finally, several laser sources are now available including a high power ion laser, tunable cw dye laser, pulsed dye laser, waveguide CO_2 laser and stabilized CO_2 laser.

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* After a realignment of the group's task structure, the work formerly described under Laser Spectroscopy of H and He^- now comes under this new title.

Future Plans

Appropriate lamps and nozzles will be further improved to obtain an optimum optically pumped hydrogen beam. This development will be transferred to the group doing parity experiments. Also the experiment to measure the infrared transition in the hydrogen Rydberg states will be done with an atomic beam to vastly improve the resolution of the spectra.

The thermionic detector will be optimized to further enhance its application to high resolution spectroscopy using the information learned from previous studies. It will also be used to study other systems such as He.

There is some possibility that the investigation of the energy of the excited state of helium may be renewed part-time by one of the staff (Luther). A renewed approach would probably replace the previous pulsed discharge excitation by either a dc discharge or a pulsed microwave discharge.

4. Gravity and Fundamental Theory*

G. Luther (50%), R. Hayward (Guest Worker), W. Towler (IPA)

Objectives

Our present objectives are twofold, and at present only indirectly related: An accurate measurement of the gravitational constant "G", and theoretical studies of the general limits of physical measurements.

The feeble effect of gravity on matter makes experimental investigation of the gravitational interaction one of the most difficult tasks in contemporary physics. The Newtonian Gravitational Constant is the least accurately known by several orders of magnitude of all the fundamental constants and has resisted efforts by many experimenters to improve its accuracy. Our primary experimental goal is a redetermination of "G" to an accuracy that reflects the current state of the art. Secondary goals include improving our understanding of the technical limitations and possible solutions to overcoming these limitations. We also hope to be able to set limits on any possible variation of "G" with distance.

Current Activities

The "G" experiment has been active since early summer, and data are being accumulated and reduced by digital methods.

The theoretical effort during the past two years has been concerned with the study of measurement at the quantum level. At the classical level, the interference by the measuring apparatus is accepted as an unwelcome, but tolerable, effect which the individual making the measurement may take into account. This is not so at the quantum level, where the interference causes uncontrollable and uncertain perturbations on the system being measured.

Accomplishments

One of the major accomplishments in the "G" measurement has been the experimental demonstration that the most important source of systematic error in our earlier attempts was related to the surface physics of the carbon fiber. The (necessary) operation of the pendulum in vacuum caused a continuing, substantial, and irregular change in the torsion constant of the fiber over a period of several months. The solution has been to return to the traditional quartz fiber, overcoated with gold to prevent static build-up. The new fiber has shown orders-of-magnitude improvement in the stability of both the quiescent position of the pendulum, and the torsion constant of the fiber.

A second major improvement has been the addition of magnetic damping of the pendulum motion of the bob. The torsion pendulum now used has a rotational Q of approximately 10000 (decay time of about one month), but lateral displacements decay in a few seconds.

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*Formerly reported under "Newtonian Gravitational Constant" and "Fundamental Theory".

The construction of the angle reading autocollimator using a Reticon photodiode array readout has been completed and the photodiode array interfaced to the control computer. The software modifications necessary to interpolate the angular position of the torsion pendulum have been completed, and the pendulum position is now interrogated about 16 times per oscillation. This data is temporarily stored until the completion of a run, and then processed off-line to determine the pendulum period.

The initial results for the data collected during the last several months indicate that we are now able to measure the torsion pendulum period with sufficient precision to calculate "G" to a few dozen parts in a million. When the dimensional metrology on the pendulum bob is completed, we expect the uncertainty in "G" to be of the order of 50 ppm. This result will be roughly a factor of 10 better than the best existing determination of "G".

We also now have sufficient data for different positions of the test masses to detect any variation of "G" with distance to better than one part in 1000. That should be sufficient to settle the present controversy over the validity of the inverse R square law at laboratory distances.

Theoretical studies have made great strides during the past year in the understanding of certain types of "quantum nondemolition" measurements, wherein a precision measurement of one specific observable is made such that the measurement causes a "reduction of the wavefunction". A subsequent measurement of the same observable will yield the identical result. The number of "quantum nondemolition" observables is rather limited for a periodic system such as a harmonic oscillator. It can be shown that the classical concepts of amplitude, phase and energy are not quantum nondemolition variables and the ultimate measurement precision obtainable will be limited by a quantum mechanical uncertainty principle, whereas the measurement of position or momentum has no theoretical limits. A scientific paper reporting these results is in preparation. As yet, no experiment has reached the quantum level where these results may be tested.

Future Plans

A full calculation of "G" using data from the last several months will be made in the near future. A new pendulum bob, with better known dimensional metrology and a new fiber, will be installed if the results of our analysis support our current belief that we are limited by knowledge of the present system.

5. Optical Physics*
J. Snyder, H. Holt (40%)

Objectives

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

Current Activities

The theoretical effort is aimed at understanding the details of the interaction of light with atoms. Two of the investigations concern experiments which are not well understood because the high laser intensities used invalidate the usual perturbation methods. One of the experiments is being conducted in the Electricity Division, and the related theoretical work is being done in collaboration with this group.

A third theoretical investigation is directed towards a possible experiment to demonstrate Doppler-free resonances narrower than the natural width, as recently proposed by Scully.

An experimental collaboration is presently underway with the Molecular Spectroscopy Division in the Center for Thermodynamics and Molecular Sciences. This collaboration involves the application of a recently developed technique for high-sensitivity saturated absorption spectroscopy to the systematic study of alkali dimers using a tunable cw dye laser.

Modification of the Fizeau wavemeter to reduce systematic errors continues, and a decision to convert the wavemeter to a new computer and I/O system has been made. The new computer control system will greatly reduce the time required to make minor modifications in the wavemeter software or electronics, and will allow the wavemeter to be routinely used as a subsidiary instrument in a laboratory environment.

A novel electronic frequency meter is being developed for use with Michelson-type "Lambda Meters". This frequency meter appears to have the capability to reduce the standard deviation in the wavelength measurement by several orders of magnitude without an increase in integration time or optical path length.

Accomplishments

The results of a collaboration between one of us (Snyder) and a group at the University of Paris-North have been published. This work, which was done in France in 1979, involved the development of a new technique for high-resolution saturated-absorption spectroscopy.

Two major problems with the Fizeau wavemeter have been solved, and the instrument has seen some use as a laboratory instrument. One of the problems was the systematic error introduced by accidental wavefront

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*These activities were previously included under "Laser Spectroscopy of H and He^-" and "Fundamental Theory".

curvature of the incident illumination. The effect of wavefront curvature is to introduce an error in the measured period of the fringe pattern. The size of the error is related to the amount of shear in the two interfering beams at the detector array. A geometry has been found for which the shear is compensated, and the curvature-induced error is negligible. The second problem was the systematic error due to the non-uniform amplitude of the fringe pattern. A solution to this problem in the form of a simple digital filter was found and incorporated into the software. Details of the filter have been published.

A remaining major source of systematic error in the wavemeter is correlated with ambient temperature and is believed related to the method of construction of the interferometer, but this has not yet been conclusively demonstrated.

The wavemeter has now seen some limited use as a laboratory instrument to monitor a dye laser wavelength as it scans a molecular spectrum. The RMS noise in the measured wavelength is about 50 MHz at the fastest update rate of about 60 msec. Signal averaging gives a resolution of about 5 MHz at a rate of 8 sec per point.

A non-exclusive licensing agreement with Molectron was negotiated by the National Technical Information Service, a sister agency within the Department of Commerce. This agreement gives Molectron the right to develop and market the Fizeau wavemeter. Unfortunately, they have not been very actively pursuing this project, and there do not seem to be any prospects for a commercial version of the Fizeau wavemeter appearing in the immediate future.

A real-time, signal-averaging frequency meter was proposed as an instrument to improve the performance of the Michelson-type Lambda meters. A "software" version of the instrument with limited frequency range has been completed and demonstrated, and a hardware version is being designed and constructed.

Future Plans

We hope to be able to demonstrate line narrowing below the natural width in a transient, Doppler-free spectroscopy experiment similar to that proposed by Scully. Our theoretical analysis suggests that line narrowing by a factor of two should be observable.

The collaboration with the Molecular Spectroscopy Division will continue. Our intention is to study simple molecular systems with high resolution.

We believe that the remaining temperature problems with the Fizeau wavemeter can be linked to the construction of the interferometer. A new interferometer, which should not have this sensitivity, has been assembled and will be tested. The wavemeter will be converted to run on the new computer system, and the software modified to be run as a subroutine call from FORTRAN. The computer will then be able to run as an experimental control and data collection system in the laboratory.

6. X-ray Spectroscopy - Synchrotron Radiation

R. LaVilla, P. Cowan, A. Henins, R. Deslattes, T. Jach, R. Spal

Objectives

The primary objective of research in this area is to exposit the finer, less understood details of X-ray spectra from atoms, molecules, and eventually of condensed matter. Specifically, we scrutinize those features of the X-ray spectra which are not explained by the simpler theories of inner-shell dynamics. As details of the X-ray spectra from free atoms are elucidated, a more precise understanding of inner-shell processes will be gained. This understanding should in turn provide the basis for deducing information on chemical binding from similar X-ray spectral features obtained from molecular gases, liquids, and simple solids. A secondary benefit of this research is the advancement of experimental technology which must necessarily accompany these studies.

Current Activities

We are trying to maintain a balanced program of work involving in-house laboratory spectroscopy, utilization of existing synchrotron radiation facilities, and development of devices, strategies and programs for the National Synchrotron Light Source to be operated at Brookhaven National Laboratory.

We have been improving and extending our in-house experimental facilities. To this end we have precisely calibrated the computer controlled angular encoder system on our vacuum double crystal X-ray spectrometer and are finishing the installation of a new X-ray power supply for it. This will greatly enhance our measurement capabilities of the L- and M-series spectra which have become of interest as a result of our precision measurement program. We are also in the planning stages of apparatus for performing X-ray standing wave experiments. X-ray spectral features involving multiple electron transitions are also being studied with on-site apparatus. Double electron excitation in sodium vapor is apparent in transmission spectra observed at SURF-II synchrotron ring. Satellite lines in the L X-ray emission spectrum from Ar were also measured by exciting Ar by electron bombardment and recording the soft X-ray spectrum with a grating spectrometer. Synchrotron radiation has properties (i.e., collimation, high flux, tunability, etc.) that make it a desirable source for X-ray spectroscopy, particularly for studying low intensity features. For this reason our group has been involved in an experiment at Stanford Synchrotron Radiation Laboratory (SSRL) and is planning an experimental facility in conjunction with the Naval Research Laboratory (NRL) to be located at the National Synchrotron Light Source (NSLS) which is being built at the Brookhaven National Laboratory.

At SSRL, X-ray spectroscopic studies of photon-excited single and multiple hole states near threshold have been made and are continuing. The wiggler beamline at SSRL is used in combination with a secondary polychromator in order to obtain spectra in the Kβ region from Ar at various excitation energies. These spectra are providing valuable information and a great promise for future experiments. Preparations for another another experimental run at SSRL before the end of the year are underway.

The beamline presently being planned for NSLS will be one of the first X-ray beamlines worldwide to be dedicated to the study of atomic physics. Since the NSLS will be comparable to the brightest existing synchrotron sources and since this beamline is being designed for our specific purposes/needs and available to users from NBS and NRL for 75 per cent of the time, we are anticipating a tremendous opportunity to lead in this area of investigation.

Accomplishments

The results obtained on near threshold excitation of Ar X-ray spectra at SSRL, although limited by a number of failures of SSRL equipment, have already excited much interest in the X-ray physics community. Spectra taken with the incident X-ray energy below the K single vacancy threshold suggest that resonant-raman scattering occurs. The origins of the $K\beta^{V}$ and $K\beta''$ satellite lines are also evident from the preliminary measurements of their excitation functions. These results have been presented at the International Conference on X-ray Processes and Inner-Shell Ionization in August 1980, and will be published.

Transmission spectra for Na vapor taken at SURF-II exhibit two features above the K threshold which have not been previously reported. By comparing these features with the MgI and MgII optical spectra, it was concluded that these features are due to double excitations to discrete states in the K continuum. These results and other details of the Na transmission spectrum were presented at the VI International Conference on Vacuum Ultraviolet Radiation Physics, June 1980.

The NSLS Participating Research Team (PRT) composed of personnel from the Naval Research Laboratory, the NBS Center for Materials Science and members of this Group received approval for our proposal to instrument two of the twenty-eight synchrotron radiation ports at the NSLS. In return the PRT is allocated 75 per cent of the beamtime available at these ports for at least the first three years of operation. Members of this group have the primary responsibility for the design and construction of one of the PRT's six planned experimental stations as well as an advisory responsibility for one other station. Designs for the beamlines are progressing on schedule so that the facility should be operational by January 1982.

Future Plans

The Group anticipates to continue the current research projects while increasing the precision and detail of our results and to study a wider range of samples as mentioned previously. We also plan to continue in developing new areas of activity.

At NBS, electron excited soft X-ray spectra from atomic and molecular gases and molecular gases and absorption spectra of metal vapors in heat pipes will be studied. Absolute L and M wavelength measurements on high Z elements will be obtained using the recently calibrated vacuum instrument to complement the K series measurements by E. Kessler on these elements. The M_V absorption edge of a bismuth foil will also be measured absolutely with the vacuum instrument to provide improved calibration for experiments performed by G.A. Beers et al on Kα radiation from pionic deuterium. X-ray standing wave experiments will commence. The purpose of the standing wave experiments will be to study new aspects of the interaction of photons with atoms in a crystal lattice and to demonstrate the use of this technique for studying structure of certain materials.

At synchrotron radiation facilities the doubly differential X-ray experiments will continue, initially at SSRL, then eventually at the NSLS. The measurements for Ar Kβ spectra excited near threshold will be completed and then extended to the Ar Kα spectra and molecular targets containing Cℓ and S. Near threshold excitation of electron spectra by X-rays will also be used to study inner-shell processes. In addition to the research program at synchrotron radiation facilities planning, constructing, and bringing into operation the NSLS beamlines at Brookhaven will be a major activity.

III. PUBLICATIONS

Quantum Metrology Group - 520.06

E.G. Kessler, Jr., R.D. Deslattes, W.C. Sauder and A. Henins, Precise γ-ray Energy Standards, Proceedings of Third International Symposium on Neutron Capture Gamma-ray Spectroscopy and Related Topics, Upton, New York, September 18-22, 1978, p. 427.

R.D. Deslattes, A. Henins and E.G. Kessler, Jr., Accuracy in X-ray Wavelengths, NBS Special Publication 567, Proceedings of Symposium on Accuracy in Powder Diffraction, NBS, Gaithersburg, Maryland, June 11-15, 1979, p. 55.

J.J. Snyder, U.S. Patent, Apparatus and Method for Determination of Wavelength, Patent No. 4,173,442 (1979).

J.J. Snyder, Algorithm for Fast Digital Analysis of Interference Fringes, Appl. Opt. 19, 1223 (1980).

J.J. Snyder, R.K. Raj, D. Bloch and M. Ducloy, High-sensitivity Nonlinear Spectroscopy Using a Frequency-Offset Pump, Opt. Lett. 5, 163 (1980).

R.K. Raj, D. Bloch, J.J. Snyder, G. Camy and M. Ducloy, High-Frequency Optically Heterodyned Saturation Spectroscopy Via Resonant Degenerate Four-Wave Mixing, Phys. Rev. Lett. 44, 1251 (1980).

R.D. Deslattes, X-ray Monochromator Development for Synchrotron Radiation Facilities, Nucl. Instr. Meth. 172, 201 (1980).

A.J. Burek, D.M. Barrus, R.L. Blake and E.E. Fenimore, Analysis of Solar X-ray Emission Line Profiles (to be published in Astrophysical Journal).

R.D. Deslattes, Primary Monochromators Using Crystal Diffraction, Nuclear Instruments and Methods (in press).

G.K. Lum, C.E. Wiegand, E.G. Kessler, Jr., R.D. Deslattes, L. Jacobs, W. Schwitz and R. Seki, Kaonic Mass by Critical Absorption of Kaonic-Atom X-rays (to be published in Physical Review).

R.D. Deslattes, The Avogadro Constant, Annual Review of Physical Chemistry (in press).

R.D. Deslattes, E.G. Kessler, Jr., W.C. Sauder and A. Henins, Remeasurement of Gamma-ray Reference Lines, Annals of Physics (in press).

R.E. LaVilla, G. Mehlman and E.B. Saloman, Double Excitations in Sodium Above the 2s Threshold (to be published in Journal of Physics B).

K.C. Harvey, Shielded Thermionic Diode Detector for Precision Spectroscopy (to be published in Review of Scientific Instruments).

R.W. Hayward, The Macroscopic Harmonic Oscillator and Quantum Measurements, Proceedings of The Second Marcel Grossman Meeting on Recent Developments in General Relativity, Trieste, Italy, July 7, 1979 (to be published).

IV. INVITED TALKS

Quantum Metrology Group - 520.06

R.D. Deslattes, "Primary Monochromators Using Crystal Diffraction", November 5, 1979, Joint USA/Japan Seminar on Synchrotron Radiation Facilities, University of Hawaii, Honolulu, Hawaii.

R.D. Deslattes, "Precise Measurements of Normal and Exotic Atom Spectra", November 15, 1979, Department of Physics Colloquium, University of Oregon, Eugene, Oregon.

E.G. Kessler, Jr., "Absolute Gamma- and X-ray Wavelength Measurements", December 5, 1979, Physics Department Colloquium, Illinois Institute of Technology, Chicago, Illinois.

R.D. Deslattes, "Accurate Short Wavelength Measurements in the Spectra of Normal and Exotic Atoms", February 6, 1980, Physics Department Colloquium, University of Arizona, Tucson, Arizona.

J.J. Snyder, "Frequency-Offset Saturation Spectroscopy", February 11, 1980, Bell Telephone Labs Colloquium, Holmdel, New Jersey.

R.D. Deslattes, "Short Wavelength Spectra of Normal and Exotic Atoms", March 27, 1980, Physics Department Colloquium, Michigan State University, East Lansing, Michigan.

R.D. Deslattes, "Precision Short Wavelength Spectroscopy", April 9, 1980, Physics Department Colloquium, Fermilab, Batavia, Illinois.

R.D. Deslattes, "Threshold Behavior of Double Vacancy Atoms", April 10, 1980, Physics Department Colloquium, University of Illinois, Champagne, Illinois.

R.D. Deslattes, "Accurate Atomic Inner-Shell Energies", April 29, 1980, Spring Meeting of The American Physical Society, Washington, D.C.

R.D. Deslattes, "Multiple Vacancy Effects in X-ray Spectra", May 14, 1980, Physics Department Colloquium, University of Virginia, Charlottesville, Virginia.

R.E. LaVilla, "The Sodium 2s Spectrum of Sodium Vapor", June 4, 1980, VI International Conference on Vacuum Ultraviolet Radiation Physics, Charlottesville, Virginia.

D. Bloch, R.K. Raj, J.J. Snyder and M. Ducloy, "High-Frequency Optically Heterodyned Saturation Spectroscopy via Resonant Degenerate Four-Wave Mixing", June 24, 1980, Eleventh International Quantum Electronics Conference, Boston, Massachusetts.

J.J. Snyder, "Fizeau Wavemeter for Pulsed and CW Lasers", August 18, 1980, Institute of Optics Colloquium, University of Rochester, Rochester, New York.

R.E. LaVilla, "1s and 2s Absorption Spectra of Sodium Vapor", September 26, 1980, Laboratoire de Chemie Physique, Universite Paris, Paris, France.

R.D. Deslattes, "Effect of Multiple Inner-Shell Vacancy on X-ray Spectra of Atoms and Molecules", September 26, 1980, Atomic and Molecular Physics Department Seminar, Argonne National Laboratory, Argonne, Illinois.

V. COMMITTEE MEMBERSHIPS

Quantum Metrology Group - 520.06

R.D. Deslattes, Member, NAS/NRC Committee for Fundamental Constants.

R.D. Deslattes, Chairman, Brookhaven National Synchrotron Light Source Users Association (resigned because of appointment to the National Science Foundation).

R.D. Deslattes, Member, Physics Advisory Panel, NSF (resigned when assigned as Director of Physics Division at the National Science Foundation).

R.D. Deslattes, International Advisory Panel, 4th International Symposium on Neutron Capture Gamma-ray Spectroscopy and Related Subjects, to be held September 7-11, 1981, in Grenoble, France.

VI. SEMINARS FOR STAFF AND GUESTS

Quantum Metrology Group - 520.06

J.D. Silver, Clarendon Laboratory, University of Oxford, England - CAPQ Colloquium, "Some Helium-Like Ions", October 1, 1979.

G.L. Borchert, European Organization for Nuclear Research, Suisse, Switzerland - CAPQ Colloquium, "X-ray Energy Shifts", October 11, 1979.

W. Wing, University of Colorado/JILA, Boulder, Colorado - CAPQ Colloquium, "Precision Spectroscopy in Highly Excited Beams", December 4, 1979.

P. Koch, Physics Department, Yale University, New Haven, Connecticut - CAPQ Colloquium, "Highly Excited Hydrogen Atoms: An Atomic Cornucopia", January 9, 1980.

J.W. Farley, Department of Physics, University of Arizona, Tucson, Arizona - CAPQ Colloquium, "The Effects of Thermal Radiation on Atoms", May 7, 1980.

M. Ohno, Department of Physics, Chalmers University of Technology, Göteborg, Sweden - CAPQ Colloquium, "Breakdown of a One-Electron Picture in AES Spectra from Atoms and Solids", May 30, 1980.

T. Åberg, Helsinki University of Technology, Laboratory of Physics, Otaniemi, Finland - CAPQ Colloquium, "Characteristic X-rays: Correlation Effects and Final-State Interactions", May 30, 1980.

M. Ducloy, Universite Paris-Nord, Laboratoire de Physique des Lasers, Villetaneuse, France - CAPQ Colloquium, "Doppler-Free High Frequency Heterodyne Spectroscopy", July 2, 1980.

G. Grynberg, Ecole Polytechnique, Paris, France and E. Giacobino, Universite Pierre et Marie Curie, Pari, France - CAPQ Colloquium, "Doppler-Free Two-Photon Absorption in He Stability Near a Two-Photon Transition", July 3, 1980.

G. Leuchs, University of Colorado/NBS/JILA, Boulder, Colorado - CAPQ Colloquium, "Sensitive Detection of Microwave and Far Infrared Radiation by Rydberg Atoms", July 3, 1980.

H. Börner, Institut Laue Langevin, Grenoble, France - CAPQ Colloquium, "Recent Experimental Results in the Actinide Region Using the Curved Crystal Spectrometer at the Institut Laue Langevin", September 17, 1980.

A. Brillet, Laboratoire de l'Horloge Atomique, Orsay, France - CAPQ Colloquium, "Saturated Absorption in an External Fabry Perot: Applications to Iodine at 612 nm", September 29, 1980.

TECHNICAL ACTIVITIES

ELECTRICAL MEASUREMENTS AND STANDARDS DIVISION, 521

FISCAL YEAR 1980

Overview

The Electrical Measurements and Standards Division (EMSD) 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 magnitudes 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.

The justification for all of the EMSD'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 EMSD's work include fundamental physical theory; electric 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 EMSD 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 several 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, the FAA, and the DoD.

To fulfill its responsibilities, the EMSD carries out work in the following 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 throughout the country to national reference standards.

4. Develop new methodologies and the required instrumentation which will lead to advances in the state-of-the-art of electrical measurements, 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 measurements 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, accomplishments and plans of the various projects underway within the EMSD which contribute to these principal areas are described in detail in the following project reports. In brief, in the area of absolute realizations, good progress is being made in the new experiment initiated last year to determine the ampere by directly equating electrical and mechanical energy; and in the experiment to redetermine the NBS farad and ohm via the calculable capacitor.

In the area of maintenance and dissemination, the needs of the EMSD's calibration clients were generally met. However, the situation remains grave because of the loss of staff as a result of the recently mandated ZBB cuts (see last year's Report). Indeed, the situation will be even more difficult in FY 81 since a number of the staff reductions did not actually take place until FY 80 was well underway. Also, due to the lack of staff, very little progress was made in furthering the automation of the calibration facilities or in developing new MAP transport standards, services, and software. However, some significant progress was made in improving the fabrication of Josephson junctions for voltage standard applications, and in understanding the interaction of microwave radiation with tunnel junctions (nonequilibrium superconductivity).

In the area of new measurement methods, an innovative, microprocessor-based ac resistance thermometer bridge was essentially completed and work begun on a similar capacitance bridge which will eventually be used in the EMSD's capacitance calibration service.

In the area of precision measurement and fundamental constants, good progress was made in constructing the apparatus required to carry out the new γ_p/α determination. Additionally, a new experiment to determine α and (simultaneously) to develop a new absolute resistance reference standard based on the quantized Hall resistance in MOSFETS was initiated.

In the area of international comparisons, participation in a CCE/BIPM-sponsored comparison of ac-dc thermal transfer standards was begun.

In the area of standardization, the EMSD staff continued to carry out their many committee responsibilities.

Finally, in the area of training and education, lack of staff once again prevented the EMSD from conducting its dc-lf Seminar. Also, the pressure on the staff to maintain the status quo, especially in the calibration area, was such that no tutorial material could be generated. (This situation will be alleviated to some extent in FY 81 with the preparation of a user's manual for ac-dc thermal converters by a recent EMSD retiree on a personal services contract.) On the other hand, a number of Guest Workers, an Industrial Research Associate, and two Summer Students were successfully trained during the FY.

To summarize this introductory section, although the EMSD has managed to survive a significant reduction of resources, in its present state it can only hope to carry out the most rudimentary aspects of its highly important mission outlined above.

REALIZATION OF THE SI AMPERE

(M.E. Cage, P.T. Olsen, W.D. Phillips, E.R. Williams)

Objective

The objective of this research is to measure the NBS 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 is periodically undertaken by NBS. This responsibility was given to the NBS in its original charter as prescribed in the Organic Act.

Although the most modern scientific tools available at a given epoch have been applied to the ampere experiment, there has not been a significant decrease in uncertainty in this measurement (presently about 5 to 10 ppm) in the past one hundred years. 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 fundamental 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 the uncertainty of the experiment by at least a factor of 50. The new experiment could (i) resolve the present inconsistencies among the measured values of a number of fundamental physical constants including the Avogadro constant; (ii) provide a new value for 2e/h to be used internationally for Josephson-effect volt-maintenance applications, thereby bringing the as-maintained electrical measurement system in closer agreement with the SI and improving the international compatibility of electrical measurements; (iii) provide a method for monitoring the stability of the kilogram; (iv) eventually lead to an artifact-independent definition of the kilogram and mole within the SI; (v) provide a new means for continuously monitoring the absolute variations in the local gravitational acceleration at a given site; (vi) provide information concerning the reliability of the US-NBS density scale; and (vii) lead to new, state-of-the-art advances in measurement science.

Current Activities

Any absolute ampere experiment involves measuring the force between current-carrying conductors and measuring the dimensions of the conductors. Previous realizations of the ampere were eventually limited by a measurement of the dimensions of some physical object, usually a coil (copper wire wound on a cylindrical form). The new approach makes this dimensional measurement indirectly, but more accurately, by measuring the distance a coil travels in some interval of time and making a simultaneous measurement of a slowly varying "d.c." voltage. This first part of a two part experiment, the calibration of the instrument, is expected to be the final limitation. The second part, the weighing, will be greatly improved in this approach over previous determinations since the mass required to counterbalance the vertical electromagnetic force will be increased from a gram in a kilogram dead weight to a kilogram in several kilograms dead weight.

The basic idea of the new experiment, which should enable an initial measurement at the few parts in 10^7 level, and an eventual accuracy of a few parts in 10^8, is to directly equate electrical and mechanical energy. It may be briefly summarized as follows: A moveable coil is made to traverse at a uniform velocity of about 0.5 mm/s a radial magnetic field generated by two pairs of fixed coils. The approximate one-volt emf generated at the terminals of the moveable coil while it is in motion is measured in terms of the NBS as-maintained unit of voltage, which is defined in terms of 2e/h as obtained from the Josephson effect. A current, known in terms of the NBS as-maintained unit of current, is then passed through the moveable coil. The force it experiences while traversing the same magnetic field path as in the first part of the experiment is measured using a balance with standard masses known in terms of the kilogram. (The NBS unit of current is defined in terms of the NBS units of voltage and resistance, the latter maintained via a group of Thomas-type one-ohm resistors.) The relevant equation is

$$K_A \equiv A_{NBS}/A = \left[\frac{mgv}{\varepsilon_{NBS} I_{NBS} (\Omega_{NBS}/\Omega)}\right]^{1/2} , \qquad (1)$$

where m is the mass equivalent of the force; g is the local value of the gravitational acceleration and is known to 0.01 ppm from absolute gravimetry; ε_{NBS} and I_{NBS} are, respectively, the above-mentioned emf and current measured in NBS units, and Ω_{NBS}/Ω is the ratio of the NBS to SI ohm, which is known to 0.02 ppm from the Thompson-Lampard calculable capacitor. Since coil dimensions need not be measured, our experimental design takes advantage of the high current densities obtainable with superconducting coils, and the dimensional stability available at liquid-helium temperatures, yet enables sensitive force measurements and velocity measurement to be conveniently made at room temperature.

Construction of the cryogenic coils has been contracted for outside NBS. While awaiting delivery of these coils, we are conducting a modified classical-electrodynameter or Pellat-balance experiment that is an equivalent approach to the new ampere experiment. In this experiment, a coil rotates in a uniform magnetic field. The induced voltage and rotational velocity are measured in the first part of the experiment, and the torque exerted on the coil is measured in the second part. Through this experiment we will develop all the measurement techniques required for the final experiment, with the bonus that this preliminary measurement will probably be the best ampere measurement ever made.

Accomplishments

A preliminary ampere experiment using the Pellat balance has been completed. The results of this work were presented to the Conference on Precision Electromagnetic Measurements (CPEM) during June 1980. The following specific accomplishments have encouraging projections for our future experiments: (1) The entire measurement process was automated, which is essential for simultaneous velocity and voltage measurements.

(2) A servo system that constrains the output voltage to be constant has proved to be a good technique for obtaining stable relative motion of the coils. (3) A two-frequency interferometer was modified to measure the "time between fringes". (4) The signal-to-noise ratio obtained for the voltage integral in the preliminary experiment is projected to give a sub-ppm noise limit in the next Pellat-balance measurement and a part in 10^8 limit in the final experiment.

The coil system for the final experiment has been completely redesigned: All superconducting coils now have the same diameter, and the moveable coil is larger in diameter and will be outside the cryostat. The new design reduced fabrication costs by a factor of two. This simpler coil system will be mechanically more stable and the moveable coil will be more accessible. Another design improvement is that the velocity and voltage measurements will now be made between two room-temperature coils, so that the velocity drift of the cryogenic system will be automatically compensated. The contract to construct the superconducting field coils has been let with an anticipated delivery date of May 1981.

In collaboration with R.S. Davis of the Length and Mass Measurements and Standards Division, we have obtained analytical solutions for the equations of motion of single-pan balances with a center knife and crossed load knives. These solutions predicted a new effect that depends upon the equilibrium angle of the balance. The existence of this effect was experimentally confirmed. Results of the calculations and the experiment will be published in the NBS Journal of Research. The calculations will be used to optimize the force balance for the new ampere experiment. The equilibrium-angle-dependent effect will be utilized to determine true gravitational horizon for the balance beam.

Future Plans

Measurements of the NBS Ampere utilizing the Pellat balance will continue. A solenoid which will provide twenty times more magnetic field strength has been completed. The accessories for this solenoid are being constructed. A new non-metallic arrestment assembly for the balance is being constructed. It is expected that the Pellat Balance will be in operation early in FY 81.

Numerous ampere measurements will then be made and sources of possible systematic errors will be studied. The Pellat Balance ampere measurements have the potential of yielding a ppm determination of the NBS Ampere. Techniques developed here are directly applicable to the eventual current balance.

The necessary apparatus for the current balance will continue to be assembled. The superconducting field coils, contracted out, will take from nine months to a year to receive. It will be calendar year 1982 before sub-ppm ampere measurements begin.

REALIZATION OF THE SI FARAD AND OHM
(R.D. Cutkosky, L.H. Lee, J.Q. Shields)

Objectives

The objectives of this project are to build, maintain, and operate equipment for calibrating the NBS standards of capacitance and resistance, 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 that are manufactured within the U.S.

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.

Current Activities

The equipment was completed a number of years ago and is among the best in the world. Work is presently concentrated on the preparation of this equipment for a new determination of the absolute farad and ohm. Other current activities include maintenance of the NBS unit of capacitance at the 10 pF level, and participation in international comparisons of capacitance.

Accomplishments

Three capacitors of NBS construction have been circulating for many years between the major national standards laboratories. This year for the first time the capacitors were sent to the People's Republic of China. Preliminary results from the National Institute of Metrology of China indicate agreement between their unit of capacitance and the NBS unit within their stated uncertainty of 0.35 ppm (standard error).

Preparation for the forthcoming absolute determinations of capacitance and resistance has resulted in the repair, replacement, or modification of several pieces of equipment. The equipment modified includes the signal generator for the frequency dependent quadrature bridge and the temperature controls for the oil bath and air baths which contain the 10 pF reference capacitors.

In addition, a period of training and familiarization was needed in order for J.Q. Shields to take over the actual measurements associated with the absolute farad and ohm determinations. One phase of this training took the form of an error analysis of the measurement system, thus providing an independent assessment of those parts of the system which had previously been considered in detail by R.D. Cutkosky alone.

Future Plans

New absolute farad and ohm measurements will be undertaken beginning early in the fiscal year and probably occupying from three to six months. Present thinking is that these measurements should be made on a yearly basis for the next year or two so as to determine the drift rates of the reference capacitors and resistors.

REALIZATION OF THE SI VOLT
(M.E. Cage, F.K. Harris, and L.H. Lee)

Objective

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 (5 ppm or more). 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,

$$\left(E^2 \frac{\partial C}{\partial Z} = 2\ \mathrm{mg}\right),$$

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 microns) 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

Using the surface of a mercury pool as a reference horizon, we have established vertical travel of the carriage-electrode system within 3 seconds over a 7 cm travel span. Over most of this distance -- except close to the end points -- the departure from vertical is no more than 1 second. Using carriage motion and a non-contacting capacitance probe, we have established symmetry of the high-voltage electrode system within 3-4 microns and vertical alignment within 3 seconds over a 5 cm carriage travel. Alignment and symmetry adjustments on the suspended electrode are not yet complete, but we have no reason to suppose these will not finally be of equal quality.

Future Plans

We expect to complete symmetry adjustments and final assembly of the electrometer early in the new fiscal year, so that force measurements can be started. The operational stability and resolution of our balance is about 1 μg. Thus, at the one-gram level, where our first force measurements will be made, we should have a 1 ppm resolution. To make force measurements at higher levels, we should lower the center of gravity of the suspended electrode system. This will require substantial modification of the suspension system, and will not be undertaken until we have assessed our results from the measurements at the one-gram level.

JOSEPHSON VOLTAGE STANDARDS

(G. Costabile, R.F. Dziuba, B.F. Field, C.J.P.M. Harmans, L.B. Holdeman, J. Toots)

Objectives

The overall objective of this activity is 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. The activity encompasses a number of interrelated projects, each having specific objectives within the purview of the overall goal.

The objectives of the Josephson Volt Maintenance Project are (i) to maintain the U.S. legal volt by the ac Josephson effect using the assigned value 2e/h = 483593.420 GHz/V_{NBS} and (ii) to improve the maintenance of the volt to a part in 10^8 or better by developing an all-cryogenic voltage standard. The objective of the AF/ARMY/NAVY/KSRI 2e/h Instrument Fabrication Project is to improve the maintenance of the unit of dc voltage at the standards laboratories of the U.S. Armed Forces and at the Korean Standards Research Institute by providing these laboratories with Josephson voltage standards. The objectives of the CCG Josephson Voltage Standards Research Project are (i) to develop an all-cryogenic voltage standard, (ii) to develop reliable Josephson junctions which are impervious to the effects of room-temperature aging and of thermal cycling between liquid-helium and room temperatures, and (iii) to develop Josephson junctions from high-T_c superconducting materials. The objective of the SRM Josephson-Device Project is to produce, for distribution through the Office of Standard Reference Materials, well characterized Josephson devices which can be repeatedly cycled, stored and shipped unrefrigerated, and packaged to be compatible with commercial Josephson voltage standards. The objects of the NASA Josephson-Device Research Project are to produce low-T_c films, fabricate devices from these low-T_c films, and to investigate their microwave response (0.1-40 GHz) in order to evaluate the high-frequency and non-equilibrium limitations of these devices in radiation-detection and voltage-standard applications. Finally, the objective of the Advanced Thin-Film-Device Research Project is to provide a vehicle for innovative research, with current emphasis on investigation of voltage standard applications of LEIT (Light Emission by Inelastic Tunneling) junctions and unbiased arrays of hysteretic tunnel junctions.

Current Activities

Approximately once a month the NBS Josephson voltage standard is used to assign new emf values to two NBS reference groups of standard cells, which are then used to assign values to customer standard cells. Development of the all-cryogenic voltage standard is continuing, with present efforts directed toward reducing noise effects that limit its precision. Five commercial Josephson-effect voltage standards are undergoing acceptance testing in the EMSD, and will be delivered in turn as they are made to meet specifications. Development of techniques for producing lead-alloy (Pb-In-Au/Pb-Bi) junctions is nearing completion, and development of niobium-based junctions will be resumed early in the fiscal year. Major modification of the thin-film deposition system that is now used for lead-alloy devices is progressing, and will enable substrate heating, mask changing, easier substrate mounting, and eventual sputter-etch cleaning of the substrates. The superconducting properties of thin films of the low-T_c intermetallic compounds $AuAl_2$ and $AuIn_2$ are being studied, and a study of microwave enhancement of superconductivity of Al films is continuing.

Accomplishments

In FY 80, there were ten comparisons of the Josephson voltage standard against NBS reference groups of saturated standard cells. The results of these measurements indicate that the primary reference group NBS-13 is drifting at the rate of -0.108 ppm/month. The all-cryogenic Josephson standard has been kept cold (<80K) during the past year with no apparent deterioration of any of its components, but external noise coupled into the system still continues to limit its performance. During FY 80 one commercial Josephson voltage standard was delivered and a second is ready for delivery following final calibration. The cause of a problem common to all instruments was pinpointed and eliminated. A combination of photolithography and stencil-mask techniques has yielded the result that better than 90% of the devices now produced are within 30 MHz of the design frequency, and about 80% are within 10 MHz; however, consistent production of sufficiently low tunnel conductance via sputter-oxidation has not yet been achieved.

A thorough analysis of magnetic torques in the Gyroscope Relativity Experiment was carried out for NASA, Marshall Space Flight Center, and some published results for certain torques were shown to be incorrect. For each torque the maximum value of the appropriate parameter (the value for which the torque equaled the design goal of 2×10^{-18} N-m) was computed, and the results were tabulated.

Thin films of the intermetallic compound $AuAl_2$ with sharp superconducting transitions near that of bulk SRM material have been produced by the technique of alternate deposition onto heated substrates of ultrathin layers with thickness ratios equal to the stochiometric ratio. The energy gap of $AuAl_2$ and its temperature dependence have been measured for the first time, and computer fitting of the data gives a BCS temperature dependence with a $\Delta(o)/T_c$ ratio slightly larger than the weak-coupling limit. Microwave enhancement of superconductivity in Al films has been observed using a configuration in which one electrode of a tunnel junction was also a 50Ω microstrip transmission line. At the frequency for which the effect was maximum, the energy gap could be increased by as much as a factor of two for temperatures near the equilibrium T_c, and the transition temperature could be enhanced up to 16 mK above its equilibrium value. A preliminary report of these results has been published (Phys. Rev. Lett. 45, 1011 (1980)).

An experimental and theoretical investigation of photon-assisted tunneling has been completed. A novel stripline-coupling scheme together with the sharp gap structure that we were able to achieve in Al tunnel junctions enabled a thorough study of junction behavior from the fully classical frequency regime to the fully quantum in a single device, and a thorough test of the Tien-Gordon theory. An account of this work will be published.

Future Plans

Monthly comparisons of the Josephson voltage standard against NBS standard-cell reference groups will continue. An improved low-noise constant-current source for the all-cryogenic Josephson voltage standard will be constructed; a higher power microwave source that will enable defluxing of the junction below the lambda point is on order. Since low-melting-point materials are not evaporated in the EMSD/TPMSD UHV Thin-Film Facility, a smaller ultrahigh vacuum deposition system acquired from NOAA will be modified to accommodate sputter cleaning and oxidation in addition to its present e-beam evaporation and codeposition capability. A gas handling apparatus capable of maintaining partial-pressure ratio and total pressure of two gases will be installed in the EMSD/TPMSD Facility and a self-contained chilled water unit will be connected to the 16 kW electron-beam power supply. The R&D for Pb-alloy Josephson devices will be completed and R&D for niobium devices will be resumed. The commercial Josephson voltage standards will be delivered in turn as they are brought into specifications. The study of microwave enhancement of superconductivity will be continued in order to increase the understanding of the phenomenon, and the investigation of low-T_c thin-film devices will continue with the goal of obtaining devices with identical electrodes and direct observation of radiation at the Riedel singularity.

QUANTIZED HALL RESISTANCE

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

Objectives

The objectives of this project are to determine the fine-structure constant, a, and to develop a resistance standard based on fundamental constants, through measurements of the Hall resistance of Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFET's) at temperatures below 2 K in magnetic fields greater than 10 T.

When a positive voltage is applied to the gate electrode of a MOSFET, a thin layer of electrons (called the inversion layer) accumulates beneath the oxide. This layer approximates a two-dimensional gas of free electrons. The number of electrons in the inversion layer can be varied over two orders of magnitude by changing the gate voltage, and thus the Fermi level of the electron gas is an experimental variable. A magnetic field B applied perpendicular to the inversion layer constrains the electron motion to quantized orbits with discrete energy levels (Landau levels).

At sufficiently low temperatures, the Fermi level can be adjusted so that a given Landau level is completely filled while higher levels are completely empty, so that an inversion layer electron cannot be scattered if the spacing between Landau levels (which is proportional to B) is sufficiently large. Under these conditions, a current flows between source and drain without a voltage drop within the inversion layer, and the Hall resistance (the ratio between the Hall voltage and source-to-drain current) is given by

$$R_H = a^{-1} m_0 c/2i \qquad (1)$$

where m_0 is the permeability of vacuum (exactly equal to $4½x10^{-7}$ H/m), c is the speed of light in vacuum, a is the fine-structure constant, and i is an integer.

Since resistances can be determined in SI units to within a few hundredths of a ppm by means of the calculable capacitor, and since the present uncertainty in the speed of light is 0.004 ppm, measurement of the quantized Hall resistance of MOSFET devices can, in principle, be used to determine the fine-structure constant. K. v. Klitzing has used this technique to obtain a value of a that is in agreement with the currently accepted best value, with an uncertainty of %1.3 ppm [Phys. Rev. Letters 45, 494 (1980), and private communication]. The magnitude of R_H falls within a relatively convenient range for small values of i: R_H = (25,813 L)/i. If experimental uncertainties can be reduced sufficiently, the technique can be used as the basis of an absolute resistance standard.

Current Activities

We are collaborating with the Solid State Physics Group of the Naval Research Laboratory (NRL) in a study of the Hall resistances of existing MOSFET devices using the NRL Magnet Facility. We are attempting to reproduce v. Klitzing's results using his measurement techniques. Our first two runs have been on a Bitter magnet at 10 and 12 T. A 15 T superconducting magnet should be ready for use early in FY 81.

Accomplishments

We have constructed a dewar probe system with which MOSFET devices can be cooled to 1.3 K. We have designed and built a battery-operated constant-current/constant-voltage source that is stable to better than 5 ppm, a battery-operated gate-voltage source with variable linear ramp speed, and incorporated into the measurement system current-reversing switches and two independent switches that can each select 12 different device functions for measurements. We have mounted two MOSFET devices that were fabricated at NRL, and results of our initial runs at 10 and 12 T indicate that the NRL devices were not suitable for these studies.

Future Plans

Dr. K. v. Klitzing sent us eight unmounted chips containing Hall devices, which we received 29 August 1980. We will attempt to reproduce his results at the few-ppm level using these devices and the superconducting (15 T) magnet at NRL in early FY 81. The results of these experiments will be helpful in determining the methods that should be used to obtain results with sub-ppm uncertainties, and in determining whether precise electrical measurements at the sub-ppm level are possible in the electromagnetically noisy, high-field, cryogenic environment that is required for the experiment.

We will continue to collaborate with NBS theoreticians S.M. Girvin and R.W. Rendell on possible theoretical limitations to the results (e.g., geometrical effects, the effects of localized states). We will continue a close cooperation with P. Roitman of the Electron Devices Division, with NBS fabrication of specialized Hall devices a future possibility. We will collaborate with NRL staff and P.J. Stiles of Brown University in the design and fabrication of mask sets for Hall devices of various geometries. The geometry dependence of these devices will be carefully studied to find the optimum shape.

ADVANCED IMPEDANCE-MEASUREMENTS RESEARCH

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

Objectives

The objectives of this project are to conceive and investigate new techniques for making various electrical measurements, and to develop and construct the physical standards necessary to support these measurements.

A significant number of electrical measurement problems are not encountered often enough to attract commercial development of appropriate instrumentation, yet are of considerable importance to persons engaged in exploratory research or in the measurement of fundamental constants. Persons engaged in such activities are generally best situated for connecting established techniques with new problems, and consequently a project of this kind must be closely linked with projects involving research activities.

Current Activities and Accomplishments

An automatic resistance-thermometer bridge suitable for small-scale production was constructed this year, detailed construction plans were prepared, and a technical paper on the instrument was published. Plans for this bridge were sent to a number of people who had requested them. Five copies of the bridge are under construction and nearing completion in Division 522. Design work has been completed for modifying the above bridges for operation up to 100 L. A new microprocessor system will be used for this work. Microprocessor program development, formerly a slow and cumbersome procedure involving the use of an Interdata 7-32 minicomputer, will now proceed much more quickly. A fair amount of experience with the new system has already been acquired.

Some preliminary work has been done on a new fused-silica capacitance standard. The geometry of the silica element has been pretty well established, but problems have been encountered with the application of the electrodes. A lot of experimentation was done with a fired-on platinum-gold material that was recommended by and provided by Englehard. The problem we had was with obtaining complete coverage of the silica within a thin groove around the circumference of the silica disk, resulting in an unacceptable voltage dependence for the capacitance. Recent results with an air-dry silver paste have been more promising, but a new temperature regulator must be built before final measurements are made.

Some other components for an automatic capacitance bridge have been made, including most of the phase sensitive detector and most of the frequency synthesizer. Final assembly and testing will probably not occur until the end of FY81.

Future Plans

The most immediate task ahead is to see that a 100 L version of the automatic resistance thermometer bridge is made available. This instrument will be more readily accepted by others than the present 32 L version, which may induce someone into manufacturing it. Together with this, it will be necessary to devise a guard driver to fit inside all of these automatic bridges, which will not be dependent upon leakage between the guard and the furnace.

We believe that the present automatic thermometer bridge is not optimum in a number of respects. Improvements can be expected in the manner of connecting the guard, in resolution, and in convenience. It would not be out of the question to contemplate designing and constructing another instrument for this work, possibly starting about one year from now.

EDDY-CURRENT NONDESTRUCTIVE EVALUATION
(B.F. Field, G.M. Free)

Objectives

The eddy-current project has three principal objectives: the development of a calibration service for electrical conductivity standards in the range 10%-100% IACS; the production of electrical conductivity standards which will become NBS Standard Reference Materials; and the development of an eddy-current flaw-detection system for measuring and graphically displaying defects in nonferrous metal components and structures.

Eddy-current testing of metal components 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 thicknesses, 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 will meet the need for accurate calibration of conductivity test systems.

In the area of defect testing, industry uses "in-house" standards for the calibration of instrument sensitivity, and consequently there is little basis for intercomparison of test results. However, before defect standards can be developed, instrumentation that will accurately characterize commonly encountered defects must be developed. Eddy-current defect imaging is a possible method for characterizing defects in metal structures. Sophisticated signal processing in the imaging system could improve the accuracy of defect characterization by at least an order of magnitude. Such an instrument would not require a highly skilled technician to interpret measurement results, thus making eddy-current defect detection more practical for industrial use.

Current Activities

The electrical conductivity calibration service and the electrical conductivity standard reference materials have as a common factor the instrumentation developed to measure electrical conductivity. This consists of a direct-current measuring system by which the resistivity of metal bars of rectangular cross section will be determined. These metal bars will 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 will be made between the primary conductivity standards and either customer samples or SRM's to determine their electrical conductivity.

For development of the eddy-current imaging system, a new probe design is being developed using an array of electromagnetic field sensors. Sensors presently being fabricated and tested are precision wound coils with geometries chosen with the help of several computer-aided-design programs for determining the defect sensitivities of the coils. The probe concept will be proven experimentally using metal standards with known fabricated defects. Using the experimental data, appropriate models will be developed for characterization algorithms to be implemented with a desktop computer. The final output of the task will be a specialized eddy-current probe and signal-processing hardware capable of real-time defect characterization and graphical (video screen) display of defect information.

A temperature controlled air bath is being developed for measuring conductivity standards. The air bath eliminates the need for doing measurements with the test samples immersed in oil, eliminating the problem of lift-off associated with this type of measurement.

A standard on the measurement of electrical conductivity by eddy currents is being written for ASTM Committee E7.07. This document is a joint effort by NBS staff and several representatives from industry. The document will be circulated for approval at the January meeting of the E7 committees.

Accomplishments

The following was achieved during FY 80: (1) Two new eddy-current bridges have been developed and are undergoing testing. These new bridges work on the variable frequency concept developed at NBS but are much faster and easier to operate. One of the bridges also holds promise of being able to measure accurately in the ppm range. (2) Three metal bars have received the final machining process and are being characterized with respect to electrical and geometrical parameters. (3) A series of Standard Reference Materials have been produced. There are four standards with approximate conductivity of 60%, 47%, 40% and 30% IACS. There are 100 samples at each conductivity value. The standards have an anodized surface to prevent surface deterioration. (4) The concept of electronically scanning a flat plate with eddy-currents to accurately locate discontinuities has been proven feasible. An experimental set-up to do this has yielded good results. However, the initial design for printed circuit coils fabricated for the defect imaging system has been evaluated and rejected. (5) Hall effect devices were also investigated as possible sensors for the imaging system. After sophisticated instrumentation was developed to eliminate pickup of stray fields, it was found that the inherent noise level in the devices makes them unsuitable for this application. (6) A joint study with the Material Science and Standards Division has been completed. The study was funded by NASA and a report entitled "Nondestructive Evaluation of 2219 Aluminum Alloy--Relationship to Processing" was issued in April 1980. (7) The Volume "Proceedings of the Symposium" on the Eddy Current Characteriation of Materials and Structures which is to be published by ASTM as an STP has been edited and the preface and introduction written. The volume should be available in early FY 81. (8) Two sessions of the ASNT Fall Conference to be held in Houston, Electrical and Magnetic Methods and Research, have been organized. Speakers have been found and other work related to the sessions has been completed. NBS personnel will be the chairmen at these sessions.

Future Plans

Plans for FY 81 include the following: (1) All dimensional and electrical tests on the dc bar standards will be completed. The bars will then be the basis for the unit of conductivity. (2) The electrical conductivity calibration service will be announced and calibration of customers samples will be initiated. (3) The 400 SRM's which have been manufactured will be calibrated and offered for sale by the Office of Standard Reference Materials. (4) Before offering (2) and (3) the details and logistics of calibrations and reports will be established. (5) Work will be completed on the characterization of the new eddy-current bridges which have been built. (6) Work will continue on the constant-temperature air bath. The goal of this work will be to make the temperature at which the bath controls variable in the range 20-30 C. (7) Theoretical studies and computer analysis will be conducted to determine the feasibility of an absolute measurement of electrical conductivity. This measurement is important in determining the existence of any error in the transfer of the unit from the dc to the ac experiment. If it can be done with a high enough degree of accuracy, this experiment would also replace the dc experiment as the point of origin for the unit of conductivity. (8) Present sensor designs will be evaluated for use in the defect imaging system. If a suitable sensor is found, a prototype array system will be assembled and tested, and development of image processing software will be started.

ELECTRICAL MEASUREMENTS FOR CORROSION

(W.G. Eicke, J.E. Sims)

Objectives

The objectives of this project are to improve, both in quality and techniques, the electrical measurements requisite to the study of underground corrosion.

Each year, tons of various metals are buried underground for various purposes: pipelines carrying oil, gas, or water; transmission lines for communications or electrical power; and support pilings, to mention a few. Corrosion of all kinds has been estimated to cost the United States billions of dollars annually, with underground galvanic corrosion responsible for a significant fraction of this loss. A variety of methods for inhibiting underground corrosion have been developed, but in order to evaluate these methods in the field, and to develop new protection methods, an *in situ* measurement of the rate at which metals corrode is essential.

One approach is to use electrical techniques to measure the rate of corrosion. In this approach, a current I is applied to the structure under study, and the change in electrochemical potential V is observed by using a standard reference electrode. By varying I, a curve V(I) is obtained. The rate of corrosion can be calculated from this measured current-voltage relationship. Since the measurements are made manually, this approach is tedious and time consuming. Therefore the immediate objectives of this project are to improve the above approach through automation or semiautomation.

Current Activities

The activities now underway in the EMSD are an evaluation, in a laboratory situation, of a superposition of an alternating current on the applied direct current as a means of improving the electrical measurements for determining corrosion rates; the development of methods to automate these measurements; and the development of computer programs to reduce the data obtained. The project activities are separated into two tasks: Fourier Analysis Program Development (Task A) and Electrical Measurements in Underground Corrosion (Task B).

Accomplishments

The computer software, written for the Interdata 7/32, essentially performs harmonic (Fourier) analysis. A BASIC program (PERIOD) determines the period of an arbitrary set of data. A subset of the data is used as a "window." This window is characterized by a minimum, a maximum, and the number of points in the subset. The rest of the data is searched until the window is located twice. This defines an estimate of the period. Using an error function, the estimate is varied until minimum error is located and an accurate value for the period is obtained. Analysis of the results, obtained from running the program using a group of simulated data sets, indicates this method is accurate to 0.1%. The initial execution time of the program was slow because of the large size of the data sets and the use of BASIC as the programming language. Therefore, the input and search portions of the program were rewritten in Assembly language to substantially reduce the execution time.

Another BASIC program (DFT) calculates the discrete Fourier coefficients using standard techniques. Although accurate values are obtained, this program usually requires several hours per data set. A new program (FFT) employing FAST Fourier Transform methods reduces the number of computations such that this program only takes several minutes to run. Analysis of results from running the FFT program using simulated data sets indicate this method has an accuracy of 0.15%.

Major problems were encountered with the 7/32 operating system (and possibly some hardware) which required that an inordinate amount of time be spent in maintaining the system. It appears that many of the problems have now been corrected and we hope that this work will be completed early in FY 81. An NBSIR will be written documenting this effort.

Major efforts have been directed toward developing an automated system for measuring corrosion rates. Originally the work plans called for developing prototype automated systems in the laboratory. However, after further study and consultation with our collaborators in the Chemical Stability and Corrosion Division (CSCD), we decided to develop a system to be used in the field because we could not duplicate field conditions well enough in the laboratory. Various parts of the overall measurement technique were studied in detail and we found that the major problem for an automated system was that of resistance compensation. A number of possible methods were considered and a very promising method was found and investigated. This method, a variation of a technique developed at NBS by Haller in the 1950's, could be applied either manually or with an automated system. Studies were made and a prototype constructed. Tests in the laboratory indicate that the manual version allowed IR compensation on a wide range of resistances with an accuracy at least as good as the methods currently in use. However, this method requires that the measuring and compensation circuits be floating.

Possible automation techniques were investigated and we decided that the best solution would be to first automate using conventional, easily characterizeable instrumentation. Because the test site is not readily accessible by computer, an HP9830 was selected as the control device because of its availability. One objective of the CSCD's program is to develop a small microcomputer-based instrument. With this objective in mind, we decided that all hardware developed for this first prototype would be compatible with that objective whenever possible. During this FY we have developed an interface between the 9830 and instrumentation that meets the microcomputer objective. In addition, a prototype solid-state scanner was designed and construction is nearly complete.

We have also collaborated with CSCP in setting up their test site and in their investigation of solid reference electrodes by designing and constructing a manual scanner for quickly measuring buried sample electrodes.

Future Plans

It is anticipated that the Fourier program will be completed in early FY 81, after which our entire effort will be directed toward Task B.

GAMMA-P AND THE FINE-STRUCTURE CONSTANT

(M.E. Cage, P.T. Olsen, W.D. Phillips, E.R. Williams)

Objective

We plan to resolve the present discrepancy between experiments and the predictions of quantum electrodynamics (QED), and to enable more critical tests of QED, by carrying out an improved (a few parts in 108) measurement of the gyromagnetic ratio of the proton, q_p. This should yield a value of the fine-structure constant that is accurate to 1-2 parts in 108.

QED is among the most successful and accurate of all physical theories. Although QED has predicted experimental results to higher accuracy than any other theory, a slight discrepancy (0.33 % 0.14 ppm) now exists between the measured and predicted values of the anomalous moment of the electron, a_e. Furthermore, a_e can be measured with greater accuracy than it can be predicted, owing to uncertainties in the fine-structure constant, a. Since the uncertainty in a is now dominated by the uncertainty in our most recent measurement, an improved measurement of q_p will either confirm or resolve the present discrepancy between theory and experiment.

Within a few years, both the experimental measurement of a_e and calculations of a_e based on QED will have accuracies (exclusive of the uncertainty in a) of 1-2 parts in 108. Therefore, obtaining a comparably accurate value of a is of high priority to the physics community. No other laboratory has achieved the accuracy in q_p obtained at NBS. Our closest competitor in quoted uncertainty, at the NPL in Great Britain, disagrees with us (and with QED) by more than ten standard deviations. The NPL work is not likely to be repeated or extensively reviewed. Therefore, it appears that only the NBS effort is likely to lead to an improvement in the present knowledge of q_p. The responsibility for improving a to the point where the most critical tests of QED may be made lies with us. We, therefore, plan to carry out a new measurement of q_p by two relatively independent methods. The first is a redetermination of q_p by improving the recently completed method. The second is to employ a new technique using Ampere's Law.

Current Activities

The gyromagnetic ratio of the proton is defined as the ratio of the angular precession frequency 1_p of a proton in a magnetic field B to the magnitude of the field, $q_p = 1_p/B$. 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 electric current in the turns of wire. In the recently completed experiment, 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 this probe. We are constructing a new solenoid and measuring apparatus that will reduce the sources of error in the recently completed 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 straight edge 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 q_p determination.

Because of the importance of this experiment to physics and because recently reported results by another laboratory disagrees with our results, we are planning to measure q_p by an independent approach employing Ampere's Law. The dimensional measurements of the solenoid will be replaced by a "mapping" of the magnetic field of the solenoid. In this new approach it should be easy to test the systematic errors and estimate the accuracy of the measurement. This is a significant improvement over the present method, which requires numerous corrections and assumptions to obtain high accuracy.

The construction of the major components for the new experiment is underway. In order to meet our strict tolerances for these components, we have been personally directing the day-to-day measurements made by shop personnel at each stage of construction.

Accomplishments

In order to measure the effect of the susceptibility of the quartz solenoid form, we have constructed a 2.4-m-long, 0.6-m-diameter auxilliary solenoid into which the actual 0.3-m-diameter solenoid can be inserted. This will allow direct measurement of the change in magnetic field produced by the 0.3-m-diameter quartz form. Construction and winding of the large solenoid, which required modification of the shop's largest lathe, is completed, and the coil is ready for installation in the nonmagnetic facility.

The 0.3-m-diameter, 2.4-m-long precision solenoid is the key to an improved value for q_p. After final lapping, the fused-silica form had diameter variations of less than 5 mm and was out of round by less than 1 mm. A groove was then ground into the cylinder and final thread lapping was begun. Accurate measurement of the entire solenoid must be made after each hour of thread lapping. It is anticipated that the form will be completed within the desired tolerances early in FY 81.

A 3-m-long straight edge has been lapped inside a 0.23-m-diameter fused-silica tube. This track is now straight to within %0.04 mm over its entire length, which is sufficient to reduce the out-of-straightness correction to about 5 parts in 108 (a factor of 5 better than the previous straight edge. Final polishing may further improve this already-adequate straightness.

We carried out an extensive design study to determine the best compensation scheme for the new long solenoid. With the scheme selected, the magnetic field will be uniform to within a few parts in 10^9 over the NMR sample (4 cm in diameter) and to within a part in 10^7 over a volume 8 cm in diameter, and will be as insensitive to diameter variations as a 2-km-long uncompensated solenoid. Thus the uncertainty in γ_p due to the diameter measurement (the major limitation in the recently completed γ_p experiment) will be completely negligible.

Finally, the CAMAC centered data-acquisition system, which will enable remote (300 m distant) control of the dimensional measurements of the precision solenoid, has been made operational. This minicomputer system is currently being used to control measurements in the absolute ampere experiment.

Future Plans

We will continue to concentrate on the construction and the measurement of the precision solenoid. This solenoid is the key element for both approaches.

We will assemble the apparatus required to improve the recently completed measurement. This will occupy most of our time during the next two years. We have chosen to concentrate on this approach rather than the new Ampere's law approach because we feel confident that an improved value will be obtained within a few years. The reason for our confidence is our recent calculation that shows that the sensitivity of γ_p to the solenoid diameter has been eliminated, and our new straight-edge reduces the out-of-straight correction.

The susceptibility solenoid will be assembled. This solenoid will stand on end with a shower of cooling water to control the temperature to 0.01 °C with 2.5 kW of power in the wire. A current source with short term stability of a part in 10^8 must be built to produce a constant magnetic field. The smaller precision solenoid will be lowered into this uniform field and the field change due to the susceptibility of the precision solenoid will be measured with an NMR magnetometer.

The lapping of the precision solenoid and the final polishing of the straight-edge will be completed at the same time as the susceptibility measuring system is being tested.

Our immediate goal is to have a preliminary pitch measurement by the PMFC II conference, June 1981. This is ambitious because the susceptibility measurement must be completed first.

LASER COOLING AND TRAPPING OF NEUTRAL ATOMS
(W.D. Phillips)

Objectives

The fundamental objective of this experiment is to use tunable lasers to cool and confine neutral atoms. These atoms, cooled to as low as 10^{-4} K, could be used for high-resolution spectroscopy in a number of applications.

Because spectroscopic techniques form the basis for the most precise physical measurements made today, NBS continues to work on extending the resolution of spectroscopy. Maintenance of time, frequency and length standards has benefitted from advances in spectroscopy. Recent advances in non-linear optical spectroscopy indicate that attempts to achieve higher resolution must address the problems of second order Doppler shift and broadening due to finite observation time. Cooling and confinement of atoms are an answer to these problems. The use of laser fields to cool and confine atoms has been suggested for a number of years; recent developments in tunable lasers indicate that it is now an experimental possibility.

This work is complementary to the trapped ion work of the Time and Frequency Division in that, while directed toward the same aim of improved spectroscopy, the use of neutral atoms presents different opportunities. For example, cooled neutral atoms in highly excited (Rydberg) states could be used for precision tests of theories of the Stark effect, precise measurement of electric fields, or the determination of the fine-structure constant from Stark splittings. Cooled neutral cesium atoms could be used in conventional atomic clocks to improve their performance. High resolution spectroscopy of neutral atoms also has other possible applications in atomic physics and fundamental constants, such as Lamb shift or Rydberg determination. Cooled and trapped atoms might also be used for very low energy or very well controlled collision studies.

Current Activities

Atoms which interact with laser light that is resonant with an atomic transition will experience forces due to the absorption and emission of light. These forces can in theory be used to confine and cool the atoms. The forces are weak enough, however, that with present technology, atoms hotter than about 1 K cannot be confined. Therefore, we need to cool the atoms considerably before trapping is possible.

We are now attempting to use the light from a tunable dye laser to slow down a beam of sodium atoms enough that they may be confined in the field of another laser beam. We are also considering confinement in static magnetic or electric fields which can interact with the permanent magnetic dipole moment of the sodium or the electric dipole moment which exists in some excited states. While the atom cooling efforts are initially directed toward eventual trapping of atoms, they could also be used to produce slow neutral beams which would be useful for atomic clocks or other atomic spectroscopy.

Accomplishments

During FY 80 we have studied the effects of long-time interaction of a resonant laser beam with an atomic sodium beam. By studying the changes in the absorption spectrum with power and polarization we have learned about the effects of optical pumping under these conditions. We have also modified our laser to allow very rapid frequency scanning and have reproduced experiments which were claimed to demonstrate cooling when initially performed elsewhere. We have shown that the apparent cooling effects are actually due to optical pumping, an effect which is so large that it masks any cooling which might be present. We have begun the construction of apparatus that will provide an unambiguous measurement of the cooling effects.

We have developed a computer program which calculates the effects of optical pumping for long interaction times. This program appears to be successful in predicting the results of some experiments, performed elsewhere, which were not previously understood, but the calculation is not wholly adequate for the present experimental situation.

Future Plans

During FY 81 we will make unambiguous measurements of the cooling effect of a laser beam on an atomic beam. We hope that this will result in the first demonstration of the ability to perform such cooling. Once this is accomplished, we will study various methods for improving cooling efficiency, such as application of magnetic fields, use of circular polarized light, and driving rf transitions between the ground hyperfine states to avoid optical pumping problems.

We will also refine our optical pumping calculation so that it treats strong laser fields and atomic coherences more realistically. We hope that this will provide us with a good theoretical discription of what happens in the experiments and will guide the development of the experimental program.

In summary, our immediate goal is to use lasers to significantly slow a neutral atomic beam and to apply this to the trapping of neutral atoms in electromagnetic fields. We hope that this will find application in spectroscopy, standards maintenance, atomic physics, fundamental constants and electrical measurements.

FUNDAMENTAL CONSTANTS DATA CENTER
(B.N. Taylor)

Objectives

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

The close relationships that exist between the fundamental constants and precision measurements, basic measurement units, fundamental physics, and state-of-the-art measurement technology makes the subject a natural one for NBS to be deeply involved in. One of the purposes of this project is to provide assistance and guidance in the general area of precision measurements and fundamental constants for both NBS staff and university scientists, and in particular, to advise them as to which experiments should be carried out and what work is currently underway in various laboratories throughout the world.

Self-consistent "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; (3) participating in the work of national and international groups (for example, the CODATA Task Group on Fundamental Constants and the NAS/NRC Committee on Fundamental Constants); (4) publishing the quarterly "Preprints on Precision Measurement and Fundamental Constants" for the OSRD (this publication lists preprints as well as reprints of PMFC papers); (5) attending and organizing national and international conferences on PMFC and visiting laboratories carrying out work in this field; (6) serving as an editor of Metrologia in the area of Electrical Measurements and Fundamental Constants; (7) carrying out collaborative work with Soviet colleagues under the joint NBS-Gosstandart cooperative agreement in metrology; and (8) answering numerous inquiries from both within and without NBS relating to the PMFC field.

Accomplishments

The following was achieved during FY 80: (i) Published four quarterly issues of Preprints on Precision Measurement and Fundamental Constants (PPMFC); (ii) Responded to numerous written and oral inquiries regarding the fundamental constants; (iii) Revised the Table of Physical and Numerical Constants for the 1980 Review of Particle Properties that was prepared by the Particle Data Group and published in Rev. Mod. Phys. 52, Part II, S1 (1980); (iv) Attended meetings of the NAS/NRC Committee on Fundamental Constants in April and August, mainly to help plan a report on the PMFC field to be written by the Committee. Its purpose will be to demonstrate to various U.S. Government funding agencies the importance of PMFC work to all of science and technology; (v) Attended a meeting of the CODATA Task Group on Fundamental Constants to discuss the plans for the 1981 least-squares adjustment (see below); (vi) Visited several laboratories to discuss on-going PMFC research. The organizations visited (and the quantities being measured) included the University of Washington ($a_e^{\pm}$, m_p/m_e); Colorado State University (Lamb shift, R_∞); Stanford University (h/m_e); University of Virginia ($\dot{G}$); and PTB (N_A, γ_p, SI Ω, α); (vii) Participated in the annual meeting of the NSF Interagency Atomic and Molecular Physics Group to represent NBS' interests in this field as it relates to PMFC; (viii) Continued organizing the Second International Conference on Precision Measurement and Fundamental Constants (PMFC-II) to be held at NBS, Gaithersburg, June 8-12, 1981. A mailing list was generated, several thousand first-announcement brochures were sent out, the three organizing committees were completed, funds were solicited from a number of organizations, the technical program was developed, speakers were invited to give review talks, etc; and (ix) Continued to collaborate with E.R. Cohen, Rockwell International, on the 1981 least-squares adjustment of the fundamental physical constants which is being prepared under the auspices of the CODATA Task Group on Fundamental Constants. The first draft of the 1981 adjustment should be ready for review in April 1981 and the final version by the end of 1981. International adoption by CODATA is expected in early 1982.

Future Plans

Plans for FY 81 include continuing the work carried out in FY 80: (i) The quarterly PPMFC will be published as usual; (ii) inquiries will be responded to as received; (iv) the May NAS/NRC meeting will be attended, and specific contributions to the NAS/NRC report will be prepared and submitted to the Committee Chairman; (v) and (ix) the June CODATA meeting will be attended, and the draft adjustment that will be prepared in the first half of FY 81 will be discussed. Based on these discussions and the new results reported at PMFC-II, the adjustment will be revised to final form by the end of 1981; (vi) laboratory visits will continue as convenient; (vii) the 1981 NSF Interagency Group meeting will be attended; and (viii) the organizational work for PMFC-II will be completed, the Conference held, and work begun on editing the Conference Proceedings.

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

Objectives

The annual objectives are to award two new Precision Measurement Grants of $25K (renewable for two additional years at the option of NBS), and to renew four existing Grants. These 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 (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 and the reader is referred there. It should be noted that 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 by awarding grants to a selected number of outstandingly qualified, creative experimentalists. 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, and thus to increase their productivity. Selection is based primarily upon the originality of the work proposed as described in formally submitted proposals.

Current Activities

There is a great deal of latitude in the kind of research which may be considered for support under the Precision Measurement Grants program. The key requirement is that it generally support NBS work in the field of measurement science. This work 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 proposal writing and evaluation 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 two 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

The procedures outlined above for selecting candidates, which were first instituted in FY 77, were again used successfully in FY 80. Proposals were openly solicited via an advertisement in Physics Today, announcements in appropriate trade journals and newsletters, and the mailing of a brochure to all of the college and university physics departments in the U.S. (about 950). Proposals were received from 29 candidates, seven of whom were chosen to submit final, full proposals. The two grantees selected from these seven were:

William C. Oelfke, University of Central Florida
Proposal Title: Quantum limited measurements of a harmonic oscillator

William H. Wing, University of Arizona
Proposal Title: Electrostatic trapping of neutral atomic particles

Oelfke will explore experimental methods of evading the quantum limited "back-action" of measurement. To be examined are alternatives to standard measurement schemes designed to measure harmonic oscillator observables which commute exactly (or approximately) with the harmonic oscillator Hamiltonian and are not limited by the Heisenberg uncertainty relation. Such measurement techniques "evade" or balance-out back action on the measurement of the oscillator. The work relates to the detection of gravitational waves and determining the quantum limit to measurement.

Wing will attempt to harmonically trap and cool excited neutral atoms having positive Stark energies in an appropriate static, non-uniform (i.e., quadrupole) electric field. Potential benefits are a new means of high-resolution spectroscopy of such diverse systems as metastable (n=2) hydrogen and positronium atoms, Rydberg atoms, polar molecules, development of frequency reference devices, etc. The initial effort will be to detect trapped sodium Rydberg atoms to demonstrate the correctness of the basic principles.

The following four $25K Grants were also renewed during FY 80: C.W.F. Everett, Stanford University (Studies of the London Moment Leading to a Precise Determination of h/m_e); R.C. Ritter, University of Virginia (Precision Mechanical Rotations for Fundamental Measurements); W.C. Sauder, Virginia Military Institute (Precise Determination of the Gas Constant); and C.E. Weiman, University of Michigan (Measurement of Fundamental Constants Using Three-Level Resonances in Hydrogen). For FY 80, the NBS Precision Measurement Grants Committee consisted of Drs. Deslattes, Hall, Taylor and Wineland; the Outside Advisory Committee of Professors Geballe, Kleppner, Rich and Robinson.

Also during FY 80, visits were made to a number of Grant recipients to see and discuss their work first-hand. These included R.S. Van Dyck, University of Washington; W.M. Fairbank, Colorado State University; C.W.F. Everett, Stanford University; and R.C. Ritter, University of Virginia.

Finally, discussions were held with NSF to see if there were any possibility of that agency supporting the NBS Precision Measurement Grants program so that it might increase in size. A very positive response was received and a formal proposal requested. After talking with a number of past Grantees and members of the two Committees, the following course of action was decided upon: to request that the NBS Director increase the level of NBS support so that each new Grant starting in FY 81 would be in the amount of $30K to partially correct for inflation; and to request sufficient funds from NSF so that the number of new Grants each year could be doubled to four. (This implies 12 $30K Grants in effect by FY 83, compared with the present six $25K Grants.)

Plans

FY 81 plans naturally focus upon awarding at least two new $25K Grants and renewing the four existing $25K Grants by 30 September 1981. However, every effort will be made to increase the size of the program effective FY 81 as outlined above. To this end, a formal request will be sent to the NBS Director and a formal proposal to NSF. Also, visits to Grant recipients will continue if convenient (i.e., if they can be accomplished in conjunction with other travel); and a number of grantees will be encouraged to submit papers and to attend the Second International Conference on Precision Measurement and Fundamental Constants to be held at NBS in June 1981.

DISSEMINATION SERVICES: SUPPORT AND OPERATION INCLUDING MAP DEVELOPMENT

(N.B. Belecki, D.E. Bruch, C.R. Childers, L.R. Cooke, R.F. Dziuba, R.C. Fronk, C.R. Levy, T.P. Moore, D.D. Prather, T.E. Wells, E.S. Williams, A.R. Wise)

Objective

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 needed levels of accuracy. The legal units are provided to the user community by means of 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's and calibrations ultimately hinges 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 world -- and indirectly through them by industry for the quality control of 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 safety-barrier crash tests performed by automobile companies in compliance with National Highway Traffic Safety Administration (DOT) regulations. 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 high 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 resistance. Some measurements are also done on ac ratio standards of the highest accuracy.

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 converters (ac V&I), resistance measurements through 10^{11} ohms, and standard cell calibrations.

In FY 80, as a result of the recent ZBB decisions, three senior staff people retired without replacement, and a senior technician who also retired was replaced by a recruit from within NBS. In order that critical functions could go on uninterrupted, much of the remaining staff's time was consumed in training by those who left. In particular, Dziuba and Moore received crucial training from Wells and Cooke on the maintenance and dissemination of the ohm. Belecki and Cage received some instruction in the area of ac-dc current and voltage measurements and standards at the hands of Williams. Also, efforts to find a suitable replace for R. Kleimann, who left NBS last year, are continuing.

Accomplishments

In FY 80, 23 MAP transfers and approximately 1600 calibrations of basic standards were performed for about 170 companies and 11 government agencies for a total income of about $355K for the year. The majority of these companies are represented by the National Conference of Standards Laboratories (NCSL), which is a major source of information for planning purposes, as well as a mechanism (through its technical committees) for disseminating electrical metrology information. These services support basic research and development work throughout NBS as well.

The self-balancing potentiometer developed last year for the comparison of thermal voltage and current converters (TVC) was incorporated in the automated TVC system and support software produced to enable the system to make square-law tests and ac-dc difference determinations automatically for any single range of voltage but over a broad frequency range. The system is in the final stages of testing before its regular use in the calibration activity.

A new commercial instrument for the measurement of alternating voltages at audio frequencies at state-of-the-art accuracy levels (potentially better than ten ppm in the frequency range from 50 to 100 Hz) is being evaluated. This instrument is based on a Wilkins multi-junction thermo-element which may be suitable for primary standards applications in general, and may offer an opportunity to upgrade our measurement capability to support new solid-state converters being incorporated in the latest electronic instrumentation.

A set of commercial, high accuracy thermal converters was evaluated for the International Bureau of Weights and Measures (BIPM) to assist in the establishment of an ac voltage measurement and standards capability there. The evaluation identified frequency-response anomalies which were removed by the modification of the unit using a different type of resistor having little inductance.

In the area of MAP development, analysis of transport standard performance data was begun by C. Reeves and K. Kafadar of the Statistical Engineering Division. The purpose of this activity is to develop the statistical base to permit fully automatic data analysis and computerized decision-making in the production of volt MAP test reports. The present study will serve as a pilot to future similar studies in other measurement areas and will lead to better documentation of uncertainties and the data from which they are computed.

A number of new solid-state voltage reference devices were evaluated for stability in the laboratory. This was done as a part of an effort to develop a voltage MAP service to cover the commonly measured voltage range from 0 to 1000 volts dc. If they prove successful, these devices will be used as transportable ten-volt standards in conjunction with existing transportable ratio dividers to provide NBS with the capability of verifying another laboratory's measurement process over the above range at sub-ppm accuracies.

Two new regional MAP's were started: one in the Los Angeles area and the other in Northern California. The initial transfers of these groups were underway at the close of the fiscal year. An additional group was organized in the Oregon area. Nine new individual companies were also added, bringing the total number of organizations served in the voltage area to forty-four. In connection with this activity, twenty-plus companies received consulting help from NBS, generally in the areas of data analysis or reduction and low-level dc measurements.

Future Plans

Objectives for FY 81 include: a) the publication of two Technical Notes regarding voltage and resistance measurements, standards, and MAP's; b) the completion of automation of the ampere-turn balance for resistance measurements; c) the completion of a statistical data base on the performance of transportable voltage standards to enable automatic data checking and uncertainty computations for voltage MAP's; and d) the design and construction of a microprocessor-based crossbar switch controller to facilitate automation in the Volt Facility and the resistance laboratory. Items b) and d) above are contingent upon the addition to staff of an automation expert to replace R. Kleimann, who left NBS in FY 79.

Publications

V.E. Bower and R.S. Davis, The Electrochemical Equivalent of Pure Silver -- A Value of the Faraday, J. Res. NBS (U.S.) 85, No. 3, 175-191 (1980).

R.D. Cutkosky, An Automatic Resistance Thermometer Bridge, Conference on Precision Electromagnetic Measurements, 23-27 June 1980, Braunschweig, FRG, p. 193, IEEE Catalog Number 80CH1497-71M.

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James T. Hall, Louis B. Holdeman, and Robert J. Soulen, Jr., Microwave Enhancement of Superconductivity in Aluminum Tunnel Junctions, Phys. Rev. Lett. 45, No. 12, 1011 (1980).

Louis B. Holdeman, Magnetic Torque Calculations for the Gyroscope Relativity Experiment, NBS Interagency Communication (NASA Government Order H-27908B) (February 1980).

P.T. Olsen, W.D. Phillips, and E.R. Williams, A Proposed Coil System for the Improved Realization of the Absolute Ampere, J. Res. NBS (U.S.) 85, No. 4, 257-272 (1980).

P.T. Olsen, M.E. Cage, W.D. Phillips, and E.R. Williams, The Realization of the Ampere at NBS, Conference on Precision Electromagnetic Measurements, 23-27 June 1980, Braunschweig, FRG, p. 43, IEEE Catalog Number 80CH1497-71M.

R.M. Schoonover, R.S. Davis, and V.E. Bower, Mass Measurement at the National Bureau of Standards: A Revision, Science 207, pp. 1347-1348 (March 1980).

R.M. Schoonover, R.S. Davis, R.G. Driver, and V.E. Bower, A Practical Test of the Air Density Equation in Standards Laboratories at Differing Altitude, J. Res. NBS (U.S.) 85, No. 1, 27-38 (1980).

E. So and J.Q. Shields, Losses in Electrode Surface Films in Gas Dielectric Capacitors, IEEE Trans. Instrum. Meas. IM-28, No. 4, 279 (1980).

E.S. Williams, A TE Comparator for Automatic AC/DC Difference Measurements, Conference on Precision Electromagnetic Measurements, 23-27 June 1980, Braunschweig, FRG, p. 349, IEEE Catalog Number 80CH1497-71M.

Invited Talks

Robert D. Cutkosky, "An Automatic Resistance Thermometer Bridge," Division of Electrical Engineering, National Research Council, Canada, 14 May 1980.

Edwin R. Williams, "Testing Theories of Physics via Precision Magnetic Measurements: Determination of the Proton Gyromagnetic Ratio and the Absolute Ampere," MIT Francis Bitter National Magnet Laboratory, Cambridge, MA, 19 May 1980.

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 Subcommittee on Reference Voltage Devices.

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

N.B. Belecki, member, National Conference of Standards Laboratories, C002, 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, Calibration Task Group, Industry/Joint Services Automation Test Project.

N.B. Belecki, member, U.S. Advisory Committee, IEC SC/13B, International Electrotechnical Commission Committee on Indicating Instruments.

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 E7.07, Electromagnetic Methods; and E7.09, Materials Inspection and Testing Laboratories.

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

G.M. Free, Secretary, American Society for Nondestructive Testing, Research Division, Research Promotion Committee.

G.M. Free, member, American Society for Nondestructive Testing, Electronic Components 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, Co-editor, Preprints on Precision Measurement and Fundamental Constants, Office of Standard Reference Data.

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, Editor, Metrologia, in area of Fundamental Constants and Electrical Measurements.

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 Electric and Magnetic Quantities; and Co-chairman, U.S. National Working Group, Reporting Secretariat 13.1, International Compatibility of National Primary Standards Used for Instrument Verification.

B.N. Taylor, NBS Sponsor's Delegate, Executive Committee, Conference on Precision Electromagnetic Measurements.

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

B.N. Taylor, member, Editorial Review Committee, Transactions on Instrumentation and Measurement, Institute of Electrical and Electronics Engineers (IEEE).

T.E. Wells, member, RCL Measurement Subcommittee of the Power Instrumentation and Measurement Committee of the Power Engineering Society, Institute of Electrical and Electronics Engineers (IEEE).

E.R. Williams, member, ANSI MD105, American National Standards Institute Committee on Medical Electronics.

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 represented OMS during the year in four meetings to advance regional MAP activities in Portland, Pittsburgh, San Francisco, and upstate New York.

N.B. Belecki was one of a team of four NBS staff sent to consult to the ORTON Foundation, a non-profit manufacturer of pyrometric cone standards for the ceramics industry. ORTON requested assistance in re-establishing their temperature standards and upgrading their measurement instrumentation.

N.B. Belecki and R.F. Dziuba consulted with D. Ober and colleagues from the Center for Building Technology in support of their establishment of apparatus for the precise measurement of the thermal conductivity of building insulators.

N.B. Belecki participated in a panel workshop on Measurement Assurance Programs at the annual meeting of the National Conference of Standards Laboratories.

M.E. Cage collaborated with R.S. Davis of the Length and Mass Measurements and Standards Division (523) in obtaining analytical solutions to the equations of motion of a single-pan balance for the freely-swinging, the underdamped, the critically damped, and the electronically-servoed cases.

M.E. Cage, R.F. Dziuba, and B.F. Field are collaborating with P.J. Stiles of Brown University, P. Roitman of the NBS Electron Devices Division (721), and members of the Mask Facility Group at the Naval Research Laboratory, in the design and fabrication of mask sets for Hall devices.

M.E. Cage, R.F. Dziuba, and B.F. Field are collaborating with B.D. McCombe, R.J. Wagner, and R. Clement of the Naval Research Laboratory in an experimental investigation of quantized Hall resistance in MOSFET devices using the NRL High Magnetic Field Facility.

M.E. Cage, R.F. Dziuba, and B.F. Field are collaborating with S.M. Girvin of the Surface Science Division (541) and R.W. Rendell of the Radiation Physics Division (533) on the theoretical considerations in the quantized Hall resistance experiment.

G. Costabile collaborated with R.L. Kautz of the Electromagnetic Technology Division (724) on the application of arrays of hysteretic junctions to a zero-bias Josephson voltage standard.

R.F. Dziuba consulted with Hughes Aircraft Co. on problems involving qualification of high-power precision resistors for inertial guidance applications.

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

W.G. Eicke has consulted with personnel in the Office of Energy-Related Inventions in the area of electrochemical power.

W.G. Eicke is collaborating with E. Escalante of the Chemical Stability and Corrosion Division (561) on improvement of electrical measurements in the field of corrosion.

B.F. Field and L.B. Holdeman are collaborating with J. Leslie, C. Waters, and T.D. Epley of Superconducting Technology, Inc., on the development of a portable, reliable, and easy-to-use 1-ppm commercial Josephson-effect voltage standard.

G.M. Free is collaborating with L. Schwartzendruber of the Metal Science and Standards Division (564) on a program to correlate electrical conductivity (determined using eddy-current testing) with the tensile strength of aluminum plate.

L.B. Holdeman and J. Toots are collaborating with P.N. Peters of NASA's Marshall Space Flight Center in an investigation of microbridge-type Josephson junctions for voltage standard and radiation detection applications.

L.B. Holdeman and G. Costabile are collaborating with R.J. Soulen, Jr., and D. Van Vechten of the Temperature and Pressure Measurements and Standards Division (TPMSD, 522) in an investigation of low-T_c superconductors (Ir, $AuAl_2$, $AuIn_2$) and low-T_c superconducting devices.

L.B. Holdeman collaborated with R.J. Soulen, Jr., and J.T. Hall (TPMSD, 522) in an investigation of enhancement of the superconducting properties of thin aluminum films by microwave radiation.

L.B. Holdeman and T.J. Jach of the Surface Science Division (541) are collaborating on an investigation of electron beam assisted oxidation of metal surfaces and on an investigation of LEIT (light emission by inelastic tunneling) junctions.

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 H. Holt (Quantum Metrology Group) on problems related to dynamic Stark effects in multiphoton spectroscopy and long-time optical pumping in strong laser fields.

J.E. Sims is collaborating with U. Bertocci of the Chemical Stability and Corrosion Division (561) on development of Fourier Analysis Program to process electrochemical data in corrosion studies.

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 1981 for international adoption by CODATA in early 1982. This work is also part of a collaborative effort with Soviet scientists from VNIIM under the Joint NBS-Gosstandart collaboration in metrology.

B.N. Taylor is serving on the NML's Merit Pay Performance Review Board, and served on the NBS Director's Task Force on Calibration and Related Measurement Services.

B.N. Taylor was a member of the IEEE Field's Award Committee that selected the recipient of the 1981 Harry Diamond Award. He also served on the committee which selected the 1980 Helmholtz Prize recipient.

B.N. Taylor organized and chaired a symposium "Standards for Physical Measurement" at the April 1980 Washington Meeting of the American Physical Society. The symposium was sponsored by the APS Division on the Applications of Physics.

B.N. Taylor is Chairman of the Conference Committee which is organizing the Second International Conference on Precision Measurement and Fundamental Constants to be held at NBS/Gaithersbug, June 8-12, 1981.

B.N. Taylor serves as a member of the Editorial Review Board of the IEEE Transactions on Instrumentation and Measurement, as an Editor of Metrologia in the area of Electrical Measurements and Fundamental Constants, and as Editor with D.R. Lide of NBS' quarterly Preprints on Precision Measurement and Fundamental Constants.

B.N. Taylor is NBS representative to and member of the Executive Committee of the Conference on Precision Electromagnetic Measurements. He is also one of NBS' representatives to NSF's Interagency Atomic and Molecular Physics Group.

B.N. Taylor compiled the Table of Physical and Numerical Constants for the 1980 Review of Particle Properties compiled by the Particle Data Group.

J. Toots made numerous thin-film depositions as an informal service to various research groups within NBS; e.g. sputtered conductive coatings onto CeO_2 samples for a fuel cell study program (J.R. Bethin, C.K. Chang; 561); sputtered and evaporated refractory films onto single-crystal sapphire for applications in high-temperature expansion coefficient measurements (L. Guidner, R. Edsinger; 522); deposition of gold contacts onto carbon wafers for low-temperature thermometry (H. Marshak, R. Soulen, B. Dove, 522).

J. Toots is collaborating with D.W. Braudaway, Sandia, on the implementation of a Josephson voltage standard at Sandia by producing Josephson tunnel junctions for Sandia.

E.R. Williams, P.T. Olsen and W.D. Phillips are collaborating with K.A. Krasnov, VNIIM, USSR, on the theoretical investigation of various new techniques for realizing the ampere using superconductivity and/or cryogenics. This is part of a collaboration between NBS scientists and Soviet scientists from VNIIM under the joint NBS-Gosstandart collaboration in metrology.

General Interest Highlights

The following is a list of the Division's accomplishments reported during the past year in the general interest publications indicated.

1. Symposium on Eddy Current Characterization of Materials and Structures - G. Birnbaum and G. Free (NBS Monthly Highlights, October 1979).

2. Recipients Selected for Two New FY 80 Precision Measurement Grants - B.N. Taylor (NBS Monthly Highlights, October 1979).

3. Codata Task Group on Fundamental Constants Meets at NBS - B.N. Taylor (NBS Monthly Highlights, November 1979).

4. The Precisely Precessing Proton - M. Baum (NBS Dimensions, November 1979).

5. In The Pursuit of Precision, NBS Grants for Research on Fundamental Constants (NBS Dimensions, January/February 1980).

6. Eddy Current Imaging System - B.F. Field (NBS Dimensions, January/February 1980).

7. Fine Structure Constant Determined to an Accuracy of 1 in 10 to the 7th - P.T. Olsen and E.R. Williams (National Measurement Laboratory 1979 Technical Highlights, NBS-SP 572).

8. Standards for Physical Measurement Symposium Held - B.N. Taylor (NBS Monthly Highlights, June 1980).

9. Fundamental Constants Data Center - B.N. Taylor (NSRDS Reference data report, May/June 1980).

TEMPERATURE AND PRESSURE MEASUREMENTS AND STANDARDS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1980

1. Overview

During the past year, the Temperature Measurements and Standards Division was renamed the Temperature and Pressure Measurements and Standards Division, (TPMSD) reflecting the incorporation into the Division of the Pressure Group from the Thermophysics Division. This report will include the past year's activities of both groups.

The Temperature Group pursues two major objectives: the provision of calibration services, instruction, and consultation in precision thermometry; and research intended to help replace the International Practical Temperature Scale of 1968. The past year saw excellent progress in both areas.

The Pressure Group has similar objectives. It provides the US technical community with pressure calibration, instruction in precision pressure measurement and consultation on pressure measurement problems. Unlike the temperature counterpart, there is no international practical pressure scale. However, there have been international comparisons of high-quality manometers and piston gages.

Requests for precision temperature calibrations continued at a level similar to that of the previous year, some 1500 calibrations costing an aggregate of approximately $150,000. In response to these requests, the Division continued to provide a full-time calibration person in both the Platinum Resistance Thermometry and the Liquid-in-Glass laboratories and a half-time person in the Thermocouple Thermometer Calibration Laboratory. Progress on the development of a computer-based calibration apparatus continued to be satisfactory; this system is being assembled and tested as part of the Measurement Assurance Program in low-temperature thermometry.

The Precision Thermometry Seminars have been consolidated as a twice-yearly, one-week instructional session devoted to lectures and laboratory work in platinum resistance, thermocouple, liquid-in-glass, and thermistor thermometers. During the past year, the instruction has been integrated into a single course rather than three separate parts, and the attendance has been limited to 25 per session to avoid overcrowding.

Twelve reports on progress in fundamental thermometry experiments within the Division were submitted to the 13th meeting of the Consultative Committee for Thermometry, reflecting the impending replacement of the 1968 International Practical Temperature Scale. These can be grouped into work on thermodynamic measurements of temperature, development of new or improved temperature reference devices, and development of new or improved standard thermometers.

Work in thermometry using funds transferred from other government agencies continued to be done by the Division staff, although the proportion of such work necessarily was reduced by the need to contribute to NBS-wide special programs.

Increasingly, the TPMSD is asked to provide instruction to staff members from less-well developed countries and to provide facilities for colleagues of the Division who come to NBS from other national laboratories. Within the past few years, we have worked with personnel from Australia, Canada, Egypt, Korea, Italy, Brazil, Japan, West Germany, United Kingdom, Saudi Arabia, Mexico and others.

The past year's work for the Pressure Group included some 80 calibrations of piston gages, pressure transducers, and manometer systems, costing an aggregate $50,000, as well as the introduction of a service in ion gage calibrations; the presentation of two Precision Pressure Seminars to a total of 19 participants; intercomparisons of both pressure and vacuum standards with other national laboratory staffs; a modest amount of work for other government agencies; and research in both pressure and vacuum physics.

During the past year, a significant beginning was made in the study of time-dependent temperature and pressure measurements. This project grew out of a budget intiative presented in various forms over the past several years. Currently staffed by a former NBS Postdoctoral Fellow who is an expert in laser physics, this project has the potential for uniting the metrology of temperature and pressure in an experimental program leading to much-needed services in the time-dependence of temperature and pressure sensors.

The Division lost the services of five individuals during the past year--Dr. H.H.Plumb, an expert in thermodynamic thermometry, and Mr. J.L. Riddle, an expert in resistance thermometry, by retirements; and Dr. D.D. Thornton, Mr. J. Hines, and Ms. D.L. Foster through resignations.

II. Technical Activities

This Section is composed of reports of laboratory work organized by NBS Task designation. The discussion is based upon reports submitted by individual staff members. Each subsection will include the names of contributing staff, to enable the reader to communicate in more detail with the appropriate scientist.

A. Task 111.21--Dissemination of Temperature and Pressure Units

1. Platinum Resistance Thermometry (Dr. George T. Furukawa)

a. Standard Platinum Resistance Thermometer Calibration

During the period August 1, 1979, to August 1, 1980, the following calibrations were performed by Mr. W.R. Bigge (with assistance from Mr. J.L. Riddle) for a variety of industrial and governmental laboratories:

SP-250 Category	No.
7.3B long stem	39
7.3C long stem	40
7.3E	4

The fees for these calibrations amounted to about $60,000. In addition, eleven calibrations were performed on in-house thermometers.

A new bridge for the SPRT calibration laboratory was tested. A thermostated reference resistor for the bridge is partially assembled. A system for switching test SPRT's to the bridge has been wired. This assembly work is being carried out by me with the help of Mr. Juan M. Figeroa, Guest Worker from Mexico, since Mr. Bigge is completely involved with calibration.

During the coming year, we expect to continue assembly of the Guildline bridge system for long-stem SPRT calibrations. We expect also to begin combining the new computer-controlled measurement system (see Section B4) and the new self-balancing resistance bridge of Cutkosky (see Section B2) to renovate the capsule PRT calibration facility.

b. Measurement Assurance Program (MAP) in SPRT's

During FY 1980 SPRT MAP measurements for a pharmaceutical manufacturing company were analyzed and reported; this company must control biological processing temperatures. Their standards laboratory calibrates industrial type PRT's as secondary standards in the range 0 to 122 °C at the level of ± 0.01 °C accuracy to check the working thermometers. Considerable consulting time was spent with them and their computation scheme and calibration table output were reviewed before the MAP thermometers were shipped to them. The MAP thermometers are now in the laboratory of an aircraft engine manufacturer, and a primary Department of Defense laboratory is next on the list.

c. American Society for Testing and Materials (ASTM) Work and Industrial PRT Studies

I have been the secretary of the Resistance Thermometry Subcommittee E-20.03 of the ASTM for the past five years. To work in other areas of the ASTM Thermometry Committee, I have asked to be replaced, effective at the next meeting in November 1980. In the meantime I agreed to be the secretary of the Newer Thermometers Subcommittee E-20.06 (B.W. Mangum, Chairman), where the amount of time required as secretary will be less than that involved as E-20.03 secretary. I will have more time for writing and reviewing the hardware aspects of the industrial PRT standards now being prepared. In April 1980, I arranged for the task chairmen preparing different parts of the standard to work at the NBS for two days in preparation for the June 1980 meeting in Chicago.

I have agreed to assist in the preparation of an ASTM resistance thermometry book similar in scope to the thermocouple book STP 470A.

I will continue to be involved in the Temperature Fundamentals Subcommittee E-20.07 for which I will prepare the first draft of a metal fixed-point standard.

The design of the ASTM round-robin measurements for determining the measurement capabilities of industrial standards laboratories was changed. The initial plan was to circulate stainless-steel-sheathed SPRT's. When the SPRT's were checked for calibration after measurements by four laboratories, the calibration had changed beyond the expected measurement uncertainties of the laboratories. Although it will mean more NBS calibrations, the SPRT's will be shipped back and forth between the NBS and the participating laboratories so that any change in calibration will be detected before the thermometer goes to the next laboratory. The ASTM round-robin measurements are now in progress.

Twelve industrial PRT's from two manufacturers were tested for stability after heat treating them at 480 °C for four hours and then measuring their resistances at the TP of water, tin point, and zinc point. Three sets of measurements show changes in the thermometer calibration that range from 2 mK to over 0.02K, depending upon the thermometer and temperature. Measurements on more thermometers are needed before any conclusion can be drawn about which thermometer design yields the best stability.

A standard PRT encased in a stainless-steel sheath apparently appears rugged to industrial thermometrists; however, the thermometer is actually as shock sensitive to calibration changes as the glass-sheathed SPRT's. Since the sheath does not break, calibration changes that are much larger than those we have normally seen with glass SPRT's have been experienced in the ASTM round-robin work. Since the glass-sheathed SPRT's are very expensive, we may use selected industrial type PRT elements assembled in glass sheaths for the ASTM round-robin work. A few elements have been purchased for testing. It is hoped that glass-sheathed thermometers will be handled more carefully. The data that we obtain will fill in some of the gaps in our knowledge of industrial PRT characteristics.

2. Thermocouple Thermometry (Mr. George W. Burns)

a. Thermocouple Thermometer Calibrations

During FY 80, some 270 thermocouple thermometers of all types were calibrated, at a total cost of $40,000, by M.G. Scroger.

Computer programs were developed that enable us to give calibration tables at 1 degree (C or F; IPTS-48 or IPTS-68) intervals for both Type R and Type B thermocouples. This service is now available to our calibration customers with no increase in our calibration fees.

b. Consultations on Thermocouple Thermometry

Many telephone calls were received last year from scientists and engineers desiring advice and information on thermocouple thermometry. No effort was made to catalog or characterize these requests or others received by mail or personal visit, since both the requests and the effort needed to respond to them varied greatly. On the average, however, one or two such requests were received each working day.

As part of our consultation activity, I made a trip to the Orton Foundation in Columbus, Ohio as part of an NBS team to assist the Orton personnel with a planned recalibration of the pyrometric cones which they manufacture. A report giving comments and recommendations concerning the production and calibration of pyrometric cones was perpared for Orton and it may be consulted if more details are needed.

c. ASTM Activity

Several drafts of a test method for measuring the insulation resistance of compacted insulated thermocouple materials were prepared and issued for Subcommittee 04 and E-20 letter ballots. A final draft of a revision to ASTM Test Method E-220 on the comparison calibration of thermocouple was completed and issued for Society ballot.

Chapters 8 and 11 of ASTM Manual STP 470A were revised. The revised manuscript was recently sent to the printer. The new publication will be STP 470B and it should be available earlier next year.

3. Liquid-in-glass Thermometry (J.A. Wise)

Well over 1,000 calibrations of liquid-in-glass and other lower-accuracy laboratory thermometers were performed during the past year. The resulting fees totaled some $70,000.

Plans were initiated to upgrade certain of the calibration baths in order to accommodate the increasing numbers of high-precision thermistors and other types of secondary thermometers. The stability limit of the present baths, several millidegrees, is not suitable for the more precise of these thermometers.

4. Precision Thermometry Seminars (Calibration Staff)

During FY 80, two seminars were held. They were attended by a total of 47 scientists and engineers, representing three foreign countries, six US utilities, four US government agencies, one university, and 23 US corporations. The seminars have been consolidated into a single entity this year, comprising four and one-half days of instruction in precision thermometry with platinum resistance, thermocouple, liquid-in-glass, and thermistor thermometers, followed by a discussion of new developments in thermometry. The participants in the seminars are encouraged to bring forward particular problems in temperature measurement within their own organization.

5. Piston Gages (Mr. J.C. Houck and Mr. Bernard E. Welch)

a. Piston Gage Calibrations

Routine calibration of piston gages within the range, 1.4 kPa to 420 MPa are provided by Walter Markus and Greg Driver. Mr. Markus is responsible for instruments operated on oil and Mr. Driver is concerned with those instruments that are used with gas. Mr. Welch contributes by scheduling work, analyzing data, checking reports, handling test folders, trouble shooting and assisting in unusual or complicated tests. Instruments tested during the past year include some 75 piston gages, manometers, barometers, dial gages, capacitance gages and various types of transducers. The estimated income for the group last year was $50,000.

b. Piston Gage--Mercury Manometer Comparison

Work was begun with Dr. L.A. Guildner on the intercomparison of the NBS gas thermometer mercury manometer with three (3) commercial piston gages (transfer standards). This work should significantly reduce the systematic uncertainties associated with the air dead weight piston gages used as NBS standards. Presently, basic concepts are being discussed and equipment ordered.

c. Air Piston Gage Quartz Standard

We have begun to set up a quartz check standard on a test bench that is used for calibrating air piston gages. The instrument will be used at 100 kPa to monitor the pressure system that provides routine calibrations within the range 1.4 kPa to 4.2 MPa. This will also allow us to observe the performance of this type of transducer over an extended period of time. Mr. Fred Long has been working on the electronics, after which the device will be installed.

d. Pressure Measurement Seminars and Consultations

Two pressure seminars were held this year, one in the spring and one in the fall. The two day sessions were limited to a maximum of eight students; but in the future, this restriction will be lifted. The course of instruction covers NBS primary standards (calibration and use) as well as secondary gages used in the field.

We consulted with industrial and other government scientists and engineers concerning the choice and calibration of equipment for pressure measurements from 1.4 kPa to 1400 MPa. This information was presented by phone, letter, or directly to visitors to our laboratory at NBS.

e. Laboratoire National d' Essais (LNE, Paris) Pressure Gage Intercomparison

An intercomparison was made with the NBS primary gas standard piston gage (PG4) over the range 0.4 to 3.9 megapascals (58 to 565 psi) and LNE's oil operated simple piston and cylinder transfer piston gage through an oil-gas capacitance-detected interface. The agreement was within 10 ppm for the area calculation of the LNE gage by NBS and their value for the area. A report is being prepared for publication.

f. PG4 replacement and calibration.

New piston and cylinders have been obtained and fall rates measured. "D" measurements, (which are the coefficients for the change in effective area as a function of jacket pressure), will be made by the Korean Guest Worker Seung Woong Han. This gage will replace the gage used in the LNE comparison.

g. 4K psi piston gage facility

A new facility is planned incorporating two similar controlled clearance piston gages for operation on both oil and gas. It will be James Houck's major activity for the next 2 or 3 years.

6. Low Pressure Transducers (Mr. Richard W. Hyland)

a. Calibrations of Low-pressure Transducers.

During the year to date, a total of 7 capacitance diaphragm transducers have been calibrated (as well as three of our own), some of them several times. In addition, we calibrated two low-range, ball-type, dead-weight testers. The income from the calibrations has been about $6200. At least 3 more calibrations are expected by the end of the year, with about $3600 of associated income.

The ball gages will be mentioned separately, because of the time and results. The gages were both the same models, and were calibrated against the long-column manometer. Three calibrations were made on the first and, on the second, differing numbers of points were taken on 12 different days, using both nitrogen and argon. Additional time was spent comparing piston gages (PG 14 and 15) against the manometer and against the ball gage. The amount of time spent was large because systematic differences between the manometer and ball gages were far outside of their combined error bands, and, at the time, we were in the process of assuring ourselves that the long-column manometer and the associated data reduction procedures, put into operation only 3 months before, were operating properly. After many discussions among ourselves and with the manufacturer of the ball gage, we decided that our calibrations were correct. These results were substantiated by the gage's owner, who checked one of the ball gages against a tilting air gage. As a result, the manufacturers revised their own calibration techniques (in essense by adding another calibration point which they had previously deemed unnecessary) to correct the situation. We expect to calibrate one of the updated versions this fiscal year.

During the course of the ball gage studies, the long column manometer was compared from 77 to 900 Torr using our own PG 14 and PG 15, as well as an Australian standard piston gage. The overall uncertainty of the manometer in this range is 13 ppm systematic and 50 ppm random, relative to the dead-weight testers. This is somewhat better than our claims of $1/10^4$. In addition, a series of long-term zero drift tests were taken, indicating a stability of 10^{-4} Torr over a period of days. One of the outstanding uncertainties still associated with the manometer is that of the speed of sound in mercury.

b. Characterization of Capacitance Diaphragm Gages

During the first quarter of the year a series of tests were conducted by Anita Calcatelli, a guest worker from the Istituto di Metrologia "G Colonnetti" (IMGC) in Italy, on 1 and 10 Torr capacitance diaphragm transducers. These tests were intended to give information on zero drifts and the effects of cycling, both with heaters on and off, and to indicate as well the effects of reference pressure. The data were analyzed in a manner now considered somewhat unsatisfactory. Firm quantitative conclusions have not yet been reached, except on the zero drift data. The latter data were the subject of a report by Calcatelli to NBS. The zero drift studies do indicate that, for work which requires the maximum sensitivity of the transducers, a warm-up time on the order of days might be required.

The remaining data indicate that changes in either the pressure or temperature environment--that is, pressurizing the transducers beyond their range, turning off the heaters for several hours, or even raising differential transducers from vacuum to atmospheric pressure with zero applied differential pressure--can shift the calibration curves of the transducers significantly.

Under stimulus of this work, six of the transducers which have been received for calibration have in fact been subjected to from 2 to 4 complete calibrations over periods ranging from one day to several weeks, with changes in ambient conditions between calibrations. These tests were under better control than those of Calcatelli, but confirm the general conclusions of her work. The quantitative results are that, while for any given calibration (which takes 2-4 hours) the transducers are capable of performing in a manner which far exceeds specifications. However, the variation encountered from one calibration to another if ambient conditions are changed decreases the overall accuracy by about an order of magnitude. As a result, beginning this month, the uncertainty statements associated with our calibrations will now quote 10 standard deviations (instead of 3) plus 1/10,000 of the reading.

c. Capacitance Diaphragm Gage Round Robins

Both the American Vacuum Society and the international laboratory round robin intercomparisons of capacitance diaphragm manometers are getting under way. Two 1- Torr transducers and two 10-Torr transducers, one of each range from two manufacturers, have been assembled into units for ease of calibration. The packages still lack an ion pump which will permit evacuation of the reference side to a level where the calibrations are effectively absolute calibrations, but they are useable and we will begin our calibrations this month.

The international comparisons will be made with the standards laboratories in England, France, Australia, and Austria, as well as at NBS. These same units will be used for the AVS series, with Boeing, Rockwell International, Sandia, and MKS Instruments being likely participants.

d. Meetings and Consultations.

The American Vacuum Society meeting was held in New York in late October. Meetings of the Standards Committee and Gaging Subcommittee provided common grounds for discussions of the legal status of standards writing groups, as well as of gaging problems. Further work was done on a procedural standard for the calibration of vacuum gages, which has been pending for several years.

In May, the American Society of Metals held a meeting in Detroit. The NBS was asked to comment on a proposed metals industry standard for calibrating gages used in vacuum heat treatment furnaces.

Also in May, a meeting was held at NBS concerning vacuum standards for the Magnetic Fusion Energy program. At this meeting, a presentation was made concerning properties of capacitance diaphragm transducers. The material presented was based upon the zero-drift work of Calcatelli and results obtained from various calibrations.

We have provided consultations during the past year to many persons seeking advice on methods, instrumentation, and available standards.

e. Pressure Transducer Characterization (S.D. Wood)

This year marked the end of the pressure transducer characterization service which we have run for four cycles. The characterization service consisted of 35 tests designed to characterize the transducers with respect to 18 parameters. Among these were zero stability, full scale stability, temperature sensitivity, and voltage dependence. Final reports usually run 150 to 200 pages and some attempt was made to accommodate special requests from contractors. In FY 79, some 25 units were examined; this year, 15 units were characterized, of which nine were from outside laboratories.

We now have accumulated a wealth of data about many types of pressure transducers. It can be used generically to correlate performance and sensor type. However, this will take both time and considerable computer coding.

B. Task 111.22-- Development of New Temperature and Pressure Standards

1. High Temperature Thermocouple Thermometers (G.W. Burns)

Some tests were conducted to study the long-term, high temperature performance of Nicrosil/Nisil and Type K thermocouples in air. Two tests were run with bare, 1.6 mm diameter thermoelements, and one test was run with 3.2 and 6.4 mm o.d. stainless steel sheathed, compacted MgO insulated thermoelements. The primary purpose of the bare thermoelement tests was to establish what effect Mg additions to the alloys have on their performance.

The first bare thermoelement test, which included four Nicrosil, four Nisil, two KP, and two KN thermoelements, whose compositions had been carefully characterized, was run for 3066 hours at 1100 °C. The KP and KN thermoelements exhibited substantial emf drift and the KN thermoelements failed as a result of oxidation after 1000 to 1800 hours of testing. None of the Nisil or Nicrosil thermoelements failed during the test. The magnitude of the drift in Nisil thermoelements was found to be inversely related to the Mg content. An alloy with 0.08 percent Mg exhibited a change of 350 μV, while an alloy with 0.21 percent Mg changed by less than 20 μV. The thermocouple formed from the most stable pair of Nicrosil and Nisil thermoelements drifted by about 4 °C during the 3066 hour test.

Post-test examinations of samples from the above test were carried out at NBS and at the Materials Research Laboratory, Department of Defense, Australia (MRL). Metallographic examinations were performed at NBS and ion microprobe analyses were conducted at MRL to determine the solute depletion in the alloys.

A second test using thermoelements from the same batches as those used in the first test was run at 1200 °C for 1270 hours. In this test the KP and KN thermoelements failed after only about 400 hours of testing, while all of the Nicrosil and Nisil thermoelements survived the 1270 hours of testing. Samples from this test will also be subjected to post-test studies at NBS and MRL. Results of these two tests will be the subject of a joint paper by NBS and MRL authors for the 6th Temperature Symposium in 1982.

A test with four stainless steel sheathed Type K and four stainless steel sheathed Nicrosil/Nisil thermocouples was also run for 2211 hours at 1000 °C. The drift in the Nicrosil/Nisil thermocouples ranged from 1.5 to 4 °C, with the drift of 6.4 mm o.d. thermocouples being about one-half that of the 3.2 mm o.d. thermocouples. The Type K thermocouples exhibited about the same drift as the Nicrosil/Nisil thermocouples, but they experienced various degrees of instability upon thermal cycling between 1000 °C and room temperature.

It is expected that additional tests and studies of Nicrosil and Nisil thermocouple alloys will be carried out during the coming year under a collaborative agreement between the NBS and the NRL and MNL in Australia. The scope of this collaborative work should be formalized before the end of this year.

2. High Temperature Fixed Points, Thermometers and Resistance Bridges (J.P. Evans, L.A. Guildner, and R.D. Cutkosky)

a. High Temperature Fixed Points. (J.P.Evans)

One of the heat pipe furnaces to be used with the high-temperature resistance thermometer testing was tested for temperature uniformity at 660 °C, 960 °C, and 1065 °C over the length of the heat pipe before a freezing point cell and its accompanying radiation shields had been installed. It was found that in the region normally occupied by the freezing point cell crucible the temperature was uniform within 0.3 °C at 960 and 1065 °C, and within 0.6 °C at 660 °C. The furnace should therefore provide an adequately uniform environment for the freezing metal when the cell and radiation shields are in place. Furnace control proved to be suitably responsive.

A silver point cell was installed in another of the heat pipe furnaces. The high-purity silver sample used in the cell was obtained several years ago from the NBS Office of Standard Reference Materials (OSRM). The cell has not yet been fully tested because of thermometry problems (see below). The gold point furnace has been assembled and tested and the gold point cell parts have been prepared, but the cell itself has not yet been assembled.

b. High Temperature Resistance Thermometers. (J.P.Evans)

Development of SPRT's capable of use at temperatures as high as 1100 °C is continuing. Many thermometers have been built and tested; most of the testing has been done in the NBS Gas Thermometry laboratory.

Resistance thermometer measurements made at high temperatures during the year, the first attempted in our own laboratory, revealed several important problems having to do primarily with the thermometer lead structure.

During the furnace probe at 1065 °C two of the thermometers suffered breakage of one or more of the leads. This experience, coupled with earlier experience in the Gas Thermometry laboratory in which thermometer leads shorted out upon cycling from high temperatures, indicated that the original lead design, consisting of short insulating tubes and disks, did not adequately accommodate thermal expansion of the leads. A new lead configuration was designed to accommodate all thermal expansion at the top of the thermometer by means of expansion coils located in an enlarged glass header. The platinum leads were placed in long, continuous silica glass lead tubes extending from the resistor to the header. The lead tubes were flared at the top end and attached to the silica glass sheath at that point. The platinum leads were anchored to the lead tubes at the bottom end before connection to the resistor. This arrangement allows most of the thermal expansion to be taken up by the coils in the header, and it has the added advantage of keeping the resistor position fixed relative to the silica glass sheath. To date, nine thermometers have been constructed with this lead configuration, and no lead expansion problems have been encountered. Extensive cycling tests are now under way on one of the thermometers to provide additional experience with the design at high temperatures.

The first two thermometers made with the new lead design were found to behave anomalously at the silver point because of electrical leakage between the leads and from the leads to ground. In these two thermometers the lead tubes were held in place close to the silica glass sheath by quartz wool packing. At the suggestion of R. Cutkosky, the next two thermometers were constructed with an electrical guard incorporated in the leads. The silica glass lead tubes were held in place by rings made of platinum wire spaced at 10 cm intervals along the leads. The rings, connected together by a platinum wire thus formed an electrical guard when connected to an appropriate potential within the resistance bridge, eliminating the effect of leakage between individual leads and between the leads and ground. It was found that the guard increased the measured resistance by as much as the equivalent of 50 mk at the silver point, and by even more at higher temperatures. The effect of the guard was barely detectable at the aluminum point and it was undetectable at lower temperatures.

The next five thermometers (8001-8005) were made with the guarded lead design, using a 20-cm guard ring spacing, and with resistors wound on a new coil winder using annealed wire. One of the thermometers (8005) had a 39 cm segment of Pt-10 percent Rh wire in one of the leads to serve as a differential thermocouple. Initial values of the alpha coefficient exceeded 0.003926 for all thermometers except 8005; its alpha coefficient was 0.003920. Three of the thermometers (8001-8003) were heated for 336 h at 1090 °C, after which the alpha coefficients were found to have decreased to less than 0.003919. Work is now in progress to determine and eliminate the source of this alpha decrease.

c. Automatic Measurements. (J.P. Evans)

The readout switches of all manually balanced instruments in the HTRT laboratory have been connected to a computer through a special interface so that dial settings can now be read into the computer automatically. The computer has also been equipped with a digital clock. A new automatic bridge (see Section B 2d) has been used extensively in routine measurements and has proven to be very advantageous. When values of resistance determined with the automatic bridge are normalized with respect to the laboratory standard 10 ohm resistor, no significant difference is found between them and values obtained with the 400 Hz bridge. A computer program has been written to record automatically all the measurements associated with the calibration of thermometers at fixed points.

Most of the coming year will be devoted to the construction of thermometers, and to assisting guest workers from Germany, Canada, Italy, and Australia in building thermometers for their own laboratories. It is expected that this effort will make the most effective and timely contribution to the information required by the CCT as a basis for revising the 1968 IPTS.

d. Resistance Bridges for Thermometers (R.D. Cutkosky)

A micro processor-based, 32 ohm, automatic-balancing resistance thermometer bridge was completed this year and a technical paper was submitted to the 1980 Conference on Precision Electromagnetic Measurements and will be published in the IEEE Transactions on Instrumentation and Measurement. Five copies of this bridge, built with the assistance of R.S. Kaeser and two NBS summer employees, L. Younkins and T. Fan, are nearing completion. Plans for this bridge have been sent to seven or eight people who have asked for them.

Design work has been completed for modifying the above bridges for operation up to 100 ohms. One or more of the new bridges will be so modified after enough of them have been completed and checked out so that I can make use of the prototype. A new microprocessor development system will be used for this work. Formerly, the microprocessor program development was a slow and cumbersome prodecure involving the use of a minicomputer. It will now be possible to develop the program much more quickly. A fair bit of experience has been obtained on the new system but it has not yet been used for program composition.

A draft of a paper has been prepared which addresses the question of guards for resistance thermometers. Comments and suggestions from colleagues are being sought.

3. Temperature Reference Points. (G.T. Furukawa, R.J. Soulen, Jr., B.W. Mangum)

a. Transportable Fixed Points (G.T. Furukawa)

The platinum resistance thermometry program includes two types of transportable fixed temperature points "sealed devices" and "open devices." Each has advantages and disadvantages. The sealed devices have the advantage of a smaller chance of contamination but over a long period the internal gas composition and pressure may change through release of absorbed gases, gas permeation, or chemical reaction. Although the open devices have a greater chance of contamination, the gas composition over the fixed-point substance can be easily monitored and controlled. Examples of sealed devices are the argon and mercury triple-point cells; open devices are tin-and zinc-point cells. Both types of device require temperature controlled environments (furnace, cryostat, or bath) before they can be used. Smaller samples require more precise temperature control relative to the "fixed temperature point." Larger samples, such as those used in tin or zinc cells, yield "freezing temperatures" that are reproducible to better than ± 0.1 mK even when the furnace is five degrees or more below the freezing point. Smaller samples require greater precaution against chemical contamination.

The purpose of the "temperature controlled bath" is to regulate the heat exchange between the fixed-point device and the bath so that the temperature gradient within the device will be minimized and the thermometer will sense the phase equilibrium temperature. In routine thermometer calibration, to avoid the error of calibrating the thermometer at the bath temperature instead of at the fixed-point temperature, the bath should preferably not be controlled extremely precisely. Otherwise, a means for avoiding the error must be a part of the measurement routine. The routine use of a check thermometer helps avoid this error.

Instead of controlling the bath temperature close to the fixed-point temperature to reduce the heat transfer between the fixed-point device and the bath, the heat transfer can be reduced by insulation. This technique is being used with the mercury triple-point cell where a vacuum space plus radiation shields are used to reduce the heat transfer during freezing or melting.

In all of the above fixed-point devices the thermal diffusivity of the device, including the thermometer, is a major factor in the selection of the technique. A device, or a measurement system including the thermometer, of lower thermal diffusivity requires closer control of the environment temperature or smaller heat transfer and a relatively longer waiting time after a thermal disturbance.

In summary, we find that:

a) a cryostat with the environment temperature controlled very close to the fixed temperature point is used with small sealed samples such as argon, oxygen, and others. This applies also to the small gallium cell developed by B.W. Mangum.

b.) the furnace with relatively coarser temperature control is used with larger samples, such as with tin, zinc, aluminum, and cadmium.

c.) the insulation technique is used with relatively large sample such as with mercury triple point when the bath temperature is necessarily very different from that of the fixed-point temperature.

i) Argon triple point

Three argon triple-point cells of different designs were assembled and temperature measurements were obtained employing six capsule SPRT'S and two cryostats. In addition to the above three cells, a fourth cell from Italy was also measured. The standard deviation of the measurements was found to be ± 0.03 mK. This result demonstrates that the argon triple point can be realized with high reproducibility, and furthermore that the calibrations are stable.

The comparison of the results of the IMGC cell with those of our cells showed that the argon in the IMGC cell is less pure than that in our cells. The argon used in our cells is nominally 99.9999 percent pure. Because of the greater slope of the melting curve that is observed with less pure samples, it is possible to obtain relatively higher values for the extrapolated "100-percent melted" temperature with less pure samples even though impurities usually depress the melting point.

One of our argon triple point cells was submitted for the Comite' Consultatif de Thermometrie program on the International Comparison of Fixed Points by Means of Sealed Cells. To date, The International Bureau of Weights and Measures (BIPM), National Institute for Metrology (INM), and Canadian National Research Council (NRC) have submitted results on the NBS-Ar cell. The measurements show that argon triple point cells of different national laboratories agree within ± 0.1 to ± 0.2 mK.

Many small refinements, particularly with respect to shape and size to reduce the cost of machine shop work, can be made in our argon triple point cell. However, in order to work with sealed cells of other substances, I plan to prepare the data obtained thus far on argon for publication. Any new thoughts on the design will be incorporated in the cells for other substances.

ii) Oxygen triple point

The oxygen triple point (54.361 K) is one of the defining fixed points of the IPTS-68. A miniature pressure cell was recently filled with a commercially available sample of 99.999+ percent purity. The cell is now being prepared for measurements. In order to obtain purer oxygen, we will prepare some oxygen by thermal decomposition of potassium permanganate. We plan to obtain some preliminary measurements on the commercial sample soon.

iii) Krypton and Xenon triple points

We are fortunate in the cases of neon and argon that their natural compositions are concentrated mostly in one isotope, i.e., ^{20}Ne at 90.9 percent and ^{40}Ar at 99.6 percent. Consequently, their melting points and triple points are relatively flat, that of argon being flatter than that of neon. The triple points of krypton and xenon have been reported to be 115.8 K and 161.4 K, respectively. These temperatures will be useful in improving platinum resistance thermometry between 90 and 273 K. Unfortunately, in the cases of krypton and xenon their compositions are distributed among several isotopes, i.e., in the case of Krypton: ^{82}Kr, ^{83}Kr, ^{84}Kr, and ^{86}Kr. are 11.56, 11.55, 56.90, and 17.37 percent, respectively; in the case of Xenon: ^{129}Xe, ^{131}Xe, ^{132}Xe, ^{134}Xe, and ^{136}Xe are 26.44, 21.18, 26.80, 10.44, and 8.87 percent, respectively. Their melting curves are therefore expected to be less flat, unless their composition yields either a congruent or eutectic system of many components. Isotopic separation at these higher mass levels are expensive, e.g., while 99.95 percent ^{20}Ne is \$54 a unit, 99 percent ^{86}Kr is \$700 a unit and 99 percent ^{136}Xe is \$35,000 a unit½

In terms of the ideal solution theory, the effect of the impurity on the equilibrium temperature of a liquid-solid phase system is given by $T_o-T_e = N_2/\underline{A}$, where T_o is the equilibrium temperature with no impurity in the liquid phase, T_e is the equilibrium temperature with mole fraction N_2 of impurity in the liquid phase, and $\underline{A} = \Delta H/RT_o^2$ where ΔH = molal heat of fusion and R = molal gas constant. The solid phase is a pure major component in the theory, but with isotopic mixtures the solid phase is most likely a solid solution of the isotopes. The theory is still useful where similar systems are being compared, i.e., where they all form solid solutions. At high purity, the liquidus and the solidus are very nearly linear. Using the distribution coefficient k, the equation for the solid solution case becomes $T_o - T_e = N_2 (1-k)/\underline{A}$. For a given N_2, the effect on the equilibrium temperature depends upon $\underline{A}$. For Ne, Ar, Kr, and Xe, $\underline{A}$ is 0.07, 0.02, 0.02, and 0.01, respectively. On this basis, Kr should yield flatter melting curves than Xe. This is corroborated by some published data.

Flatness of melting curves or freezing curves is highly desirable, particularly when the measurement technique does not readily permit accurate definition of the equilibrium condition. However, the calorimetric technique is able to define the temperature when the solid phase is vanishingly small. Hence, as long as the equilibrium temperature corresponding to the definable phase state is highly reproducible, that temperature will be a good thermometric fixed point. The question then is how reproducible is the temperature at 100 percent melted krypton and xenon of natural composition.

To test these questions, a sample of 99.995 percent krypton has been obtained for making triple point measurements in a sealed cell. When funds permit, a sample of xenon will also be obtained.

b. Cryogenic Temperature Reference Points (R.J. Soulen)

Interest in the SRM 768 superconductive fixed points has been encouraging: 31 units have been sold since 1978, with strong indications from many attendees of the 1980 Cornell He^3 Conference that more orders are likely. Preparation and calibration of both SRM 767a and 768 are continuing.

An interesting and controversial aspect of the low-temperature reference point work right now centers on a W sample calibrated at NBS (T_c = 15.45 ±.1 mK) and sent to Helsinki where they assigned (by extrapolation from a He^3 fixed point at 1.04 mK) a value of 16.9 ± 0.1 mK. There are ± 5 percent differences in the temperatures assigned the fixed points of He^3 by various laboratories, and the temperature extrapolation error can explain the discrepancy. I have been asked to spend a month in Helsinki to assist them in resolving this discrepancy.

c. Gallium Temperature Reference Point (B.W. Mangum)

Seven steel cells were filled with Ga samples, six from one source (each of a different lot) and one from another. The cells were pumped and leak tested. Checks were made for outgassing of the teflon holder and of the Ga in the cells.

It was necessary to construct a lid for a temperature-controlled bath for testing and storage of the 10 Ga triple point cells after their preparation so that intercomparisons could be made efficiently. It was found that electrical noise from the heater coil of the bath was too large, however, to permit testing with SPRTs directly in the bath, although zero-volt switching SCRs are used in the controller. The pick-up from the field produced by the heater just produced too much interference on the SPRTs.

After checking the SPRTs for "wetness," it was determined that three of the five were "wet." Furthermore, it was determined that two had leaks which must have developed when they were rewired after the previous drying. Those two had not been used since. They were repaired, leaks eliminated and then dried under vacuum at 225 °C. The three dried SPRTs plus one other were then recalibrated without the usual annealing.

The correct procedure was developed for attaining melting curves of the Ga samples in the seven sealed steel cells. Melting curves give an indication of the purity of samples. Consequently, melting curves were obtained for each of the seven samples to check for reproducibility of the melt following the standard preparation of the Ga mantles, to check for effects of rapid freezes of the mantles, and to check the behavior of the melting after the standard triple point had been prepared.

Immersion characteristics of the SPRTs in the steel cells containing the Ga samples at the triple point were determined and hydrostatic head effects were measured.

Direct comparisons of Ga samples by a.c. techniques using the 400 Hz Cutkosky bridge were attempted but found to produce results different from those obtained using d.c. techniques (Guildline bridge). This is unfortunate since a.c. techniques are much easier to use, are much less sensitive to vibrations, and in our own case have ten times better resolution than the d.c. bridge. Intercomparisons of the different Ga samples are currently being made using the Guildline bridge. These are being made for different mantles of each sample.

4. Low Temperature Scale (EPT-76) Realization (E.R. Pfeiffer)

In 1978, a new international temperature scale, the 1976 Provisional 0.5 K to 30 K Temperature Scale (EPT-76), was promulgated. This scale involves a wide variety of measurements and thermometers, so that NBS has undertaken the task of correlating and collecting information and apparatus for the new scale in a single laboratory.

Preliminary runs prior to FY 80 revealed serious problems with the performance of the EPT-76 cryostat. During the first quarter of FY 80 improvements were made to the radiation shielding of the cryostat, and an extensive experimental run was performed during which time intercomparison data were obtained on ten germanium resistance thermometers (GRT), 2 platinum resistance thermometers (PRT), one rhodium-iron resistance thermometer (RIRT), one platinum-cobalt resistance thermometer and 2 SRM 767 superconducting fixed point devices. During the run, 7 additional "housekeeping" thermometers, at various locations in the cryostat, were monitored to observe the cryostat performance. The cryostat was found to operate successfully over the EPT-76 range of 0.5 K to 30 K, and actually reached temperatures as low as 0.33 K. Further improvements to the cryostat are expected to be only minor ones, and are contemplated mainly to make its operation more economical.

An analysis of the above described intercomparison data, begun during the second quarter of FY 80, revealed that some serious problems still existed in the hardware and software of the data acquisition system and in the design of the experiment. Our (E.R. Pfeiffer and R.S. Kaeser) efforts during much of FY 80 were directed at identifying and correcting these problems:

i) A digital voltmeter with greater resolution than earlier types was purchased and installed. This voltmeter was expected to give an order of magnitude greater precision in the measurement of low resistances, as encountered, for example, in PRT and RIRT. The installation of the new voltmeter in the automated data acquisition system required substantial familiarization time and extensive revision of the laboratory computer programs. In several respects, the new voltmeter proved inferior to the original one; the latter therefore has been re-installed in the measurement system. It may be possible to adapt the new resistance bridge built by R. Cutkosky (see Section B.2) for these measurements.

ii) A temperature-regulated oil bath was built to contain the standard resistors used during the resistance measurements, and efforts also were made to obtain better temperature control of the laboratory environment. Some time was spent developing a better measurement routine for the in-situ calibration of the Julie "reference" resistors used in the thermometer measuring circuit. The results (obtained using the original voltmeter) indicate that d.c. resistance measurements can be made with an absolute error of about 10 ppm plus 3 standard deviations of the measurement imprecision. The in-situ calibration routine that was eventually developed produced agreement within 5 ppm for 2 Julie resistors also calibrated by the NBS Electricity Division.

Additional efforts during the year included the loan of two calibrated GRT from the above intercomparison experiment to a typical (NBS) user. Over the temperature range of interest, 0.33 K to 0.67 K, the agreement of the two GRT was always within 0.7 mk--much better than the resolution required for the experiment (1 percent). In addition to these results, our participation in the experiment provided some insight into the problems of resistance thermometry measurement that may be encountered by a (typical) user. Recently, a third calibrated GRT was loaned to another user at NBS for use in a helium lambda-point determination. Over the range 0.90 K to 5.0 K the calibration data are smooth and reproducible to about ± 0.3 mK. Our goal is to improve the reproducibility to about 0.1 mK in subsequent runs.

Our plans for the closing months of FY 80 and into FY 81 include an adaption of the new Cutkosky a.c. resistance bridge to our measurement needs and a final test run of the EPT-76 cryostat to check out the hardware, software, and design of the experiment. Based on those measurement results, estimates will be made of the error and imprecision in our realization and dissemination of EPT-76. At that time, dissemination of the scale to outside users either through calibrations or a MAP, should commence.

5. Low Temperature Thermometers (C. T. Van Degrift)

a. Resonant-Circuit Gas Thermometer.

The low temperature gas thermometer and the pressure sensor of the supercooled water experiment are of the same design except for the power gain of the tunnel diode. The following test results are therefore mutually applicable.

We made long term drift tests of our new design which utilizes coin silver material and has a removable circuit insert and a cross bar coupling the diode to the diaphragm end of the resonator. These tests were made with zero pressure differential across the diaphragm and therefore determine the extent to which aging of the diode, bypass capacitor, or relief of internal stresses affect the frequency. Tests at temperatures up to 144 °C allowed us to measure the creep rate associated with annealing of internal stresses caused by our press-fit assembly of the sensors and allowed us to estimate an 0.001 ppm/day room temperature drift rate. Direct measurements for several weeks at room temperature showed a drift of less than 0.04 ppm/day even when the sensor was temperature cycled between -100 °C and room temperature. Preliminary tests of the creep under pressure were obscured by temperature instabilities, outgassing, and internal creep. We will be making pressure driven creep tests during the coming year from 0.7 K to 40 K and from -100 °C to +30 °C.

The low temperature gas thermometer has been vacuum sealed and thoroughly annealed at room temperature. We are now selecting a low power tunnel diode. When the thermometer is charged with 0.1 MPa helium gas at room temperature, it will have a temperature coefficient of 330 KHz/K. The frequency noise should be smaller than 3 Hz and hence the precision may be better than 10 uK. Direct testing, which will commence in September 1980, will reveal the magnitude of drifts and irreproducibilities. Four more thermometers of similar design are expected to be built during FY81.

b. Low Temperature Carbon Resistance Thermometers (R.J. Soulen)

Following suggestions from colleagues in West Germany we have studied the R(t) characteristics of four carbon resistors from 10 mK < T < 200 mK. The resistors follow a very simple law

$$\sigma = \sigma_0 + \sigma_1 \exp (at^{-1/4})$$

which we can fit and use for interpolation to within a few tenths of a mK. D. Van Vechten and I will continue to study their reproducibility in collaboration with H. Marshak.

6. Thermodynamic Temperatures.

a. Gas Thermometry (L.A. Guildner)

Only one set of measurements has been made with the newly-built high-temperature gas thermometer bulb during this fiscal year. There was an additional run made in September 1979. Both runs commenced in the region of the silver point, and also included 800 °C and 660 °C. These measurements were exploratory, for the purpose of determining apparatus settings and studying the behavior of the various parts. In these measurements, we found that the gas thermometer shows good long term stability, and is almost free of hydrogen. This latter has been a severe problem, of a nature that leads me to suppose that all other gas thermometry is very likely to have been subject to it. The gas thermometer already has survived a very long time at the silver point (∼ 2000 h) in addition to appreciable times at 800 °C and 660 °C.

With continued use, however, we experienced failure of some of the high temperature platinum resistance thermometers (See Section B2). In addition, the furnace essentially failed and had to be rebuilt. The trouble was shorting of the heaters by metal oxides that spalled off the furnace parts.

There were severe temperature gradients in the thermostat, but in retrospect that was to be expected in view of the poor condition of the heaters. More modest gradients have been a continuing problem.

We undertook to rebuild the furnace, with motivation to reduce the work, to protect the windings from shorting and to give better control over the temperature distribution. Special guard heaters and sensors were incorporated that should be useful in dealing with immersion (i.e., tempering) of the gas thermometers and of the PRT's.

We also have been assembling a new gas thermometer, with a change of design in the suspension to reduce asymmetric heat flows (and through total heat flow also). The present bulb is Bulb III, discussed in our last paper. It has mixed compositions (i.e., 80 percent Pt 20 percent on top, 88 percent Pt - 12 percent Ph on the sides and bottom) through a misunderstanding in procurement. Such a design is undesirable, although the thermal expansion of these two alloys is similar between 0° C and 460 °C (and the same at some point between 300 °C and 400 °C). Further, the present bulb has spent too long at high temperatures. We are concerned about contamination from the surrounding Inconel. There are other changes involved that should improve the overall result, or make it easier to obtain. R. Edsinger has worked on the thermal expansion apparatus, in particular correcting some problems with the thermocouple network, and installing some guard heaters to improve immersion. He must find the right combination of coatings for his interferometer plates, in order to measure the samples at 1100 °C. The present coatings melted in going to that temperature. Work is now directed at improvement of the controls, to get adequate stability and sensitivity. It is straightforward in the sense that we have solved these problems with the big thermostat already.

b. Gamma Ray Anisotropy Thermometry (H. Marshak)

The overall objective of this program is to develop a low temperature scale covering the range of ∿ 1mK to 1K, and as close to thermodynamic as possible, using γ-ray anisotropy thermometry. Only two γ-ray anisotropy thermometers are needed to cover this temperature range, namely single crystal ^{60}Co <u>Co</u> (that is, ^{60}Co nuclei included in a Co single crystal) and ^{166m}Ho <u>Ho</u> thermometers. This γ-ray anisotropy temperature scale will be compared to other primary temperature scales either directly, as R.J. Soulen and I are doing with the Johnson noise thermometer, or indirectly using superconductive fixed point devices and secondary thermometers. It will also be possible to put together γ-ray anisotropy SRM units.

i) ^{60}Co Co Single Crystal γ-Ray Anistropy Thermometer (∿ 1 mK to 50 mK).

The comparison experiments between this thermometer and R.J. Soulen's Johnson noise thermometer have been completed and the results published in the journal Cryogenics. Our results, which cover the temperature range of 10.2 mK to 50.5 mK show that both thermometers define the same temperature scale to within 0.5 percent. Although the agreement probably can be improved to 0.1 percent, it may be more important to work below the 10.2 mK limit imposed by the present NBS dilution refrigerators.

ii) ^{166m} Ho Ho Single Crystal γ-Ray Anisotropy Thermometer (∿ 50 mK to 1 K).

Work on this thermometer is progressing well. I have completed the first extensive measurements on this thermometer covering the range of 20 mK to 700 mK. Since the hyperfine interaction (energy level splittings) for this system has not been accurately determined, I used the ^{60}Co Co thermometer and calibrated germanium and carbon resistance thermometers to determine these quantities. The results of my measurements have enabled me to obtain values for the nuclear magnetic dipole and electric quadrupole moments for ^{166m}Ho. The magnetic dipole moment value is in excellent agreement with that recently obtained by the Oxford group. However, the quadrupole moment has the opposite sign to what is expected in this mass region. It is possible that the sign of the electric field gradient is wrong. Measurements are presently being made using a more intense single crystal ^{166m} Ho Ho thermometer to resolve this problem. Further measurements are also planned to compare this thermometer directly to some of the superconductive fixed points of SRM 767 and 768 and also to the EPT-76 scale. There is also a possibility that we can directly measure the hyperfine splitting in this system by an NMR/ON measurement. If this is possible this thermometer would then be a primary thermometer like the ^{60}Co Co single crystal thermometer.

c. Johnson Noise Thermometry with Josephson-Junction Detection (R.J. Soulen, Jr.)

H. Marshak and I published an article in Cryogenics which summarized the results of our latest comparison. It is this work, coupled with noise thermometry up to 0.5K and paramagnetic salt thermometry using cerous magnesium nitrate (CMN) (30 mK $<T<$520 mK), which constitutes the basis for NBS-CTS-1 (our first cryogenic temperature scale). All of these results have been obtained with an rf biased resistive superconducting quantum interference detector (R-SQUID) in which the rf frequency is 22-25 MHz. By the end of FY 80 we hope to make at least one improvement in this system: i.e., to use an audiofrequency phase locked loop to reduce the circuit noise and thus to shorten the measurement time. An NBS summer employee, D. McQueeney, has devoted 2-3 weeks of his stay at NBS to the design and construction of this circuit.

Progress also has been made in a more adventuresome improvement in R-SQUIDS--Gavin Park, a visitor from King's College, London, and D. Van Vechten were able to markedly improve the 10GHz R-SQUID noise thermometer. A first phase, accomplished by a former colleague and me, was to get a 10GHz R-SQUID working at 1.5 K using waveguides to inject the microwaves. Phase II was to replace the waveguide (inimical to dilution refrigerators) by coaxial cables. The experiments were successful to the extent that (1) the R-SQUID worked, (2) we obtained some resistively-shunted Josephson junction data similar to that obtained for the 24 MHz R-SQUID, and (3) we obtained convincing noise measurements of the temperature of the He^4 bath of 1.7K. Phase III is more complicated. It requires redesign of the R-SQUID and adaptation of the coaxial cables to a dilution refrigerator for measurements of the T_c values of Cd, Zn, Al, In and possibly Pb.

Needed yet for Phase III are coaxial cables of high quality, yet compatible with dilution refrigerators. No satisfactory cables are commercially available, so R.B. Dove constructed three prototype cables. We have sent them to W. Ganz, NBS Boulder, who will examine their rf properties (0-10GHz) (attenuation and reflection).

The program is nearly settled for the 6th International Conference on Noise in Physical Systems to be held at NBS (Gaithersburg) from 6-10 April, 1981. The second Announcement has been sent out.

7. New Pressure Standards (J.C. Houck)

a. Viscosities of Liquids Used in Piston Gages.

Six fluids were compared using a 40,000 psi re-entrant piston gage by measuring fall rates. These results indicate suitability of the fluids for use in calibration; the results will be combined with V. Bean's measurements to 100,000 psi for selection of a fluid for use in our 100,000 psi standard gage. Probably within the next six months one of the above fluids will be tried in the 100 K psi Standard Piston Gage, necessitating recalibration of the gage.

C. Task 111.23--Fundamental and Applied Research in Temperature and Pressure Measurement.

1. Industrial Thermometry.

a. Thermometry for Coal Conversion (G.W. Burns)

The project concerned with thermocouple instrumentation for coal conversion processes undertaken for the Fossil Energy Division of DOE was terminated in February 1980. Several NBS-fabricated thermocouple assemblies were evaluated in the reactor of the Bi-Gas pilot plant in Homer City, Pa. during the latter part of the project. Stainless steel sheathed, compacted insulated Nicrosil/Nisil thermocouples installed in alonized type 310 stainless steel thermowells showed substantial improvement in performance in Stage 2 of the gasifier over Type K thermocouple assemblies previously used. Post-test examinations of a Nicrosil/Nisil thermocouple after 200 hours of operation (at about 950 °C) revealed no evidence of chromic oxide formation in the positive thermoelement as had been found previously in the KP thermoelements of Type K thermocouples which had been operated in the gasifier.

Two NBS-fabricated thermocouple assemblies also were evaluated in Stage 1 of the gasifier. Molybdenum sheathed W-Re thermocouples were used in both assemblies. One assembly had a BeO thermowell and the other had a thermowell of chemically vapor-deposited SiC. These assemblies failed after less than 50 hours of operation (at about 1500 °C) showing no improvement in performance over previously used assemblies having Cr_2O_3 coated molybdenum thermowells.

G.W.Burns organized and chaired a session on temperature and other instrumentation at the 1980 Symposium on Instrumentation and Control for Fossil Energy Processes in Virginia Beach, Va. June 9-11.

b. Thermal Conductivity of Industrial Insulation (L.A. Guildner)

The thermal conductivity apparatus badly needs increased reliability, to be achieved by greater ruggedness and simplicity. On the other hand, the additional complexity of the apparatus has been most instructive. It is not a production-line instrument, but is capable of reliable interpretation. The measurements so far have been on two samples (one load) of Fiberfrax, at 100 °C and 300 °C, and we are presently seeking to measure them at 500 °C. We expect to continue up to 800 °C, then invert the samples and repeat one or more temperatures. The next material we expect to measure is Teflon.

2. Superconductivity Research

a. Inelastic Electron Tunnelling Spectroscopy (J.T. Hall)

I have completed a study (in collaboration with John Kirtley, IBM Watson Laboratory) on the quantitative intensities in inelastic electron tunnelling spectroscopy. The results will appear in Phys. Rev B, July 15 (1980).

b. Resistively-Shunted SQUID Research (R.J. Soulen)

The goal of this project is to understand the impedance and noise of an rf-biased R-SQUID circuit in order to gain greater confidence in the temperature scale defined by the device.

For noise thermometry the impedance need only be measured to 100 ppm and the simple "RSJ model" published by Soulen & Giffard is quite adequate. Another application of the R-SQUID as a secondary thermometer however, dictates an inaccuracy of 10 ppm for a resolution of 0.1 mk. Our measurement imprecision is presently at the 5-10 ppm level, and we have seen interesting and curious departures at the 100-1000 ppm level from the simple RSJ model. The burden of the effort then is to characterize these departures and to improve the RSJ model by building into it a more advanced circuit representation.

Drs. Soulen and Van Vechten have been collaborating with Dr. Robert Peterson (NBS Boulder), who has been attempting to solve, with the aid of the computer, a more elaborate RSJ model. The results show considerable success, the major deficiency being that the model could not simulate the effect of the rf tank circuit. More recently, with J. Gavin Park, we have made a breakthrough in characterizing the effect of the tank circuit. We are developing a model with which we may finally be able to simulate our results to the 10-ppm level½ The final outcome of these 5 years of research will appear next FY.

c. Microwave properties of superconducting films and tunnel junctions. (R.J. Soulen, Jr.)

J. Clarke (University of Califronia, Berkeley) reported superconducting gap enhancement in Al tunnel junctions irradiated by microwaves. We estimated that the effect would be even larger and easier to see in Ir tunnel junctions. In collaboration with L.B. Holdeman and J.T. Hall we looked at Ir junctions, but ran into problems. We saw heating due to (1) poor quality rf coaxial cables and (2) poor absorption of microwaves by the junctions due to unsuitable tunnel junction geometries. We decided to put off the Ir measurements and work at higher temperatures using Al junctions. Because of the persistence and insight of Holdeman and Hall, we finally observed the effect. We were only the second laboratory to observe gap enhancement and we saw some new phenomena, too. This work appeared recently in Physical Review Letters.

3. Measurements with Resonant Circuits. (C. Van Degrift)

a. Solid He-3 Experiment. With the thermometer calibration of FY 1979 complete we prepared the apparatus to measure P(T,H) at constant V. During March and April 1980 we tested the complete apparatus using an external phase-locked loop to monitor the frequency of the pressure sensing resonator. The 8 tesla magnet was successfully tested at its full field and the effect of the field on the pressure sensor and thermometers was measured. At temperatures below 80 mK, we saw anomalies which were subsequently traced to inadequate heat lagging of the three germanium thermometers. The pressure sensor worked properly up to its design maximum of 7 MPa but only had a precision of 500 Pa. The Hall probe performed better than expected attaining a resolution of 10 uT at a field of 8 T. A slow decay of 200 uT/hour when the magnet was persistent could easily be measured.

During May the pressure sensor resonator was repolished and set with a five times smaller capacitive gap for five times greater sensitivity. The thermometers were more carefully heat lagged and our special SRM 768X was attached to recheck the thermometers. A run from June to July confirmed that the thermometers were now reading correctly and have changed their calibration during the last year by no more than 0.05mk. We were able to make good measurements of the thermal conductivity of our favorite construction material, coin silver (90% Ag-10% Cu) in zero field. It was also determined that we should change from the phase-locked loop readout of the pressure resonator to a tunnel diode oscillator.

Even though the phase-locked loop method can in principal have less noise and power dissipation than a tunnel diode oscillator, it is too difficult to avoid systematic errors associated with cable resonances when used to measure a low Q resonator such as we must use in our 8 tesla magnitic field.

We are now selecting the best tunnel diode for the pressure sensor and will prepare the apparatus for a complete P(T,H) run early in FY81. Calculations indicate that a measurement which is made in 100 ms will require a dc energy of 400 nJ and have a precision of 0.07 Pa while a 10 ms measurement will require 40 nJ and have a precision of 0.22 Pa.

b. He-4 Lambda Point Experiment

Postdoctoral Research Associate Michael DiPirro has nearly finished fabrication of the apparatus to measure the dielectric constant of liquid He-4 near the lambda point. His apparatus consists of three reentrant resonators made using four pieces of polished niobium all sintered together at 2000 °C. The sintering assures excellent thermal contact and mechanical alignment and rigidity.

A crucial part of the apparatus is the gas thermometer which was separately tested and shown to have a precision of better than 100 nK, to drift by less than 10μK/day, and to have a reproducibility of 1 mK upon temperature cycling to 100 K. The frequency noise test was limited by ambient vibrations and the drift test by the precision of a companion germanium thermometer. The 1 mK change upon temperature cycling to 100 K leads us to believe that the gas thermometer is likely to be reproducible to better than 1 nK for excursions around 2 K. Other experiences with creep in coin silver and copper have indicated that creep diminishes by roughly an order of magnitude for every 10 to 20 percent drop in temperature.

The complete apparatus including a vacuum can, 2 K cold plate, and wiring will be tested just before M. DiPirro leaves for a permanent position elsewhere. He will, however, remain associated with the experiment to its conclusion.

c. General Tunnel Diode Oscillator Work.

A paper entitled "Modeling of Tunnel Diode Oscillators" by Craig Van Degrift and David P. Love (Texas A&M) has been written. It describes three progressively more accurate and complicated methods of modeling the performance of tunnel diode oscillators with particular emphasis on non-linear effects.

We have been able to obtain some tunnel diodes manufactured by a new planer technique and packaged in a nearly non-magnetic casing. We are testing these for their 1/f noise and ability to withstand thermal shock and cycling. Preliminary results show that they do indeed temperature cycle very well and furthermore that they change only slightly from room temperature. However, they have more capacitance than we desire. We expect that the manufacturer can produce diodes with much smaller junction capacitance and that this new manufacturing technique will produce diodes which are superior in all respect to previous designs.

Isadoro Campisi, a graduate student at Louisana State University has visited for a week to discuss his work on a triple superconducting reentrant resonator tunnel diode oscillator experiment. This type of oscillator is described in literature in the Soviet Union as promising exceptional frequency stability for gravitational radiation detector purposes. For the past two years we have been supplying Mr. Campisi with advice and minor hardware.

4. High Pressure Research. (Vern E. Bean)

a. Properties of CCl_4 Under Pressure

S.D. Wood and I have carried out the first part of a study of spherical molecules using pressure as the probing mechanism. Specifically, we have investigated the melting and freezing curves of CCl_4 between 0 and 350 MPa and between 225 K and 350 K. This molecule forms the so-called plastic crystals found among spherical molecules.

CCl_4 has three solid forms over the region of interest which are characterized by face-centered cubic (fcc), rhombohedral, and monoclinic structures. The fcc phase is metastable with respect to the rhombohedral phase. The melting and freezing curves of these two phases are separated by a few kelvins. However, what is of greatest interest to us is the behavior of the fcc phase at high temperature and pressure. At a point near 275 K and 100 MPa, this phase slowly ceases to exist. The change is not particularly sharp or well defined. In addition, while the fcc phase may be encountered during a cooling toward the rhombohedral phase, it will never be encountered while melting the rhombohedral phase.

The data leading to a paper on the dual melting curves of CCl_4 have some features that tend to make one think that CCl_4 violates the 1st law of thermodynamics as the various solid phases are formed. Having far greater confidence in the 1st law than in our understanding of CCl_4, we built a high pressure adiabatic calorimeter to look at the energy involved in the formation and fusion of these solid phases. The driving energy for these phases is provided by pressurized N_2 which allows us to freeze and melt along an isotherm. The CCl_4 and the N_2 are separated by a lead balloon, a critical feature of the device. We have tested the apparatus only enough to have confidence that it will work. There are almost certainly many other fluids that have yet undiscovered dual melting curves. We shall pursue study of them as time permits.

b. Capacitance Measurement as a Function of Pressure.

Using two sample cells, one of the Naval Academy design and construction and one designed at NBS we have made absolute capacitance measurements of CCl_4 in both of the plastic crystal phases and in the liquid phase as a function of pressure along several isotherms which will contribute to our understanding of these rather unusual phase transformations. This part of the CCl_4 work is now complete and will be published. These measurements were made at the Naval Academy under a NBS cooperative research agreement.

The next step in this program is to study the capacitance changes due to pressure induced rotor-nonrotor phase transitions in plastic crystals to see if this phenomenon is metrologically useful. We are also interested in looking for a capacitance anomaly in super-pressed polar fluids that is of interest to fluid theoreticians.

c. Compressibility of Fluids Having Spherical Molecules.

Originally, we expected to use ultrasonic techniques to make these measurements, but it is now felt that the experiment will be cleaner and easier if we use capacitance techniques. The concept is to make simultaneous capacitance measurements as a function of temperature and pressure on two samples of fluid, one of constant volume, the other having a constant number of molecules of sample. The only necessary correction to the data accounts for the compressibility of the stainless steel of the sample cell (a very small effect). Point by point differences in the two data sets gives the fluid compressibility directly. I have designed an apparatus for this experiment which is intended for use over the temperature range -100 °C to 200 °C and at pressures up to 1.4 GPa. D. Martin is building it. It is in the final stages of assembly and will become operational in early FY 81. The data will be taken at the Naval Academy using their automatic bridge operated by a Trident Scholar who will use this project as his senior thesis.

Fluids to be studied include CCl_4, of course. This work is of interest because it:

i) is an essential element in the testing of models for equations of state of fluids; and

ii) is expected to be a useful probe into the metastable super-pressed fluid state before freezing occurs.

d. Viscosity as a Function of Pressure.

A certain amount of oil flow in the annular space between the piston and cylinder is an essential feature for the operation of piston gages. As pressure increases, viscosity increases logarithmically resulting in decreased oil flow and so viscosity is a vital concern of pressure metrologists. We designed and built a high pressure viscometer to study candidate piston gage fluids. D. Martin, F. Long and I created the hardware and Martin Turner, an NBS summer employee, made most of the measurements. We have studied 8 fluids at room temperature and up to 700 MPa (10^5 psi) which is half of the maximum design pressure of the apparatus. We have corresponded with other national metrology laboratories seeking their suggestions for fluids of interest.

e. Light Scattering Under Pressure.

Dr. V. Fratello, an NBS Postdoctoral Fellow, has been studying the scattered light from super pressed liquid ortho-terphenyl looking for features that may give theorists a handle on the calculation of such metastable conditions. In order to know when one has super-pressed conditions, one must know where the melting curve is. We set about to find it using equipment of my design and construction and a sample purified by Dr. Fratello. He is nearly finished with the measurements. He has good data up to 500 MPa (75,000 psi) which we will publish in the late winter. We have also spent some considerable time working on his sample pressure cell for the light scattering experiment which he borrowed from W. Daniels of the University of Delaware.

5. Low Pressure Research. (Ken McCulloh)

A high vacuum ion gage comparator was constructed starting from a surplus high vacuum coating system. This comparator allows the calibration of vacuum gages between 10^{-2} and 10^{-6} Pa by comparison with reference gages calibrated at the National Physical Laboratory in England and the Physikalisch-Technische Bundesanstalt in West Germany. The comparator has been used to determine nitrogen sensitivities from 10^{-5} to 10^{-2} Pa for lots of from 2 to 4 each of 5 different types of commercial hot cathode ionization gage tubes by direct comparison with a reference gage. Two types which show promise for use as transfer gages have been identified for further evaluation.

A prototype ion gage controller has been designed and built. Minor refinements will be made, and several copies will be produced in early FY 81. These controllers, which are not commercially available, are required for precise control of ionization gage tubes.

The present ion gage comparator is effectively limited to use with nitrogen by its ion pump. This defect and several other less serious problems are being remedied by the construction of an improved high vacuum calibration system utilizing a mercury diffusion pump. This system is largely completed but awaits the delivery of the mercury diffusion pump. Operation by early fall of 1980 is anticipated. Initially the system will be used as a flow comparator for calibration by direct comparison with a reference gage. However, since this is a two-chamber system with an orifice of accurately calculable conductance, it will eventually be converted into a primary standard by addition of a throughput meter.

A two day workshop exploring the vacuum measurement problems of the magnetic fusion program was held during April 1980. This discussion significantly improved the understanding of both the NBS and DOE attendees of the fusion program problems and the capabilities and limitations of vacuum metrology.

6. Studies of Aircraft Altimetry Equipment (S.D. Wood)

The Pressure Group has been interested in aviation safety for some time. The aeronautical industry is a large, important and visible part of the economy which depends very directly on pressure measurements for safety. Our first survey of altimeters was done several years ago. After meeting with the FAA several times, NBS was asked to assess the current performance of altimeter setting indicators (ASIs) and the effectiveness of the FAA calibration procedures.

The first part of our task was to obtain or design a suitable transfer standard. The unit needed to be rugged and reliable under various field conditions and needed to maintain its precision and accuracy (0.01% full scale) throughout the survey. We relied heavily on the results of several years' data from the transducer characterization service to select a pressure sensor. This sensor was then packaged with a level, heaters, and a DVM in a rugged case. The unit was designed to fit under an airplane seat and was "portable" (40 lbs). Associated with the unit were a piston gage (which stayed at NBS) and a small vacuum pump.

The survey consisted of visiting nine airports at least once and checking the ASIs and local calibration equipment (other ASIs and Weather Service manometers) and discussing performance histories and problems with the people who maintain the units. In the course of the study, it became apparant that the Weather Service is the cornerstone of the FAA ASI calibrations and so we visited the regional headquarters in New York where we compared our transfer standard to their standard manometers. Finally, we stopped at the National Airways Facilities Experimental Center, the FAA's research facility, where we checked their manometer and talked with the staff.

We have recommended to the FAA that their calibration procedure be strengthened and that they maintain a transfer standard which could be used to check all of their ASIs against a single source. The results have been discussed in three reports.

7. Physics of Thin Films. (W.S. Hurst and M.L. Reilly)

The aim of the thin film work this year was to (1) investigate Si-based capacitance structures as temperature sensors and (2) investigate some of the promising cermet materials for use in resistive temperature sensors.

A collaborative effort was begun to work on Si-based capacitance sensors. This has been with Stephen J. Fonash and S. Ashok of Penn State and James Comas of the Naval Research Lab. In addition we have received some help from the semiconducting processes group here at NBS. The Si devices are now in the process of fabrication and testing. Comas provided ion implantation of selected impurity levels into the Si, and

Fonash is performing the annealing schedules and investigating the semiconductor parameters. We will investigate the temperature sensitivity and stability. These devices are now at Penn State, and we will begin looking at some of them in September. In addition, we have worked some with Fonash on the modeling of the device characteristics in the temperature-sensitive barrier region where the impurities are implanted.

The depositions for more ZrO_2-based capacitance sensors have been done. These will be fabricated into probes, tested at NBS and then delivered to the National Institutes of Health (NIH) for further testing by R. Berger.

8. Laboratory Automation. (W.S. Hurst)

Various problems were solved in assembling the laboratory computer systems. However, the systems are well suited to many calibration and research tasks in the division and provide us with relatively powerful and cheap laboratory automation. M.L. Reilly and I learned enough of the machine-language encoding procedures that drivers could be written to properly implement the printers. This was done after software bought outside proved to be poorly written and indadequate.

These systems now support the IEEE-488 general purpose instrumentation bus and our older data collection systems. In addition, as a bonus, a moderately powerful text editor has been implemented. A limited hard-copy graphics capability is also in operation.

The following tasks face us this coming year. First, some time will be required to acquaint new users with the system. This seems to run between 1/2 to 4 days per new user, depending upon conditions. Secondly, we should create one or two new systems for other division laboratories. Next, it seems clear that some effort should be spent connecting to the NBS National Measurement Lab word processing facility, and then instructing the division staff how to make use of it. These tasks can probably be finished during FY81. In addition, there are other tasks that would be worthwhile accomplishing. The first would be to replace the outdated MIDAS data collection systems with something else. A prime candidate is the CAMAC data collection system, which exists as an IEEE standard and for which there are many manufacturers of modules. We need to implement more powerful graphics, perhaps screen graphics as well as high-resolution pen graphics. (For the latter we have the hardware, but need to upgrade the software). Lastly, a more powerful operating system is available and may be required in some experiments. It will run 5 to 10 times faster than the present one and would more than double the amount of memory available for programming.

9. Characteristics of Industrial Resistance Temperature Detectors (RTD's) (Dr. B.W. Mangum)

a. Characteristics of Industrial Resistance Temperature Detectors (RTD's).

A study of RTD's was begun and work on this is progressing well. After 15 thermal cycles of 20 RTD's from room temperature to 235 °C (total time of ~ 200 hrs. at 235 °C), followed by measurements after each cycle at 0 °C, 20 °C, 40 °C, 60 °C, 80 °C and 100 °C, we discovered that the lead solder junctions on the leads had severely oxidized (although sensors and solder junctions were heated in an Ar atmosphere), causing an apparent change in the RTS's resistances. Ten RTD's with AuSn solder junctions and 10 RTD's with welded junctions are now being tested. Following this evaluation, the remaining RTD's will be appropriately connected to the leads and investigated for stability upon thermal cycling. An interesting feature found for almost all of the 20 RTD's investigated so far is that although they may show changes equivalent to a few (2-5) mK at any temperature between 0 °C and 100 °C upon thermal cycling, they undergo a considerably larger change (a decrease) in resistance (equivalent to 20 - 30 mK) subsequent to being tested over the range 0 - 100 °C. The amount of the decrease appears to be a function of time after calibration from 0 - 100 °C. It is possible that this is due to shunting of the RTD by moisture inside the thermometer.

b. Standards Activities.

I wrote three sections of a "Guide to Accurate Temperature Measurements in the Clinical Laboratory" and participated in writing three others for the Temperature Subcommittee of the Area Committee on Instrumentation of the NCCLS. This Subcommittee has now finished writing "Guide to Selection of Thermistors" for the NCCLs.

In ASTM, we completed writing proposed standards on thermistors, electronic fever thermometers, and disposable melting-point-type fever thermometers. We are working on drafts for disposable liquid crystal fever thermometers and on draftsfor thermometers using thermistors. The standard on liquid-in-glass fever thermometers has been adapted and published. The proposed standards listed above are ready for E 20 ballot.

c. Hydrated-Salt References Points.

D.D. Thornton, working with two Guests Workers, R. Magin and J.A. Statler, has studied transitrons in hydrated salts as possible medical reference temperatures. They have submitted a manuscript on the temperatures of hydration of $Na_2\ SO_4 \cdot 10H_2O$, $KF \cdot 2H_2O$, $Na_2HPO_4 \cdot 7H_2O$ salts as temperature fixed points for publidation in NBS Journal of Research.

10. Time-Dependent Temperature and Pressure Measurements (G. Rosasco)

The major effort over the last 8 months has been in obtaining the resources to start our program in optical measurements of temperature and pressure. We have obtained the promise of re-programmed staff assistance to augment my own efforts, and some $250,000 has been spent to equip a laboratory.

I have prepared work plans for FY 81 and FY 82. We should have reached two major goals at the end of this period:

GASES: Definitive predictive equations for the line intensity, position and width of nitrogen gas for use as a temperature and pressure measurement probe.

SOLIDS: Tests of the utility of a line position/width standard for temperature measurements above room temperature by optical fluorescence.

11. Thermometry in Resource Recovery (M.L. Reilly)

As a response to the reprogramming effort in TPMSD, in February of 1979 Martin Reilly began working with various members of the Chemical Thermodynamics Division (CTMS) on the design and construction of a large-scale flow calorimeter for the determination of the calorific value of resource-derived fuel (RDF). Because of his background in both thermometry and calorimetry, the transition to the new program was smooth. He spent nearly full time with the program as well as coordinating the activities of members of TMSD in support of the program. Beginning in March, D. Thornton set up the data acquisition system which was used in trial experiments of a prototype combustor for the 25-gram calorimeter. He then designed and wrote specifications for the data acquisition and computation system to be used for the 25-gram as well as the large-scale calorimetric experiments.

During FY 80 Reilly has continued to work full time on the calorimetry problem. Thornton, while on temporary assignment at a university, continued to be active through consultation by telephone. He also made two trips to NBS to assist in the installation of specific components of the data acquisition and computation system. Thornton resigned from the NBS in May and Reilly has taken over responsibility for the continuing development of that phase of the program.

John Evans, using his own system, tested the performance of a number of individual components of the new data acquisition for their implementation. Evans has helped in the construction of the thermocouples used in the 25-gram calorimeter. He has taught Reilly and Ryan of the NBS Center for Thermodynamics and Molecular Science (CTMS) how to correctly weld thermocouple junctions and helped them to use the equipment in his laboratory to fabricate thermocouples for the prototype large-scale combuster.

George Burns provided advice about the selection, location and installation of thermocouples for use in the prototype large-scale combuster. He supplied the wire used to make the thermocouples. He also supplied a high-pressure thermocouple feedthrough for use in special experiments designed to determine RDF ashing temperatures within a combustion bomb.

Wilbur Hurst, although not officially assigned to the resource recovery program, has contributed significantly to the TPMSD effort through his guidance and assistance in the setup of analysis of experimental data. He has provided operating systems which extend the capabilities of the laboratory computer to satisfy the particular needs of the calorimetry program. He has also willingly loaned components from his system for troubleshooting and made his portable system available for logging thermocouple data from the prototype large-scale combustor located at the hazards laboratory.

During November and December of FY 80 a series of experiments were carried out in the prototype 25-gram calorimeter. The major contributions from TPMSD were (1) the design and construction of the thermocouple systems to measure temperatures in the input and exhaust gas streams, (2) construction of the exhaust stream gas-analysis train, (3) furnishing a Mueller bridge system (complete with operator) for measuring the temperature of the working fluid using platinum resistance thermometry and (4) writing all the computer programs and software necessary to log and analyze the data. These measurements were discussed at an April meeting of ASTM and at the August meeting of the Calorimetry Conference.

In February and March further experiments were conducted to determine heat-leak corrections from the prototype 25-gram calorimeter. The Mueller bridge system was modified to make measurements semi-automatic. Additional computer programs were written to refine the logging and analysis of the data. Also in March, a series of experiments were conducted to determine the ashing temperature of RDF combusted in a bomb calorimeter. For these experiments TPMSD contributed advice on thermocouple design as well as a high pressure feedthrough for the thermocouple wires. The results of these experiments were also discussed at the April ASTM meeting.

During May and June the design and construction of the prototype combustor for the large-scale calorimeter were carried out. TPMSD input involved the selection of the thermocouple material and the design and construction of the couples.

In July and August more than 14 trial burns were carried out in the prototype combustor. After each burn significant modifications were made to the combustor, the thermocouple network and the sample configuration.

These experiments were also discussed at the Calorimetry Conference in August and a film sequence of a burn will be shown at the ASME meeting at NBS in September.

In September the final version of the 25-gram calorimeter is to be assembled in the new laboratory space in the Engineering Mechanics building. Test measurements will begin as soon as the assembly is complete (perhaps by mid-October).

During FY 81 the measurements to establish correspondence between the results obtained with the 25-gram flow calorimeter and those of the combustion bomb are to be completed. The construction of the large-scale calorimeter will begin.

III. PUBLICATIONS AND INTERACTIONS

During Fiscal Year 1980, the Temperature and Pressure Measurements and Standards Division staff participated in a great variety of activities. Many of these have been mentioned in passing in the previous sections of this report; for the convenience of the interested reader, however, they are categorized in this section.

a) Sponsored Conferences. Two conferences were sponsored by the Division during the past year. On the 29th, 30th, and 31st of October, 1979, a Topical Conference, "Problems in Modern Thermometry" was held at the NBS. The conference featured five lectures by well-known US scientists;

"Coherent Anti-Stokes Raman Spectroscopy Thermometry in Gases", by A. C. Eckbreth of the United Technologies Research Center, East Hartford, Connecticut;

"The Effect of Crystalline Imperfections on the Low Temperature Behavior of Cerous Magnesium Nitrate," by G. Zimmerman, Department of Physics, Boston University;

"A Temperature Scale Based on High Temperature Platinum Resistance Thermometry," by L.A. Guildner, TPMSD, NBS, Gaithersburg;

"Noise Thermometry Methods and Applications," by T.V. Blalock, Department of Electrical Engineering, University of Tennessee, Knoxville;

"Time Response Characteristics of Temperature Sensors," by T. Kerlin, University of Tennessee, Knoxville.

These lectures, occurring over a three-day period, provided the staff of NBS as well as other scientists in the Washington, D.C. area with an opportunity to discuss timely problems in temperature measurement.

A second conference, "Vacuum Measurement Standards for Magnetic Fusion Energy," covering the two-day period May 20-21, 1980, was jointly sponsored by the TPMSD and the Office of Fusion Energy of the U.S. Department of Energy. The topics included;

"Vacuum Measurement Problems in Plasma Confinement and Surface Physics Diagnostics," involving J. DeGrassie of General Atomics Corporation, I. Henins of Los Alamos Scientific Laboratory, A. Razdow of MIT, W. Schwenterly of Oak Ridge National Laboratory, F. Dylla of Princeton Plasma Physics Laboratory, and M. Malinowski of Sandia Livermore Laboratory;

"Ion Gage Sensitivity Problems," by R. Hseuh of Brookhaven National Laboratory;

"Neutral Beam Cryopump Development," by N. Schwenterly of Oak Ridge Laboratory and T. Batzer of Lawrence Livermore Laboratory;

"Tritium-Related Problems in the TFTR Acceptance Testing," by F. Dylla of Princeton Plasma Physics Laboratory;

"TSTA--Tritium Problems," by C. Walthers of Los Alamos Scientific Laboratory;

"State of the Vacuum Measurements Art," involving C.R. Tilford of the NBS TPMSD, G. Messer of Physikalisch-Technische Bundesanstalt, Berlin, K. Poulter of the National Physical Laboratory in England, W. Taylor of Sandia Laboratory, and N. Wilson of Los Alamos Laboratory;

"Commercial Ion Gage Sensitivities," by K. McCulloh, of the NBS TPMSD;

"Capacitance Diaphragm Gage Performance," by R. Hyland of the NBS TPMSD;

"TSTA Tritium Pressure Gage Performance," by S.D. Wood of the NBS TPMSD;

As a result of this conference, particularly troublesome problems in vacuum measurements and vacuum standards were highlighted, and potential solutions to these problems were suggested.

b) Talks by Division staff.

V. Bean. Plastic Crystal Phases in Carbon Tetrachloride, Gordon Research Conference on Orientational Disorder in Crystals, Santa Barbara, California, Jan. 15, 1980.

M. DiPirro. Heat Capacity Studies of ^{3}He in ^{4}He Films, Sigma Xi Luncheon Talk, NBS, November 1979.

M. DiPirro. ^{3}He on the Surface of ^{4}He: A nearly Ideal 2-Dimensional ZD Fermi Liquid, Center for Absolute Physical Quantities Colloquium, NBS, March 1980.

M. DiPirro. ^{3}He in ^{4}He Films: A Doubly Two Dimensional System, International Conference on ordering in Two Dimensions, Lake Geneva, Wis., May 1980.

G.T. Furukawa. A measurement Assurance Program--Thermometer Calibration at the Conference on Testing Laboratory Performance Evaluation and Accreditation, Sept. 25-26, 1979, Gaithersburg, Maryland.

L.A. Guildner. A Temperature Scale Based on High Temperature Platinum Resistance Thermometry, (co-author J.P. Evans). A Topical Conference on Problems in Modern Thermometry (presented by CAPQ) Oct. 29, 30, 31, 1979, NBS.

J.T. Hall. Photon-Assisted Quasiparticle Tunneling in the Region Intermidiate Between the Classical and Quantum Limits, March 1980 meeting of American Physical Society, New York.

J.T. Hall. Search for Microwave Enhancement of the Energy Gap in Aluminum Films, March 1980 meeting American Physical Society, New York.

J.T. Hall. Tunneling Spectroscopy. Catholic University Physics Department, April 1980, Wayne State University, Physics Department April 1980, Hewlett-Packard, Research Division, June 1980, Florida Atlantic University, Physics Department, May 1980.

R. Hyland. Capacitance Diaphragm Gage Performance, at NBS-sponsored meeting on Vacuum Standards for the Magnetic Fusion Energy Programs. May 21, 1980.

B.W. Mangum. Standard Reference Materials, (gallium melting point temperature standard), for the 1980 meeting of the American Physical Society.

H. Marshak. Nuclear Orientation Thermometry and the NBS Comparison of Scales, Low Temperatures Group, The Institute of Physics, London, England, October 1, 1979.

H. Marshak. Nuclear Orientation of ^{166m}Ho in ^{165}Ho Single Crystal, July 1980. West Berlin.

H. Marshak. New Developments in Thermometry and Related Research, July 1980. Bonn, West Germany.

H. Marshak. Ordered Nuclear Spin Systems: Thermometry, Magnetism and Nuclear Physics Katolieke University Leuven, Institution Voor Kern-en Stalingsfysika, Leuven, Belgium, September 18, 1979.

H. Marshak. Nuclear Orientation Thermometry Using ^{60}Co$\underline{Co}$ and $^{166\mu}$Ho$\underline{Ho}$, Kamerlingh Onnes Lab der Rijksuniversiteit te Leiden, Leiden, Nederland, September 21, 1979.

K.E. McCulloh. Nitrogen Sensitivities of a Sample of Commercial Hot Cathode Ionization Gage Tubes, (co-author C.R. Tilford) paper given at AVS meeting, Detroit, Mich., Oct. 1980.

R. Soulen, Jr. Development of an Absolute Temperature Scale Using Noise and Nuclear Orientation Thermometry, (co-author H. Marshak) International Institute of Refregeration, Venice, Italy, Sept. 25, 1979.

R. Soulen, Jr. Noise Thermometry at NBS and Superconductive Fixed Point Determinations Below 0.5 K, Institute of Physics, London, Oct. 1, 1979.

R. Soulen, Jr. Use of Superconductivity for Thermometry, October 1979, New Brunswick, New Jersey.

C.R. Tilford. Vacuum Standards, American Vacuum Equipment Manufacturers Association, New York, Oct 15, 1980.

C.R. Tilford. Survey of Altimeter Calibration Accuracy, (co-authors S.D. Wood and A.J. Linquist) 1980 Air Data Systems Conference, Colorado Springs, Colo. May 8, 1980.

B.G. Turell. Magnetic Structure Determined by Nuclear Orientation, (co-author H. Marshak) Solid State Commun. 30, 677 (1979)

S.D. Wood. Survey of Altimeter Setting Indicators, (co-author C.R. Tilford) 1980 Air Data Systems Conference, Colorado Springs, Colo, May 8, 1980.

c. Publications.

Vern E. Bean, "The Dual Melting Curves of Carbon Tetrachloride," High Pressure Science and Technology, B. Vodar and Ph. Marteau, editors; p. 638, Pergaman Press, Oxford (1980).

Vern E. Bean, "Absolute High Pressure Measurements," High Pressure Science and Technology, B. Vodar and Ph. Marteau, editors; p. 231, Pergaman Press, Oxford, (1980).

Vern E. Bean and Sharrill D. Wood, "The Duel Melting Curves and Metastability of Carbon Tetrachloride,," J. Chem. Phys. 72, 5838 (1980).

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LENGTH AND MASS MEASUREMENTS AND STANDARDS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1980

I. OVERVIEW

The Length and Mass Measurements and Standards Division activities during the past year were directed towards: (1) activities pursuant to goals and programs identified during the April 1978 reorganization of the Bureau and, (2) providing laboratory facilities and measurement capabilities necessary to accomplish these tasks.

The responsibility of the length program is to maintain, develop, and improve the foundations of length metrology and to provide the means and methods of making length measurements consistent with the primary standard of length. This goal is being realized through several activities: through laser intercomparisons which maintain concordance in the definition and the realization of the meter with other national and international laboratories, by developing improved and innovative technology which will increase the accuracy of length measurement, and by providing calibration and transfer services at the highest level for domestic civil, academic, and industrial institutions which have measurement responsibilities, and finally, by providing assistance to public and private organizations whose measurement activities are in the national interest and who cannot obtain adequate technical support from the private sector. It is important to remember that the responsibilities for length measurements and standards as compared to routine length calibration (gage blocks, line scales, etc.) are administratively distinct functions, the former residing in the National Measurement Laboratory and the latter in the National Engineering Laboratory.

The activities of the length group to build up laboratory facilities and to re-establish an iodine stabilized helium-neon laser capability have been largely completed. Efforts will now be focused on the stabilized mercury laser project and a program of innovation and development into new areas of relevance.

The mass group has the responsibility for the scientific aspects of mass measurements including development of mass comparators of the highest precision. The group also concerns itself with those scientific experiments where the most stringent mass measurements are required, in NBS and in the scientific community. Finally, it includes participation in the international comparison of national realizations of the SI mass unit, the kilogram. The small size of the mass group (two people) dictates that efforts be carefully focused on areas chosen for their importance to primary mass metrology and their efficient exploitation of available resources. Current projects included the improvement of our primary kilogram comparator, the determination of air buoyancy corrections in the weighing process, the certification of silicon density Standard Reference Materials (SRM's), and documentation of the load cell mass comparator in order to facilitate wide-spread use of this device.

II. Technical Activities: Length

Stabilized Helium-Neon Lasers

The iodine stabilized helium-neon laser is the φε □αψτο length standard in this country as well as internationally. The responsibility for maintaining and promulgating the length standard in the United States rests in the CAPQ and in large measure in the Length and Mass Division. While the prototype design and testing was completed in the previous year, full implementation and application have occured this year. In all, eight complete units have been completed: one is being used in NEL for calibration services, two for local gravitational acceleration (small g) measurements (JILA and U.S. Air Force), two for spectroscopic calibration, two for Length and Mass Division measurements and one as a loaner for use in experiments which occur from time-to-time such as the calculable capacitor and the γ_p measurement. Additional experience with these systems has served to reinforce the observation that state-of-the-art stability has been achieved in a portable instrument. The frequency stability for the 1000 sec. measurement period is about 3×10^{-13} ($\Delta\nu/\nu$), and, because of the wide-band servo system (400 Hz at the unity gain point), the system stays locked in environments which cause lower gain, narrower band-width systems to break lock. This is an asset for applications in locations which cannot be made as quiet as a laser laboratory. Several visits have been made to electronic instrument manufacturing firms in an effort to promote commercial production and sale.

International intercomparisons have resulted in the observation of several systematic frequency offsets, the origins of which have not been clearly identified (power dependent shift and absorption cell specific shift). Because the elimination of these offsets in an internal cell stabilized laser is made difficult as a consequence of the nonlinear interaction between the gain characteristic of the He-Ne gain tube and the absorption of the iodine cell, experiments have been initiated which utilize an external absorption cell. While the technology involved in external stabilization is significantly more complex than internal cell technology, it is the only way to measure the offsets between the lock point of the stabilized lasers and the center of the iodine hyperfine line. We anticipate absolute reproducibility to improve to several parts in 10^{12}. It is apparent that, for the short term, such a system will replace the internal cell laser as our principle reference laser. With this system other neon and iodine transitions can more easily be studied and their suitability for wavelength markers in the visible spectrum determined.

Stabilized Mercury Laser

The iodine-stabilized helium-neon laser system is providing an inexpensive and compact length standard at the 5 parts in 10^{11} level. The characteristics which limit it to this value will not be easily ameliorated and substantial motivation exists to explore and develop other systems whose performance will exceed 5 10 10^{11} or which have other desirable characteristics. The efforts in the Length Measurements and Standards Division in this direction are complementary to similar efforts in other Divisions in CAPQ in which much of the pioneering work has occurred in the past and is continuing. Several versions of an optically pumped mercury laser have been constructed which operate at 546 nm and which will be stabilized using an internal and external iodine absorption cell. Output powers of up to 2 mW have been obtained but thermal stability and pump lamp cavity problems have prevented reliable operation. The goal is to design an instrument which is more complex than the widely used argon-ion laser and which is as reliable as the helium-neon laser. At the present time the difficulties are primarily engineering.

The importance of the mercury green line in many classical measurements is well known and interest exists in some quarters (for example in sugar polarimetry) to utilize laser technology in its present activities. Mercury is a good candidate for a laser system as it is heavy and has a narrow gain-bandwidth which promotes single-frequency operation. In addition a coincidence has been found between the ^{198}Hg lasing line and an iodine ^{129}I absorption line thereby assuring the possibility for intra-cavity saturated-absorption stabilization. It is also interesting to observe that the mercury laser is in proximity to the frequency doubled 1.15 μμ He-Ne line and that a direct frequency comparison between the two can be made with the addition of a CO_2 line (10 μm) and 17 GHz from a klystron. Thus the mercury laser represents the highest frequency oscillator in the microwave to visible frequency chain and will become important in the efforts to redefine the meter in terms of the second and a conventional value for the speed of light.

Staff and Equipment Needs

The length effort presently has three professionals, two physicists and a mechanical engineer who are involved with laser systems - their stabilization, characterization, and application to measurements and standards for spectroscopy and metrology. While the present personnel are versatile and can perform a wide variety of tasks, insufficient time exists to accomplish all of the goals which are desirable.

A modest increase in staff would allow our interest in fundamental quantities to be transformed into productive activity. A NRC postdoctoral fellow will be energetically sought to work on this program.

Long Range Plans

It is the responsibility of the Length and Mass Division, along with other Divisions in the Center for Absolute Physical Quantities, to provide the highest precision length standards and measurements capabilities for spectroscopy and metrology. The contribution of the Length and Mass Division complements those previously-established capabilities which exist in other Divisions in the CAPQ by providing coupling between the highest resolution work (e.g. involving molecular beam technology) and the academic and industrial communities through intermediate-precision standards (e.g. the intra-cavity iodine stabilized helium-neon laser) and activities which promote their use. Much ground has been gained in re-establishing the capability of providing laser length standards for use within the Bureau and information, in the form of blueprints and schematic diagrams, for institutions outside of the Bureau who have the need for such a standards. In addition, while most of the necessary laboratory facilities are now operational, a large amount of specialized electronic control equipment must still be constructed. Such a program, because of the initial absence of laboratory capability, will require substantial effort as it must be remembered that each active electro-optic component requires at least one electronic servo control and sometimes nested control loops. The design of these systems, however, is now routine because of the theoretical work on the I_2 stabilized system. When adequate control electronics is available some of the more interesting aforementioned studies will be begun in earnest among which are the measurement of Rydberg Constant (in collobration with W. Lichten, Yale University) and the stabilization of optically-pumped molecular and dimer lasers. It is now clear that many candidates for length standards exist and, when resources allow, they will be investigated.

III. Technical Activities: Mass

A. Kilogram Conservation.

1. Objectives. The kilogram is now unique among S.I. units in that its definition still relies on a mutable artifact. The precision with which two such artifacts may be compared approaches 1 ppb. It is of obvious importance that a mass comparator with this precision be maintained in order that inchoate problems with the mass unit be identified well before they impinge on the measurement system derived from the kilogram artifact. It is an objective of our program to maintain such a comparator and to make use of it as outlined above.

2. Current Activities. Work continues on improving our primary kilogram comparator. This balance was built commercially several years ago and is based on the design of NBS-2. (This latter balance was designed and built at NBS and now serves as the prime comparator at the BIPM.) A new hydraulic cylinder to raise and lower the weight table in our balance is being installed. In addition, we are fabricating platinum counterweights for use with the balance. Such counterweights will enable us to intercompare platinum kilograms on the single-pan balance while maintaining the balance in buoyant equilibrium.

3. Accomplishments. The prototype kilograms of the United States, K4 and K20, have been placed in new enclosures which are designed to offer improved protection from atmospheric pollutants. In addition, physical security for the prototypes has been strengthened. The precision of our kilogram comparator has been improved by a factor of two during the past year. We believe that the present precision of this balance, 3 ppb, may yet be improved upon.

4. Future plans. We believe that the precision of our balance is now high enough to warrant recalibration by the BIPM of our kilograms K4 and K20. We will arrange such measurements in the coming year. In addition, we expect to contribute to the working groups established by the CIPM to examine the major problems in primary mass metrology.

B. Air Buoyancy.

1. Objectives. We are undertaking a program to improve our understanding of buoyancy corrections in the weighing process. Such corrections, now based on Archimedes' Principle and a semi-empirical equation of state for moist air, dominate the uncertainty when platinum and stainless-steel kilograms are compared on the best balances. By making use of an evacuable enclosure and a kilogram balance with servo control, we intend a systematic study of this problem.

2. Current Activities. The stainless-steel enclosure is being completed. A force transducer for the servo-controlled balance has been made; the servo electronics have been designed and are being assembled.

3. Accomplishments. Reports of our experiments testing normal air buoyancy correction practices have appeared in Science and the NBS Journal of Research. The construction of the apparatus described above is well along although not yet complete.

4. Future Plans. During the next year, we expect to complete both the vacuum chamber and the modifications of the balance which it will enclose.

C. Density SRM's.

1. Objectives. The motivation for this project is to make available to interested users the highly-precise density information contained in the silicon artifacts which were used in the determination of the Avogadro constant by Deslattes et al. In the latter experiment, the volumes of four single-crystal pieces of silicon were determined through a direct link to the krypton length standard. The final uncertainty for the volume determination was less than 2 ppm--considerably better than could have been achieved using standard techniques, which rely on turn-of-the-century data for the density of distilled water. We believe the density of the four silicon crystals has not (nor could it) change significantly since the initial density determination. It is, therefore, our intention to transfer volumetric knowledge of these crystals to other silicon crystals which may then be provided to users through the Standard Reference Materials (SRM) program.

2. Current Activities. Approximately 15 kg of single-crystal silicon have been purchased. In conjunction with the NBS Optical Shop, we are now beginning the tedious task of fashioning this raw material into objects of 200 g and 100 g. We are also modifying a commercially available top-loading balance for use in the hydrostatic comparisons of our "new" and "old" silicon and recalibrating our working standards of mass.

3. Accomplishments. We have demonstrated the feasibility of the balance modification mentioned in the preceding paragraph using a 1 kg top-loading electronic balance. Briefly, the force transducer and pan of the balance are separated from the electronics and completely submerged in an inert fluorocarbon liquid. The servo electronics are then altered slightly with the result that the submerged balance meets virtually all of its original performance specifications. One now has a hydrostatic balance with no suspension wire breaching the fluid-air surface and with all the convenience of a modern top-loading balance. The SRM program, which will require our certification of some seventy-five artifacts, will benefit from this technology as applied to a similar top-loading balance of 30 g capacity and 0.0001 g precision.

4. Future Plans. We expect to complete the SRM project in the next fiscal year. At this time, there are several national laboratories independently pursuing programs to acquire a density metrology of the same level of accuracy as our own. It would be extremely useful to arrange a round robin calibration of silicon objects with these laboratories when feasible.

D. Load Cell Mass Comparator.

1. Objectives. The Office of Weights and Measures (OWM) has a goal of providing state laboratories with a convenient device for tolerance testing of 50-pound weights. The proposed device must offer advantages of speed and ease of use. Additionally, the resolution must be well in excess of the 2 g tolerance on these weights. A concept, developed by R. M. Schoonover of this Division, for achieving the desired goals has been supported by OWM.

2. Current Activities. Because the load cell mass comparator has evoked considerable interest in the metrological community, both from users and manufacturers, we are now documenting the mechanical and electronic package in order to facilitate wide-spread use of this device.

3. Accomplishments. A working 50-pound comparator with a precision of 0.03 g has been constructed. In addition, an inexpensive electrical package has been designed and fabricated. The package (based on a circuit of R. D. Cutkosky of this Center) has the merit that its large on-scale range (100 g) is useful in adjusting weights to tolerance.

4. Future Plans. The OWM intends a field test of the device in the state laboratory of Texas. We expect to be involved in this project as consultants.

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Randall M. Schoonover and Frank E. Jones, "Buoyancy Correction & Weighing on Analytical Balances", Analytical Chemistry.

INVITED TALKS

Length & Mass Measurements & Standards Division (523)

H. P. Layer, "Recent Developments in Iodine Stabilized Helium-neon Lasers", June 25, 1980, Conference on Precision Electromagnetic Measurements, Braunschweig, Germany.

H. P. Layer, "Design, Construction and Performance of Iodine Stabilized Lasers", Hewlett-Packard Laboratories, Palo Alto, California, July 14, 1980.

H. P. Layer, "Design, Construction and Performance of Iodine Stabilized Lasers", Boeing Aerospace Co., Seattle, Washington, July 16, 1980.

R. M. Schoonover, presented a lecture at a George Washington University Continuing Engineering Education Program, "Operating Techniques for Standards and Calibration Laboratories", April 17, 1980.

R. M. Schoonover, "Quick and Accurate Density Determination of Laboratory Weights", 8th Conf. of IMEKO Tech. Comm. TC3, Measurement of Force & Mass, Weighing Technology, September 9-11, 1980, Krakow, Poland.

COMMITTEES

Length & Mass Measurements & Standards 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

SUMMARY OF ACTIVITIES

FISCAL YEAR 1980

I. OVERVIEW

The Time and Frequency Division provides innovative product prototypes, research results, and services to a variety of users that include small businesses, various U.S. Government agencies, the systems synchronizer, the researcher, and the average citizen. Innovative product prototypes include the TV time system which introduced the technology that resulted in TV captioning for the deaf; the prototype satellite time receiver which has stimulated receiver development by several companies for new product lines; the new quartz standards with improved stability and accuracy which may grow into an industrial product; and the passive hydrogen standard which has the promise to be a major product line in a rapidly expanding position-location market.

Commercial TV time systems are currently being manufactured by eight companies but the number of units sold is being limited by several network stations using frame synchronizers, which breaks the NBS-to-user direct link. The concept--created by NBS staff--of TV captioning has been developed through efforts of PBS (Public Broadcasting System) into captioning for the deaf. A National Captioning Institute has been created to caption TV programs.

The NOAA GOES satellite time system was initiated as a joint program to serve the NOAA data collection programs and to disseminate highly accurate time. Commercial versions of the time code receiver have been developed by three manufacturers. To date, several hundred receivers have been sold and delivery backlogs of several months have been reported by the manufacturers.

The quartz and rubidium standards improvements are more recent, and the extent of industrial application have yet to be measured. The latest innovative potential product is the passive hydrogen standard which has demonstrated parts in 10^{15} stability for one week averaging times. Because of the small size, relatively small power requirements, and favorable stability/cost ratio, the passive hydrogen standard may have great demand (many hundreds of units) for high stability applications.

An embryonic prototype product presently under development is a reasonably priced Global Positioning System (GPS) receiver which is designed to allow nanosecond time coordination utilizing the GPS system. Although GPS receivers are available at $150,000 per unit, the NBS receiver is being developed for common-view time coordination applications, is anticipated to have a market price of approximately $20,000, and will be a user alternative to maintaining his own primary standard.

Research outputs have been concentrated in removing the limitations of atomic standards and developing high accuracy measurement technology. Trapped ion cooling research is in progress to remove the Doppler limitations of present atomic standards. Although not applicable to cesium, the techniques could lead to parts in 10^{15} accurate atomic standards, and open up new fields in very high resolution spectroscopy. Frequency synthesis that extends frequency based measurements in the infrared and visible region has allowed the measurement of benchmark frequencies that are being used in atmospheric and isotope separation programs in other agencies. The development of laser stabilization techniques has allowed the adoption of standard lasers--most notable are the helium-neon and the carbon dioxide laser systems.

In addition to the removal of Doppler effects from primary standards, one of the most notable problems in time, frequency, and wavelength standards development is the multiplication or division of frequencies between the visible and the microwave. Division efforts at multiplication will lead to a proposal to redefine the length standard in terms of frequency techniques in the 1982 time period. However, the practical utilization of a microwave standard as a visible length standard, or an optical length standard as a one-tick per second clock is yet to be demonstrated. One possible solution to this problem has been suggested by Division personnel--the synchrotron divider. Because of the radical nature of the suggestion, 3 to 5 years will be required to demonstrate and prove the technique. Although success is not certain, the potential impact of the device, in operational standards in particular, and in applications in general, is so high that this technique could be one of the most important NBS outputs to date.

The services provided by the Division cover a wide spectrum. Time and frequency information, as well as general interest information, is transmitted on several frequencies from radio stations in Hawaii and Fort Collins, Colorado. Higher precision information is available from code transmissions from the NOAA GOES satellite, and the highest precision information, where available, is provided by a calibration of the color subcarrier from major network stations originating programs on the east and west coasts and from calibrations of selected Loran-C broadcasts. In addition to these general services, a limited Measurement Assurance Program (MAP) service is being developed which will allow locally available time and frequency information to be calibrated and made "traceable" through an NBS computer operated system.

Although not strictly a service, the time scale and time coordination is fundamental to the research and services provided by the Division. The time scale is developed from the output of a set of commercial cesium standards and NBS-4 and NBS-6. The time scale is required to evaluate the national standards of frequency (NBS-4 and NBS-6) and new and highly stable standards such as passive hydrogen; to provide time information for services; to provide a measure of the SI second for the international time scale (TAI), and to provide time on a working basis to assist along with others in the generation of TAI and its companion time scale, UTC. However, without effective coordination mechanisms, NBS would be an island of standards without effective access by the users or known relation to other international standards. At present, international coordination is accomplished through several Loran-C links to Europe. These links are not accurate enough to transfer time at the limits of the time scale accuracy. Experiments utilizing GPS and other satellite systems are being planned to improve the international coordination of time.

The users of our products are diverse. Division innovative prototype products have led to the establishment of GOES satellite receiver product lines in three companies. The TV prototype receivers have led to 8 companies manufacturing line-10 and frequency calibration equipment. The technology developed in the Division and broadened by PBS has led to the sale of over 17,000 captioning systems to date, an order rate of 1800 per month, and a backlog of 4 weeks by the manufacturer.

The output from the frequency metrology programs is being used by astronomers to identify molecules in space, by NOAA and NASA for pollutant measurement and monitoring programs, by DOE research labs for isotope separation programs, by other NBS Divisions as calibrations for molecular spectra, and by NOAA and NCAR in atmospheric modeling programs. The stabilized lasers are being used in precision spectroscopy by researchers in state, federal, and private labs. The aggregate of laser frequency measurement data will be the foundation of a set of spectral tables from 100 GHz to 1,000 THz which will become as important as the microwave spectrum tables that have been developed over the years at NBS.

The hardware outputs of the frequency metrology program in the Division and in JILA have resulted in a "defacto" methane stabilized laser length standard in industry. The stabilized laser geodimeter being developed for high accuracy, long baseline measurements will be integrated into Geological Survey earthquake monitoring and prediction programs, can be used by NOAA and the military to accurately measure water vapor content over long baselines, and could be a first step in developing intrinsic standards for atmospheric measurements.

The improvements in application standards such as rubidium and hydrogen are being studied for the Global Positioning System (GPS) and the findings are available to manufacturers to improve the stability of their commercial standards. High stability passive hydrogen standards may have significant impact on high stability timing systems and scientific experiments, and commercial applications should lead to the introduction of a new industrial product line. The promised improvement in cesium standards will increase the accuracy of prototype primary standards, and will be available for commercial exploitation for the higher accuracy segment of the market.

The users and applications of Division dissemination services include the small boat owner as a sole source for navigation, the larger ship as a routine time reference and to gain access to other navigational systems or as a back-up navigational source, the power distribution companies for fault location and system synchronization, the communication system operator for system calibration, the FAA and other federal agencies for event documentation, the remote military unit for setting navigation aids, the large computer system user to document events, and the citizens to set their watches. It has been estimated through NBS surveys, receiver manufacturers, and trade journals that tens of thousands of people and systems use Division services. The users are numerically distributed in a pyramidal shape with the lower accuracy user at the base, and the highest accuracy user at the apex.

II. TECHNICAL ACTIVITIES

1. Primary Standards

During the last five years, the Division has followed the internal strategy of concentration on standards research, to maintain a minimal effort in the operational time scale, to completely evaluate the primary standard for absolute accuracy about once each year and not continuously operate the primary standards as clocks in the time scale, and to utilize research results for quantum step improvements in frequency standards and the time scale. There are several reasons for this strategy--the availability of external research funds due to the influence of the GPS system, the specialized talents that have been aggregated in the Division, the apparent desire of NBS management to pursue high quality research, and the confidence that research will result in significant improvements in NBS standards and credibility in the scientific and standards fields. In addition, present microwave frequency standards are based on concepts developed 15 to 25 years ago. These concepts have generally reached maturity. In order to provide a thrust for further advancements, conceptual changes in the approach rather than better engineering are required.

The major emphasis during the last year has been research to remove the limitations of atomic beam standards and the updating of the time scale. Cesium is, and will continue to be, the international standard of time and frequency for the next decade. In conventional cesium beams, the first-order Doppler shift is avoided--to first order--by using a Ramsey cavity. However, fixed phase differences between the cavity ends cause biases in the frequency. These phase differences are caused by the finite conductivity of the cavity, and cannot be removed except by using superconducting cavities. Continuous sweeping of the phase difference (with a second frequency) removes the fixed phase offset. The two-frequency experiments conducted during the last year indicate that crosstalk between microwave cavities may have been responsible for an observed frequency offset. Further work in FY81 should determine the importance of crosstalk related systematics in a future standard.

Optical state selection increases signal-to-noise by pumping all atoms into the desired state, decreases sensitivity to distributed phase shift across the opening of the cavity, and provides a means to increase the understanding of the frequency shifts caused by Majorana transitions. The goal of this effort is to demonstrate that all the atoms can be pumped into the $F = 4$, $m_F = 0$ state. The attainment of this goal would result in a factor of 16 enhancement in usable beam and greatly reduce the background as compared to present Cs designs. Moreover, the lack of population in the other hyperfine sub-levels should permit a study of Majorana transitions. These transitions occur between the magnetic state selection region and the Ramsey cavity region in current Cs beam designs and are a concern in the accuracy of cesium standards. In addition, the lack of population in other sub-levels should reduce the influence of their Rabi peaks by one or two orders of magnitude as compared to traditional designs, thus permitting operation at a lower C-field. Experiments are underway to evaluate the improvements due to optical pumping. During FY81, diode lasers will be evaluated in state selection. Success in this effort will simplify operational implementation of this state selection technique. Development of the two-frequency method and optical pumping state selection are key areas of research directed toward improving the accuracy of cesium primary standards by almost an order of magnitude.

A major limitation of all atomic standards is due to Doppler effects. When ions stored in an electromagnetic trap are cooled with laser radiation within the Doppler linewidth but at a frequency below the line center, kinetic energy is removed from the ion system by radiation. In addition to the radiatively selected ion, other ions in the trap will also be cooled because of Coulomb interactions. Experiments conducted during the last year indicate that ions can be radiatively cooled into the milli-Kelvin range, ions can be stored for hours to days, and hyperfine linewidths of 0.2 Hz can be achieved. Further improvements should lead to linewidths between 0.001 to 0.1 Hz with high signal-to-noise. Given hyperfine transition frequencies of order 10^{10} Hz, quality factors of order 10^{11} to 10^{13}, approximately 10^3 to 10^5 times larger than present cesium devices, are anticipated.

While laser cooling is much more difficult to achieve with cesium, cooled ions have many potential advantages. The ions can be stored for long periods in a container which has small, calculable perturbations to the energy levels; first and second-order Doppler effects can be essentially eliminated; and once trapped and cooled, either microwave or optical transitions (or both) can be used as frequency and length standards. Projected frequency stability of a cooled ion microwave standard is of the order of 10^{-12} to 10^{-14} $\tau^{-1/2}$, and the stability of the device will be limited by the available local oscillators to drive the transition, while for optical frequency standards, projected frequency stabilities are of order 10^{-14} to 10^{-16} $\tau^{-1/2}$. In order to achieve the best performance, it is likely that a full sized passive or active hydrogen maser or a greatly improved crystal oscillator will be required for the local flywheel microwave oscillator. Work on more stable laser flywheel oscillators is also being pursued in conjunction with the stored ion effort. Absolute accuracies of 10^{-15} and frequency stability in the low 10^{-16} range for days to weeks are anticipated. In addition to the advantages for standards, the cooled ion technique is ideal for spectroscopic research on ions. Because of its broad impact on high precision metrology, it is anticipated that cooled ion technology will be an active Division program for at least the next 5 years.

During the next year, the two-frequency excitation and laser state selection experiments on cesium will be completed and experimental results will be evaluated and published. If anticipated results are obtained, preliminary designs and experiments toward NBS-7 will be undertaken in FY82, and a schedule for construction, operation, and testing will be established by the end of FY84.

Since the initial development of passive hydrogen standards in the Division two years ago, significant progress has been made toward introducing improved clocks to the time scale. Prototype devices have been constructed, tested, and delivered to OA sponsors who have shared in the development costs. Stability of 1×10^{-14} in one week has been measured for the passive standard and two more are planned for inclusion in the time scale by December 1980.

A prime obstacle to an optical time standard has been the inability to develop an operational means to run a one pulse per second clock from an optical frequency laser. Frequency division using a one electron synchrotron may remove this obstacle. This concept, developed in the Division, is based on the cyclotron, synchrocyclotron, and synchrotron method to accelerate charged particles. Instead of using a localized microwave field to drive the charged particle, a well collimated, Gaussian laser beam, focused to a spot diameter of approximately one wavelength, will be used to drive an electron in a Penning trap. The electron should absorb energy from the laser radiation field, and will cycle at and be phase locked to a very small subharmonic of the laser frequency if the electron spends on the order of one cycle of the laser radiation in the laser beam. The subharmonic frequency is observed by an image current, hence a single electron is required to precisely define the phase of the output signal. During FY81, microwave synchrotron division will be attempted to determine the stability of the one-electron orbit. If stability and image current signal-to-noise are sufficient, infrared laser division will be attempted in FY82. Results of preliminary experiments and pressures due to other high priority programs will determine the direction and speed of this project.

During the last year, the time scale has been completely rebuilt. A PDP-11/70 is the heart of the new system; dual mixer techniques are utilized in the new measurement system (capable of 10^{-16} accuracy); a totally new time scale algorithm based on Kalman theory has been initiated; and input capability of up to 30 clocks has been built into the system. The driving force for the new time scale was two-fold. First, the old time scale could not handle more than 9 clocks, requiring major disruptions in time scale operation to test new clocks. Second, the precision of the old time scale hardware limited the ability to measure high stability clocks, like the NBS passive masers, and to evaluate NBS-6. When completed, the time scale will allow completely automated time scale operation; the evaluation of high stability standards against the ensemble; the real time testing of new time scale algorithms; and the evaluation of the primary standards. With the addition of the three passive masers, the new NBS time scale should be the most stable scale in the world. Time scale algorithms will be the subject of a special conference to be held in Boulder in conjunction with the 1982 CPEM conference. Although the implementation of the time scale was the single largest program in the standards area, most of the milestones should be completed in the first months of FY81 and resources can be diverted to other high priority programs, although some work on new time scale algorithms will continue.

NBS-6 was completely evaluated during the last year. Evaluations include the measurement of cavity phase shift by reversing the beam direction several times, calculating second-order Doppler shift from the velocity distribution which is determined by de-volving the Ramsey pattern line profile, measuring the magnetic field and checking the various operating conditions of the device, and accounting for all the error sources. The one-sigma accuracy of NBS-6 is 8×10^{-14}.

NBS-6 actually calibrates the frequency of the NBS time scale, which, in turn, is compared over many months with other national and international time scales, and then to the NRC and PTB primary frequency standards. Since NBS is approximately one mile above sea-level, NBS-6 is corrected for a gravitational blue-shift of 18 parts in 10^{14}. The Loran-C link adds an uncertainty of nearly 10×10^{-14} between NBS and the BIH. NRC, PTB, and NBS have agreed to a few parts in 10^{14} over the last three years with an uncertainty of 15×10^{-14}.

2. Coordination

The coordination group is the newest group in the Division and was created when it was determined that coordination of time scales was the weakest link in the international time program. Currently, time is coordinated over long distances by monitoring Loran-C (with an accuracy of under one microsecond over a period of a year) and by periodic portable clock trips (with an accuracy of tens of nanoseconds). The Loran-C link to the BIH is the operational link between NBS and international time scales, but satellite coordination experiments have been carried out by several countries, including the U.S. In 1979, a series of experiments was carried out between NBS, USNO, and NRC in one link, with NRC and BIH on another link. These experiments demonstrated the potential of nanosecond (precision) operational coordination over large distances. The initial NBS satellite link was made available through the cooperation of an NIH contractor at the University of Colorado Medical Center in Denver, and included a clock carry to Denver for every experiment. In a later portion of the experiment, Comsat Labs loaned NBS a transportable satellite terminal, which permitted on-site operation from NBS.

Although many satellite systems have been investigated in an attempt to find a suitable combination to adequately serve national and international needs, the costs and hardware requirements at all the potential locations made the resource problem significant. Although the military can conceive of and initiate large capital equipment projects, the Bureau and the Division find capital intensive programs difficult to justify. Therefore, alternative systems were investigated and two potential options were identified--two way Loran-C, and common-view GPS. Common-view GPS coordination takes advantage of a military position location system and, because of geometric considerations, is not critically dependent on ultimate accuracy of ephemeris data (e.g., a 25 nanosecond ephemeris error corresponds to only a 2 nanosecond timing error). In normal position location applications, the receiver costs are approximately $150K, which makes this another capital intensive system. However, because of an historic involvement with satellite and time receivers, and a unique digital electronics capability, the Division is completing a GPS receiver, which can be used for common-view coordination, for parts and assembly costs of appoximately $6K and an estimated commercial cost (after NBS prototype development) in the $20-$25K range. During FY81, the receiver will be completed and tested, and initial GPS experiments will be performed and evaluated. By FY82, if evaluation tests are successful, prototype GPS common-view coordination experiments will be conducted between NBS, the Naval Observatory, and NRC. Because of the potential importance in high accuracy time coordination for space as well as military applications, other agency funds have been made available to partially support the receiver development effort. For example, NASA requires parts in 10^{13} coordination at their tracking sites in Australia, Spain, and California for their deep space programs. In August 1981, an extremely critical correction will be made to navigate the Voyager 2 around Saturn and on to Uranus. Estimates indicate that time coordination using GPS and the NBS developed time receivers would save in excess of $1M per year over using their antenna system and deep space noise correlation techniques.

Position and time are intimately related, therefore research on position location systems have direct impact on time dissemination systems. NBS and NOAA are engaging in a joint program to use the GOES time code combined with the GOES position as a means of finding the location of unanchored buoys reporting data through the GOES data retrieval system. This program is scheduled for completion in FY81.

Because of the size, potential, and importance of the GPS system, GPS will likely play an important role in the future of time dissemination and time coordination. However, the political and military questions of degredation of accuracy for nonmilitary users, the economic questions of receiver costs, the military questions of access to the system, and the technical questions of standards performance in space remain as potential roadblocks to the full realization of GPS. On the other hand, the Division cannot dismiss the GPS potential and turn to other options until the roadblocks are proven to be insurmountable. The Division will maintain its input into the GPS design and implementation through contacts with the USNO and SAMSO, and its efforts to make the GPS time transfer as accurate and general as possible within national security guidelines. Definitive answers to all questions should be available before the scheduled 1985 implementation date.

3. Dissemination

Access to the NBS standards of time and frequency is via 2.5, 5, 10, 15, and 20 (at WWV only) MHz services from two radio stations located at Ft. Collins, Colorado and Kauai, Hawaii; a 60 KHz service from Ft. Collins; a satellite time code from the NOAA GOES satellite; and non-NBS broadcasts usable as transfer standards (such as calibrations of the color subcarriers of major east and west coast TV networks and Loran-C and Omega Navigation System transmissions); and occasional portable clock trips.

WWV was relocated and WWVB was built at Fort Collins in the 1962-65 period at a cost of $1.5M, and WWVH was relocated to Kauai in 1970 at a cost of $1.2M. Using the GNP deflators, the present capital value of the radio stations is $6.1M in plant, facilities, and land in Fort Collins (WWVH is located on a military establishment). After a major cost reduction program due to automation and substantial staff reductions in the 1974-1977 period, the radio stations began a period of minimum subsistance level operation that will be continued for the foreseeable future. During the last year, the stations transmitted at better than 99.9% of the time indicating the success of the automation programs which were carried out inhouse.

Current annual operational expenses at the stations have been cut by $400K relative to the level projected before automation, in spite of the fact that electric power bills have increased dramatically in the last few years and presently stand at the $254K level.

In addition to routine maintenance at the station, the transmitters, time code generators, environmental control systems, antenna support systems, and electric power systems at WWVB have been updated during the last year, so that a 15 year lifetime can be expected from the improved systems.

During the last ten years, the dissemination research program was born, blossomed, and faded, but operational programs resulting from this research are in place within and outside the Division. Late in the 1960's, an effort to identify new options for time and frequency dissemination was undertaken. As a result of this effort, Congress allocated $455K to the Dissimination Reseach program for TV, satellite, and Omega Service implementation in FY73. This Congressional initiative, plus the WWVH initiative, made the time and frequency dissemination programs the most successful of all NBS programs in obtaining Congressional initiative funding for NBS programs. These research programs resulted in the development of the GOES service, TV time and frequency calibrations (and captioning for the deaf), and the beginnings of the MAP program. In addition to numerous technical papers regarding the research results, the dissemination research program earned 6 NBS awards including the Harris Applied Research Award, 2 Department of Commerce awards (a Bronze medal and an Inventor's Award), two patents, an IR-100 award, and an Emmy Award (for the modification of the Division developed TV Time technique for captioning for the deaf). Today, there is essentially no time and frequency dissemination research being conducted in the Division.

The GOES time code, transmitted at 468 MHz from two NOAA satellites and fed from an uplink from Wallops Island, VA, has been operational for three years. This time code was the first routine time broadcast from a satellite, but because it was established mainly to serve the NOAA data buoy system, the transmission frequency is in the satellite meteorology band, not in the 400 MHz time and frequency allocated band. During the last year, the automation and upgrading of the Wallops Island time code instrumentation was completed. The new triply-redundant system allows updating and troubleshooting via phone lines from Boulder, more frequent updating of the satellite position information included in the format, and improved monitoring and control of the timing signals. The updating was extremely successful, and no maintanance travel to Wallops Island was required during the year. During FY81, direct access to the NOAA computer in Suitland, MD for satellite position information is planned. This direct access (assuming that suitable arrangements can be made with NOAA) will eliminate Division ephemeris calculations, provide better real time data, and reduce the Division costs for the operation. In FY82, the GOES time code operation will join the radio stations in the minimum subsistence mode of operation. Although the present formal agreement between NBS and NOAA for the GOES time code ends in 1982, another 5 year commitment is anticipated.

The TV frequency calibration service is one of the most accurate means to access the NBS standards outside of portable clock trips. However, TV technology is changing and the industry trend towards the use of frame synchronizers at some network stations may gradually reduce the usefulness of the TV technique for frequency calibrations except within local geographical areas. It is anticipated that sales of commercial TV calibration systems will decline during the next few years, and the future of this system is uncertain. However, the NBS calibration system is completely automated and now requires only a few hours per month of effort to keep the system operating.

The only program in the dissemination area that is not on a minimum subsistence level is the Measurement Assurance Program (MAP). The concept of the MAP technique is the automated calibration of locally received time and frequency information coordinated through a telephone connection to an NBS computerized monitoring system. The MAP service is being developed on other agency funding using off-the-shelf commercial equipment (no NBS responsibility to repair or calibrate this equipment). The locally received time information can be from GOES, WWVB, Omega, Loran-C, or TV. The MAP concept is extremely important in long range planning because high precision time and frequency transfer will increasingly be piggybacked on other types of communication systems. In the long run, most access to the NBS standards will be through the calibration of other transmissions, i.e., the stabilized transmission frequency of a communication system, the transmission from a GPS satellite, etc. Therefore, the MAP concept--calibration of locally available signals--will be important for cost-effective traceability to NBS standards.

4. Frequency Metrology

The objective of the frequency metrology task is to develop and apply frequency based metrology from the microwave to the visible. The task has two important parts--frequency synthesis and applications.

The frequency synthesis effort is motivated primarily by the needs of the international standards community and the needs of other agencies requiring precise frequency based measurements and metrology. The Division has demonstated that frequency synthesis to the visible was feasible through a joint experiment with the Canadians, where a 1.15 micron laser was doubled to a visible frequency in a crystal and a saturated absorption was used for stabilization. This experiment completed the feasibility demonstration phase of the frequency multiplication into the visible.

During the last CCDM meeting in 1979, it was recommended that if length metrology could be accomplished more accurately by frequency based metrology, the definition of the meter should be changed to take advantage of the increased measurement accuracy. NBS made a commitment to extend frequency based metrology to the visible region with parts in 10^9 uncertainty before the 1982 CCDM meeting.

For the CCDM effort, a scheme has been developed to mix the fifth harmonic of a locked 11.5 micron CO_2 laser with a signal from a color center laser operating at 2.3 micron, whose second harmonic is locked to a 1.15 micron HeNe laser. The second harmonic of the 1.15 micron laser is locked to a saturated absorption line in iodine. During the last year, the 130 THz CO_2 line was measured to a precision of 0.6 parts in 10^{-9}, design and parts ordering for the YAG pumped KCl:LiCl $(F_2{+})_A$ color center laser was completed, and the iodine saturable absorption system was completed. During FY81, an NRC postdoc will complete the construction of the color center laser, and preliminary attempts at the 10^9 measurement will be completed. By early FY 82, final measurements of the 520 THz iodine line will be completed, an error estimate will be made and documented, and the results will be forwarded to the CCDM in advance of the 1982 meeting.

The CO_2 laser is one of the main lasers used in the frequency metrology program. These lasers have been in a state of development and refinement at NBS since 1969, and serve a multitude of functions including routine frequency synthesis up to 100 Thz, where they serve as secondary standards and as high power optical pumps for infrared lasers (such as the alcohol lasers). The latest versions have increased mechanical stability and no Brewster windows in order to reduce the spectral linewidth to approximately 6 KHz, a factor of three better than previous designs.

The first significant milestone in the synthesis effort occurred in 1973 when two CO_2 lines (one at 32 THz in the 9 micron band and one at 29 THz in the 10 micron band) were measured with respect to the cesium standard, each carbon dioxide line being measured with an uncertainity of about 25 KHz ($\sim 10^{-9}$). Since that time, over 80 lines in the normal CO_2 bands have been measured at NBS, and over 600 lines have been measured by other laboratories using the original NBS 9 and 10 micron benchmark frequencies. All of these lines were measured with lasers stabilized by CO_2 saturated absorption techniques. The uncertainty of the NBS measurements is about one part in 10^9.

During the last year, 18 lines in the $[01^1 1 - 11^1 0]$ band of $^{13}C^{16}O_2$ near 11.6 microns were measured with the stabilized $^{13}CO_2$ laser as the source. In addition to the 100 plus carbon dioxide lines, 287 alcohol and difluoromethane FIR laser lines have been measured and published. The measurement of these FIR lines was made possible by the highly stable carbon dioxide lasers ability to generate a near continuum of far infrared frequencies which can be beat with the alcohol laser frequencies. The alcohol and difluoromethane laser lines were measured because of the importance of these alcohol lasers in infrared spectroscopy, and because of the need for these measurements for space and astromonical research.

In other areas of the frequency synthesis program, the frequencies of new $^{13}CO_2$ laser hot band (01^11 - 11^10) were measured. These new hot band measurements were required to supplement the normal $^{13}CO_2$ laser frequency range and thus extend frequency measurements of the ν_1 band of OCS at 11.6 microns across the band center. Both normal and hot band lasing lines of $^{13}CO_2$ were also used to measure key [20^00 - 10^00] hot band lines of OCS in order to predict frequencies for the $2\nu_1$ band at 5.8 microns. OCS is one of two molecules selected for use as an absorption frequency/wavelength standard-- the other molecule is N_2O. These linear molecules were selected because they lend themselves to exact analyses and hence to reliably calculated frequency values. Additionally, they have many lines in the 5 to 12 micron range and the frequency spacing between lines is the same order as the tuning range for a tunable laser, i.e., 15-30 GHz. Current state-of-the-art for tunable lasers requires such absorption frequency/wavelengh standards to provide spectroscopic calibrations to better than 3 MHz. These calibrations are important in federal and commercial isotope separation, in atmospheric pollution monitoring, and in space research programs.

In the 11.6 micron measurements, the diode laser was locked to the center of the OCS absorption line, and the beat frequency between the diode laser and a known $^{13}CO_2$ laser frequency was measured. The accuracy of these measurements is ± 2MHz in the best cases. The experimental range of the frequency measurement system will increase upon receipt of a 1500 MHz bandwidth HgCdTe detector to replace an existing 100 MHz device. In FY81, the OCS $2\nu_1$ band measurements will be completed by using the same technique except with a CO reference laser and, in turn, the laser reference lines will be measured with respect to the CO_2 standards.

These same techniques will also be applied to several isotopic species of OCS such as ^{18}OCS, $O^{13}CS$, and $OC^{34}S$ in order to expand the total number of reference frequencies available. Frequency measurement on N_2 will also start in FY81. The [10^00 - 00^00] band at 8 micrometers is of greatest interest. The ideal method of making these measurements at 8 microns with a MIM diode will require a technological breakthrough and some effort will be directed toward that goal. An alternate approach will involve an indirect route through measurements of the [00^01 - 00^00] band at 4.4 microns and calculations performed in the Molecular Spectroscopy Division. The measurement of these reference standard frequencies is directed toward NASA programs for atmospheric pollution monitoring and analysis and other research programs being undertaken at major university and government labs, such as the University of California, Berkeley (to search for OCS in the atmosphere of Venus), and Los Alamos (for potential isotope separation programs). The ultimate objective of this program is to provide accurate reference frequencies between 1 and 20 microns based on the CO_2 laser frequency measurements which are measured with respect to the cesium standard. The priorities in the completion of these measurements are determined by user needs.

Ramsey fringes have long been used to stabilize microwave oscillators and as an analytic tool to determine the velocity pattern in atomic beam standards. Two years ago, Ramsey fringes were observed for the first time in the visible using a Ne beam at NBS, JILA. One of those original contributors to optical Ramsey fringes in neon helped bring the method to fruition in calcium a year later. However, a present experiment using a CO_2 laser, Ramsey fringes, and a cooperative effort of French and Division personnel may result in a factor of approximately 50 increase in resolution at 10 μm over the best previous measurements. A large 70 cm cell (at the University of Northern Paris) is being used to observe 10 μm transitions in the OsO_4 molecule with three interrogation regions. A highly stabilized CO_2 laser beam is used to observe an infrared Ramsey pattern. Although the experimental setup is not yet complete, the large lasers operation necessary for narrow Ramsey fringes, the long cell length (20 m), the large beamwidth necessary for signal-to-noise, and the high stability of the laser and retroflector system may result in the observation of a 30 Hz transit time limited linewidth. The significance of this is that heretofore undetected molecular structure which can affect line shapes can be investigated. Also, this system makes it possible to measure the relative frequency separation of a number of 10 μm lines with much higher accuracy than previously possible. Once the frequency of one of these lines is carefully measured, an absolute frequency reference in the 10 μm region with at least a factor of 10 improvement over the present CO_2 grid will be established. Plans for FY81 include the completion of the 10 micron Ramsey work to observe narrow lines in OsO_4, and the completion of the analysis of the original calcium recoil pattern to theoretically explain the observed power shift. Because of budget limitations and the high priority of the CCDM experiments, this area of the 10 micron and optical standards program will be terminated during FY81, unless outside resources can be obtained. The extension of this work to attempt to observe theoretically predicted structure on the Ramsey pattern at the 1 to 2 Hz level will be left to the French labs, which are able to obtain funding from the the French equivalent of the NSF.

Laser Magnetic Resonance (LMR) was initiated in a 1966 experiment at NBS. Laser Magnetic Resonance spectroscopy expanded because of its high sensitivity and the advent of the optically pumped far-infrared lasers. During the last year, LMR spectrometers were transferred to NOAA in exchange for funds to purchase a new computer controlled magnet and parts for a better LMR spectrometer system. The new magnet will result in a 3 times improvement of signal-to-noise because of the larger, more homogeneous field area. The new laser system will eliminate a previous positive feedback loop from the alcohol laser to the pump laser. LMR work completed during the year includes the measurement of the CH and OH spectra. Spectroscopy planned for FY81 includes remeasuring the atomic carbon fine structure levels to obtain a more precise value of the ^{12}C and ^{13}C frequencies, fit the observed spectra of CH to obtain transition frequencies and molecular constants important in radio astronomy, and to search for the rotational spectra of SiH. Although the emphasis for the next two years will be the observation and measurement of free radical parameters, flexibility will be maintained in order to make specific measurements required by atmospheric modelers or for pollution controversies.

Another major area of frequency application is the laser geodimeter. This instrument is an outgrowth of previous work on laser strainmeters. In the early 1970s, a 30-meter interferometer was constructed in the Poor Man Mine in Boulder Canyon as part of the measurement of the velocity of light. The interferometer was converted to a laser strainmenter by the addition of a methane-stabilized helium-neon laser. This strainmeter was able to detect earth tides, as well as higher frequency disturbances (e.g., earthquakes and nuclear explosions). A study of the earth tides led to one of the most definitive measurements to date of the nearly diurnal resonance produced by the interaction of the core and the mantle. The system was also used to set an upper bound on the gravitational wave flux reaching the earth from the crab pulsar. This work received some NSF funding through the University of Colorado, but was supported mostly by Division funds.

At the same time as the strainmeter was being used for earth tide work, its limitations--mostly the fact that it was not in a tectonically active area and that it was almost impossible to move--became more apparent, and interest shifted to the possibility of constructing a portable instrument. Such an instrument would measure distances directly through the atmosphere rather than through an evacuated pipe, and so some means of determining the refractivity of the atmosphere was essential.

Several attempts at constructing such an instrument had been undertaken by other groups in Boulder in the past (in NOAA and what is now ITS), and some of the equipment was inherited. A three wavelength one-way device was planned that, in principle, would be limited solely by the fluctuations and the chromatic aberration of the atmosphere. Partial NASA funding was received, and most of the instrument was completed. In the meantime, the Geological Survey has come to appreciate the utility of the multiple wavelength approach, and has offered additional funds to complete the project.

As designed, the geodimeter should be able to measure distances on the order of 50 km with an uncertainty of a few mm. It could also be used as a refractometer; that is, an instrument that determines the index of refraction of the atmosphere. In this application, it would be used to correct distance measurements obtained by other techniques (e.g., single wavelength terrestrial instruments or satellite measurements).

During the last year, the microwave portion of the device was completed and the two laser systems are being completed. During FY81, the instrumentation will be completed. In FY82, the geodimeter will be field tested to determine its accuracy, and field tests are planned in earthquake active areas in California. The precision length measurement potential of the geodimeter are also expected to be applied for accurate range measurements to satellites to be used in precision measurement experiments by NASA to determine crustal motion, to accurately determine survey benchmarks, and to measure atmospheric water vapor. Atmospheric water vapor is of great interest in remote sensing, especially by the military for the prediction of path effects on high power lasers.

In parallel with the geodimeter efforts, other agencies have requested the development of other geophysics instrumentation. During the last year, the development of an array of very high precision tiltmeters was begun for the Air Force, and the operation of a cryogenic gravity meter for the University of California was undertaken. These efforts were mostly in response to solicitations from these agencies in recognition of Division expertise in the area of precision measurements.

The interest in atmospheric water vapor, potential ability to accurately measure it, the longer term goal to replace calibrated measurement systems with intrinsic measurements, the availability of other agency funds, and the availability of inhouse expertise resulted in the initiation of a program to determine the physics of phase changes in atmospheric water vapor. This three year program was begun last year and the first experimental results are not expected until FY81.

III. PUBLICATIONS AND INTERACTIONS

Included in the pages of this section are the following:

§ Publications

§ Invited Talks

§ Technical and Professional Committee Participation and Leadership

§ Seminars

§ Consulting and Advisory Participation

§ Special Reports

§ Trips Sponsored by Others

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INVITED TALKS

Time and Frequency Division (524)

J. C. Bergquist, "Saturated Absorption Optical Ramsey Fringes and Synchrotron Frequency Dividers," Yale University, New Haven, CT, March 7, 1979 and University of Connecticut, Storrs, CT, March 8, 1979.

A. S. Risley, "Study of the Dependence of Frequency Upon Microwave Power of Wall-Coated and Buffer Gas Filled Passive Rb^{87} Frequency Standards," 33rd Annual Symposium on Frequency Control, Atlantic City, NJ, May 31, 1979.

D. A. Howe, "A Small Passively Operated Hydrogen Maser," 33rd Annual Symposium on Frequency Control, Atlantic City, NJ, May 31, 1979.

J. C. Bergquist, "Laser to Microwave Frequency Division Using Synchrotron Radiation," 33rd Annual Symposium on Frequency Control, Atlantic City, NJ, May 31, 1979.

J. C. Bergquist, "High Resolution Spectroscopy of Calcium Atoms," 4th International Conference on Laser Spectroscopy, Rottach-Eagern, West Germany, June 12, 1979.

S. R. Stein, "Frequency and Time: Present Status and Future Prospects," 33rd Annual Symposium on Electromagnetic Compatibility (EMC) and Instrumentation & Measurement (I&M) IEEE, Boulder, CO, April 27, 1979.

J. A. Barnes, "Time Standards," Kiwanis Club, Boulder, CO, June 13, 1979.

F. L. Walls, "Future of Quartz Resonator Thermometry," Workshop on: Techniques for Measurement of Thermodynamic Properties, Linn-Denton Junior College, Albany, Oregon, August 21, 1979.

L. L. Lewis, "Parity Nonconservation in Atomic Bismuth," International Workshop of Neutral Current Interactions in Atoms, Cargése, Corsica, September 10-14, 1979.

K. M. Evenson, "Unification of Time and Length Standards via Laser Frequency Measurements," American Physical Society, Rochester, NY, October 12/13, 1979.

D. J. Wineland, "Limitations on Long-Term Stability and Accuracy in Atomic Clocks," Eleventh Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Greenbelt, MD, November 27, 1979.

S. R. Stein, "Impact of Improved Clocks and Oscillators on Communications and Navigation Systems," Eleventh Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Greenbelt, MD, November 27, 1979.

F. L. Walls, "Prospects for Advances in Microwave Atomic Frequency Standards," Eleventh Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Greenbelt, MD, November 29, 1979.

K. M. Evenson, "Essentials of Frequency Measurements to the Visible and Redefinition of the Meter," NBS Center for Absolute Physical Quantities, Gaithersburg, MD, November 13, 1979.

K. B. Persson, "Theory of the Hollow Cathode Discharge and Modeling of Lasers Based on Sputtering and Charge Transfer," Lasers '79 Conference, Orlando, FL, December 20, 1979.

J. A. Barnes, "The Solar Sun Spot Cycle as an ARIMA Process," American Geophysical Union, Boulder, CO, November 13, 1979.

R. E. Beehler, "Operational Time Dissemination via GOES and TRANSIT Satellite Systems," Eleventh Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Greenbelt, MD, November 28, 1979.

D. J. Wineland, "Laser Induced Magnetron Compression (Expansion) of Ions Stored in a Penning Trap," American Physical Society (DEAP) Meeting, Houston, TX, December 11, 1979.

W. M. Itano, "Frequency and Time Standards Utilizing Laser Cooled Ions," American Physical Society (DEAP) Meeting, Houston, TX, December 11, 1979.

S. R. Stein, "Frequency Stability Results for a Modified Cesium Beam Tube," 34th Annual Frequency Control Symposium, Philadelphia, PA, May 28-30, 1980.

D. J. Wineland, "Laser Cooling of Stored Ions," University of Chicago, Chicago, IL, April 18, 1980.

D. J. Wineland, "Optical Pumping and Double Resonance Experiments on Laser Cooled Ions," IEEE, Quantum Electronics Conference, Boston, MA, June 23, 1980.

J. S. Wells, "Heterodyne Measurements and Frequency Calibration Tables for the 11.6 μm Band of Carbonyl Sulfide (OCS)," 35th Symposium on Molecular Spectroscopy, Columbus, OH, June 19, 1980.

W. M. Itano, "High Resolution RF Spectroscopy of Laser Cooled $^{25}Mg^+$ Ions," International Conference on Atomic Physics, Cambridge, MA, August 7, 1980.

J. C. Bergquist, "Methods of High Resolution Laser Spectroscopy - From Ramsey Fringes to Radiation Pressure Cooling," Colorado State University, Ft. Collins, CO October 10, 1980.

W. M. Itano, "Laser Cooling of Trapped Ions," Molecular Physics Labs, SRI International, Menlo Park, CA, September 11, 1980.

D. J. Wineland, "Spectroscopy of Laser Cooled Ions," Washington University, St. Louis, MO, September 10, 1980.

D. J. Wineland, "Particles at Rest in Space: The Spectroscopist's Ideal," University of Colorado, Boulder, CO, September 24, 1980.

L. L. Lewis, "Atomic Parity Violation Experiments," U.S.-Japan Seminar on Nonlinear Laser Spectroscopy, Kauai, Hawaii, September 8-12, 1980.

D. J. Wineland, "Atoms at Rest in Space: The Spectroscopist's Ideal," Johns Hopkins University, Laurel, MD, November 5, 1980.

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, Program Chairman, 1982 CEPM

D. W. Allan, Consultative Committee for the Definition of the Second (CCDS).

D. W. Allan, IEEE IM TC-3 Frequency and Time

R. L. Barger, International Union of Radio Science (URSI)

J. A. Barnes, Consultative Committee for the Definition of the Second (CCDS), CCIR.

J. A. Barnes, IEEE Technical Committee on Frequency and Time: Subcommittee on Frequency Stability

J. A. Barnes, JPL, Hydrogen Maser Comparison Test Formal Review Board

R. E. Beehler, CCIR Study Group VII; International Chairman of Interim Working Party 7/4 on "Improved Time Coordination and Dissemination Using Satellites"

R. E. Beehler, PTTI Editoral Committee

D. D. Davis, Member Technical Advisory Committee for TDRSS, NASA Satellite Program

K. M. Evenson, URSI Commission D

J. L. Jespersen, Chairman IRIG Timing Committee

J. L. Jespersen, CCIR

G. Kamas, Measurement Assurance Subcommittee, National Conference of Standards Laboratories

S. L. Howe, PTTI Editorial Committee

S. R. Stein, PTTI Technical Program Committee

F. L. Walls, IEEE IM TC-3 Frequency and Time

F. L. Walls, Steering Committee, 3rd Symposium on Frequency Standards and Metrology

F. L. Walls, Technical Program Committee, PTTI

D. J. Wineland, Committee for NBS Precision Measurements Grants

SEMINARS

Time and Frequency Division (524)

Time and Frequency Users' Seminar, Boulder, CO, April 30 - May 1, 1980.

Time and Frequency Users' Seminar, Boulder, CO, August 27-28, 1980.

CONSULTING AND ADVISORY PARTICIPATION

Time and Frequency Division (524)

J. L. Jespersen Consulting with the Defense Communication Systems on TV captioning techniques.

J. L. Jespersen consulting with National Telecommunications and Information Administration on TV captioning techniques.

J. L. Jespersen consulting with National Oceanic and Atmospheric Administration on development of weather dissemination on GOES Satellite.

D. D. Davis consulting with National Oceanic and Atmospheric Administration on maintenance and operation of GOES equipment.

A. J. D. Clements consulting with National Oceanic and Atmospheric Administration on maintenance and operation of GOES equipment.

J. A. Barnes consulting with IAU, Commission 31.

SPECIAL REPORTS

Time and Frequency Division (524)

Final Report - CCG 79-142: "Satellite-Controlled Clock Study," R. E. Beehler, Principle Investigator.

Final Report - NOAA Contract No. 31 USC 686: "Study of the Feasibility of Using GOES for Position Location," J. L. Jespersen, Priciple Investigator, A. J. D. Clements, D. D. Davis, M. Weiss, Contributors.

Final Report - Samso Contract No. SMS 0400, "Global Positioning System Clock Development for Time and Frequency Division," D. W. Allan and F. L. Walls, Principal Investigators.

TRIPS SPONSORED BY OTHERS

Time and Frequency Division (524)

K. M. Evenson	October 11-13, 1979 - Webster, New York Invited speaker at October American Physical Society Fall Meeting. Presented "The Unification of Time and Length Standards via Laser Frequency Measurements." Sponsor: American Physical Society
J. Levine	October 10, 1979 - Houston, Texas Invited speaker at joint Physics/Geology colloquium. Sponsor: Dept. of Physics, Rice University
	November 8-9, 1979 - Washington, D.C. Attended a meeting of the Panel on Global Positioning System, National Academy of Science. Sponsor: National Research Council
J. L. Jespersen	April 8 - 29, 1980 - New Delhi, India Served as technical consultant in India to organize an International Telecommunications Union (ITU) sponsored seminar on Time and Frequency Technology conducted by the National Physical Lab of New Delhi. Sponsor: ITU in cooperation with the United Nations Development Commission
D. J. Wineland	April 17-18, 1980 - Chicago, Illinois Presented colloquium concerning Laser Cooled Ions. Sponsor: The Enrico Fermi Institute, University of Chicago
	September 11, 1980 - St. Louis, Missouri Presented colloquium entitled "Spectroscopy of Laser Cooled Ions." Sponsor: Physics Dept., Washington University

QUANTUM PHYSICS DIVISION

SUMMARY OF ACTIVITIES

Fiscal Year 1980

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.

When JILA was formed in 1962, "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 the understanding of reaction mechanisms in the atmosphere; to the collection and evaluation of the scientific data; and to the education of scientists.

Recognizing the dynamic nature of the unique partnership, and the need for the formal agreement between institutions to allow for evolving goals with changing national interests, Dr. Ernest Ambler, Director of the National Bureau of Standards and Dr. Roland Rautenstraus, President of the University of Colorado, in March 1976 signed an ammendment to the Memorandum of Understanding which states:

> "In view of these contributions and the importance of atomic and molecular science as basic to the principles and standards of modern measurements, as well as the vitality of astrophysics as a major science in the academic environment, the purpose and role of the Joint Institute for Laboratory Astrophysics shall continue to evolve and expand beyond the areas of science outlined in the original Memorandum of Understanding.
>
> - It will, for the fields of atomic and molecular science, astrophysics, and broadly related areas such as laser physics and chemistry, continue to provide a center for the dissemination and exchange of ideas and data through, for example, the Visiting Scientists Program.
>
> - It will, in these fields, continue to provide for the education of scientists at the graduate and postdoctoral levels.

- It will, through the collaboration of its scientists from the National Bureau of Standards and the University of Colorado, and through research and teaching in these fields, continue to be cognizant of and responsive to the missions of its parent organizations as well as the national needs which are affected by these missions. Toward these ends it will continue to promote close interactions with its colleagues in both institutions."

At the time of the April 1978 reorganization of NBS, the Bureau stated that the QPD as part of the Center for Absolute Physical Quantities:

- 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 association 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.

- Maintains a staff and structure to respond quickly to new ideas and reprogramming.

The Quantum Physics Division currently has substantial research programs in five general areas, to be discussed in more detail later:

1. Fundamental precision measurements. Work here includes programs in laser stabilization, Ramsey fringes, Rydberg levels, quantum defect, blackbody radiation shift of atomic energy levels, tests of special relativity, Eotvös experiment, fundamental limitations in interferometry, and detection of gravity waves.

2. Chemical physics. Programs are in laser-initiated, chemical chain reactions, ion-molecule reaction dynamics, and photofragmentation infrared emission spectroscopy.

3. Astrophysical measurement. This includes programs investigating solar atmosphere convection, thermodynamic properties of solar flare plasmas via Skylab spectra, cool star atmospheres via IUE satellite observations, chromospheres and coronae of stars, and radiation transport.

4. Atomic and molecular physics and interactions. Current programs are in excitation/ionization/recombination of ions by electron impact, trapped ion dynamics, ion-molecule processes, rate coefficents, line broadening, potential functions, laser photoionization and Raman spectroscopy, atoms in intense chaotic radiation fields, theory of multiphoton processes, laser-induced collisions, electron scattering from polar molecules, secondary electrons from ionization, modeling of electric discharges, and atomic and molecular processes involved in depositions of amorphous silicon hydride films.

5. Geophysical measurement methods. The programs here are in laser ranging, crustal movement, plate tectonics, portable gravimeter, and a gravity gradiometer. Other NBS programs in JILA, but managed by a member of Div. 524, involve a three wave geodimeter and gravity tiltmeters.

Before discussing the various programs in more detail, it is appropriate to elaborate a bit more on JILA as an institute, since it is difficult to discuss the Quantum Physics Division out of context with JILA.

Currently, there are 148 total staff in JILA distributed according to Fig. 1. This figure fluctuates substantially over a year's time, since there is an annual scientific turnover of 40 to 50 persons.

The permanent Ph.D. Staff or "Fellows of JILA" of which there are 26 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-ennially as the principal officer of the Institute, and is responsible for operating the Institute within the limits of policy set forth by the Fellows. An Executive Committee assists the Chairman with policy matters of shorter duration or lesser moment that would command attention of the Fellows, and the Executive Officer deals with most administrative matters as delegated by the Chairman. Of the 26 Fellows, 11 are CU full-time faculty from the Departments of Physics, Chemistry, and Astro-Geophysics, 14 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 same staff member were that person rostered in another administrative unit and location, without consideration of

JILA STAFFING
1980-81
(148 Total)

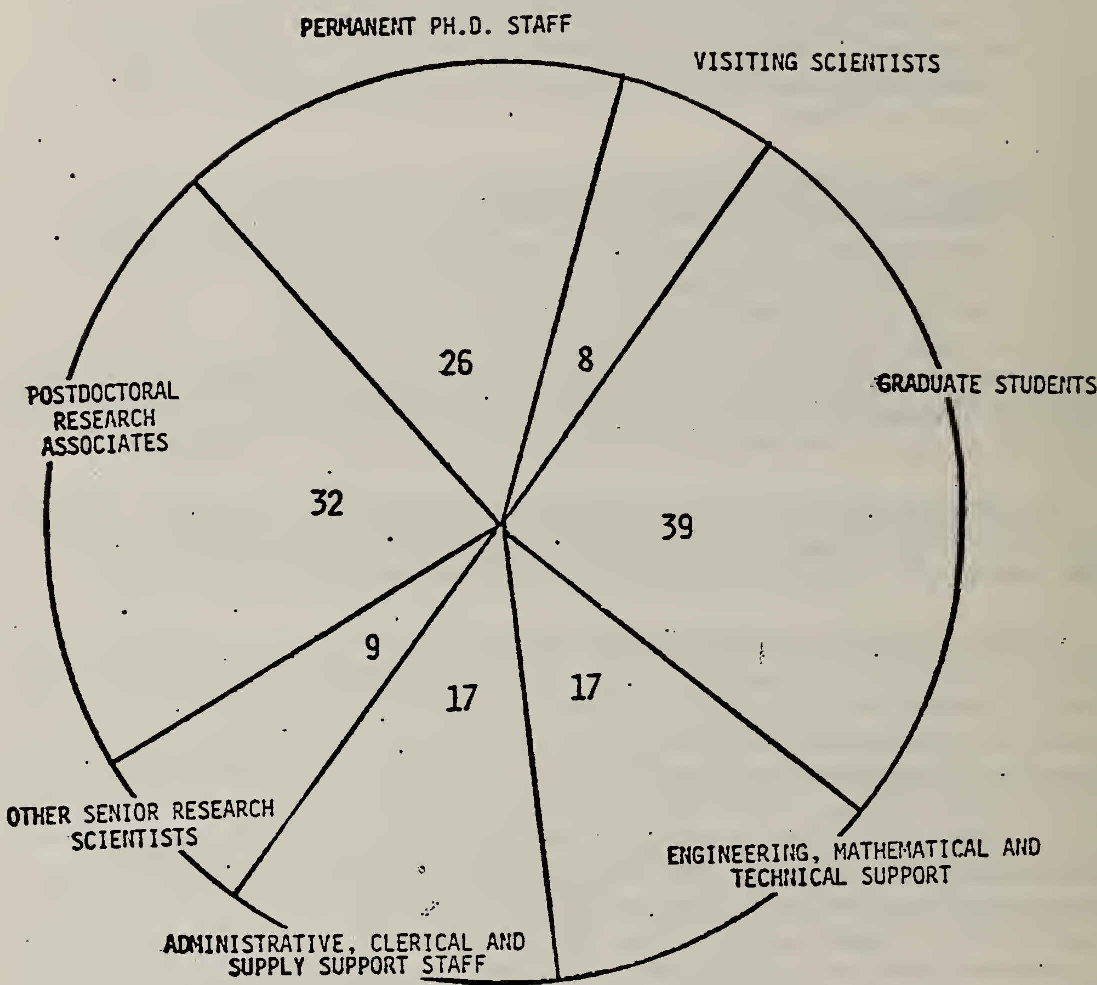

Figure 1.

any special privileges or liabilities deriving from participation in JILA or from designation as a Fellow.

One notes from the figure that of the 114 research scientists in JILA, that 71 (or 62%) are postdoctorals and students. There is thus a high level of youthful vitality and turnover in the scientific staff. Of the 39 graduate students, 22 are supervised in their research by NBS scientists through their adjoint appointments. Of the 32 postdoctoral research associates, 18 work on research supervised by NBS scientists. There is thus a tremendous amplification of the efforts or "leverage" of the NBS scientists, achieving at once both University and NBS goals.

The Visiting Fellows program is perhaps one of the main components of "glue" that holds this unique partnership together. This program is funded by NBS by a contract with CU, and provides for the order of 10 senior level scientists to spend from 6 months to 1 year in the Institute. The participants are chosen competitively from a large number of applicants, and the program which has operated for 17 years now has been a spectacular success. Scientific productivity of this group who come with no duties has been very high. For example, of the 324 publications listed in this year's and last year's annual reports by QPD staff and Visiting Fellows, approximately 42% were by Visiting Fellows. This program again provided tremendous amplification of NBS staff. Visiting Fellows for 1979-80 and for 1980-81 are listed in Sec. III.

Goals

The five-year plan for the Center for Absolute Physical Quantities, including the five-year plan for the Quantum Physics Division and the Time and Frequency Division, are in the document by that title. However, it is useful to discuss these goals in a somewhat generic sense, commenting both on the scientific goals and on institutional goals. One of JILA's greatest strengths lies in the expertise it has developed in laser physics. A new era in measurement has been ushered in by the "laser revolution," accompanied by other technological advances. The development and investigation of lasers, and other new technologies for purposes of measurement is a high NBS priority as new orders of accuracy not envisioned before now become possible, exposing new frontiers in scientific investigation. These new techniques make it possible to attack major measurement problems associated with national programs in energy, space, environment, national defense, and earthquake hazard prevention. As the laser is refined as a measurement tool, fundamental postulates of physics become open for new and more refined examination and testing. JILA has played a major role in starting this measurement revolution which is still in its infancy.

Possibilities ahead excite the imagination. The laser revolution will closely parallel the great revolution initiated by digital electronics. Indeed, these two great developments go hand-in-hand, promising a far-reaching "measurement" revolution through the concurrent functions of sensing (with lasers) and recording-processing-controlling (with digital electronics). This process will pervade technology. JILA will continue to be an active player pushing the frontiers of laser physics and laser measurement ahead.

Many projects in progress already are exciting both from the scientific and from the application points of view. Thus, we will continue to work on the exciting new technique we have recently developed for using lasers to excite and measure chain reactions occurring in combustion processes. Laser methods applied in the gravimeter and geodimeter being developed at JILA will help push measurements of earth movement, plate motion, earthquake prediction, etc., into a brand new arena. With the next generation of highly stable lasers being developed at JILA, it may be possible to detect and measure gravitational waves using satellites in stationary orbits. Such an experiment, which would provide the first observation of gravitational waves, is in the design stage at JILA. This new generation of lasers will also make possible new tests on the dilation of time and the isotropy of space.

Growth and technological sophistication of national programs in alternative energy sources, laser development, environmental protection, space activities, defense, and civilian product development have strained the limits of our fundamental understanding of the behavior of atoms and molecules. Needs that have grown out of these programs have highlighted many fundamental processes which it is critical that we understand, but for which no adequate measurement techniques have been developed, and for which theoretical methods and models are not developed or advanced. In many of these areas JILA has unique expertise which is being used to develop measurement methods and make measurements to further the understanding of such processes and to develop theory and make calculations for complementary advances. Such is the case particularly in the areas of electron scattering, energy transfer, molecular photolysis, ion physics, and chemical reaction dynamics. As the above national programs are foreseen to be of high national priority for some time, JILA will continue to have parallel priorities so it can contribute in its unique way to these efforts. An area of rich promise for the future which is closely related to the current expertise in particle collisions and laser physics is that of laser induced collisions. It is an extremely exciting and rapidly blossoming scientific problem today and there are a number of projected applications which may or may not materialize as our understanding of the basic processes increases. One attractive possibility, for example, lies in some day being able to redirect and control chemical reactions at will by the use of lasers.

An area which is new in JILA, but which holds a place in the future, impinges the solar energy and semiconductor fields. Hydrogenated amorphous silicon films are emerging as exciting candidates for inexpensive photovoltaic cells. These amorphous films are poorly understood compared to crystalline cells, but rapid progress is being made in an increasing number of solid state laboratories. In fact, a worldwide competition between industrial laboratories for marketable and patentable cells appears to be under way. The amorphous silicon hydride is produced in discharges of silane. One of the difficulties encountered in trying to understand these films is a lack of comparability between films produced in different laboratories and at different times in the same laboratory. This problem, as well as the inability to systematically control the film properties, is related to poor understanding and control of the discharge. Atomic and molecular collision processes and plasma behavior are important parts of this discharge problem. Members of the Quantum Physics Division at JILA have expertise in these areas, and a new research effort has been launched to understand the detailed atomic and molecular processes involved in formation of these films. It is anticipated that this will be an exciting area for the next few years.

The nation continues to recognize the importance of space exploration and astrophysics. Thus, in the next few years, the space shuttle and important measurement satellites will be launched and used. Most of the astrophysical effort in JILA comes through the CU side of the Institute; however, NBS continues to maintain a "window on astrophysics" through 2 1/2 persons' efforts in JILA. JILA/NBS scientists serve on science commissioning teams for space shuttle experiments. They are active participants in satellite and projected shuttle experiments, and heavily impact measurements made with these instruments. Since the shuttle is just at the stage of coming to realization, these efforts will continue into the future.

Institutionally, JILA recognizes the need to maintain health and viability. With the Visiting Fellows Program, the large postdoctoral program, and graduate students, the turnover in the Institute is about 50 scientists each year. This great flowthrough helps to insure an up-to-date outlook and provide a vitality and excitement for which JILA has come to be known. It is essential that these programs be kept healthy. The most recent addition to JILA's permanent staff on the CU side was a brilliant young scientist, who is only 28 years old. Similarly, the last addition to the NBS permanent staff, which occurred three years ago, was an outstanding young man of similar age. JILA will continue to build with young scientists of the highest qualifications as vacancies are created. Our goal, to insure the continuing health of JILA, is to add such a person every two or three years. Since growth is not needed, it is hoped this can be accomplished mainly within the framework of normal turnover. The focus of JILA's science has in the past evolved to keep abreast of national priorities. It will continue to be the case that NBS research in JILA will be cognizant of national needs in a way that optimum contribution to these needs can be made.

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 precision measurements

Progress was made during the year by Faller and Bender on studies of whether future laser experiments in space can detect gravitational waves with enough sensitivity to see signals from known rotating binary stars, as well as probably signals from other sources. A search for better spacecraft orbits for such experiments has been started, and preliminary papers discussing earlier ideas have been presented at two conferences. Path lengths of the order of one million kilometers are being considered at present. B. Bertotti, who is a Visiting Fellow, is heavily involved in plans to search for possible gravitational waves from stronger sources using microwave Doppler measurements during the International Solar Polar Mission. Measurements with sensitivity approaching 10^{-15} at 1000 second period and requiring hydrogen maser frequency standards at the Deep Space Network tracking stations are planned during the interval when the spacecraft are out near the orbit of Jupiter.

This year J. Faller, M. Keiser, and P. Keyser obtained the first significant results using the fluid (surrogate) fiber Eötvös apparatus. The value obtained for the fractional difference in the ratio of gravitational to inertial mass for copper and tungsten was $\eta = 0.6 \pm 4 \times 10^{-11}$, where

$$\eta \equiv \frac{(M_G/M_I)_{Cu} - (M_G/M_I)_W}{1/2[(M_G/M_I)_{Cu} + (M_G/M_I)_W]} .$$

Study of non-thermal noise sources have indicated mechanical (geometrical) instability of the float and sensor were most probably the reason that the observed float performance was 10× the kT limit. Attempts to improve on the geometrical limitations are now underway. A new 50" diam float which as a result of being 5× larger (diameter) should provide 55× more sensitivity for the same integrating (observation) time is in the final stages of machining. Futher initial contacts have been made with potential suppliers of the needed ~1000 kg of mass material -- most probably Pb and Zn.

Super Spring

This past year, Faller and Rinker devised and built a shake table (providing a truly vertical sinusoidal motion from dc to approximately 40 Hz) in order to experimentally test and verify the super spring performance. The results of this testing are extremely gratifying: the spring provides outstanding isolation (for example >50 db at 1 Hz!) over the frequency range they are able to test which extends from dc up to about 20 Hz. Use of this spring to isolate (suspend) the cube corner in the reference arm in our absolute gravity apparatus reduces our drop-to-drop scatter in "g" by a factor of more than 20. Further, the design and mechanical fabrication has been completed on two new super springs (in which simplicity in construction as well as ease of assembly and disassembly has been emphasized). These two (identical) new units are now in the assembly state. Figure 2 shows an isolation curve where the period has been made abnormally short (12 sec) in order to show up the natural resonance on the curve.

A significant part of the efforts this year of F. Kowalski and J. Hall have been invested in preparing the new laser wavelength-determining interferometer ("Lambdameter") for use at the sub-MegaHertz level ($<10^{-9}$). Several optical improvements have led to a more precise alignment technique for the reference and unknown laser beams. A clever computer averaging algorithm, suggested by J. Snyder of Div. 520, should reduce the random measurement noise of the Lambdameter by a significant factor and thus make the systematic effects more conspicuous. Considering the near-term availability of JILA's new frequency-stabilized ring dye lasers, it was decided to delay final tests and the high accuracy wavelength measurements since the present commercial stabilized dye laser is not really suitable for use at the target accuracy level. The new JILA ring dye laser system developed by J. Goldsmith, L. Hollberg and J. Hall is giving very good performance (20% power conversion and stabilized line width <100 kHz). We plan to build 4 such systems for experiments underway within JILA.

Visiting Fellow, H. Robinson and J. Hall have been studying the laser stabilization technique suggested by R. Drever (Cal Tech) in connection with interferometric gravity wave detection. Some technical improvements, especially in the electro-optic modulator subsystem, promise locking to an accuracy of about 10^{-3} transfer-cavity line widths (~1 kHz). Improved calculations by Visiting Fellow, W. Wing (and J. Farley at Arizona), of the theoretical Rydberg atom level shifts due to their coupling with the 300 K thermal fields give much smaller shifts than our previous estimates. Wing finds an asymptotic value of 2.4 kHz with a T^2 dependence from explicit integration of the light shift formula over the blackbody spectrum. Because of the 10-fold decrease in the theoretical estimate, before attempting the experiment, it seemed valuable to refine the analysis of some two-photon Ramsey fringe data taken earlier by S. A. Lee, J. Helmcke and J. Hall. The Ramsey profile theory was extended further to contain the light shifts produced by the measurement laser fields. A very effective integration technique was developed (J. Shirley [consultant] and C. Kunasz) which made it possible to use the theoretical profile in an interactive way to least-squares fit the data. Excellent fits were obtained. We note that the sharp Ramsey fringe arises from absorbers that evolve most of their phase in the darkness, giving a "dilution" of their light shift. Thus it was possible to use the shift of the background resonance (~10 kHz) to estimate the residual shift of the fringe itself (~1 kHz). The conclusion is that the centers of the optical resonances can be determined to well

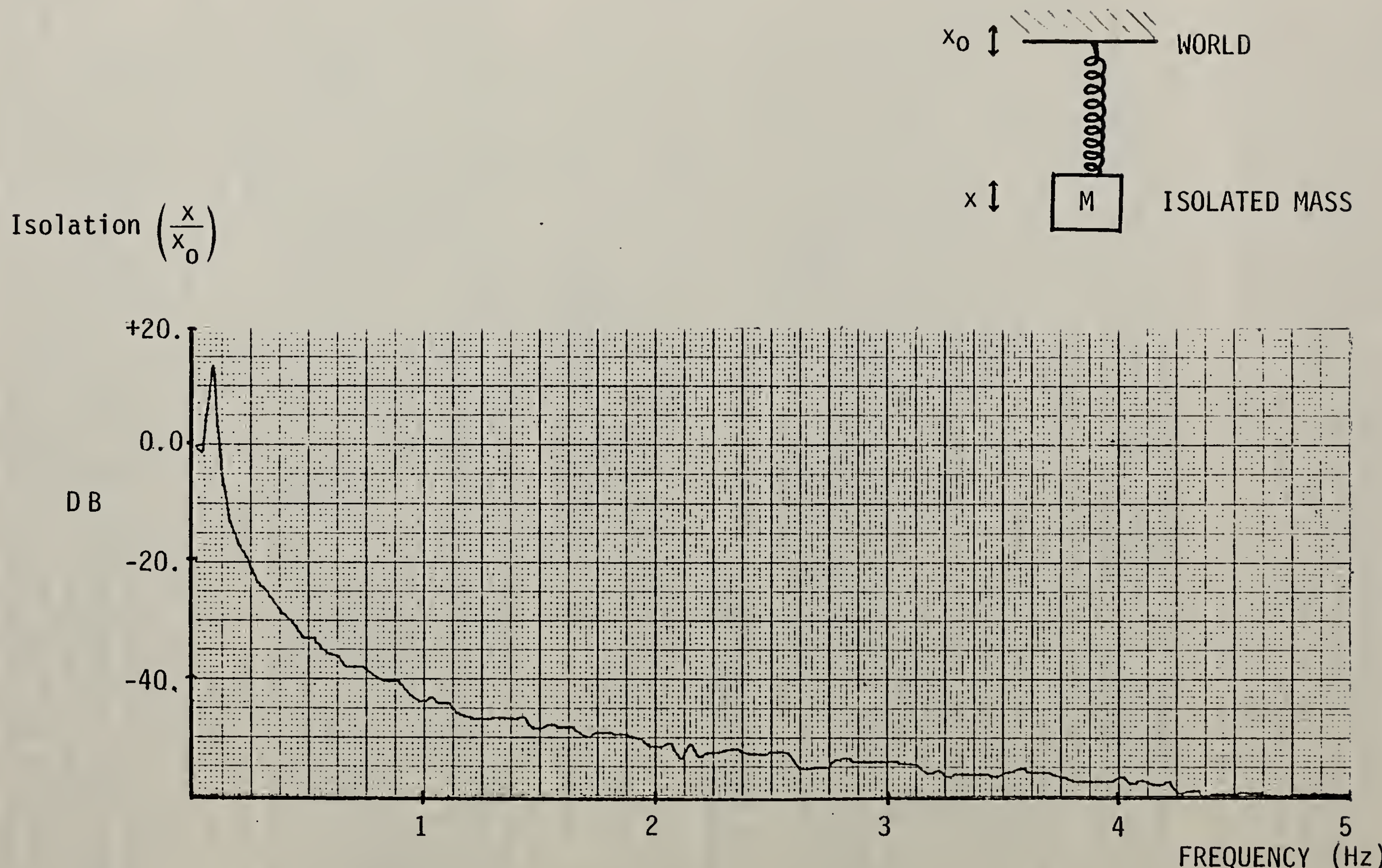

Figure 2. Super Spring Isolation. Period set at 12 seconds -- shorter than usual -- in order that the spring's resonance (at 1/12 Hz) shows up within the resolution of our measurement system.

within 100 Hz, limited mainly by signal/noise considerations. Thus, we still expect to be able to observe and measure the shift of the absolute position of rubidium Rydberg energy levels due to their coupling with the background thermal radiation, and this is being pursued by Hall and Robinson.

A new concept for measuring the relativistic time dilation to high accuracy was developed by Hall as an extension of our program to measure the helium Rydberg energy levels in a fast atomic beam. Basically the idea is to use a longitudinal interaction geometry with two-photon absorption techniques in an optical standing wave to pump He atoms from 2^1S to 5^1S and 5^1D and from 2^3S to n^3S and n^3D. Detection will be via fluorescence for the lower states, and state-sensitive collisional charge transfer for the upper states. The excitation spectrum will show three main two-photon peaks. The central "Doppler free" peak will have only the second-order Doppler shift (time dilation). It will be flanked by two Doppler-shifted peaks. The displacement of some 30 Å by the first-order Doppler effect will give very precise knowledge of the actual beam velocity. If a sufficiently stable reference line can be found, these first-order-shifted peaks will also allow a very sensitive search for a possible P_1 (cos θ) anisotropy in the speed of light. Finally, it should be recalled that a fundamental by-product of this entire project is a precise knowledge of the absolute energy levels of HeI. Our optical intervals and series limit information, taken with the finestructure and intersystem microwave intervals measured by Wing and Farley, will lead to a definitive knowledge of the excited states of He, with expected accuracy no worse than 5 MHz.

D. G. Hummer has found exact analytic solutions to a class of severely non-linear integral equations derived by JILA Visiting Fellow J. Katriel in 1978-79, from a generalized Bose operator treatment of optical harmonic generation. These operators are used to linearize the relevant equations of motion in various ways, some of which reproduce results obtained by other workers, while others yield new approximations. The integral equations obtained in this way describe the number of photons in the relevant modes and are of the general type (for four-wave mixing)

$$n(t) = a \sin^2 \left(\varepsilon \int_0^t \{[b-n(t')][c-n(t')]\}^{1/2} dt'\right)$$

where a, b, c, and ε are parameters of the system. The solutions are expressed in terms of Jacobian Elliptic functions. This work is described in a paper submitted for publication to the Journal of Physics A. Hummer has subsequently solved substantial generalizations of the prototype equation.

J. Jeffries, S. Barlow and G. Dunn have observed the onset and quenching of collective behavior of a sample of molecular ions confined in a Penning configuration ion trap. A sample of ions in a Penning trap forms a unique single component plasma. When the sample is produced, the spatial extent of the ion cloud is very small compared to the Debye length. As the ion cloud evolves, the Debye length becomes about the same as the spatial extent of the ion cloud (Fig. 3a). When this happens, the onset of collective behavior is observed. This is seen as a rise of a bump in the observed noise power (Fig. 3b). The ion cloud evolution time in the Penning trap is sufficiently long that the details of the changes in the coherence of the ion sample can be monitored by observing the z frequency noise power line width (Fig. 3c). The line width of the z frequency noise power has the same time evolution as the Debye length. The onset of collective behavior is characteristic of the ion sample cooling mechanisms, which reduce the Debye length and are dominated near equilibrium by ion-neutral binary collisions. As the ion sample continues to evolve, the collective behavior is quenched as the Debye length grows again. The radial transport of ions across the magnetic field lowers the ion density, hence the Debye length increases. This is monitored by the growth of the noise power line width (Fig. 3c) and the decay of the coherent bump in the noise power temporal evolution (Fig. 3b). This ability to observe collective behavior evolve makes the ion plasma in the Penning trap unique. The observations appear to be the clearest yet of an example of self-organization of a non-equilibrium system.

Atomic and Molecular Physics and Interactions

D. W. Norcross and D. G. Hummer have completed the first phase of a computational program designed to help satisfy the long-standing need for an absolute calibration standard for electron scattering by atoms and molecules. This involved elastic scattering by neutral helium, an ideal candidate for such a standard that is already being used extensively for this purpose. Results for the position (19.365±0.004 eV), width (10.7±0.1 meV), and background phase shift (1.792±0.02 rad) of the oft-studied ^2S resonance are in very good agreement with measured values of 19.366±0.005 eV, 11.0±0.5 meV, and 1.813±0.015 rad, respectively. These values are the results of the most accurate measurements ever made for helium, indeed for any resonance in electron-atom scattering. The latter two values were measured by A. Gallagher, R. Kennerly and R. Van Brunt. The table below compares the calculated ^2S elastic scattering phase shift with the results of another recent high precision calculation, illustrating both the kind of precision attained and the general convergence of recent theoretical results.

Table 1. ^2S elastic scattering phase shifts for He, with uncertainties in the last figure in parentheses

k^2, Ryd	0.04	0.16	0.36	0.64	1.00
present	-0.2645(8)	-0.537(2)	-0.793(1)	-1.014(2)	-1.201(3)
Nesbet	-0.2655(6)	-0.539(1)	-0.793(1)	-1.015(2)	-1.206(4)

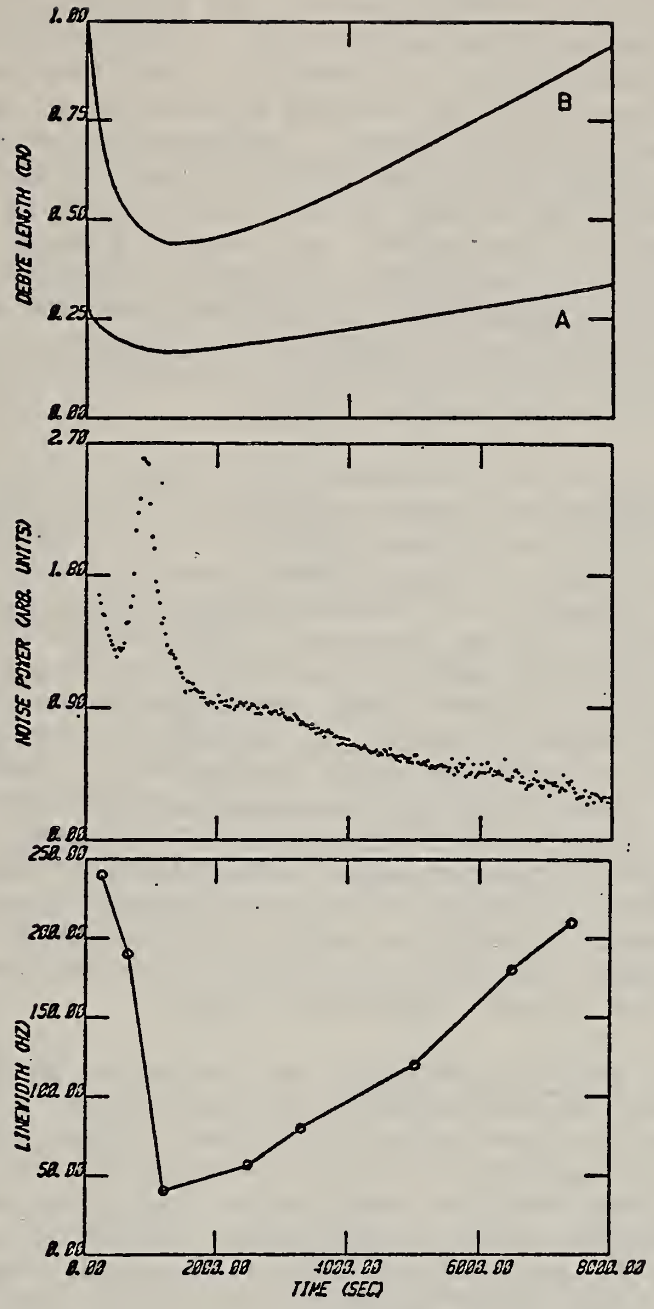

Figure 3. (a) Debye length versus time, (b) Noise power versus time, and (c) line width of noise power signal versus time for ion cloud stored in a Penning trap. At about 1200 sec. where the Debye length is a minimum, the minimum in line width and maximum in noise power show coherent motion of the ions -- an example of self-organization of a non-equilibrium system.

A. K. Pradhan, D. G. Hummer and D. W. Norcross have submitted the first paper of several on cross sections and excitation rates for electron impact excitation of helium-like ions. Autoionizing resonances were included through the use of correlation functions in the solution of the scattering equations and through application of the powerful techniques of Quantum Defect Theory. The resonances were found to make a considerable contribution to the cross sections in many cases, and to consequently enhance the excitation rates by significant factors. Illustrative results for the ion Be^{2+} are shown in Figures 4 and 5. Computation of detailed and exhaustive rate coefficients for several ions in this isoelectronic sequence is in progress, and they expect the results to have very important consequences for practical application in the analysis and modeling of a variety of laboratory (e.g. fusion) and astrophysical (e.g. X-ray sources) plasmas.

D. W. Norcross and R. Christensen are engaged in a detailed computational study of electron impact excitation of the helium-like ion Li^+, the only atomic ion for which measurement of an excitation cross section for anything other than a dipole-allowed transition have been accomplished (by W. T. Rogers, J. O. Olsen and G. H. Dunn). The transition of greatest interest, the one measured, is the 1^1S to 2^3P transition, that due to its optically forbidden nature is expected to be quite sensitive to the details of short-range correlation and exchange effects. It has accordingly been the subject of numerous studies recently, as being prototypical of electron impact excitation of atomic ions so important in the fusion program. The experimental results, shown in Figure 6, appear to be influenced by resonance effects, further stimulating the interest in these results. The results of two recent theoretical studies are also shown, along with those of their preliminary work. None of these calculations include resonance effects, the subject of their future work, but the improved wave functions used in their work appear to yield the correct background trend.

N. T. Padial and D. W. Norcross are continuing to study aspects of the theory of electron scattering by polar molecules. These are important constituents of a wide variety of plasma systems, e.g. the coal-fired MHD power systems and the interstellar medium, and are known to have very large cross sections for electron scattering and unusual properties with respect to electron attachment. Attention has been devoted most recently to the molecule $HC\ell$, that is relatively weakly polar. In one recent publication (Norcross with L. A. Collins and R. J. W. Henry) the importance of a careful treatment of exchange and polarization was demonstrated, with results that appear to have important implications for vibrational excitation. They are also exploring the utility of approximations to a complete treatment of the interaction potential in the region of intermediate angular momentum, where the scattered particle neither penetrates very deeply the molecular charge distribution nor is the process amenable to the simplest perturbation-theoretic treatments. Some of the results of this study are shown in Figure 7, that compares transition matrix elements from a very elaborate calculation with those from an essentially exact calculation for a point dipole, and from the use of the Born approximation with the inclusion of quadrupole effects.

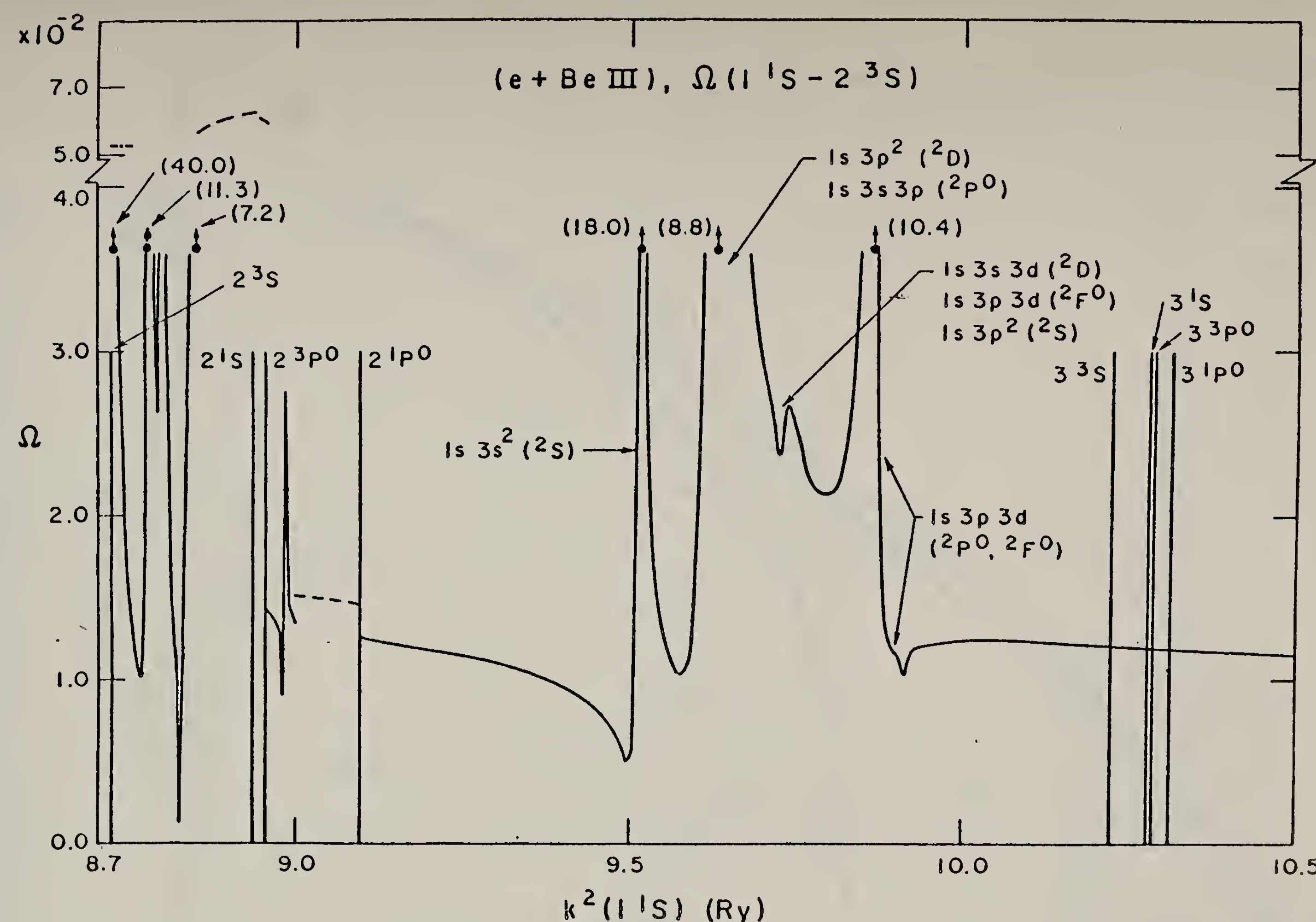

Figure 4. Collision strength for the transition 1^1S to 2^3S in Be^{2+}, as a function of the free electron energy (in Ryd) relative to 1^1S.

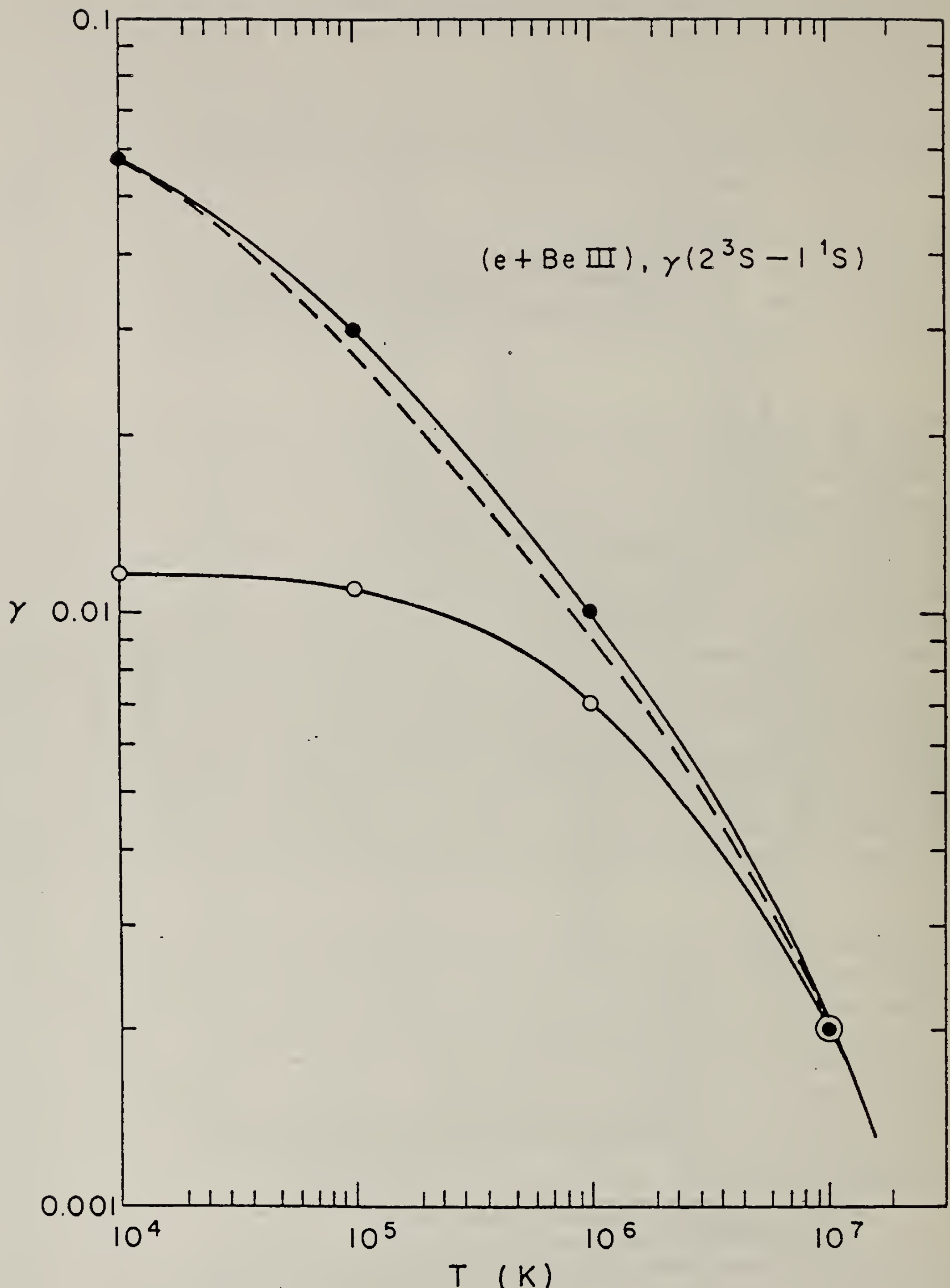

Figure 5. Rate parameter for the transition $1^1S - 2^3S$ in Be^{2+} as a function of electron temperature. Curve —o— is without resonance contribution, curve —●— includes it.

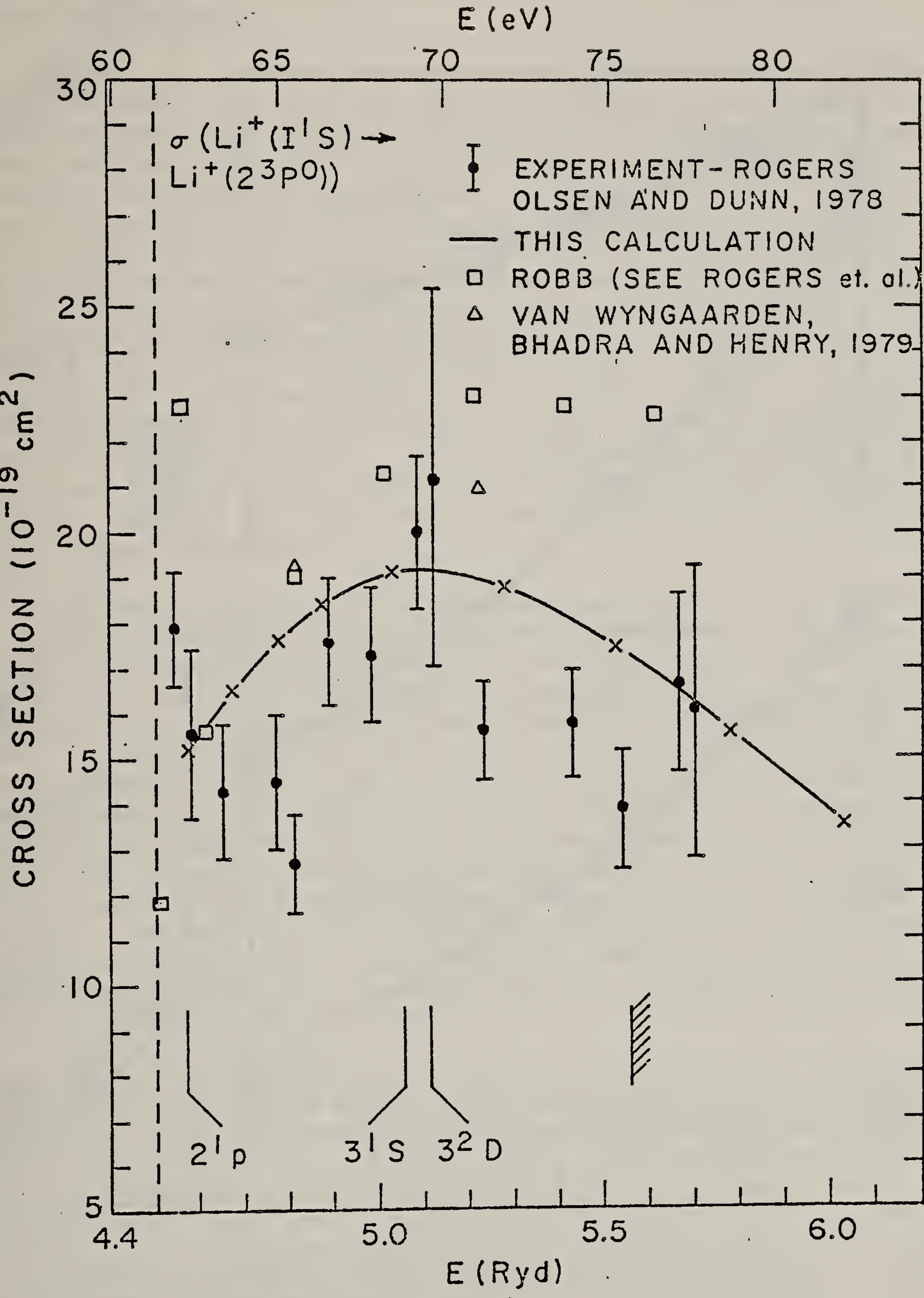

Figure 6. Cross section for excitation of the 2^3P state of Li^+ as a function of electron energy relative to the 1^1S state. Solid circles are the results of Rogers et al., ▲ and ■ those of other calculations, and x the present results.

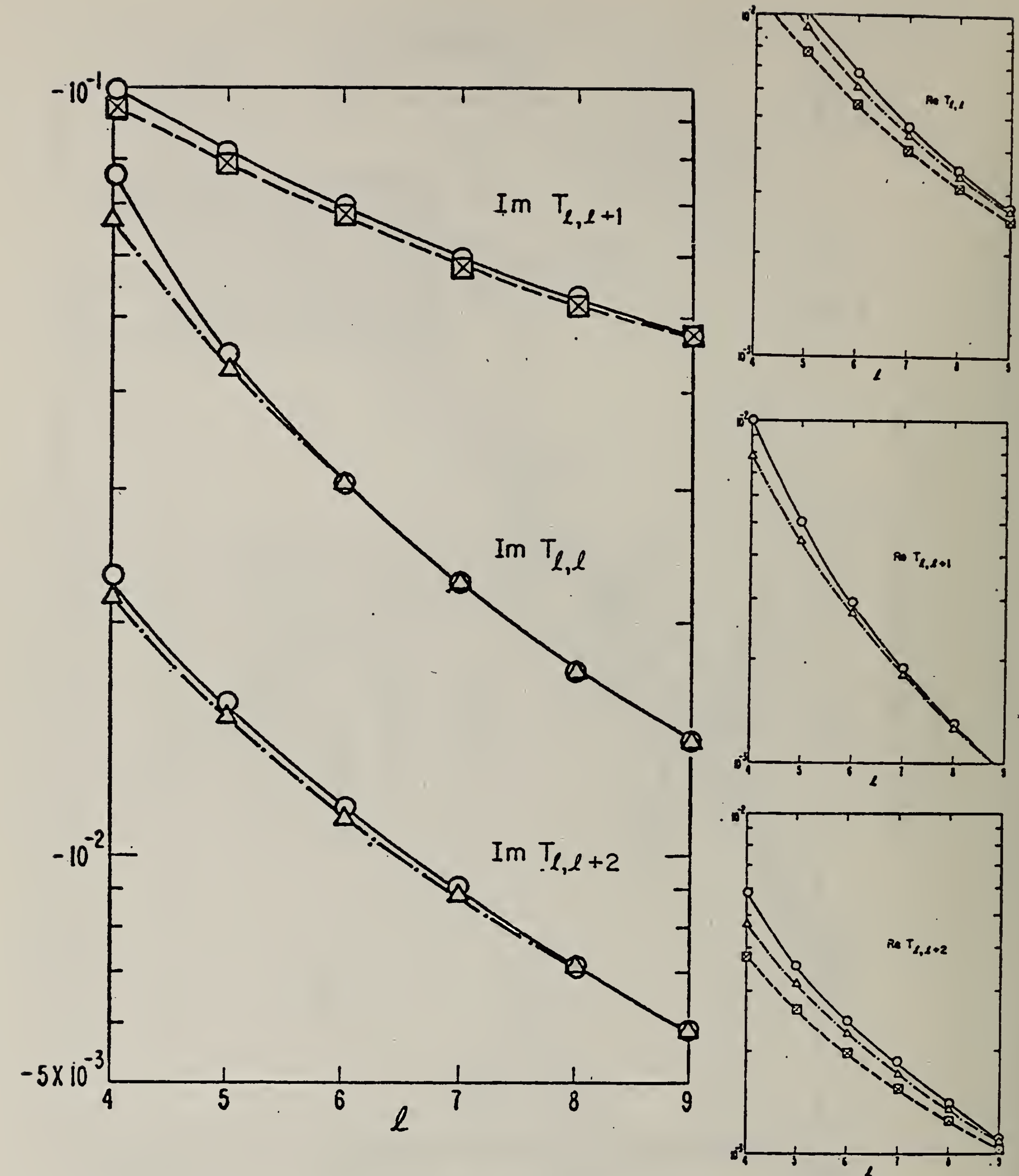

Figure 7. Transition matrix elements for Σ symmetry scattering of electrons by HCl as a function of the angular momentum of the electron. The circles are from close-coupling calculations for the full molecular potential, the crosses from an exact calculation for a point dipole, and the triangles and boxes from the unitarized Born approximation with and without, respectively, inclusion of the quadrupole effects.

The importance of the latter, and the utility of the simple Born approximation are manifest.

G. Steffani, R. Camilloni, A. Falk and G. Dunn used crossed beams techniques to measure the electron impact ionization cross section of B^+; and R. Phaneuf and D. Crandall at ORNL and A. Falk and G. Dunn measured the cross sections for C^{+2} and O^{+2}. The B^+ and C^{+2} work along with previous measurements by the ORNL/JILA team on N^{+3} and O^{+4} give a nice body of data on ionization of ions in the Be sequence. Similarly, for the Li sequence Falk and Dunn recently completed measurements on Be^+, which together with the earlier work of the ORNL/JILA team on C^{+3}, N^{+4}, and O^{+5} gives a satisfactory set of data for this sequence. For the Li sequence, excitation-autoionization plays an increasing role with increasing Z, being barely discernable for Be^+, but playing a very prominent role for O^{5+}. Work has recently begun on ions of the Na sequence, and A. Falk, G. Dunn, D. Crandall and R. Phaneuf recently completed measurements on ionization of $A\ell^{+2}$. Excitation-autoionization involving the $2p^53s^2$ and $2p^53s3d$ states plays a significant role in this ionization process. Work on Si^{3+} will be done shortly, and work on K-like Ti^{3+} will also be undertaken.

J. Luine and G. Dunn have made a major breakthrough in measurement techniques for ion-molecule reactions at low temperatures. It is believed such reactions play a major role in the formation of the complicated molecules observed in interstellar space at 10-20 K. However, other workers have not been able to make laboratory measurements below about 80 K -- and even this has only been achieved in recent months. The Luine/Dunn method employs an ion trap operated at 4 K, and makes measurements possible in a temperature regime never accessed before in the laboratory for this type of study. Figure 8 shows preliminary results for a key process in one of the modeling chains, and it is seen that at low temperatures a second process becomes operative in producing the reaction. The points at 77 K and 200 K are not yet published, and modelers had previously extrapolated the high temperature data -- giving essentially zero at 10-20 K. The measurement of a number of key processes will be pursued in the near future.

A. V. Phelps, in collaboration with K. Tachibana of Kyoto Technical University, has succeeded in applying his electron drift tube technique to the measurement of electron excitation coefficients for the lowest metastable state of O_2, i.e., the $a^1\Delta_g$ state. This metastable state is particularly difficult to detect because it radiates in the infrared (1.27 μm) and has a very long radiative lifetime (3900 sec). This metastable state is of particular interest because it can serve as an energy source for the excitation of iodine atoms in the iodine laser. Thus far, only chemically excited oxygen molecules have been used for this purpose. These metastables are also of importance in ionized air because of the ease with which they cause electron detachment from negative ions. In collaboration with C. Yamabe this work will be extended to O_2-N_2 mixtures and to a search for previously unmeasured metastable states.

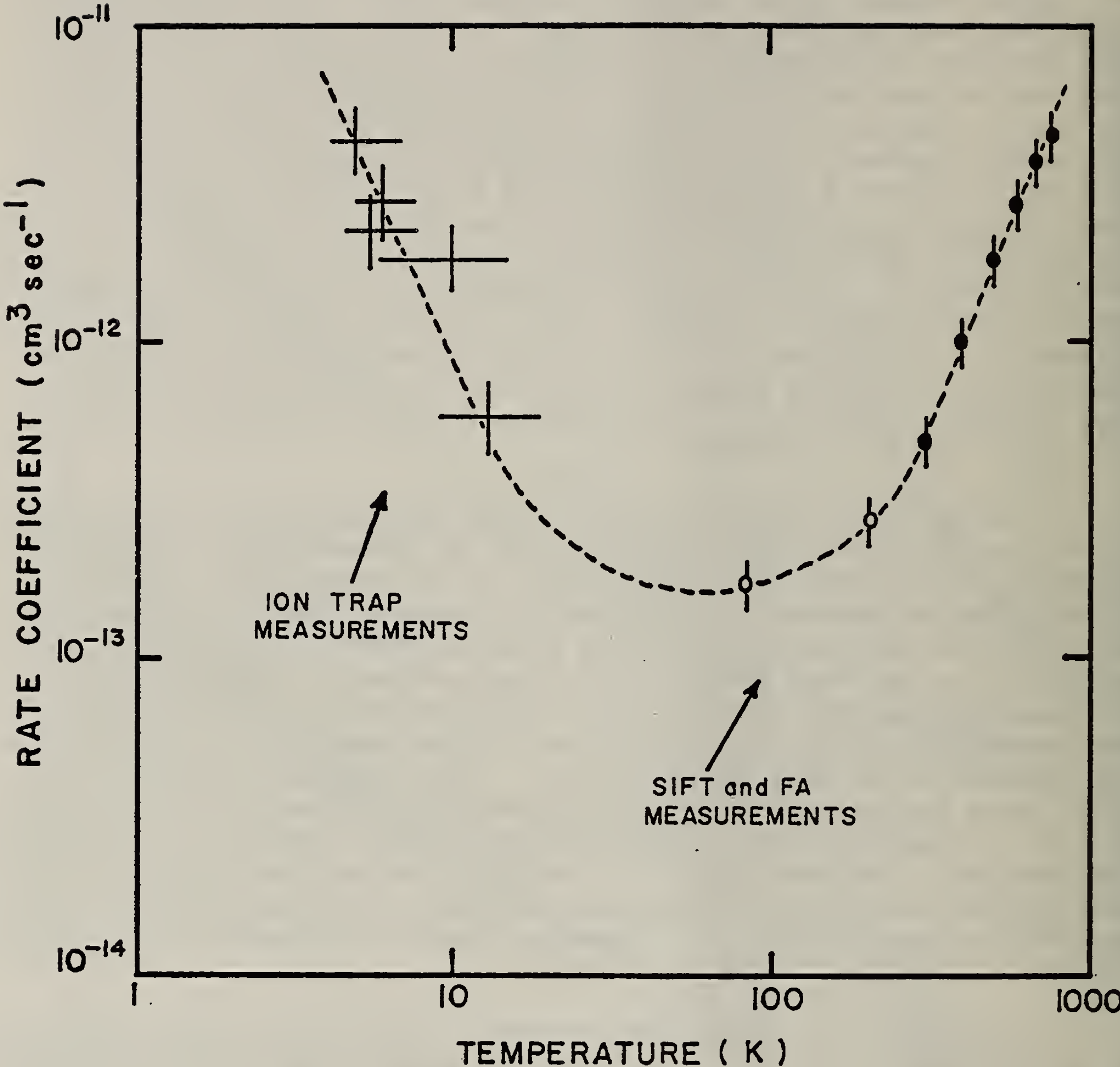

Figure 8. Reaction rate coefficient ($cm^3\ sec^{-1}$) versus temperature (K) for the process $NH_3^+ + H_2 \rightarrow NH_4^+ + H$. Ion trap measurements at low temperatures are the first ever for any ion at such low temperatures. Higher temperature data are the flowing afterglow (FA) data of the NOAA group ⧫, and the selected ion flow tube (SIFT) data of the Birmingham group ◊ (unpublished).

A. V. Phelps, in collaboration with L. C. Pitchford of the JILA Information Center, has applied the techniques developed by Pitchford, ONeil and Rumble for the solution of the Boltzmann equation for electrons in gases to the analysis of transport, excitation and ionization coefficients in nitrogen. These calculations show that previous analyses of experimental data were in error by as much as 40 percent and that corresponding adjustments must be made in the cross section sets derived from transport data. Unfortunately this change causes a serious and, as yet, unresolved discrepancy between calculated and measured excitation rate coefficients for the nitrogen $A^3\Sigma$ metastable state. In addition, Monte Carlo techniques have been used to test the Boltzmann equation results and to simulate the perturbing effects of electrodes used in the experimental measurements. Because of the termination of other agency funds, this work is being terminated.

A. V. Phelps has completed an extensive correlation of theoretical predictions of the rates of loss of electrons and ions from the positive column of electrical discharges. This correlation covers a very wide range of the discharge parameters of pressure, electron density and tube radius. The results show good agreement with experimental data obtained previously in collaboration with C. F. Muller.

A. V. Phelps plans to complete the development of simple models for the calculation of the role of highly excited atoms in electrical discharges. This includes extension of models in which electron-excited state collisions dominate to cases in which neutral atom-excited atom collisions dominate.

T. Baer and J. Hall have undertaken a study of collisional damping and dephasing of molecular dipoles using the technique of coherent optical transients. In these frequency-switching experiments, T. Baer has observed a rather well-marked maximum in the dipole collisional-damping rate of HF near 1 millimeter laser mode size. Through the mode size/solid angle duality, this value correlates reasonably well with the ≈100 cm/sec rms velocity shift per collision typically found using a Keilson-Storer collision kernel representation of the collision process. They believe that these sub-Doppler techniques, coupled with their ability to select a different collisional angular sensitivity by manipulation of the laser mode parameters, plus the well-defined dipole-dipole long-range force law should enable formulation of a rather detailed microscopic model of the collision process. For example, in the sub-Doppler regime, it seems clear that momentum transfer at large impact parameters will be manifest as a central narrow notch in the collision kernel for $\Delta V \ll \Delta V_{rms}$.

S. Geltman and S. Haan are continuing a theoretical study of the time development of the resonant (3s-3p) ionization of Na by monochromatic radiation. The ejected electron energy distributions are being studied as a function of time in the radiation pulse, and pulses with sudden and ramp turn-ons are being used. Although the total ionization probabilities are very low at these early times in the pulse, one sees a very rich structure in the ejected electron energy distribution due to the real excitation of intermediate states by photons corresponding to the Fourier transform of the pulse turn-on function. They are also studying the frequency and intensity dependences of the transient ionization. This phenomenon is important as it will appear as an unavoidable source of background ionization in schemes to detect single atoms by resonance ionization spectroscopy [Hurst et al., Rev. Mod. Phys. 51, 767 (1979)].

Geltman carried out a theoretical study of the two-photon ionization of Cs in the region of the interference minimum (near the $7p_{1/2}$ state) in conjunction with the recent successful Saclay measurement of this [Morellec et al., Phys. Rev. Lett. 44, 1394 (1980)]. He used the most accurate bound-bound dipole matrix elements available and quantum defect theory for the bound-free matrix elements, and retained the intermediate states 6p, 7p, 8p, 9p (taking complete account of fine structure effects). The results for the position of the minimum are seen to be approaching the experimental result as additional intermediate np states are included in the calculation, but the effects of the so far omitted 10p-∞p plus continuum states are hard to estimate. The calculated cross section magnitude at the minimum lies about an order of magnitude below the measured value, and it is likely that this discrepancy is largely due to a background of electric quadrupole transitions. These are presently being studied. The calculation is being done for both linear and circular polarized radiation, and we find less pronounced differences for these two cases than are reported by other theoretical workers.

The theory of laser-induced collisional ionization is being applied by S. Geltman to the case of

$$Sr(5p\ ^1P) + Cs(7s\ ^2S) + \hbar\omega \rightarrow Sr(5s\ ^1S) + Cs^+ + e \quad ,$$

which has been studied experimentally by Brechniac et al., J. Phys. B 13, L383 (1980). The laser which resonantly excites the Sr(5p ^1P) also provides the photons for the above process, and an asymmetric resonance profile is observed. He is using a quasistatic molecular model for the collision in which the larger value for the van der Waals C_6 for Sr(5p ^1P) + Cs(6s ^2S) than for Sr(5s ^1S) + Cs(6s ^2S) explains the direction of the asymmetry. The width of the profile is consistent with the Stark width or Rabi frequency for the resonant excitation of Sr. He is setting up to incorporate the above physical model into detailed calculations for the ionization probabilities as a function of impact parameter. He will then make detailed comparisons with the experimental results for the variation of peak cross section, spectral width, and asymmetry as a function of laser intensity (range of 1-15 MW/cm^2).

A new project is being initiated in a collaboration between S. Geltman and M. J. Conneely (visiting JILA from the University of Galway, Ireland) to calculate electron free-free transition cross sections that are accompanied by changes in the state of the target atoms. This is partially motivated by an experiment in progress by J. Zorn at Michigan to look for the $1s^2\ ^1S \rightarrow 1s2s\ ^1S$ excitation in He by the joint action of a monochromatic electron beam (of about 19.3 eV, near the $1s2s^2\ ^2S$ Schulz

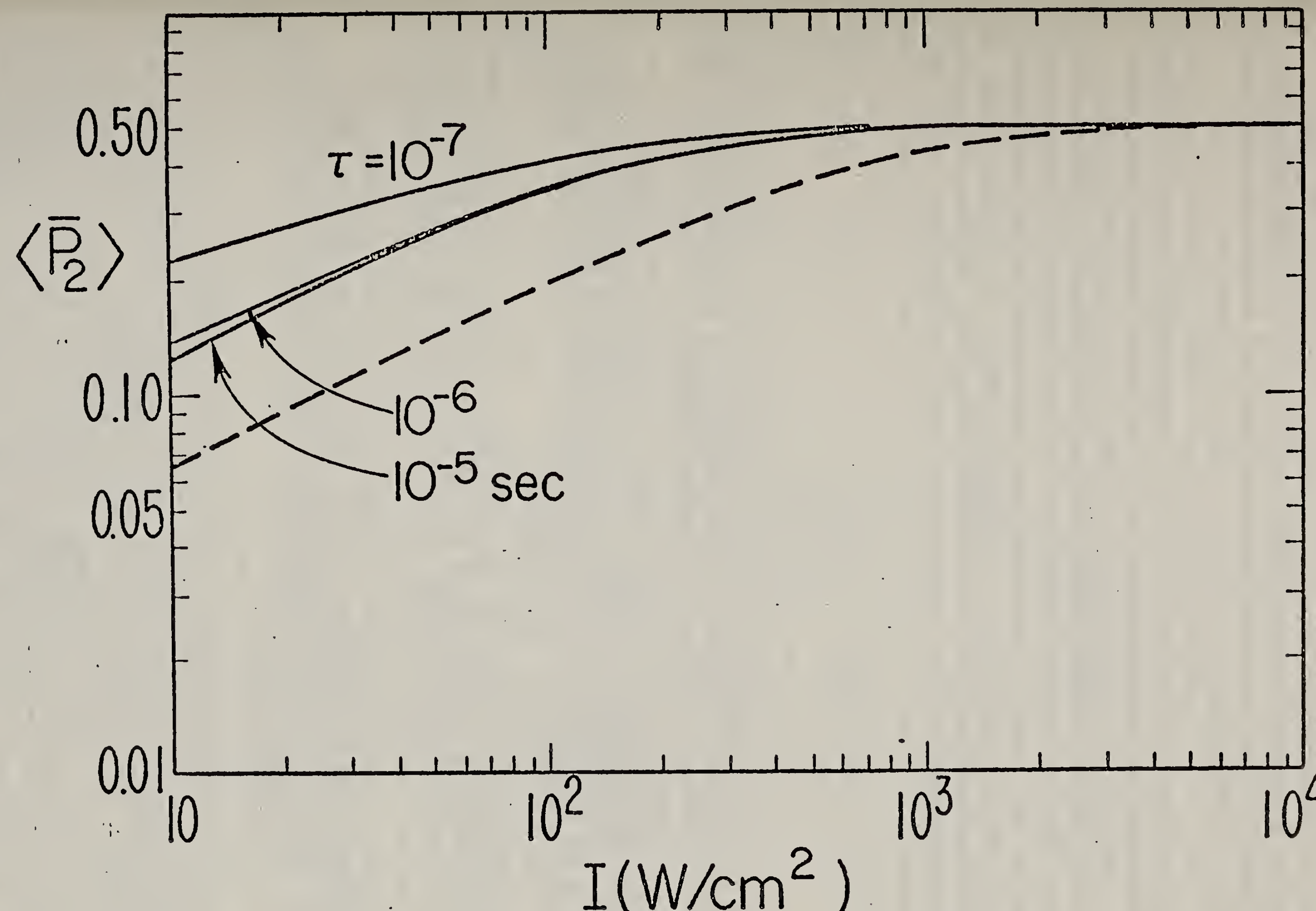

Figure 9. Doppler-averaged excitation functions of the upper level as a result of rectangular pulses (dashed line) and triangular pulses of various lengths (solid lines) of the multimode radiation described in the text acting upon the Na 3s → 3p transition.

resonance of He^-) and a laser beam of $\hbar\omega \cong 1.5$ eV. They will initially confine themselves to electron-hydrogen and electron-helium systems and use the IMPACT computer programs to obtain electron-atom scattering wave functions. They will pay particular attention to scattering resonance regions, where it is expected that the free-free processes will be greatly enhanced over their nonresonant values. At very high energies of electron impact it is expected that semiclassical methods can be used and the process becomes mainly collision-induced absorption.

Geltman has been collaborating with an experimental group at Saclay who have been carrying out measurements in the laser-induced ionization of Na vapor. They use a pulsed dye laser which puts out a pulse of about 1 μsec and which contains about 350 modes with mode spacings of about 200 MHz. The saturation conditions for the 3s-3p transition under the influence of this type of radiation must be known for the interpretation of these measurements, and so Geltman studied the theory of the response of a two-level system to multimode radiation. He found that an approximate expression for the average excitation of the upper state for square pulses is

$$\bar{P}_2 = \tfrac{1}{2}\left[1 - \prod_j \frac{\Delta_j^2}{\Delta_j^2 + \Omega_j^2}\right]$$

where Δ_j and Ω_j are the detuning and Rabi frequency associated with the power contained in the j^{th} mode. If the analysis is carried out for the more realistic triangular pulses, $\bar{P}_2$ becomes dependent on the pulse lengths. The saturation characteristic we obtain for the Na 3s-3p transition and the Saclay laser is shown in Fig. 9, after averaging over the expected Doppler distribution. This indicates that the transition can be expected to be saturated for $I > 10^3$ W/cm^2, which covered the intensity range for the ionization measurements.

In experiments of R. Dang and A. Gallagher, an atomic beam of Na is optically excited to the 3P state by laser radiation, and an electron beam further excites these 3P atoms. The radiation from these higher states is detected, so that total excitation cross sections are obtained. The 3P atoms are also highly polarized, and polarization dependences of the cross sections can be observed. In FY 1980 the apparatus has been adapted and tested for this experiment and the laser put into service. Cross-section measurements are planned for FY 1981, initially for the 3P → 4D and 3P → 5S excitations.

A relatively dense Na vapor is being strongly excited by pulsed laser radiation, and the time dependent intensities of fluorescence and scattering from many excited states is being measured by J. Huennekins and A. Gallagher. The processes of radiation scattering, radiation diffusion, and collision processes between excited atoms and with electrons all occur in this situation. In order to isolate and understand these many processes they are measuring the dependence of the Na excited-state densities on Na density, laser power and laser pulse width. Considerable survey data have now been taken, raising a variety of mysteries that require more systematic studies in the various density and power regimes. Use of a cw dye laser as a probe of excited atom densities is also planned for FY 81.

Collisional line shapes are a very powerful diagnostic for atomic interactions, but it is very difficult to definitively test the line-shape theories due to incomplete knowledge of the atomic interactions. The mixed alkali pairs are a very interesting system for such tests since they have very long-range interactions that should be closely related to the known transition moments of the separated atoms (e.g. the van der Waals coefficients are 10-100 times those for most atom pairs). K. Niemax, L. Brillet, W. Kamke and A. Gallagher have thereby been studying the line shapes of these colliding atoms. In FY 79 they measured the wing shapes of the Na resonance lines due to Rb perturbations, and in FY 80 the broadening of the line cores by Cs. These experiments are complicated by the high density of Na impurities in available Rb and Cs, but they expect to complete these Rb and Cs broadening experiments in FY 1981. In addition, the Li-Na system is now of considerable interest as theoretical interaction potentials have recently become available, and the K-Rb system is of particular interest due to the exceptionally long-range interactions. Collisional line shapes have normally been applied only to non-reacting colliding atoms. They are starting a study of the N_2 broadening of the Na resonance lines, since this is a quasi-reactive system in which the Na electronic energy is transferred to N_2 vibrational energy. The broadening of the Na resonance line cores has been measured, and measurements of the far wings are under way.

Hydrogenated amorphous silicon films are potentially useful for low-cost, thin film solar cells. H. Chatham, R. Robertson and A. Gallagher have been constructing an apparatus (FY 1980) to study the important processes and parameters involved in the electric discharge production of these films. Measurements and interpretations of the plasma parameters and the radiation and species emitted from the plasma are planned for FY 1981. Their results will be integrated into an R & D effort, sponsored by the Solar Energy Research Institute, that involves a number of industrial and university laboratories.

A. V. Smith, J. E. M. Goldsmith, D. E. Nitz and S. J. Smith have used a new saturation method to measure absolute photoionization cross sections of the 4D and 5S excited states of sodium. Two cw dye lasers are used to stepwise excite a continuous, stable population of the 4D or 5S state in an atomic beam, and the number of ions generated by single pulses from a Q-switched Nd:YAG laser is measured as a function of ionizing pulse energy (see Fig. 10). The photoionization cross section is then deduced from the energy at which the photoionization process saturates. This is an attractive method since the only calibration required is that of the ionizing photon flux. The excited-atom density and the absolute number of ions generated need not be known. Their cross-section measurements are the first for excited states of the alkali metals other than P states, and their results represent reliable, accurate excited-state photoionization cross sections. They have been careful to specify

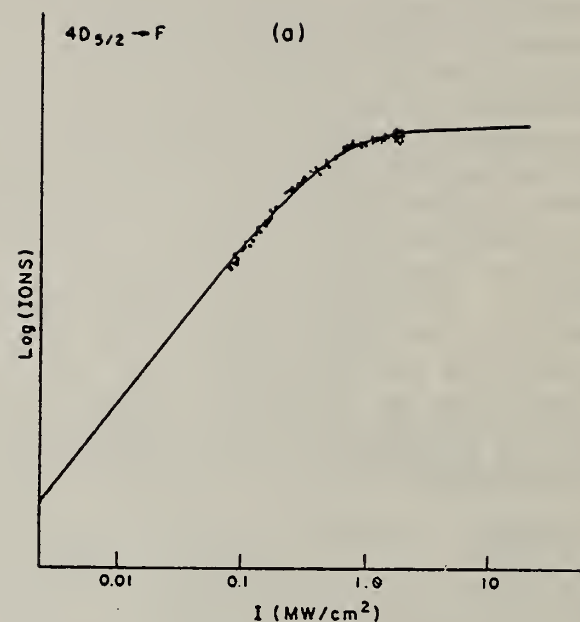

Figure 10. Dots are data points for single pulses of the Nd:YAG laser. The solid line is best fit computed saturation curve in which the cross section is the only free parameter. This experiment was carried out with all laser beams circularly polarized. This produces a definite alignment of the excited atomic state and a well defined transition to the continuum. Measured cross sections are converted to those for unaligned atoms by use of angular momentum algebra.

the atomic alignment when necessary and to otherwise perform the measurement in a manner which leads to straightforward analysis. The quoted error limits are conservative and include all systematic as well as statistical uncertainties. The measured cross sections for ionization of unaligned atoms are 15.2±1.7 Mb for the 4D state and 1.49±0.13 Mb for the 5S state, both in excellent agreement with calculated values.

D. Meschede and S. J. Smith have developed an apparatus for observing super-fine rotational structure in symmetric molecules with the objective of searching for and measuring the clustering effects predicted by W. E. Harter, former JILA Visiting Fellow. A stimulated Raman gain method is based on the use of an intense diffraction limited tunable YAG laser beam as a pump, and a He-Ne laser beam probe. The laser beams are superposed and sent into an absorption cell containing a multipass optical system. After one hundred passes the beams are extracted, separated, and the He-Ne component directed into a red-sensitive multiplier. The essential requirement is the complete isolation of the final He-Ne component from measurable contributions in the wings of the YAG beam. Stimulated Raman emission at the He-Ne frequency is enhanced when the difference frequency between the two lasers coincides with intervals between components of the superfine rotational structure. They anticipate carrying out intensive studies of several symmetric molecules, initially CF_4, during FY 81.

S. J. Smith and G. Leuchs are measuring and analyzing the angular distributions of photoelectrons from atoms prepared in well-specified spatially anisotropic states by means of step-wise resonant excitation using polarized laser beams. The states of interest are excited states with angular momentum quantum numbers $\ell \geqslant 1$ and with non-uniform populations of the magnetic sub-states m_ℓ. The signatures of the magnetic substates (ℓ,m) are the spherical harmonics $P_{\ell,m}$. The photoelectron distributions exhibit these signatures. Of particular interest are the signatures of the continuum states reached in the photoionization process, which are ordinarily restricted to those allowed by the dipole orbital angular momentum selection rule $\Delta L = \pm 1$. Careful analysis of the resulting distributions and identification of these signatures can lead to accurate information about the relative strengths of the $\Delta L = +1$ and $\Delta L = -1$ processes, as well as their relative phases. Such information is needed to test new calculations of processes involving excited states in hot gaseous plasmas. For atoms such as barium and strontium, which have autoionization structure in their electron continua, they hope to develop the angular distribution technique as a device for identifying characteristics of such autoionizing states. Of fundamental interest is the ultimate possibility of studying angular distributions from states sufficiently highly excited that the size of the atom (orbital diameter) is no longer negligible compared to the wavelength of light. This would be observed in the angular distribution as a breakdown of the "dipole" selection rule $\Delta L = \pm 1$, a matter of some significance.

D. E. Nitz, A. V. Smith, M. D. Levenson and S. J. Smith have been conducting research to provide well-characterized quantitative data for the influence of field fluctuations on near-resonant absorption by atoms in intense laser fields. The absorption characteristics obtained using a carefully stabilized, very intense continuous wave laser field will be compared with the characteristics when statistically well-characterized fluctuations are imposed on the same laser beam, using acousto-optic and electro-optic modulating devices. Techniques are being developed to impose frequency fluctuations and amplitude fluctuations, to obtain data in forms appropriate to test various theoretical models. Measurements will be carried out using a beam of atomic sodium in high vacuum, optically pumped to a specific substate so the absorbing $3S_{1/2} \rightarrow 3P_{3/2}$ transition is completely defined, and Doppler effects are reduced. A specially developed cw ring laser, with a line width of <100 kHz obtained by advanced stabilization techniques will provide the intense field. Absorption will be studied by observing in fluorescence and also in ionization by using an additional laser as a probe to excite $3P_{3/2}$-4D transitions, which leads to ionization by the intense laser field. Of interest in these studies are the effects of fluctuations on the shifting and splitting of atomic energy levels by the intense laser field, effects which may have practical significance in technological applications of high power lasers. A representation of such splitting effects is given in Fig. 11, showing plots of some data presently being analyzed. In this work the carrier/frequency of the intense laser field was tuned away from atomic resonance by about 2000 laser line widths. The traces represent this limiting case for the effect of a "nearly monochromatic" laser (below) and with the residual field fluctuations substantially suppressed by a Fabry-Perot filter tuned to the laser frequency (above).

Following the suggestion of J. A. Rees, who found a serious inconsistency in elastic scattering in Ne, Visiting Fellow M. G. Menendez and E. Beaty undertook measurements of the angular distribution of elastically scattered electrons from neon in the energy range 50 eV to 100 eV. The differential cross section for elastic scattering shows a pronounced minimum at angles near 100° for energies in this range. The energy at which this minimum is deepest is the critical energy E_c, and its prediction is a sensitive test of theory. For energies close to E_c the electrons scattered at angles close to the critical angle will be highly polarized. Previous measurements were in serious disagreement with theory. The JILA results are in excellent agreement with calculated values, and give $E_c = 64.0 \pm 1.0$ eV at a critical angle of 102°.

Chemical Physics

It is difficult -- and perhaps from some points of view artificial -- to distinguish some of the programs in the above subsection (atomic and molecular physics and interactions) from the programs noted here. Nevertheless, it is important to point out that JILA has a very strong chemical physics program with three Fellows rostered in the Chemistry Department: W. C. Lineberger (CU), W. P. Reinhardt (CU), and S. R. Leone (NBS). It is, of course, the work of Leone's group which is listed here as part of the QPD program.

Low power laser pulses are used by D. J. Nesbitt and S. R. Leone to initiate chain combustion reactions by specific dissociation of molecules

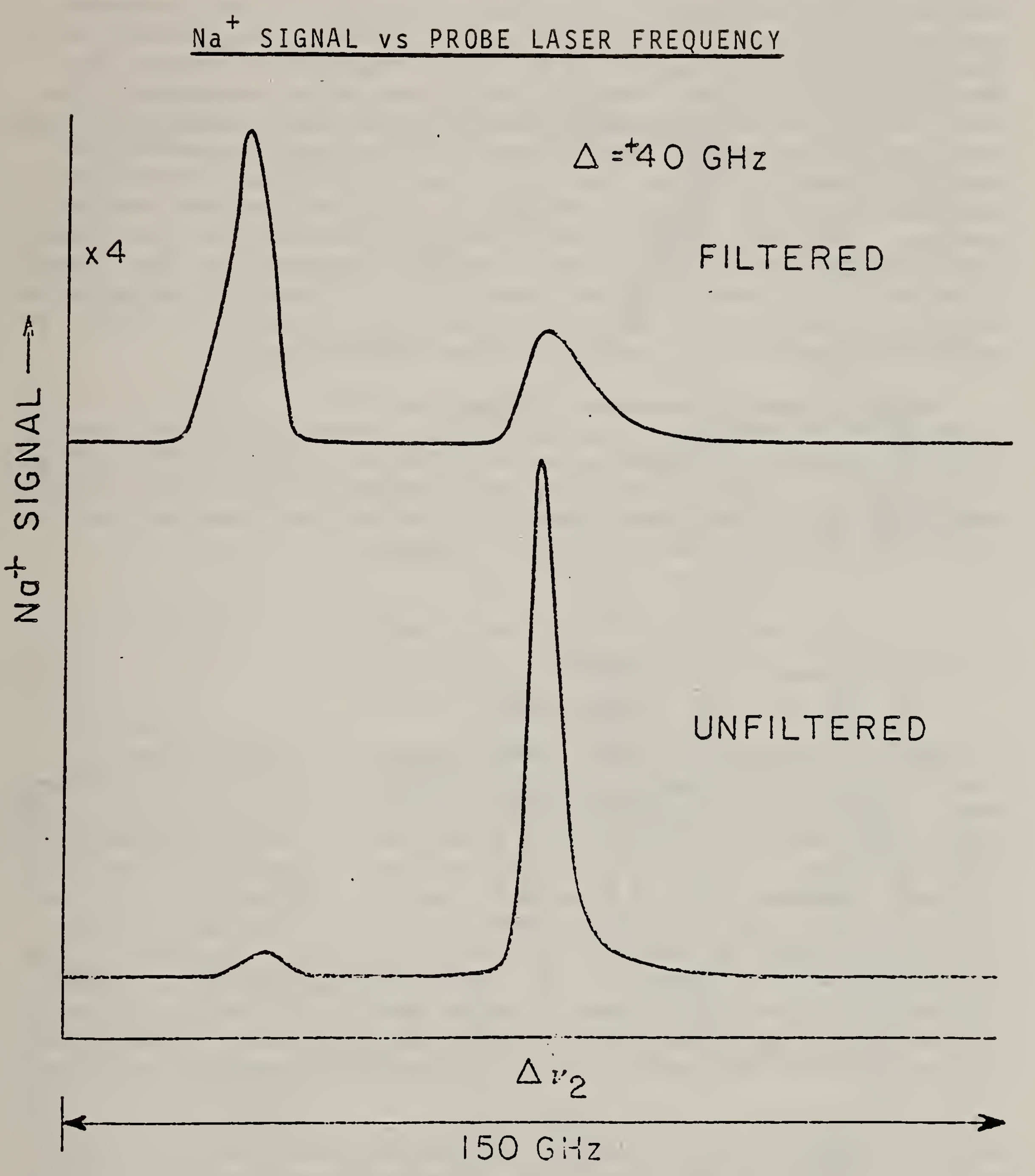

Figure 11. Comparison of ac Stark effect signals at a fixed detuning of 40 GHz demonstrating explicitly the change in asymmetry resulting from filtering the intense laser background light.

into atoms or radicals. The full time development of the chain reaction is monitored by infrared chemiluminescence from vibrationally excited products of the reactions. A complete mathematical formalism has been developed and experimentally verified for a series of chain reactions such as $C\ell_2/H_2$, $C\ell_2/H_2S$, $C\ell_2/CH_3SH$, and $C\ell_2$/butane. Experimental rate constants can be obtained for each of the propagation reactions and termination steps. Chain reactions which proceed on exceedingly slow time scales have been observed and can be sensitively detected and measured by this technique. More recently, it has been discovered that specific product molecules, such as various chlorobutane derivatives, can each be detected by their "fingerprint pattern" infrared emission spectrum. The development of individual product molecules in a complex mixture of combustible gases can be followed completely in time. Work is proceeding to develop further capabilities for specific molecule detection in complex chain reaction systems and to study the kinetics of oxygen-hydrocarbon chain systems at higher temperatures.

Infrared chemiluminescence is being used by T. S. Zwier, J. C. Weisshaar, G. B. Ellison, V. M. Bierbaum, Z. Hermann and S. R. Leone to study the dynamics of ion-molecule reactions in a device called a flowing afterglow. These are the first measurements of this kind. Recently complete product vibrational state distributions have been obtained for many of the simple proton abstraction reactions:

$$C\ell^- + HBr, HI \rightarrow HC\ell(v) + Br^-, I^-$$

$$F^- + HC\ell, HBr, HI \rightarrow HF(v) + C\ell^-, Br^-, I^-$$

and for the associative detachment reactions:

$$C\ell^-, F^- + H \rightarrow HC\ell(v),\ HF(v) + e^- \quad .$$

An example of results for the F^- + HBr reaction is shown in Fig. 12. These results provide some of the first detailed examinations of thermal energy ion-molecule reaction dynamics through analysis of product states. They already have had a significant impact on the theoretical description of ion reactions. Certain ions play a prominent role in the chemistry of the upper atmosphere and in interstellar molecule formation. Ions are also important infrared emitters, with consequences for sophisticated military detection technology. In continuing studies, the methods developed here will be applied to ion reactions of atmospheric interest. Experiments will be established to probe ion-molecule product states in the collision-free regime and to increase the sensitivity of detection by many orders of magnitude using laser-induced fluorescence detection.

A new technique has been developed by S. L. Baughcum, H. W. Hermann and S. R. Leone to obtain complete infrared emission spectra of free radicals produced by dissociation of polyatomic precursors. This method was first applied to the CH_2I radical. It was discovered that, in addition to the usual stretching and bending modes, the radical exhibits a broadband background emission due to the very dense number of states at high levels of excitation. The technique has recently been applied to the bending mode of the CH_3 radical, which is excited from v = 1-10 upon dissociation of CH_3I. It will be possible from this data to unravel the

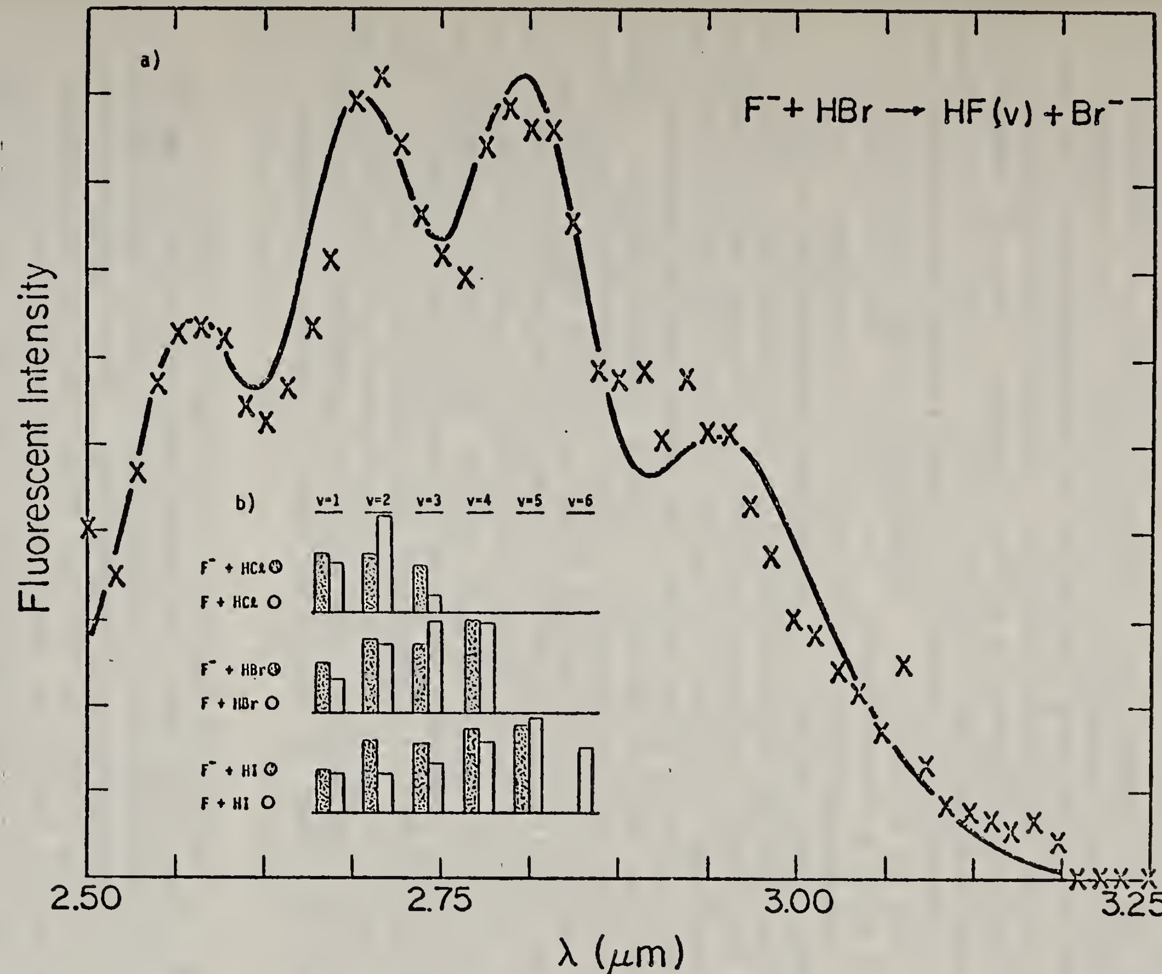

Figure 12. a) Infrared chemiluminescence spectrum from the v = 1-4 levels of the HF product in the reaction $F^- + HBr \rightarrow HF(v) + Br^-$. Relative populations into the various vibrational levels are obtained from a computer fit (solid line) of the data points (x).

b) Results of ion experiments obtained are compared to results from neutral analog experiments of Setser.

complex series of negative anharmonic bands. Thus far this has only been treated theoretically. These studies are being developed to provide new methods of detecting free radicals, to obtain information about their spectroscopy, and to measure radical kinetic processes such as vibrational deactivation and reactivity.

Astrophysical Measurement

K. B. Gebbie and J. Toomre, in collaboration with L. J. November and G. W. Simon (SPO) have now completed the analysis of their observations of supergranular velocities obtained with the University of Colorado UV Spectrometer on the OSO-8 satellite. Steady Doppler velocities were determined from data obtained in a Si II spectral line and compared with simultaneous ground-based measurements in Fe I and Mg I using the SPO diode array instrument. The heights of formation of these spectral lines span about 1400 km or nearly 11 density scale heights from the photosphere to the middle chromosphere. The striking results of these observations are that supergranular flows are able to penetrate into the middle chromosphere, where regions of approaching and receding motion correlate well with velocity fields observed in the photosphere. The dynamic range of the steady Doppler velocities observed at radius vector 0.8 increases from 800 ms^{-1} in the photosphere to over 3000 ms^{-1} in the middle chromosphere. Seen at disk center, the corresponding increase in the vertical velocities is from 200 ms^{-1} to again about 3000 ms^{-1}. Here the regions of downflow tend to correlate with the bright Ca II emission network, those of upflow with the darker areas. Despite the increase with height in the velocities, the vertical momentum associated with the flow decreases by a factor of 10^3 owing the decrease in gas density. From the three spectral lines studied, it appears that the scale height for the decrease in this momentum component is about 135 km in the first 400 km above the photosphere, increasing to about 260 km in the subsequent 1000 km. Thus a distinct change appears to occur in the flow structure: in the low photosphere, the horizontal component of velocity predominates, whereas higher in the atmosphere, the motions appear to become increasingly isotropic.

K. B. Gebbie, J. Toomre and F. Hill, in collaboration with L. J. November and G. W. Simon (SPO) have confirmed their detection of an intermediate scale of mesogranulation, an intermediate scale of convective motion in the solar photosphere and chromosphere. These mesogranular flows become evident only when the strong 5 minute oscillations are accurately filtered out by long time averages of the Doppler velocity. Analysis of recent SPO diode array observations at disk center show that these flows are space filling and cellular in structure, the same patterns of steady velocity being clearly identifiable for periods spanning nearly two hours. The dynamic range in the amplitudes of these vertical motions is about 200 ms^{-1}, compared with about 100 ms^{-1} in the larger scale supergranular flows. Spatial transforms suggest that the primary power for mesogranulation lies in the 5-8 Mm range of horizontal scales. These results suggest that mesogranulation may be the result of convective overshooting into the stable atmosphere. Such intermediate scales of convective motions may be driven by the ionization of He at a depth of about 7 Mm or they may simply reflect higher spatial harmonics of the primary supergranule cell.

The same research group is carrying out an observational study of steady flows in the upper chromosphere and transition region as a guest investigator program on the Ultraviolet Spectrometer and Polarimeter experiment on the Solar Maximum Mission satellite. In collaboration with the UVSP experiment team at Goddard, they have observed Doppler velocities in the quiet Sun and in active regions in Si II, Si IV, C II and C IV spectral lines. Time averaged over one or more orbits, such data yield the steady component of the velocity fields over a range of heights in the atmosphere. Further, the time sampling in the observations is sufficient to permit analysis of the Si II data for the chromospheric mode in the five-minute oscillations. These SMM/UVSP observations have been coordinated with simultaneous SPO diode array observations of the photosphere and lower chromosphere.

D. G. Hummer, in collaboration with M. J. Barlow and J. C. Blades of University College London, has analyzed spectra of the O VI type Wolf-Rayet star Sand 3 obtained by Barlow and Blades, and has identified recombination lines of O VII, O VIII and C V. These ions are among the most highly stripped species seen in the optical spectra of stars, and their presence in this star points to a very high energy source of excitation, probably through X-rays. The identification of the members of the helium-like iso-electronic series was made quite difficult by the fragmentary state of the relevant pages of Atomic Energy Levels, the multiplet tables and the periodical literature, a situation that emphasizes once again the importance to astrophysics of basic spectroscopic measurements. This work is described in an Astrophysical Journal Letter now in press. Ultraviolet spectra of this object have been obtained by means of the International Ultraviolet Explorer (IUE) and analysis of the extended spectra will start shortly. In the next year, a substantial effort will be made to construct models of this object, in the hope of learning more of the elusive nature of the Wolf-Rayet stars through this rather pathological case.

D. G. Hummer and G. B. Rybicki (SAO) have developed a generalization of the escape-probability approximation for radiation transport in spectral lines that is valid for both static atmospheres and those with arbitrary flow speeds. This work bridges the gap between previously-obtained approximations that were valid in only the static and high velocity limits, and makes it possible to establish *a priori* conditions for the validity of the limiting-case approximations. A further new feature of this work is the exploration of the effect of line wings, arising from collision damping, on the conditions for validity of the high-speed limiting cases, which is much used; the presence of such line wings has the effect of making these conditions much more difficult to satisfy. Most of the work to date has been concerned with planar flows, although the formulation for cases with spherical symmetry has been carried out and preliminary results obtained. An account of this work is being prepared for publication in the Astrophysical Journal. This work is exceptionally timely, as the limiting forms of this approximation are becoming very widely used because of their relative simplicity. In particular the study of stellar winds depends strongly on such approximations. This work has shown that much of the work for late-type stars using this kind of treatment is invalid, and provides a basis for a more accurate treatment. Further generalizations of this approach to include the effects of partial frequency redistribution and continuous absorption, are under way and will be developed in the coming year. The approximate solutions obtained in this way will be compared with accurate numerical solutions. The first application of these generalizations will be to the interpretation of the Bowen cycle lines of O III and N III formed in nebulae surrounding galactic X-ray sources, which should provide useful diagnostics for the physical conditions, including the state of motion, of this gas.

J. Linsky continues several strong and multifaceted programs to understand phenomena occurring in the outer atmospheres of the Sun and related stars using satellites and ground-based telescopes and state-of-the-art radiative transfer techniques in order to produce detailed atmospheric models consistent with observations. In particular, he is trying to understand stellar chromospheres, coronae, flares, winds, and other manifestations of nonradiative heating in the atmospheres of stars primarily by the detailed analysis of ultraviolet and visible spectra and X-ray flux measurements. Two essential aspects of this work are the development and testing of non-LTE radiative transfer techniques for optically thick transitions and of spectroscopic diagnostic techniques for inferring density, temperature, departures from thermodynamic equilibrium, and other plasma parameters from the observed spectrum.

A. (Stellar Ultraviolet Astronomy) Linsky has a number of Guest Observing programs under way to use the spectrographs on the International Ultraviolet Explorer (IUE) satellite to study the spectra of stars with properties that may be similar to the Sun.

a) Stellar Surveys. One of these IUE observing programs was to test whether the chromospheric radiative loss rates in a representative sample of stars depends on stellar effective temperature and gravity in a manner consistent with the acoustic wave theory of heating or is inconsistent with the theory. Using the Mg II resonance lines as indicators of chromospheric heating rates Linsky and G. S. Basri found that the heating rates range over two orders of magnitude for stars of similar effective temperature and gravity with little trend on stellar gravity. This result is inconsistent with simple acoustic wave heating, but is what one would expect if magnetic fields (which presumably differ greatly from star to star) play a critical role in the heating process, as for example through magnetoacoustic waves.

One of the important early results from IUE was the discovery by Linsky and B. M. Haisch that giant stars warmer than about 4400 K generally show ultraviolet emission lines indicative of plasmas with temperatures extending from 2×10^4 K to at least 2×10^5 K, atmospheric layers called transition regions, whereas cooler giant stars (spectral types K2 III and cooler) generally do not show any evidence for outer layers any hotter than 1 × 10^4 K (extended chromospheres). During the last year Linsky and his collaborators observed a large sample of stars which show that transition regions probably do not exist in stars cooler than their proposed dividing line, but the situation in the hotter stars is more complex. During the last year Stencel and D. J. Mullan presented evidence for a Mg II asymmetry dividing line in the Hertzsprung-Russel Diagram (approximately vertical near spectral type K2 III) in which the Mg II double emission features change from emission primarily on the blue side or emission features of equal strength to emission primarily on the red side. They interpreted this change of asymmetry as indicative of the onset of strong cool winds in stars cooler and more luminous than spectral type K2 III.

Haisch, Linsky and Basri have investigated the role that radiation pressure in the Lyman alpha line might plan in initiating cool winds in late-type stars. They found that this mechanism can indeed initiate flows but some other mechanisms, such as Alfven wave pressure, is needed to continue the flow.

In another IUE observing program Linsky and N. C. Marstad observed stars somewhat hotter than the Sun (spectral types A and F) to see if chromospheres and transition regions do not occur in the hotter stars. They concluded that the rapid increase in ultraviolet emission from the photospheres of these stars with increasing effective temperature makes it very difficult to see ultraviolet emission from the hotter layers, and thus the question cannot be answered at this time.

Two other surveys using IUE have now been completed. T. R. Ayres, Marstad and Linsky have correlated ultraviolet emission line strengths and coronal X-ray emission in 28 stars observed by IUE and the Einstein satellite. They found that the radiative loss rates from transition regions and coronae are proportional to the second or third power of the corresponding chromospheric loss rates, suggesting that transition regions and coronae are heated by different processes than coronae. A similar conclusion was reached by Linsky, P. L. Bornmann and collaborators at Ohio State, Arizona, and the Air Force in their survey of 3 dM (nonemission line) and 7 dMe (emission line) stars. They found that the radiative losses from chromospheres and transition regions are far larger in dMe than dM stars, and that ratio of the heating rates of transition regions to the rates for chromospheres increases rapidly towards cooler stars.

b) Close Binary Systems. Stars in close binary systems can be very interesting as tidal forces can produce synchronism of rotation and revolution and thus rapid rotation. For stars with convective zones, rapid rotation leads to enhanced dynamo processes, strong magnetic fields, and more exaggerated phenomena like flares and coronal heating than is seen in magnetic regions on the solar surface. T. Simon and Linsky obtained IUE spectra of two spectroscopic binary systems of the RS CVn-type, HR 1099 and UX Ari, and derived a model for the chromosphere and transition region of the more active stars in these systems by matching fluxes of strong lines of Mg II, C II, Si II and Si III and using density-dependent line ratios. They also observed UX Ari with IUE during a major flare in which the chromospheric and transition region lines were enhanced and the Mg II lines developed strong emission in their red wings. They proposed that the flare may be due to the annihilation of magnetic fields when loops from the two stars interact. They also observed HR 5110 during a flare, but found no enhancement in the emission lines compared to the nonflare state. They proposed that this system is similar to Algol systems and the radio flare may be a consequence of mass exchange. Additional studies of RS CVn systems with IUE are under way.

c) Stellar Model Chromospheres and Transition Regions. Over the last few years Linsky and his collaborators at JILA pioneered the techniques for computing models for stellar chromospheres by matching computed and observed spectral features, in particular the resonance lines of Ca II and Mg II. During the last year Basri and Linsky extended this chromospheric modeling program to the supergiants ε Gem and α Ori. This task was particularly difficult because supergiants have very low chromospheric densities and thus the scattering of photons in the wings of strong resonance lines is nearly coherent. As a part of this Ph.D. thesis, Basri carefully considered the important role played by non-LTE continuum transitions and the Doppler drifting of core photons to the line wings with multiple scattering.

They have also extended their models to the hotter layers in a stellar atmosphere (up to 3×10^4 K) by analyzing IUE spectra of emission lines of C II, Si II, and Si III. Using these lines Basri and Linsky computed a model for β Dra (G2 II), Simon, W. L. Kelch and Linsky computed a model for ε Eri (K2 V), and Simon and Linsky computed a model for the active stars in the HR 1099 and UX Ari binary systems.

d) Future Programs. Linsky and his collaborators at JILA will be extending their studies of the chromospheres and transitions of stars through new Guest Observer programs on IUE. The next generation ultraviolet spectrometer in space will be the High Resolution Spectrograph (HRS) instrument on Space Telescope. Linsky is a Co-Investigator on the HRS Instrument Definition Team with responsibilities for defining the late-type star observing program and analyzing these observations, advising on absolute radiometric calibration. Another important effort to be done over the next year is the incorporation into the radiative transfer-statistical equilibrium equations for the coupled Lα-Lβ-Hα lines of hydrogen the new redistribution theory being developed by J. Cooper and colleagues at JILA.

B. (Stellar X-Ray Astronomy.) Linsky also is pursuing a number of Guest Observing Programs using the HEAO-1 (High Energy Astrophysical Observatory) and HEAO-2 (Einstein) satellites to study X-ray emission from analogues of the solar corona.

a) Stellar Surveys. With collaborators at U. California, Berkeley and Cal Tech, Linsky searched the HEAO-1 all sky survey data for X-ray emission from dwarfs and subgiants of spectral type F-K. They detected

6 definite and 15 probable sources, and argued that the X-ray luminosity from the most active single late-type stars is typically 10^{-4} of the stellar bolometric luminosity. The first survey of stellar X-ray sources by the Einstein satellite was recently completed by a large consortium of observers including Haisch and Linsky. As a result of this survey, Linsky has proposed a broad scenario of coronal X-ray emission in which remnant or dynamo-regenerated magnetic fields play a predominant role in heating stellar coronae.

Ayres, Linsky and collaborators at the Harvard-Smithsonian Center for Astrophysics have an observing program under way with Einstein to determine whether solar-like coronae ($T > 1 \times 10^6$ K) do not occur in the cooler and more luminous stars. They measured only upper limits on stars cooler and more luminous than spectral type K2 III, suggesting that hot coronae do not exist in these stars and the G-M supergiants. This important result is consistent with their results from IUE that transition regions also do not exist in these stars but that strong cool winds take their place.

b) Flare Stars. Haisch and Linsky presented Einstein X-ray flares and IUE ultraviolet emission line fluxes for the flare star Proxima Centauri (dM5e) during quiescent times. Haisch, Linsky and collaborators at the Center for Astrophysics also observed Proxima Centauri with Einstein during a flare and estimated temperatures, luminosities, emission measures, and emitting volumes as a function of time during the flare. X-ray emission during two very large flares each on the flare stars AT Mic and AD Leo were observed with HEAO-1 and discussed by Linsky, Haisch and collaborators at Berkeley and NASA Goddard.

c) Future Work. The study of stellar coronae and flares by the analysis of X-ray observations is continuing through several Einstein Guest Observer programs and the analysis of this data.

Geophysical Measurement

P. Bender has collaborated with C. C. Goad and J. D. Bossler of the National Geodetic Survey on a theoretical study of the use of signals from the NAVSTAR Global Positioning System (GPS) satellites for accurate determination of geodetic baselines. They showed that a new approach called the REconstructed CArrier Phase (RECAP) method is likely to give as high accuracy as can be achieved by long baseline radio interferometry measurements for baseline lengths of up to hundreds of kilometers. This conclusion also was reached independently by C. C. Counselman and I. I. Shapiro at MIT. The results of the two groups led to a decision by the Defense Mapping Agency to fund the development of prototype GPS receivers which will use the RECAP method. The National Geodetic Survey and the U.S. Geological Survey also expect to procure GPS receivers which use this method for establishing geodetic control in the many new areas where it is needed and also for detecting crustal movements.

More complete theoretical studies of the accuracy achievable with the RECAP method have been carried out by D. Larden of the University of

Colorado and Bender. A "modified worst case" analysis was used, and gave an expected accuracy of 1 cm for the horizontal coordinates and 2 cm for the radial coordinate with only two hours of measurements at a given site. This accuracy hopefully will be demonstrated in the next 18 months by two groups in the U.S., even though only the first 6 of the 18 or 24 GPS satellites which are planned are now up. It also was shown that the present 6 satellites are sufficient to permit measurements of the same accuracy to be obtained once per day in most of the major seismic zones of the world. Since the apparatus required is much simpler than for VLBI measurements or laser ranging to satellites, it now is expected that most of the mapping of crustal movements in seismic zones by space techniques in the next decade will be done with GPS receivers.

Two review papers connected with improved measurement techniques have been completed by Bender. One covered both ground and space techniques, and is in a book which is being published as part of the final report of the International Geodynamics Project. The second is on the expected contributions by space techniques to establishing suitable reference frames to which measurements of worldwide tectonic plate motions and distortions within plates can be referred. It now appears likely that geometric reference frames based on the new techniques will replace the reference systems which long have been traditional in geodesy, where the height above the geoid plus two horizontal coordinates were used.

J. Faller and Zumberge made substantial progress towards reaching the 1981 goal of a portable and absolute (3 parts in 10^9) gravimeter employing the free falling laser interferometric method. At the present, the precision obtained doing a 10 minute data run (150 drops) is 3 μgal (3 in 10^9). With a 24 hour data run they are able to see (follow) the earth tides (amplitude 1-2 parts in 10^7). A study of various possible error sources is well under way. They expect shortly to incorporate the Howard Layer developed I_2 stabilized laser into the system. The wavelength stability of the present Lamb-dip stabilized laser is only 5-10 parts in 10^9; the Layer-developed I_2 laser however provides more than the stability required for our parts in 10^9 application. Initial contacts have been established regarding possible cooperative scientific programs with groups in West Germany and Canada involving both field testing and the application of this portable absolute gravimeter to important geophysical problems.

Faller has pursued the possibility of using the Eötvös-developed fluid-fiber technology for other purposes, and in particular its possible applications to the construction of an ultra-sensitive almost dc gradiometer is being explored. It appears such a development would be effective both for finding tunnels (such as are being dug from North to South Korea) as well as for intrusion detection in connection (for example) with nuclear stockpiles.

JILA Information Center

The activities of the JILA Information Center to survey the world literature and produce comprehensive bibliographies on the subjects of electron and photon collisions with atoms and molecules, heavy-particle collisions and multiphoton collisions with atoms and molecules are ongoing. The following publications have resulted in FY 80:

"Bibliography of Low Energy Electron and Photon Cross Section Data (1978)," JILA Information Center Report No. 18, 150 pages (January 1980), J. W. Gallagher and E. C. Beaty.

"A Bibliography of Electron Swarm Data," JILA Information Center Report No. 20, 252 pages (December 1979), E. C. Beaty, J. Dutton, and L. C. Pitchford.

"Energy Transfer Collisions of Atoms and Molecules," JILA Information Center Newsletter, Number 11 (November 1979) and Number 12 (January 1980), J. W. Gallagher.

Production of NBS Special Publication 593, "Data Index for Energy Transfer Collisions of Atoms and Molecules - 1970-1979," J. W. Gallagher, Janet Van Blerkom, E. C. Beaty, and J. R. Rumble, Jr., has been a significant effort of the Information Center this year. This publication is currently in press at the Government Printing Office. Production of this document combined with the enforced change of computing facilities from the NOAA XDS 940 to an in-house computer combined with the NOAA CDC 6600 has delayed production of the 1979 electron-photon and 1979 multiphoton bibliographies. The latter two publications are currently in production. The computer changeover has been time-consuming, but has gone well. A system of indexing sources of data which is more comprehensive than that currently in use is in its planning stages.

Ongoing work to build and utilize a file of numerical data on electron collisions with atoms and molecules is exploiting the capabilities of the Tektronix 4051 graphics system with dual disk drive. The work this year has concentrated heavily on collection and analysis of differential cross sections for elastic scattering in collaboration with J. A. Rees of the University of Liverpool, England. Dr. Rees has been in residence working with E. Beaty and the Center staff. The review and evaluation of these data are coming to an end. Rees has now left JILA and is completing the manuscript in Liverpool. The Information Center is preparing figures and tables. A general and preliminary account of the findings is given here. Approximately 1100 samples of data were found, collected and examined. These represent data on many atoms at various electron-impact energies. In no case has a "reliable" measurement been made in the sense that a convincing analysis of possible errors has been given with the result that uncertainty limits could be reasonably assigned to the cross section values. In some cases the researchers did not report enough detail of their procedures. Substantial errors have probably arisen because the researchers assumed things which seemed credible but which were not true. An evaluation of these assumptions requires firstly knowing what they are and secondly knowing enough about the measurement situation to appraise (in the light of newer data) whether they are to be believed. In spite of the frequent lack of specific information it has been possible to find some basis for making value judgments. An interesting situation occurs in helium at energies less than 20 eV. In this case a calculation done by Nesbet presumes to take account of all possible computational inadequacies. We have not sought to evaluate his procedures, but the report is in a class by itself in addressing the problem of error. The most credible measurements agree with Nesbet's calculations. Unfortunately the two most recently reported measurements disagree substantially, and the descriptive material included with the reports of these does not allow them to be counted as among the most credible. For other atoms the conclusions are even less clear. It is widely recognized that normalization is a severe experimental problem, and in many cases it seems to have attracted all the experimentalist's efforts. The pattern of results indicates that in many cases electron energies are reported incorrectly. A practice is developing of using a phase shift analysis to supply a normalization. In appropriate circumstances this works. However little consideration has been given to the impact of angle-dependent errors. In neon we found little data between 50 eV and 100 eV, and those available concerned the energy and angle of a striking minimum near 60 eV. M. Menendez, a Visiting Fellow at JILA, was able to fill this gap using our electron scattering apparatus. A striking observation was that the prior data reporting the minimum was in error by nearly 10 eV.

The Information Center has also been heavily involved with a compilation of swarm data in collaboration with J. Dutton of the University of Swansea, Wales. Some evaluation of these data with regard to reliability is being made. The Information Center is currently obtaining microfilm output for this compilation using our new computer program which produces publication-quality figures. Manuscripts for both the elastic scattering review and the swarm compilation will be submitted to the Journal of Physical and Chemical Reference Data.

Drs. Pitchford and Allis have been working on different aspects of the relaxation of cross sections to swarm data. This program has led to a substantial improvement in our ability to generate accurate numerical solutions to the Boltzmann equation. Allis has been concerned with analytic trends and limits. The general procedure can provide a test of reliability of cross section data.

The Information Center has initiated discussions to expand its scope to include a program on dielectric breakdown in gases. The data scope includes sparking potentials and other quantitative information which is related to, but more applied than, the swarm data. The proposed program would include a retrospective and current literature search to identify publications reporting the desired data, construction of a computer file containing the numerical data and an evaluation of the data. This program has been proposed in collaboration with R. J. Van Brunt of NBS, Gaithersburg, J. Dutton, J. A. Rees, and O. Farrish of the University of Strathclyde, Scotland.

III. PUBLICATIONS AND INTERACTIONS

Included in the following pages of this section are tables of

- JILA Visiting Fellows for 1979-80 and 1980-81.
- 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 colloquiums.

III. PUBLICATIONS AND INTERACTIONS

VISITING FELLOWS

Quantum Physics Division (525)

VISITING FELLOWS - FY 1980	HOME INSTITUTION	AREA OF WORK
W. P. Allis	Research Laboratory of Electronics Massachusetts Institute of Technology Cambridge, Massachusetts	Gaseous electronics and ionized gas physics.
A. Ben-Reuven	Institute of Chemistry Tel-Aviv University 61390 Ramat Aviv, Tel Aviv Israel	Theory of environmental effects on molecular and atomic spectra, including non-linear laser spectroscopy.
G. Chanmugam	Department of Physics and Astronomy Louisiana State University Baton Rouge, Louisiana	Stellar magnetism and condensed stars (white dwarfs and neutron stars).
T. Cool	Applied and Engineering Physics 228 Clark Hall Cornell University Ithaca, New York	Photodissociation, lasers.
Z. Herman	Institute of Physical Chemistry and Electrochemistry Czechoslovak Academy of Sciences Machova 7 121 38 Prague 2 Czechoslovakia	Ion-molecule collision processes application of lasers in molecular physics studies.

VISITING FELLOWS

Quantum Physics Division (525)

VISITING FELLOWS - FY 1980	HOME INSTITUTION	AREA OF WORK
G. Leuchs	Sektion Physik University of Munchen 8046 Garching Am Coulombwall 1 West Germany	Investigation of Rydberg-atoms.
M. Menendez	Department of Physic & Astronomy University of Georgia Athens, Georgia	Study of ionization.
S. J. Peale	Department of Physics University of California Santa Barbara, California	Theoretical astrophysics, space physics.
R. V. Pound	Lyman Laboratory of Physics Harvard University Cambridge, Massachusetts	Experimental and theoretical physics.
G. Shaviv	Department of Physics & Astronomy Tel Aviv University Ramat Aviv, Israel	Stellar evolution with mass-loss; nova explosions.
D. F. Walls	Department of Physics University of Waikato Private Bag Hamilton, New Zealand	Research into the interaction of light fields with atoms and molecules.
W. Wing	Physics Department University of Arizona Tucson, Arizona	High-precision spectroscopy and molecular beam techniques.

VISITING FELLOWS

Quantum Physics Division (525)

VISITING FELLOWS - FY 1981	HOME INSTITUTION	AREA OF WORK
Bruno Bertotti	Istituto di Fisica Teorica Universita di Pavia Pavia, Italy	Feasibility studies for and the planning of gravity experiments in space.
H. Warren Moos	Department of Physics The Johns Hopkins University 34th & Charles Streets Baltimore, MD 21218	Ultraviolet observations of planetary atmospheres from sounding rockets, satellites, and planetary spacecraft.
Francis M. Pipkin	Lyman Laboratory of Physics Harvard University Cambridge, MA 02138	Experimental atomic physics and elementary particle physics.
Saul A. Rappaport	Massachusetts Institute of Technology Center for Space Research Cambridge, MA 02139	X-ray astronomy including the observation of binary X-ray pulsars and the spatial imaging of X-ray emission from supernova remnants.
Edward L. Robinson	Department of Astronomy University of Texas at Austin Austin, TX 78712	Observational astronomy; oscillation of white dwarfs and cataclysmic variables.
Hugh G. Robinson	Department of Physics Duke University Durham, NC 27706	Precision measurements with optical pumping.
David Spence	Argonne National Laboratory 9700 S. Cass Avenue Argonne, IL 60439	Electron collisions with atoms and molecules using trapped-electron techniques.

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* 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.

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N. T. Padial, D. W. Norcross, and L. A. Collins, Electron Collisions with Polar Molecules: Treatment of Intermediate Values of Angular Momentum, J. Phys. B: Atom. Molec. Phys. (submitted).

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Quantum Physics Division (525)

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* (R. T. Reynolds), S. J. Peale, and (P. Cassen), Io: Energy Constraints and Plume Volcanism, Icarus (submitted).

A. V. Phelps, Applications and Needs, in Electron-Molecule Scattering (S. C. Brown, Ed., Wiley, New York, 1979), pp. 81-106.

A. V. Phelps, The Determination of Electron Collision Cross Sections from Swarm Data, in Proceedings, International Seminar on Swarm Experiments in Atomic Collision Research, September 6-7, 1979, Rikkyo University, Tokyo (Rikkyo University, Tokyo, Japan, 1980), pp. 23-32.

K. Tachibana and A. V. Phelps, Excitation of the $C^3\Pi_u$ State of N_2 by Low Energy Electrons, J. Chem. Phys. 71, 3544-3546 (1979).

R. Shuker, A. Gallagher, and A. V. Phelps, Models of the High-Power Discharges for Metal-Xe Excimer Lasers, J. Appl. Phys. 51, 1306-1320 (1980).

C. H. Muller and A. V. Phelps, Low Current ELectric Discharges in H_2-He Mixtures, J. Appl. Phys. (in press).

* (K. Niemax, M. Movre), and G. Pichler, Near-Wing Asymmetries of the Self-Broadened First Rb and Cs Resonance Lines, J. Phys. B: Atom. Molec. Phys. 12, 3503-3509 (1979).

* L. Rosenberg, Sum Rule and Classical Limit for Scattering in a Low-Frequency Laser Field, Phys. Rev. A 20, 1352-1358 (1979).

* L. Rosenberg, Infrared Radiation in Potential Scattering, Phys. Rev. A 21, 157-162 (1980).

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* (D. W. Fahey), L. D. Schearer, and (W. F. Parks), Alignment of Ions in Penning Collisions, Phys. Rev. A 20, 1372-1375 (1979).

* (M. Contini, B. Z. Kozlovsky), and G. Shaviv, The Calculation of the Optical Spectra of the Cygnus Loop, Astron. Astrophys. (in press).

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Quantum Physics Division (525)

* (M. Livio, O. Regev), and G. Shaviv, Kelvin-Helmholtz Instability in Clusters of Galaxies, Astrophys. J. (in press).

* (M. M. Shara, D. Prialnik), and G. Shaviv, What Determines the Speed Class of Novae? Astrophys. J. (in press).

* (M. Livio) and G. Shaviv, The Stability of Accretion Disks to Short Wavelength Perturbations, Astrophys. J. (in press).

* (M. Contini) and G. Shaviv, The Calculation of the UV Spectra of the Cygnus Loop, Astrophys. J. (submitted).

* (N. Brosch) and G. Shaviv, Multiaperture Photometry of Isolated Galaxies, Astrophys. J. (submitted).

* (O. Regev) and G. Shaviv, Formation of Protostars in Collapsing Rotating Turbulent Clouds, Astrophys. J. (submitted).

* (W. P. Blair), R. E. Stencel, G. Shaviv, and (W. A. Feibelman), HM Sagittae: Symbiotic Cousin of the RS CVn Stars? Astron. Astrophys. (submitted).

* (D. Prialnik), G. Shaviv, and (A. Kovetz), The Effect of Diffusion on Asymptotic Branching Evolution, Astrophys. J. (submitted).

S. J. Smith and P. B. Hogan, Laser Bandwidth and Intensity Effects in Multiphoton Ionization of Sodium, in Laser Spectroscopy IV, Proceedings 4th International Conference, Rottach-Egern, Germany, 1979 (H. Walther and K. W. Rothe, Eds., Springer-Verlag, New York, Berlin, Heidelberg, 1979), pp. 360-367.

(G. Leuchs), S. J. Smith, and (H. Walther), High Resolution Spectroscopy of Rydberg States, in Laser Spectroscopy IV, Proceedings 4th International Conference, Rottach-Egern, Germany, 1979 (H. Walther and K. W. Rothe, Eds., Springer-Verlag, New York, Berlin, Heidelberg, 1979), pp. 255-263.

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A. V. Smith, J. E. M. Goldsmith, D. E. Nitz, and S. J. Smith, Absolute Photoionization Cross-Section Measurements of the Excited 4D and 5S States of Sodium, Phys. Rev. A 22, 577-81 (1980).

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Quantum Physics Division (525)

(G. Leuchs, T. Hellmuth), S. J. Smith, and (H. Walther), Angular Distribution of Photoelectrons in Two-Step Photoionization--Influence of the Hyperfine Structure, in Digest of 11th International Quantum Electronics Conference, Boston, June 23-26, 1980.

* G. A. Victor and (E. R. Constantinides), Double Photoinization and Doubly Charged Ions in the Thermosphere, Geophys. Res. Letters 6, 519-522 (1979).

* (C. Laughlin) and G. A. Victor, Intercombination Line Oscillator Strengths for the Mg I Isoelectronic Sequence, Astrophys. J. 234, 407-410 (1979).

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* G. Wallerstein, The Behavior of Hα in Delta Cephei, Pub. Astron. Soc. Pacific 91, 772-774 (1979).

* G. Wallerstein and (E. W. Brugel), The Absolute Magnitude of the Field Population II Cepheid XX Virginia, Astron. J. 84, 1840-1845 (1979).

* G. Wallerstein and (W. M. Fawley), Additional Radial Velocities of Maser Stars and Related M Supergiants, Pub. Astron. Soc. Pacific 92, 183-187 (1980).

* G. Wallerstein and (J. L. Greenstein), The Spectrum of the Nebulosity Around the Symbiotic Long Period Variable R. Aquarii, Pub. Astron. Soc. Pacific 92, 275-283 (1980).

* D. F. Walls, (P. D. Drummond, and K. J. McNeil), Bistable Systems in Nonlinear Optics, Proceedings, International Conference and Workshop on Optical Bistability (in press).

* D. F. Walls, (P. Zoller, and M. L. S. Ross), Optical Bistability from Three Level Atoms, IEEE Journal of Quantum Electronics, Special Issue on Optical Bistability (in press).

* J. C. Wheeler, Stars with Anomalous Mass: Is There Funny Business on the Main Sequence, Comments on Astrophysics 8, 133-147 (1979).

* J. C. Wheeler, Blue Stragglers as Long-Lived Stars, Astrophys. J. 234, 569-578 (1979).

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Quantum Physics Division (525)

* (D. S. King), J. C. Wheeler, J. P. Cox, (A. N. Cox, and S. W. Hodson), Pulsation of High Luminosity Helium Stars, in Nonradial and Nonlinear Stellar Pulsation (H. A. Hill and W. A. Dziembowski, Eds., Springer-Verlag, New York, Berlin, Heidelberg, 1980), p. 161.

* J. C. Wheeler, Supernovae in Molecular Clouds, Astrophys. J. 237, 781-792 (1980).

* (D. E. Tolliver, G. A. Kyrala), and W. H. Wing, Observation of the Infrared Spectrum of the Helium Hydride Molecular Ion $^4HeH^+$, Phys. Rev. Letters 43, 1719-1722 (1979).

* W. H. Wing, Electrostatic Trapping of Neutral Atomic Particles, Phys. Rev. Letters (submitted).

* (J. T. Shy, J. W. Farley), and W. H. Wing, Observation of the Infrared Spectrum of the Triatomic Deuterium Molecular Ion D_3^+, Phys. Rev. Letters (submitted).

INVITED TALKS

Quantum Physics Division (525)

P. L. Bender, "Instrumental Networks for Monitoring Short Period Tectonic Motions in Seismic Zones," IUGG Symposium No. 9 on Recent Crustal Movements, Canberra, Australia, December 14, 1979.

P. L. Bender, "Establishment of Terrestrial Reference Frames by New Observational Techniques," IAU Colloq. No. 56 - Reference Coordinate Systems for Earth Dynamics, Warsaw, Poland, September 8, 1980.

G. H. Dunn, "Electron-Ion Collisions," X Symposium on Physics of Ionized Gases (SPIG), Dubrovnik, Yugoslavia, August 25, 1980.

G. H. Dunn, "The Technical Difficulties and Future of Electron-Ion Experiments," U.S.-Japan Workshop on Atomic Collision Data for Fusion," JILA, October 28, 1980.

J. E. Faller, "Some Gravitational Experiments at JILA," Department of Physics, Princeton University, Princeton, New Jersey, February 7, 1980.

S. Geltman, "Model Calculations of Atom Ionization by Strong Static and Oscillating Electric Fields," DEAP Session of American Physical Society Annual Meeting, Chicago, Illinois, January 23, 1980.

J. L. Hall, "High Resolution Spectroscopy Using Stabilized Dye Lasers," presented at:

University of Waterloo, Waterloo, Canada, November 28, 1979,

IBM, San Jose, California, December 14, 1979,

University of British Columbia, Vancouver, British Columbia, Canada, March 20, 1980.

J. L. Hall, "An Improved Test of the Isotropy of Space Using Laser Techniques," presented at:

University of Toronto, Toronto, Canada, November 29, 1979,

Colorado School of Mines, Golden, Colorado, December 11, 1979.

J. L. Hall, "Precision Laser Spectroscopy from Atoms to Improved Tests of Relativity," Department of Physics, Harvard University, Cambridge, Massachusetts, April 7, 1980.

J. L. Hall, "Tunable Laser Stabilization Techniques for Ultra High Resolution Spectroscopy," presented at:

Conference on Precision Electromagnetic Measurements, Braunschweig, West Germany, June 24, 1980,

International Conference on Lasers, Shanghai PRC, May 21, 1980.

INVITED TALKS

Quantum Physics Division (525)

J. L. Hall, "Using Stabilized Lasers to Test Fundamental Physical Postulates," International Conference on Atomic Physics, Cambridge, Massachusetts, August 8-12, 1980.

S. R. Leone, "Infrared Emission Studies of Laser Photofragmentation," American Chemical Society Meeting Symposium on Laser Dynamics and Spectroscopy of Excited Species, Syracuse, New York, October 4, 1979.

S. R. Leone, "State-Selected Kinetics of Laser Excited Species," Department of Chemistry Colloquium, Cornell University, Ithaca, New York, October 1979.

S. R. Leone, "Laser State-Selected Kinetics," Physical Chemistry Seminar, Northwestern University, Evanston, Illinois, November 1979.

S. R. Leone, "New Laser Techniques in Chemical Kinetics," US-France Seminar on Lasers in Chemistry, NSF-CRNS sponsored workshop for collaborative scientific efforts, Philadelphia, Pennsylvania, November 1979.

S. R. Leone, "State-Selected Kinetics of Laser Excited Species," Department of Chemistry Colloquium, Indiana University, Bloomington, Indiana, December 1979.

S. R. Leone, "Laser Studies of Chemical Chain Reactions and Free Radicals," Argonne National Laboratory, Argonne, Illinois, March 1980.

S. R. Leone, "Laser State-Selected Near Resonant Collision Processes," Symposium on Inelastic Molecular Collisions, American Physical Society Meeting, New York, New York, March 25, 1980.

S. R. Leone, "Infrared Emission Studies of Photofragment Dynamics," 14th Informal Conference on Photochemistry, Newport Beach, California, April 2, 1980.

S. R. Leone, "Infrared Chemiluminescence Studies of Reactive Dynamics," presented at:

Chemistry Department Seminar, University of California at Berkeley, Berkeley, California, April 7, 1980,

Departmental Seminar at the University of Toronto, Toronto, Ontario, Canada, May 1980.

S. R. Leone, "Electronic and Ionic Processes Related to Atomic and Molecular Lasers," Gordon Conference on Atomic and Molecular Interactions, Wolfeboro, New Hampshire, July 1980.

INVITED TALKS

Quantum Physics Division (525)

J. L. Linsky, "Theoretical Interpretation of X-ray Emission from Non-degenerate Stellar Sources," Invited review paper presented at the High Energy Astrophysics Division of the American Astronomical Society, Cambridge, Massachusetts, January 28, 1980.

J. L. Linsky, "Stellar Coronae and Winds in Late and Middle-Type Stars: Observations and Theory," Invited review paper presented at the Santa Fe Meeting on Solar Astronomy of Kitt Peak National Observatory, Sacramento Peak Observatory, and the High Altitude Observatory, Santa Fe, New Mexico, May 21, 1980.

J. L. Linsky, "Evidence for Chromospheres and Coronae in Stars," Invited review paper presented at the NATO Advanced Study Institute on Solar Phenomena in Stars and Stellar Systems, Chateau de Bonnas, France, August 27, 1980.

J. L. Linsky, "Chromospheres of Late-Type Stars," Invited review paper presented at the Workshop on Physical Processes in Red Giants, Brice, Italy, September 8, 1980.

J. L. Linsky, "Winds from Late-Type Stars: Mechanisms of Mass Outflow," Invited review paper presented at International Astronomical Union Colloquium No. 59 (Effects of Mass-Loss on Stellar Evolution), Trieste, Italy, September 16, 1980.

J. L. Linsky, "Stellar Chromospheres: Are Recent Observations and Theoretical Calculations Beginning to Answer the Basic Question," presented at:

Physics Department Seminar, Gettysburg College, Gettysburg, Pennsylvania, October 29, 1980.

Center Science Colloquium, NASA Goddard Space Flight Center, October 31, 1980.

D. W. Norcross, Member of a panel on "Electron Atom and Ion Scattering," at the Fourth Johns Hopkins Workshop on Current Problems in Physics," March 28-29, 1980.

S. J. Smith, "Photoionization of Excited States of Atomic Sodium," Department of Physics, University of Missouri, Rolla, Missouri, May 1, 1980.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

P. L. Bender, Member, Committee on Earth Sciences of the Space Science Board, National Academy of Sciences and National Research Council.

P. L. Bender, Member, Ad Hoc Committee on Gravitational Physics of the Space Science Board, National Research Council.

P. L. Bender, Member, Space Science Board, National Academy of Science and National Research Council.

P. L. Bender, Member, Panel on Crustal Movement Measurement, Committee on Geodesy, National Academy of Science and National Research Council.

P. L. Bender, Chairman, Working Group on Instruments and Methods, Commission on Recent Crustal Movements, International Association of Geodesy.

P. L. Bender, Member, Laser Geodynamics Satellite (LAGEOS) Working Group, NASA.

P. L. Bender, Member, Physics Department Advisory Council, Princeton University.

G. H. Dunn, Chairman, Organizing Committee, Conference on Atomic Processes in High Temperature Plasmas. To be held in Baton Rouge, Louisiana, February 1981. A Topical Conference of the American Physical Society.

G. H. Dunn, Member, Graduate Committee, Department of Physics and Astrophysics, University of Colorado.

G. H. Dunn, Member, Program Committee, Division of Electron and Atomic Physics, American Physical Society.

G. H. Dunn, Member, Fellowship Committee, DEAP, American Physical Society.

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.

A. C. Gallagher, Member, ICPEAC Organizing Committee.

K. B. Gebbie, Member, Search Committee for Faculty Appointment in Solar Physics, Department of Astro-Geophysics, University of Colorado.

K. B. Gebbie, Vice Chairman, Colorado Passenger Tramway Safety Board.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

K. B. Gebbie, Member, Electorate Nominating Committee, Section D, American Association for the Advancement of Science.

K. B. Gebbie, Member, Search Committee for Director of Cooperative Institute for Research in Environmental Sciences (CIRES), Enviromental Research Laboratories of NOAA and University of Colorado.

K. B. Gebbie, Member, The Billings Award Committee, Department of Astro-Geophysics, University of Colorado.

K. B. Gebbie, Member, Examinations Committee, Department of Astro-Geophysics, University of Colorado.

S. Geltman, Member, International Organizing Committee, Second International Conference on Multiphoton Processes, Budapest, Hungary, April 14-18, 1980.

S. Geltman, Member, Graduate Committee, Department of Physics, University of Colorado.

J. L. Hall, Member, National Research Committee on Fundamental Constants, National Research Council/National Academy of Sciences, July 1, 1976 - June 30, 1979, extended to June 30, 1982.

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.

J. L. Hall, Director-at-Large, Optical Society of America.

D. G. Hummer, Member, Computer Policy Committee, University of Colorado.

D. G. Hummer, Member, Editorial Board, Computer Physics Communications.

S. R. Leone, Associate Editor, Optics Letters.

J. L. Linsky, Member, IUE (International Ultraviolet Explorer) Astronomy Working Group, NASA.

J. L. Linsky, Member, Solar Physics Working Group of the Astronomy Survey Committee, National Academy of Sciences and National Research Council.

J. L. Linsky, Co-Investigator, ST (Space Telescope) High Resolution Spectrograph Experiment.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

J. L. Linsky, Member, Committee to Evaluate the Future of the Cloudcraft 48-inch Telescope of Sacramento Peak Observatory, AURA (Association of Universities for Research in Astronomy).

J. L. Linsky, Member, Committee on Space Astronomy and Astrophysics of the Space Science Board, National Academy of Sciences and National Research Council.

J. L. Linsky, Member, Solar Terrestrial Theory Program (STTP) Evaluation Committee, NASA, January 2 - February 6, 1980.

J. L. Linsky, Member, Panel on Ultraviolet, Optical, and Infrared Astronomy of the Astronomy Survey Committee, National Academy of Sciences and National Research Council.

D. W. Norcross, Member, Data Center Advisory Committee.

A. V. Phelps, Research Advisory Committee of NBS.

A. V. Phelps, Member, The 1979 Earle K. Plyler Prize Committee (American Physical Society).

A. V. Phelps, Steering Committee for DARPA Charged Particle Beam Theory Review, June 1980.

S. J. Smith, Member, Committee on Atomic and Molecular Sciences, National Academy of Sciences.

S. J. Smith, Member, Organizing Committee, Seventh International Conference on Atomic Physics, August 4-8, 1980, Cambridge, Massachusetts.

S. J. Smith, Chairman, Local Committee for Annual Meeting of Division of Electron and Atomic Physics, Boulder, Colorado, 1982.

S. J. Smith, Co-Chairman, NAS-NRC Survey of Atomic and Molecular Science.

S. J. Smith, Member, Organizing Committee, Eighth International Conference on Atomic Physics, Götteburg, Sweden, 1982.

S. J. Smith, Chairman, Nominating Committee, Division of Electron and Atomic Physics of The American Physical Society, 1980.

CONSULTING

Quantum Physics Division (525)

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.

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 lasers and charged particle beam devices.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

E. C. Beaty

May 16-25, 1980 - Paris, France.
Attended the Technical Committee Meeting of the International Atomic Energy Agency (IAEA) and the Data Center Network Consultants Meeting.
Sponsor: International Atomic Energy Agency.

P. L. Bender

October 10-13, 1979 - Washington, D.C.
Attended the meeting of the Panel on Crustal Movement Measurements, National Academy of Sciences.
Sponsor: National Research Council.

October 22-25, 1979 - Washington, D.C.
Attended the meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

October 31 - November 2, 1979 - Washington, D.C.
Attended the meeting of the Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

January 28-31, 1980 - Los Angeles, California.
Attended the meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

February 5-9, 1980 - San Francisco, California.
Attended the meeting of Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

April 10-13, 1980 - Scottsdale, Arizona.
Attended the meeting of Proposal Review Panel for the Office of Earthquake Studies of the U.S. Geological Survey.
Sponsor: U.S. Geological Survey.

April 20-24, 1980 - Cambridge, Massachusetts.
Attended the meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

P. L. Bender

June 2-7, 1980 - Menlo Park, California.
Attended the meeting to review the Earthquake Prediction Research Program of the U.S. Geological Survey.
Sponsor: U.S. Geological Survey.

July 28 - August 2, 1980 - Woods Hole, Massachusetts.
Attended the meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences.
Sponsor: National Research Council.

G. H. Dunn

August 23-30, 1980 - Dubrovnik, Yugoslavia.
Attended the X Summer School & Symposium of Ionized Gases (SPIG '80) and gave an invited lecture at the Summer School on "Electron-Ion Collisions."
Sponsor: The Organizing Committee of the X Summer School and Symposium on the Physics of Ionized Gases.

J. E. Faller

November 12-13, 1979 - Washington, D.C.
Met with the National Science Foundation & other members of the Physics Community to discuss the Foundation's Fiscal Year 1980 budget for the Physics Division.
Sponsor: National Science Foundation.

K. B. Gebbie

June 2, 1980 - July 11, 1980 - Greenbelt, Maryland.
Worked at NASA Goddard Space Flight Center as a Guest Investigator on the SMM/UVSP Experiment.
Sponsor: NASA.

S. Geltman

March 31 - June 1, 1980 - Paris (Gif-sur-Yvette), France.
Work visit to Service de Physique Atomique, Centre D'Etudes Nucleaires de Saclay at the invitation of Dr. Claude Manus, the head of the Service de Physique Atomique at Saclay.
Sponsor: Centre D'Etudes Nucleaires de Saclay.

J. L. Hall

November 29, 1979 - Toronto, Canada.
Presented all-University lecture on "Improved Test of the Isotropy of Space Using Laser Techniques," at the University of Toronto and visited the research group of Prof. B. P. Stoicheff and discussed collaborative effort on Rydberg atom spectroscopy.
Sponsor: University of Toronto.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Hall

December 13-14, 1979 - San Jose, California.
Presented invited lecture at IBM on "High Resolution Spectroscopy Using Stabilized Dye Lasers."
Sponsor: IBM.

February 19-21, 1980 - Ann Arbor, Michigan.
Presented an invited colloquium lecture in the Department of Physics, University of Michigan and discussed the feasibility of several advanced experiments to test the postulates of special theory of relativity with Prof. A. Rich.
Sponsor: University of Michigan.

March 20-21, 1980 - Vancouver, British Columbia.
Presented an invited lecture at the University of British Columbia entitled, "High Resolution Dye Laser Spectroscopy."
Sponsor: University of British Columbia.

April 6-8, 1980 - Boston, Massachusetts.
Presented an invited lecture, "Precision Laser Spectroscopy from Atoms to Improved Tests of Relativity," and visited MIT laser labs to discuss scientific problems of mutual interest with Profs. M. Feld, S. Ezekial, D. Pritchard, and R. Fields.
Sponsor: Harvard Department of Physics.

June 22-26, 1980 - Braunschweig, Germany.
Presented an invited paper at the Conference on Precision Electromagnetic Measurements and attended the Conference, "Tunable Laser Stabilization Techniques for Ultra High Resolution Spectroscopy."
Sponsor: Conference on Precision Electromagnetic Measurements.

D. G. Hummer

January 20 - December 8, 1979 - London, England.
Conducted research at University College London with Dr. Mike Seaton. Research involved applying relativistic effects to electron-ion collisions and in extending the theory of radiation transport.
Sponsor: University College London.

March 19 - April 1, 1980 - Boston, Massachusetts.
Collaborated with Dr. G. B. Rybicki on completing two papers on the escape-probability method in radiative transfer.
Sponsor: Smithsonian Astrophysical Observatory.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

S. R. Leone — October 4-5, 1979 - Ithaca, New York.
Gave a Chemistry Department Seminar at Cornell University on "State Selected Kinetics of Laser Excited Species," and visited Cornell University.
Sponsor: Cornell University.

November 25-28, 1979 - Philadelphia, Pennsylvania.
Attended the National Science Foundation-CRNS Workshop on lasers in chemistry and presented a review paper, "New Laser Techniques in Chemical Kinetics."
Sponsor: The National Science Foundation.

December 4-6, 1979 - Bloomington, Indiana.
Visited Indiana University and presented Departmental Seminar on, "State Selected Kinetics of Laser Excited Species."
Sponsor: Indiana University.

March 28 - April 3, 1980 - Newport Beach, California.
Attended the 14th Informal Conference on Photochemistry and presented an invited lecture on "Infrared Emission Studies of Photofragment Dynamics."
Sponsor: Conference on Photochemistry.

April 7-9, 1980 - Berkeley, California.
Presented a talk on "Infrared Chemiluminescence Studies of Reactive Dynamics," at a Chemistry Department Seminar, and visited the University of California at Berkeley.
Sponsor: University of California at Berkeley.

April 24-27, 1980 - Toronto, Ontario, Canada.
Visited the University of Toronto and presented a Departmental Seminar on "Infrared Chemiluminescence Studies of Reactive Dynamics."
Sponsor: University of Toronto.

J. L. Linsky — November 2-3, 1979 - Chicago, Illinois.
Attended a meeting of the UVOIR (Ultraviolet, Optical, and Infrared) Panel of the Astronomy Survey Committee of the National Academy of Sciences.
Sponsor: National Academy of Sciences.

November 30 - December 2, 1979 - Tucson, Arizona.
Attended a meeting of the UVOIR (Ultraviolet, Optical, and Infrared) Panel of the Astronomy Survey Committee of the National Academy of Sciences.
Sponsor: National Academy of Sciences.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Linsky

January 17-18, 1980 - San Francisco, California.
Attended a meeting of the UVOIR (Ultraviolet, Optical, and Infrared) Panel of the Astronomy Survey Committee of the National Academy of Sciences.
Sponsor: National Academy of Sciences.

January 24-26, 1980 - Sunspot, New Mexico.
Attended the meeting to evaluate the future of the Cloudcraft 48-inch telescope of Sacramento Peak Observatory as a member of the committee appointed by AURA (Association of Universities for Research in Astronomy).
Sponsor: Association of Universities for Research in Astronomy, Inc.

February 3-6, 1980, Greenbelt, Maryland.
Attended meeting of the Solar-Terrestrial Theory Program Evaluation Committee at Goddard Space Flight Center.
Sponsor: NASA.

February 13-17, 1980 - Washington, D.C. and Greenbelt, Maryland.
Attended the meeting of the Committee on Space Astronomy and Astrophysics at the National Academy of Sciences Building in Washington, D.C., and attended a meeting of the UVOIR Panel of the Astronomy Space Committee of the National Academy of Sciences.
Sponsor: National Academy of Sciences.

February 24-29, 1980 - Santa Cruz, California.
Attended the meeting of the UVOIR Panel of the Astronomy Survey Committee of the National Academy of Sciences.
Sponsor: National Academy of Sciences.

March 12-13, 1980 - Huntsville, Alabama.
Attended meeting of the Space Telescope Data and Operations Team.
Sponsor: NASA.

April 14-15, 1980 - Greenbelt, Maryland.
Attended the meeting of the Management Operations Working Group for the NASA Astronomy Program at Goddard Space Flight Center.
Sponsor: National Academy of Sciences.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Linsky

April 30 - May 2, 1980 - Greenbelt, Maryland.
Attended Critical Design Review of the Space Telescope (ST) High Resolution Spectrograph.
Sponsor: NASA.

May 7-9, 1980 - Greenbelt, Maryland.
Attended Conference on the Universe at Ultraviolet Wavelengths and present 3 contributed papers.
Sponsor: NASA.

May 19-20, 1980 - Austin, Texas.
Attended the meeting of the Committee on Space Astronomy and Astronomy Physics.
Sponsor: National Academy of Sciences.

August 8, 1980 - Tucson, Arizona.
As a member of the Thesis Committee of Mark Giampapa, as astronomy Ph.D. candidate at the University of Arizona, attended his defense on August 8.
Sponsor: University of Arizona.

August 23 - September 18, 1980 - Toulouse, France. Trapini, Italy, and Trieste, Italy.
Presented an invited review paper and lectures at the NATA Advanced Study Institute on "Solar Phenomena in Stars and Stellar Systems," in Toulouse, France.
Sponsor: NATO.
Presented an invited review paper and lectures at the Erice Workshop on "Physical Processes in Red Giants," in Erice, Italy.
Sponsor: Erice Workshop.
Presented invited review paper at the IAU Colloquium No. 59 on "Effects of Mass Loss on Stellar Evolution," in Trieste, Italy.
Sponsor: IAU.

D. W. Norcross

September 1980 - September 1981 - Extended travel to Smithsonian Center for Astrophysics, Cambridge, Massachusetts.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

A. V. Phelps	December 5-9, 1979 - Menlo Park, California and Livermore, California. Discussed physics of propagation of electron beams in the atmosphere with Dr. Simon Yu at the Lawrence Livermore Laboratory and presented a seminar to Dr. W. L. Morgan's laser group on the role of excited atoms in high pressure discharges in metal vapor rare gas mixtures. Sponsor: Lawrence Livermore Laboratory.
	April 30 - May 2, 1980 - Ft. Collins, Colorado. Participated in a Research Review Panel for the Department of Physics of Colorado State University. Sponsor: Colorado State University.
	June 15-22, 1980 - La Jolla, California. Attended a comprehensive review of all the theoretical efforts currently supported bythe Charged Particle Beam Program of the Defense Advanced Research Projects Agency (DARPA). Sponsor: Naval Surface Weapons Center.
S. J. Smith	May 1, 1980 - Rolla, Missouri. Gave an invited colloquium at the Department of Physics, University of Missouri. Sponsor: University of Missouri.

SPONSORED CONFERENCES

Quantum Physics Division (525)

A JILA Workshop on photoionization of excited atomic states, including cross-sections, angular distributions, spin polarization and wavelength dependence is planned for early March 1981. S. J. Smith and G. Leuchs are co-organizers.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

Laboratory Reports Seminars

Name/Affiliation/Title/Date

F. Kowalski (JILA Postdoctorate) - A proposed new measurement of electromagnetic momentum in a (gaseous) dielectric using the techniques of high resolution laser spectroscopy, October 11, 1979.

J. Levine (JILA Fellow) - Laboratory Minicomputers in JILA--One person's view of how we got where we are, what we (cooperative) are trying to do, and what the future may hold, November 15, 1979.

L. Pendrill (JILAL Postdoctorate) - Laser Spectroscopy of Caesium Atoms. I. Rydberg Radius 100 Å, November 29, 1979.

L. Pendrill (JILA Postdoctorate) - Laser Spectroscopy of Caesium Atoms. II. Rydberg Radius 1, December 6, 1979.

A. Smith (JILA Postdoctorate) - Photoionization of Excited States of Na, January 31, 1980.

L. Pendrill (JILA Postdoctorate)/K. Niemax (JILA Visiting Fellow) - Isotope Shifts of Rydberg Atoms, February 20, 1980.

R. Dang (JILA Postdoctorate) - Electron Impact Excitation of Sodium Atom in the $3^2P_{3/2}$ State, February 21, 1980.

P. Schulz (JILA Postdoctorate) - Photodetachment of OH^-, March 5, 1980.

T. Baer (JILA Postdoctorate) - A Cheap Frequency Standard: Stabilized Zeeman HeNe Laser, March 20, 1980.

J. Jeffries (JILA Graduate Research Student) - Ion Trappology: What Do We Really Understand?, April 3, 1980.

D. Van Baak (NBS-NRC Postdoctorate) - Rydberg States of Rubidium and What They're Good For, April 10, 1980.

J. Goldsmith (NBS-NRC Postdoctorate)/L. Hollberg (JILA Graduate Research Student) - A Few of the Things You Might Have Wanted to Know About Ring Lasers, But Never Bothered to Ask, April 17, 1980.

T. Zwier (JILA Graduate Research Student) - Vibrational Product-State Distribution in the $C\ell^-$ + H Associative Detachment Reaction, April 24, 1980.

B. Rinker (JILA Graduate Research Student) - Isolation Characteristics of Super Spring, May 22, 1980.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

Informal Seminars on Atomic and Radiation Theory

Name/Affiliation/Title/Date

N. Padial (JILA Postdoctorate) - Spin-Orbit Effect in Electron-Photon Coincidence Experiments, October 16, 1979.

A. Maquet (JILA Senior Research Member) - Padé Approximants in Physics for Pedestrians, October 30, 1979.

A. Ben-Reuven (JILA Visiting Fellow) - Resonance Absorption and Scattering of Strong Coherent Radiation, November 6, 1979.

R. Christensen (JILA Postdoctorate) - Charge Exchange Between Hydrogen and Multiply-Charged Ions, November 13, 1979.

P. Thomann (JILA Postdoctorate) - Two-State Atoms in a Strong Monochromatic Field: A Non-Perturbative Approach, November 20, 1979.

A. Pradhan (JILA Postdoctorate) - Electron Impact Excitation of He-Like Ions, November 27, 1979.

A. Barut (Professor, Physics and Astrophysics, University of Colorado) - Narrow Resonances as an Eigenvalue Problem: An Exactly Soluble Model, December 4, 1979.

G. Petite (Saclay and MIT) - Resonant Multiphoton Ionization of Atoms: Theory and Experiment for Cesium, January 15, 1980.

W. Wing (JILA Visiting Fellow) - Electrostatic Trapping of Neutral Atoms, January 29, 1980.

J. Pascale (Saclay and SRI) - Theoretical Model for Collisions of High Rydberg Atoms with Neutrals, February 12, 1980.

L. Spruch (New York University) - Thomas-Fermi Theory and Some of its Ramifications--A Pedagogical Talk, June 27, 1980.

D. Walls (JILA Visiting Fellow) - Proposed Schemes for Optical Bistability, July 22, 1980.

M. Gavrila (FOM, Amsterdam) - Higher Born Approximations, July 29, 1980.

J. Gazeau (Univ. P. et M. Curie, Paris) - Sturmian Technique for the Discrete Spectrum of the Schrödinger Equation, August 27, 1980.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

Chemical Physics Seminars

Name/Affiliation/Title/Date

N. Adams (University of Birmingham, England) - Laboratory Studies of Natural Plasmas Using Flow Tube Techniques, September 7, 1979.

T. Cool (JILA Visiting Fellow) - Spectroscopy of Yttrium Halides, September 21, 1979.

H. Strauss (University of California, Berkeley) - Vibrations and Structures of Strained Systems: Cyclohexane Cyclooctane and Cubane, September 28, 1979.

R. Zare (Stanford University) - Recent Studies of Multiphoton Processes, October 5, 1979.

G. Atkinson (University of Syracuse) - Time Resolved Laser Detection of Reactive Intermediates, October 12, 1979.

J. Hall (JILA Fellow) - Precision Laser Spectroscopy, Optical Frequency Standards--And All That Jazz, October 19, 1979.

C. Lineberger (JILA Fellow) - The Saga of Methylene, October 26, 1979.

C. De Puy (University of Colorado) - What Can Organic Chemistry Contribute to Studies of Gas Phase Ion-Molecule Reactions?, November 2, 1979.

D. Kley (NOAA) - How Dry is the Sky?, November 9, 1979.

J. Levine (JILA Fellow) - How Great is the Gulf Between Physics and Chemistry?, November 16, 1979.

A. Gallagher (JILA Fellow) - Molecular Continuum Radiation, November 30, 1979.

F. Fehsenfeld (NOAA) - Recent Flow Tube Studies of Ion-Molecule Reactions and Their Application to Interstellar and Atmospheric Ion Chemistry, December 7, 1979.

W. Reinhardt (JILA Fellow) - What Do We Know About the Relationship Between Classical Mechanics and Quantum Mechanics and Why Are We Interested?, February 1, 1980.

E. Grant (Cornell University) - On the Dynamics of Infrared Multiphoton Excitation: Some Simple Results of Experiment and Theory, February 8, 1980.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

Chemical Physics Seminars (continued)

Name/Affiliation/Title/Date

D. Spence (Argonne National Laboratory) - Negative Ions, Autoionizing States, Post-Collision Interactions and Confusion in Atomic Spectroscopy, February 15, 1980.

B. Kohler (Wesleyan University) - Polyene Photophysics--Isomerization at Absolute Zero, February 22, 1980.

Z. Herman (J. Heyrovsky Institute of Physical Chemistry & Electrochemistry, Prague) - Beam Studies of Ion-Molecule Reaction Dynamics, February 29, 1980.

U. Fano (University of Chicago) - The Physics of Dissociation, March 14, 1980.

N. Carlson (Stanford University) - Two-Step Polarization Labeling of Rydberg States in Na_2, March 21, 1980.

A. Nozik (Solar Energy Research Institute) - Aspects of Photoelectrochemical Energy Conversion, April 11, 1980.

B. Ladanyi (Colorado State University) - Light Scattering from Flexible Molecules, April 18, 1980.

A. Carrington (University of Southampton, England) - Spectra of Molecular Ion Beams, April 25, 1980.

E. Mason (Brown University) - Determination of Ion-Molecule Forces From Transport Measurements, May 9, 1980.

L. Allamandola (University of Leiden) - The Laboratory Simulation, Photochemistry, and Spectroscopy of Low Temperature Interstellar Dust Grain Molecular Mantles and Their Role in Interstellar Chemistry, June 16, 1980.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

JILA Colloquium Speakers

Name/Affiliation/Title/Date

B. Edlén (Fysiska Institutionen, Lunda Universitet) - The Low Configurations in 3- to 9-Electron Ions, September 18, 1979.

*J. Bokor (University of Illinois) - Multiphoton Ultraviolet Excitation of Atoms and Molecules, September 25, 1979.

I. Smith (University of Cambridge, England) - Laser Studies of Gas Phase Energy Transfer, October 2, 1979.

J. Farley (University of Arizona) - Studies of Rydberg States of Helium, October 3, 1979.

S. Werner (University of Missouri) - Gravity and Inertia in Quantum Mechanics, October 9, 1979.

S. Rice (University of Chicago - James Franck Inst.) - Collision Induced Vibrational Redistribution in Electronically Excited Molecules, October 16, 1979.

R. Miller (University of Chicago) - Collisions Between Galaxies, October 23, 1979.

S. Holt (NASA-Goddard) - Spectra of Cosmic X-Ray Sources, October 30, 1979.

S. Bobashev (Acad. of Sci. of the USSR, Leningrad - JILA Visiting Fellow) - Two-Step Photoionization of Helium Via the 4P $^1P_1$ State, November 6, 1979.

V. McKoy (California Institute of Technology) - The Applications of Schwinger Variational Principle to Electron-Molecule Scattering, November 13, 1979.

*W. Fowler (California Institute of Technology) - Experiment and Theory Relevant to Nucleosynthesis in Supernovae, November 15, 1979.

*J. Harrison (University of Colorado) - New Ideas on Earth Tides, November 21, 1979.

A. Georges (University of Toronto) - Resonant Multiphoton Processes in Fluctuating Laser Fields, January 8, 1980.

*Joint JILA/Physics Colloquium.

SEMINARS AND COLLOQUIUMS

Quantum Physics Division (525)

JILA Colloquium Speakers (continued)

T. Gallagher (Stanford Research Institute) - Interaction of Black Body Radiation with Rydberg Atoms, January 29, 1980.

M. Aaronson (Steward Observatory) - A New Determination of the Hubble Expansion Rate, February 5, 1980.

*J. Lawler (Stanford) - Doppler-free Optogalvanic Spectroscopy, February 6, 1980.

J. Polanyi (University of Toronto) - Recent Studies of Reaction Dynamics by Laser Spectroscopy, February 12, 1980.

D. Crandall (Oak Ridge National Lab.) - Atomic Collisions with Multi-charged Ions--Basic Physics and Applications in Fusion and Astrophysics, February 19, 1980.

E. Lee (University of California) - Photochemistry and Spectroscopy of Small Molecules and Dimers, February 26, 1980.

*A. Ferguson (Oxford University) - Picosecond Light Pulse Spectroscopy, February 27, 1980.

*P. Koch (Yale University) - Highly Excited Hydrogen Atoms: An Atomic Cornucopia, March 3, 1980.

*B. Lutz (Lowell Observatory) - Laboratory Astrophysics and Planetary Atmospheres: It's All Done With Mirrors, March 4, 1980.

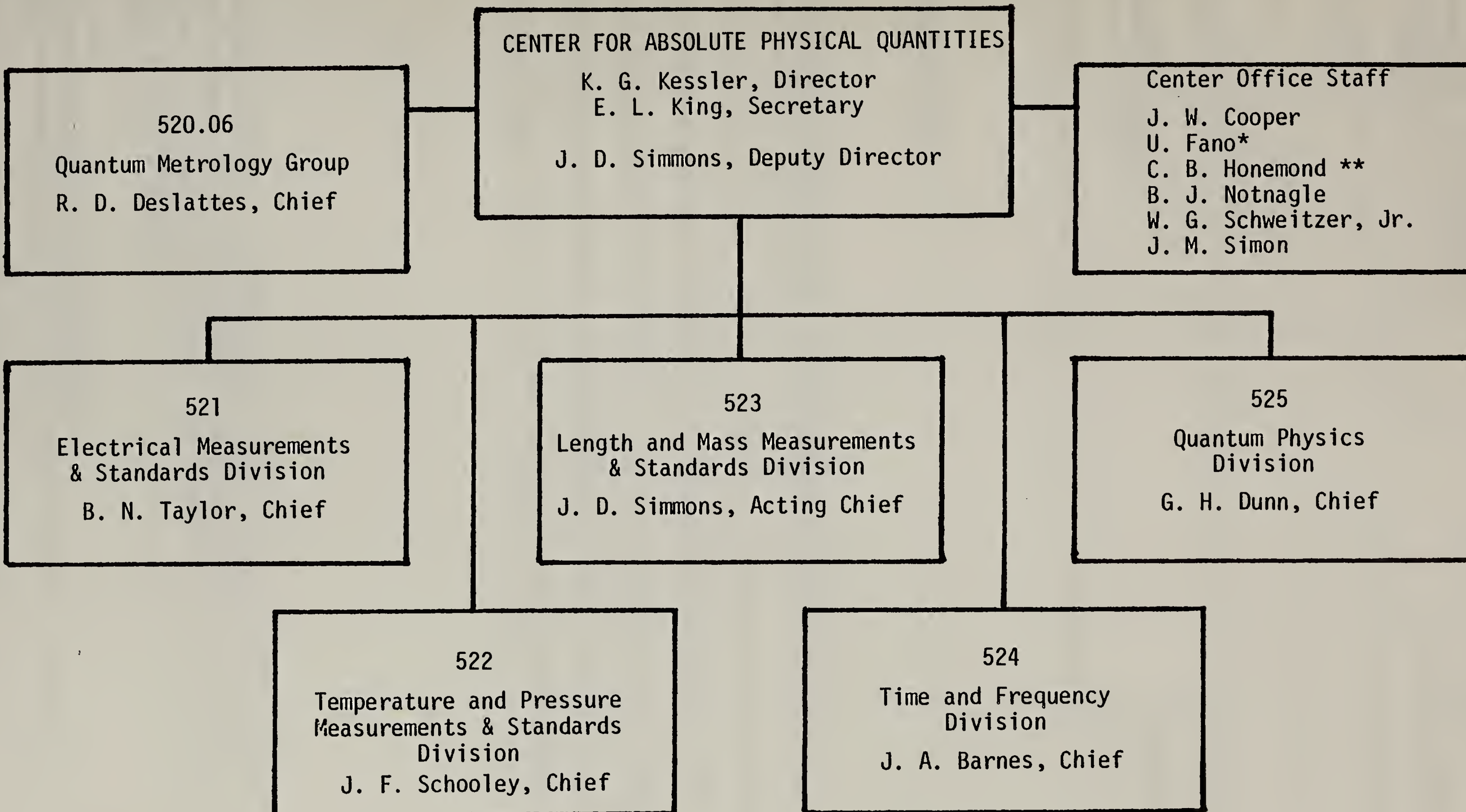
*T. Baer (JILA Postdoctorate) - Photon Echoes, Free Induction Decay and Other Coherent Transient Probes of Atomic and Molecular Collisions, March 7, 1980.

S. Moody (Mathematical Sciences Northwest) - HG_2: Something That Doesn't Laser and Why It Doesn't, March 11, 1980.

J. Moseley (University of Oregon) - Photodissociation and Photofragment Spectroscopy of Molecular Ions, March 18, 1980.

J. Steinfeld (MIT) - Chemistry, Physics, and Applications of Multiple Infrared Photon Excitation in Molecules, April 15, 1980.

M. Levenson (IBM, San Jose) - Laser Spectroscopy and Non-Linear Optics in the More-or-Less Real World, July 1, 1980.



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This report summarizes research projects, measurement method development, calibration and data evaluation activities carried during Fiscal Year 1980 in the NBS Center for Absolute Physical Quantities. These activities fall in the areas of: quantum metrology; measurements and standards for the electrical units, temperature and pressure, length and mass, time and frequency; and quantum physics.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

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